GIS Based Tools for Watershed and Agriculture

A MTP Report
submitted in partial fulfillment of the
requirements for the degree of
Master of Technology
by,

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Dissertation Approval

This dissertation entitled **"GIS Based Tools For Watershed And Agriculture"**, submitted by **Swapnil Patil (Roll Number: 173050062)** is approved for the degree of **Master of Technology in Computer Science and Engineering** from **Indian Institute of Technology, Bombay**.

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Declaration

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Abstract

Despite the increase in the numbers of farmers and people working on farms from 98 million in 1951 to 273 million people working in farms as of 2015 (as per Registrar General of India and Census report), there is low productivity in farming[1]. The low profitability and fluctuations in the prices can be effectively controlled if the farming is done by the well-established research practices.

This brings us to a need to have a sound mechanism to analyze and emphasize research-driven technologies to be implemented in the core farming practices. Farming is mainly impacted by the rainfall, access to water, soil type, and the cropping pattern, which are required to be understood and improved based on scientific research and ground truth as a whole. The Project on Climate Resilient Agriculture (PoCRA) of Govt. of Maharashtra, primarily aims at enhancing climate resilience and profitability of small-holder farming systems in various districts of Maharashtra.

The overall goal of this work is to provide GIS (Geographical Information System) based tools and technologies for watershed and agriculture which in turn will help to provide advisory support to administrators for village/zone level planning and improve the farm level agricultural practices with a view of better yields and associated profits.

Our work is primarily divided into the following components (i) improvements in point-wise water budget application, validation, (ii) analysis of micro-planning data and generating charts, (iii) improving soil data in model by soil sampling analysis and its Android app, (iv) automation and improvement of zones, and finally (v) regional analysis of surface water flows, (vi) stream-flow simulation framework, (vii) stream proximity maps, etc. The existing point-wise water budget application provides the water indices at farm level, which were improved to provide crop end summary values, modification of sowing logic, and other utility features. The micro-planning activity conducted at the field level brings the data related to structures, population, cropping pattern, etc. Our task was to integrate the field data and the zone level plugin outputs to generate village summary data for better intervention planning and advisory support. The soil data used in the model/plugin does not match at the field level resulting in variations in model results. Our task was to analyze and integrate the soil data from other sources and provide a soil sampling application to collect first-hand field information about the soil and other farm-level parameters to improve and validate the primary level soil data from MRSAC and NBSS&LUP. The existing model is computed on village area divided into zones, for which our work aims at implementing a methodology to form zones based on mini watershed and update the zoning logic in case of conflicts. The surface water flows are a crucial part to identify the amount of water flowing intra- and across zones, so my task is to build a framework to identify the partitions called as regional decomposition of the village area. This was based on watershed principles, using points representing the intersection of village boundary and stream network and other points representing potential water storage structure locations. This also brings us to a need of identifying when water storage structures will get filled for which the stream-flow simulation framework is designed which will output the capacity of CNB at daily interval based on CNB, watershed and channel parameters. The stream forms one of the core water resources and is likely to impact the area around it concerning soil properties, cropping pattern, and farming practices. Our work aims at building proximity maps based on the order of the stream and elevation from the stream segment as the approaches to form the buffer around the stream network representing the area of impact around the stream.

Keywords: *GIS, Agriculture, Water, Soil, Stream, Zones, Watershed*

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List of Abbreviations

QGIS	Quantum Geographic Information System
PoCRA	Project on Climate Resilient Agriculture
MRSAC	Maharashtra Remote Sensing Application Centre
NBSSLUP	National Bureau of Soil Survey and Land Utilisation Planning
LULC	Land Use and Land Cover
DEM	Digital Elevation Model
ET	Evapo -Transpiration
AET	Actual Evapo -Transpiration
PET	Potential Evapo -Transpiration
SM	Soil Moisture
WP	Wilting Point
FC	Field Capacity
ESP	Eliminate Sliver Polygons
TAW	Total Available Soil Water
RAW	Readily Available Soil Water
FAO	Food and Agriculture Organization
WALMI	Water And Land Management Institute
SWAT	Soil & Water Assessment Tool
GPS	Global Positioning System
GSDA	Groundwater Surveys and Development Agency
OGR	OpenGIS Simple Features Reference Implementation
MFD	Multiple flow direction
PMU	Project Management Unit
API	Application Programming Interface
MLP	Micro Level Planning
DPR	Detailed Project Report

Chapter 1

Introduction

1.1 Objective

Govt. of Maharashtra, in partnership with the World Bank, has conceptualized the PoCRA (Project on Climate Resilient Agriculture) for about 5000 villages in 15 districts of Maharashtra. The PoCRA aims at achieving farm resilience, through improved water availability, agricultural practices and soil health.

Our work aims at understanding, analyzing and improving the existing water balance tools for practices like zoning, stream proximity maps, water balance application, regional decomposition, stream flow simulation and related data analysis and incorporation of those in the implementation of current water balance framework. The big picture of the work is focused on providing tools and efficient agricultural practices especially those connected with water. Those will not only help the administrators in making effective decisions or advisory support but will also help the farmers in optimizing the cost and resource utilization. This will be done given diverse agricultural practices studied taking into account the farmers of Maharashtra.

1.2 Background

This section will give a brief overview of PoCRA project; then we will have a rough outline of point-wise and regional water balance. It will also explain the stream and watershed theory and the overall PoCRA planning approach.

1.2.1 PoCRA project information

The Project on Climate Resilient Agriculture (PoCRA) is a World bank funded Government of Maharashtra project. The scope of this project is as shown in fig.1.1. It aims at providing climate resilience by providing adequate water access, which is likely to stabilize their yields and improve profitability. The goal of the project is to improve the efficiency of water, resulting in better crop yield and should be able to cater to the field needs in case of adverse climatic conditions.

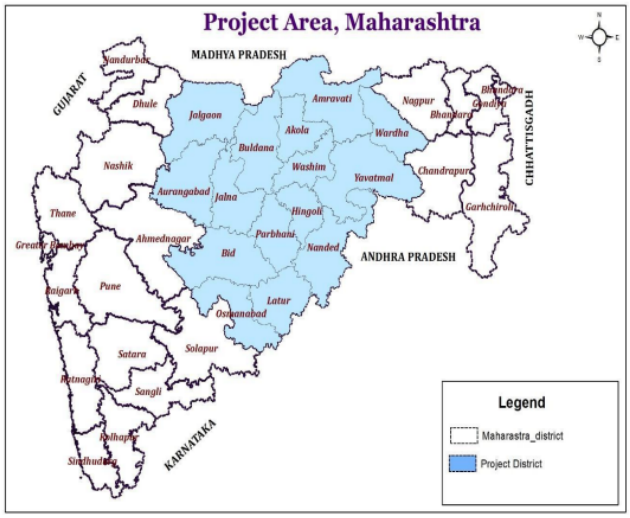
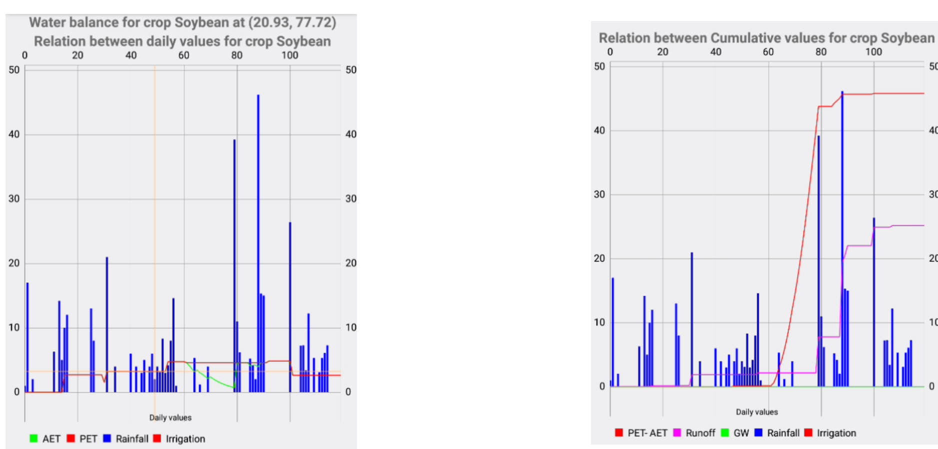


Figure 1.1: Project Districts of PoCRA [4]

1.2.2 The Point-wise water balance

The pointwise water balance is the methodology to calculate the water budget at the point level, which is a farm. The water budget is the calculation of the division of rainfall on a given area in terms of infiltration which is groundwater recharge and soil moisture, runoff which is water flowing out of the farm boundary, amount of water taken by crop which is evapotranspiration. Generally, a crop needs 400mm water, and say the rainfall is 600mm and if we are doing cropping of 800 mm (rabbi + Kharif) then additional 200mm water is required, or half of the rabbi is to be taken, i.e., half land under a rabbi and full land under Kharif. This crop water requirement is to be met on time or a dry spell is noted. The difference between the demand and supply of water for a particular crop is its water deficit or crop stress shown as the area between green and red line in fig.1.2. So, water budget answers what kind of cropping and water availability mapping is possible, and this helps the farmer and officials to decide the village/farm level cropping pattern (proposed).



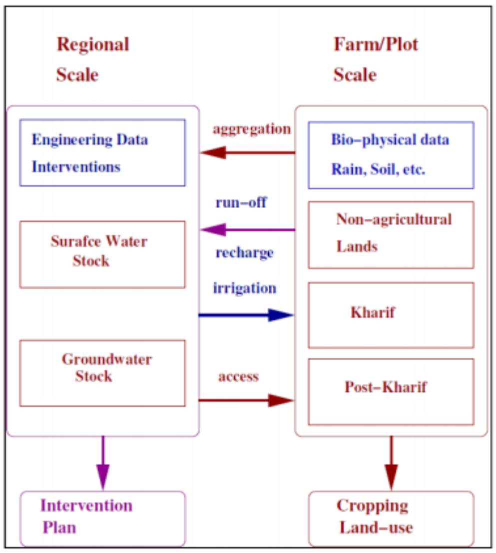
(a) Daily Values For Soyabean Crop

(b) Cumulative Values For Soyabean Crop

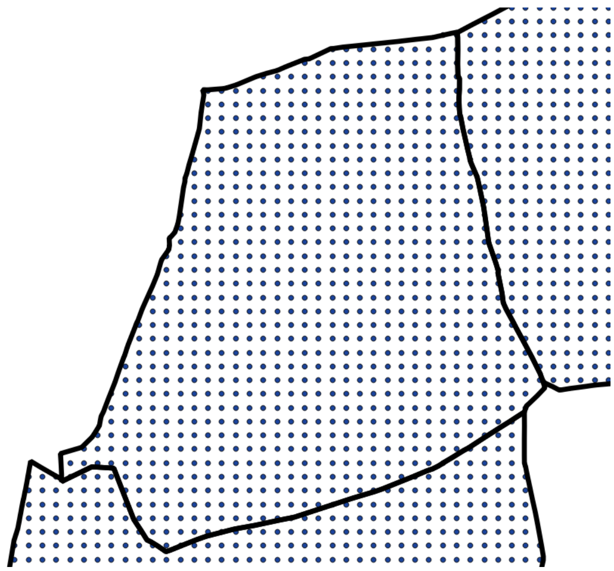
Figure 1.2: Output graph Generated based on User & Server Inputs

1.2.3 The Regional water balance

The point level iterator is run on 100m interval in each zone of the village and is aggregated at the zone level as shown in fig.1.3b. The output is the zone level water balance. The criteria for deciding the area on which aggregation to be performed is on a watershed basis, which is discussed later in detail. The regional water balance can be generated at cadastral, zone, village level, and appropriate plans can be developed.



(a) Farm and Regional level water balance planning [23]



(b) Sampling Points on GIS for aggregation

1.2.4 Stream and Watershed theory

The Stream is one of the important resources of water availability. The attributes associated with the stream are length, order which is a number assigned to stream segment based on its relative size, width, etc. The proximity to stream shows different soil and water viability characteristics and thus form an essential factor of identifying stream and nonstream zones around the streams. Watershed is the area of land through which water flows across the region and drain into a collective water body as shown in fig.1.4. The point established at such drain points can answer the availability of water at that location and so form the potential water storage structures. The differential watershed is the area in which the water to that point is not part of any of its predecessor drain points. Watershed is generally used in a water budget model for zoning and are used as a basis to depict the water availability in that area.

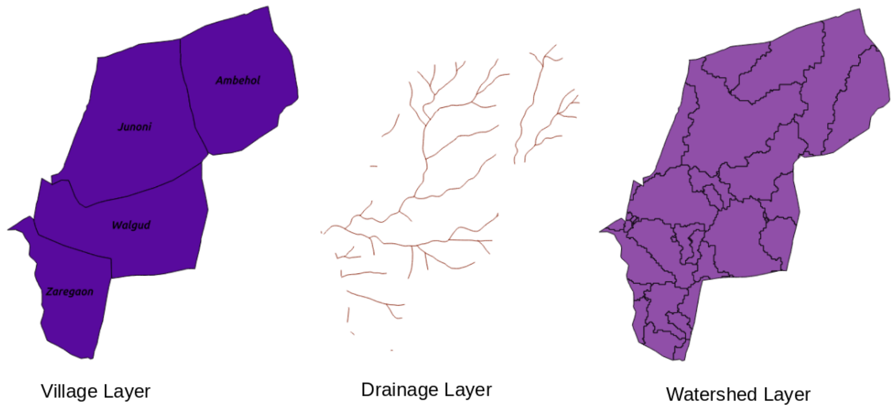


Figure 1.4: Village,Drainage and Watershed Layer

1.2.5 The PoCRA planning approach

Initially, the water balance plugin is run, which takes slope, land use, zones, rainfall, soil type, etc. as input and provides water indices like demand and supply of crop, groundwater recharge, water deficit at the zone level. Here, the zones can be assumed as the partition of village area based on a watershed basis. This zone level information is then fed to in the micro-planning application. The village level officials perform a seven-day micro planning procedure which includes mapping of village assets and feeding the water balance related information in the micro-planning app. This information includes population, structure, and most importantly cropping pattern information. The cropping pattern information gives us the idea of the area under each crop, which is used to generate a village level water budget in TCM. Based on the amount of runoff generated and the proposed and allowed interventions, the water deficit is tried to be tackled. This also involves tuning of runoff and groundwater parameter results to match the ground truth.

1.3 Key contributions

We will look into the key contributions of my work which are as below:-

1. Improvements in point-wise water budget application.
2. Analysis of MLP data, charts.
3. Validation of MLP data and implementation of soil app.
4. Automation of zones.
5. Regional analysis for surface water flows.
6. Streamflow simulation framework.
7. Stream Proximity maps.

1.3.1 Improvements in point-wise water budget application

Our work involved updating the existing point level water budget application with logical and utility features. The app takes the farm location as the input and fetches from the Postgres database server the associated parameters concerning the selected farm. The fetched parameter include soil type, slope, soil depth, land use, etc. The cropping pattern, irrigation amount, and rainfall year are the variable parameters given as the input. Based on these input values graphs and summary values are generated as shown in fig.1.5. The crop water deficit is the key parameter output, which is the difference between demand and supply for the input crop. The graph represents the amount of rainfall and the respectively associated water deficit with other parameters like PET, AET, runoff, groundwater recharge, etc. Similarly, cumulative values are also provided in a separate graph. The summary table gives the numerical values of the above water indices, and the respective associated dry spell is displayed. The dry spell is a period of unavailability of the water. The improvements include providing crop end summary values, updated sowing logic, local storage of daily values for the associated parameters, terracing, and other utility features, details of which are explained in the subsequent sections.

Summary Values

Parameter	Monsoon End	Crop End
Rainfall	509 mm	428 mm
Runoff	58 mm	25 mm
Total Crop AET	339 mm	339 mm
Soil Moisture	93 mm	66 mm
GW Recharge	0 mm	0 mm
Total Deficit	46 mm	46 mm

(a) Monsoon and Crop End Values

Sowing Date: 15-06-2017

Dry Spell 1: From 18/06/2017 to 25/06/2017
Dry Spell 2: From 10/08/2017 to 18/08/2017
Dry Spell 3: From 31/08/2017 to 08/09/2017
Dry Spell 4: From 24/09/2017 to 05/10/2017

(b) Dry Spell Dates

Figure 1.5: Summary Output Generated based on User & Server Inputs

1.3.2 Analysis of MLP data and charts

The micro planning activity discussed earlier is expected to produce village summary plan. Our work is to integrate the water balance plugin output, and the additional parameters like cropping pattern, structure, population generated from the micro-planning activity. This integration results in the generation of a database which can produce graphs related to cropping area, runoff, rainfall, etc. and is displayed at village level in the form of charts as shown in fig.1.6. This helps the villagers to understand the overall village water-crop scenario and to change the cropping pattern accordingly to cater to the water deficit if any. This exercise involves a lot of cleaning and validation of data generated from the ground level activity and making it compatible enough to be integrated with the existing water balance plugin output.

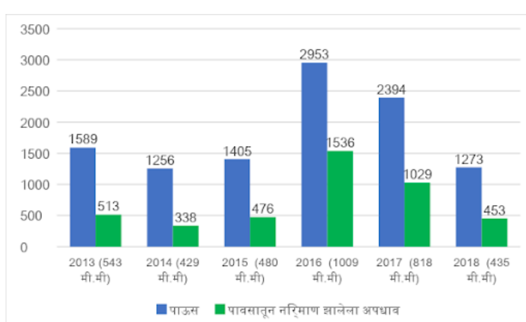


Figure 1.6: Rainfall Runoff Graph for 6yrs

1.3.3 Implementation of soil app

Soil data forms a crucial parameter in the water budget results. The more is water holding capacity of the soil more is the runoff, and less is the groundwater recharge. This work aims to analyze the soil type used in the model and the actual ground values and their respective impact. It was found that the model soil values taken from MRSAC have more clayey content resulting in the less groundwater recharge and more runoff. The outputs are so tuned in the water budget to meet the ground truth. This brings us to the need of resampling the soil data which will be now done by NBSS&LUP in their new MoU signed with PoCRA, GoM. Our work is to build a soil sampling application as shown in fig.1.8 which will take the soil and other related data as input as perceived by the farmer who will be used to interpolate at a broader scale concerning the NBSS&LUP data. This will act as a validation of the primary data from the secondary data.

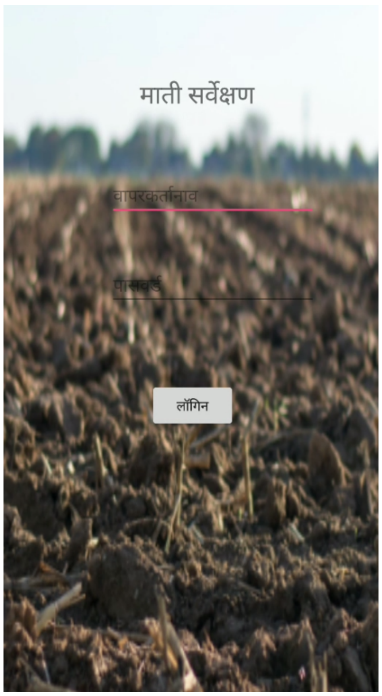
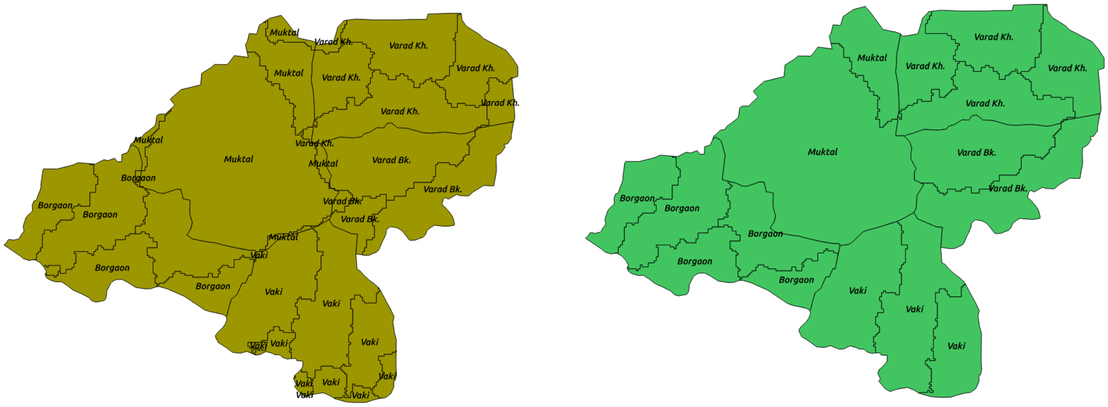


Figure 1.7: Login Soil

Figure 1.8: User Input 1

1.3.4 Automation of zones

Recall that the water budget fed into the MLP plan during micro planning activity has zone level water balance. These zones are nothing but the spatial variations of the area being captured to distinguish them from other zones. The parameter for zoning is mini-watershed. A procedure is formulated to build zones as shown in fig.1.9 given a DEM and cluster boundary as the input. The conflicts in the previous zoning procedure are handled by assigning an additional merging parameter to zone in the recent approach. The details of zoning can be found in the subsequent sections.



(a) Jalgaon Cluster Before Zoning (b) Jalgaon Cluster After Zoning

Figure 1.9: Final Jalgaon Cluster Results of Zoning Automation

1.3.5 Regional analysis for surface water flows

The methodologies or tools discussed so far involved computations at a point level and did not take regional or intra-zonal flows as the parameter in the model. Regional decomposition tries to formulate a procedure to divide the administrative boundary into partitions as shown in fig.1.10 such that the points triggering partitions have special importance. This point is inlet or outlet points of village representing the water flow within or out of the village. Some points are marked on the stream network, which is potential water storage structure locations. So this methodology takes DEM and cluster boundary as the input and provides a framework for identifying such partitions within the village.

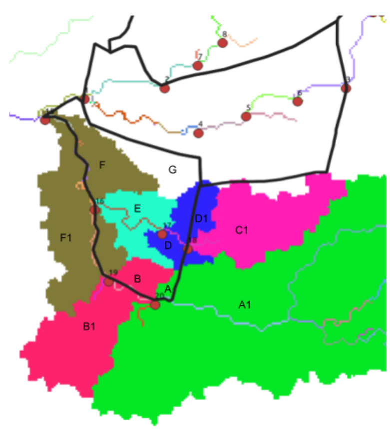
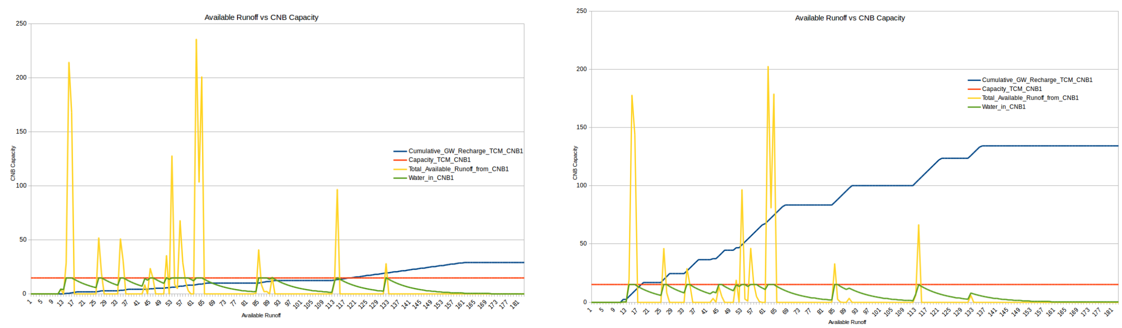


Figure 1.10: Zonal Decomposition of Zaregaon Village

1.3.6 Stream flow simulation framework

Once such regional decomposition is obtained, the water storage and levels of the points representing potential water structure locations are to be identified. It means to answer when will a particular water storage structure like CNB will be filled based on a mathematical model as shown in fig.1.11. This model takes point and other water balance parameters as the input. The other parameters are a differential watershed, channel dimension between the points. This outputs a graph which depicts how many times the water structure is full, or it's capacity at each time interval, which is till crop or monsoon ends.



(a) CNB_1 Capacity vs Available Runoff-Clayey Soil (b) CNB_1 Capacity vs Available Runoff-Gravelly Soil

Figure 1.11: Available Runoff vs CNB Capacity for CNB_1

1.3.7 Stream Proximity maps

The proximity around the stream helps to identify potential locations of wells, as the proximity will have more water availability. A buffer generated around the stream and is expected to have different soil, cropping, and water holding characteristics than that of non-stream zones. The maps are generated on two criterion's viz. stream order and elevation. The procedure for both of the parameters is formulated. The order is the relative size of the stream, so higher the order higher is the buffer. The elevation parameter answers how wider the buffer will be to have water in the area and its respective associated wells as shown in fig.**??**.

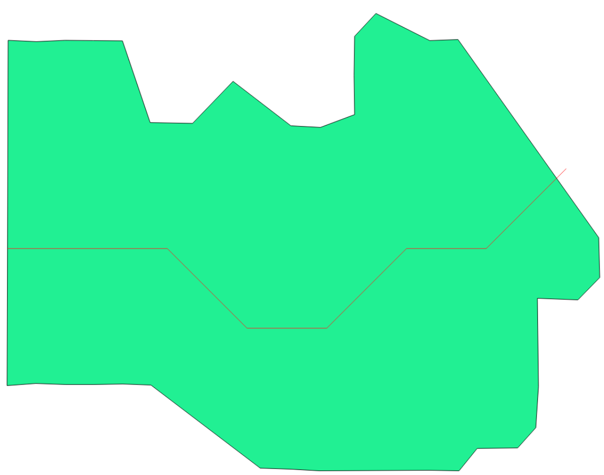


Figure 1.12: Buffers Merged

1.4 Chapter Organization

Chapter 1 will give a brief introduction to the problem statement and workflow.

Chapter 2 will provide a brief overview of Maharashtra Project on Climate Resilient Agriculture henceforth referred to as PoCRA. We will focus on its objectives, scope, and various components involved in the project and the expected outcomes from the same. This forms the big picture of the overall work.

The concept of water balance, water budget, and its components are divided into three primary sections. **Chapter 3** will dwell into briefs of various aspects of water balance and the methodology involved in computing the respective water budget for the given set of inputs. We will also discuss the input and output components involved in the computation of the water budget. This will also involve a discussion about how GIS is used as the aggregation tool.

Chapter 4 will focus on the android application for water balance computation and further improvements in it. We will discuss the core utility features of the application and the use cases of it concerning village level planning and similar applications.

Chapter 5 will explain in detail the attributes involved in the water budget computations and their comparative results in last five years. This chapter will also put-forth the issues while gathering actual field data about structures, population, etc. and their cleaning methodology. The output of this exercise is the graphs displayed in chart format generated from the Postgres database having the required derived attributes and their comparison.

Chapter 6 is related to a methodology called Zoning in which we divide the area of interest concerning certain criteria like the mini-watershed for water balance computation. We will understand the need for zoning and the detailed methodology and its automation.

Data being the backbone of the water budget model its correctness concerning ground truth decides the accuracy of the results generated. **Chapter 7** will focus on the data required for water balance computation related to soil characteristics and cropping pattern. We will look into the need for such data, and it's analysis with a comparison of MRSAC and NBSS&LUP sources. The attributes of interest for comparison will be soil depth and surface texture. The integration of cropping pattern data from Mahabhulekh source will also be evaluated. This will also brief about its overall impact on water budget results and will explain the need of soil sampling application, and it's core utility features.

The update on the current water budget modeling framework concerning geography is about considering regional flows. **Chapter 8** will explain about the need and methodology of regional decomposition to answer the water flow and availability questions. This will primarily try to answer the amount of water coming into the administrative boundary, the amount of water percolated or used within the boundary and the amount of water that is being flown out of the boundary.

Chapter 9 will explain the concept of stream flow simulation. It is the consideration of the flow of stream in-order to analyze the water availability in the water storage structures concerning factors like storage capacity, percolation, length, etc.

Chapter 10 will focus on the formulation of a process to generate stream proximity maps. We will start with the basics of the stream, stream order, and stream proximity and the need for such maps. We will look into some sample examples of stream proximity and the process of generating those maps and discuss some of the possible advancements in the same. The two primary approaches for proximity based on stream order and elevation will be addressed.

Chapter 11 will conclude the work and summarize the future work of the project.

Note that this report is the integration of the thesis work done in both of the semesters. The detailed split up of work is as below:-

Sr.No.	Problem Statement	Phase I Work	Phase I Chapter/Section	Phase II Work	Phase II Chapter/Section
1	Water Budget Application	Critical Improvements	Chapter 4	Minor Improvements	Section 4.5.10
2	Water Budget Components	-	-	Complete	Chapter 5
3	Zoning	Zoning Methodology	Chapter 6	Polygon Merging Logic and Implementation	Section 6.4.1, 6.7.1, 6.6.3 and 6.6.4
4	Data Analysis for Water Budget Improvement	Complete	Chapter 7	-	-
5	Regional Decomposition for Water Budgeting Purpose	-	-	Complete	Chapter 8
6	Stream Flow Simulation	-	-	Complete	Chapter 9
7	Stream Proximity	Stream Order based Proximity	Chapter 10 (till Section 10.4.1)	Elevation based Proximity, Stream Order based Proximity Automation	Chapter 10 (Section 10.4.2)

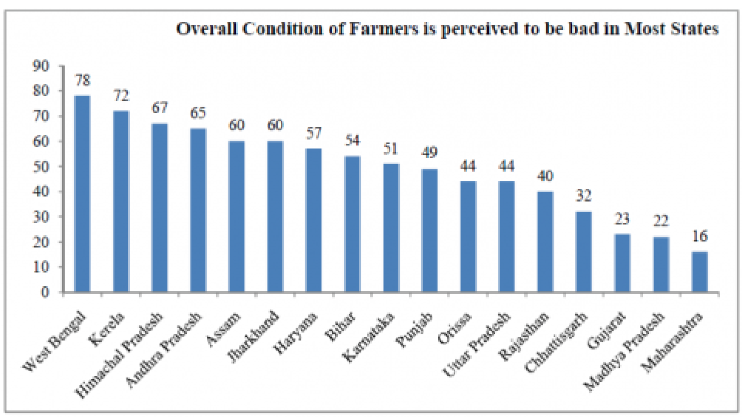
Table 1.1: MTP Phase-wise Work Division

Chapter 2

Project on Climate Resilient Agriculture (PoCRA)

2.1 Background

According to Economic Survey of Maharashtra 2017-18, Maharashtra accounts for 9.3% of the total country population and 9.4% of the total geographical area of the country[5]. Being the third most populated state and agriculture as the primary source of livelihood we need to carefully examine the system of farming with respect to its productivity, threats, and labor involved.



Note: All figures are in percentage.

Figure 2.1: Overall Farmer Condition [6]

According to a survey by the Centre for the Study of Developing Societies (CSDS), Delhi, and released by NGO Lokniti, "State of Indian Farmers: A Report", conducted in 274 villages spread over 137 district of 18 Indian states it has been found that Western and Central India farmers are least unhappy with the farmers' condition as on 2015[6]. But due to lack of climate resilience and unsound farming practices the condition is deteriorating at a higher rate. In Maharashtra, Vidarbha and Marathwada region are particularly vulnerable for this kind of phenomenon.

The problems which farmers generally face are as below:-

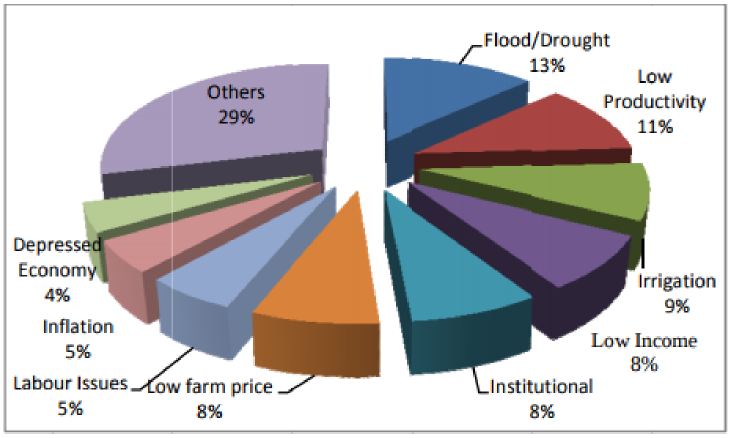


Figure 2.2: Biggest Problems Faced by farmers [6]

The land wise distribution constitutes 60% of the small farmers and so issues related to growing water scarcity, degrading land resources, increased cost of cultivation, stagnant farm productivity, and the impacts of climate change need to be systematically addressed in order to achieve not only sustainability and profitability of smallholder farming system but also to reduce the distress among the farmers. It is under this backdrop that the Government of Maharashtra, in partnership with the World Bank, has conceptualized the Project on Climate Resilient Agriculture (PoCRA) for about 5000 villages in 15 districts of Maharashtra[4].

2.2 Objective

The vision of the project is to scale up the technologies and practices related to agriculture.

Below are the prime objectives of the PoCRA project[4]:-

1. Enhancing the availability of water at the farm level
   (a) through the adoption of latest technologies for increasing water use efficiency in agriculture, increase in surface water storage capacity, groundwater recharge, and in situ water conservation to address on-farm water availability and reduce the risks associated with intra-and inter-seasonal climate variability
2. Improving the health of the soil
   (a) through the adoption of good agricultural practices to improve soil fertility, soil nutrient management, and promotion of soil carbon sequestration
3. Improving the productivity of the farms
   (a) through the adoption of climate-resilient seed varieties (short maturity, drought resistant, salt tolerant) and market- oriented crops with a clear potential for income security derived from the integration of farmers in corresponding value-chains.
4. Crop Diversification

Our work will be in compliance with objective 1 and 3 given above which are related to water availability and productivity in the farming.

2.3 Scope of the Project

The proposed project will be implemented in 8 districts of Marathwada (Aurangabad, Nanded, Latur, Parbhani, Jalna, Beed, Hingoli, Osmanabad), 6 districts of Vidarbha (Akola, Amravati, Buldhana, Yavatmal, Washim, Wardha) and Jalgaon district of Nashik Division. In these districts, the project will cover about 4000 villages characterized by high climate-vulnerability [4]. The project will also include about 1,000 villages located in the Purna river basin and showing high levels of soil salinity and sodicity. These villages are spread over Akola, Amravati, Buldhana, and Jalgaon districts.

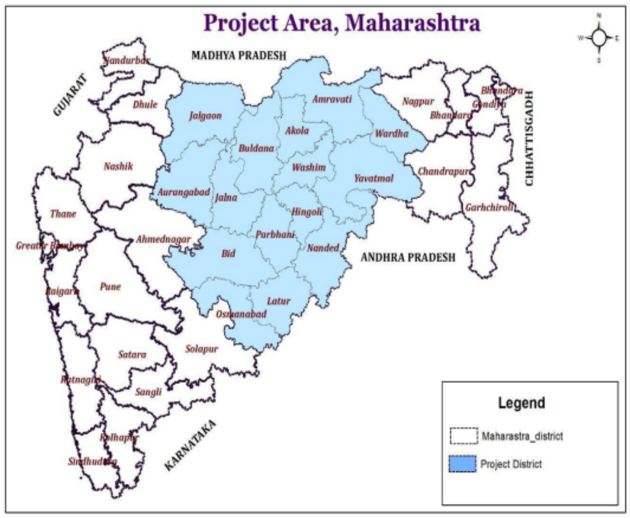


Figure 2.3: Project Districts of PoCRA [4]

2.4 Input Output Components

Following are the Primary Components of the PoCRA project[4]:-

1. Promoting Climate-resilient Agricultural Systems
   - (a) Participatory development of mini watershed plans.
   - (b) On-farm climate-resilient technologies and agronomic practices.
   - (c) Climate-resilient development of catchment areas
2. Climate-smart Post-harvest Management and Value Chain Promotion
   - (a) Strengthening Farmer Producer Companies
   - (b) Strengthening emerging value-chains for climate-resilient commodities
   - (c) Improving the performance of the supply chain for climate-resilient seeds
3. Institutional Development, Knowledge and Policies for a Climate-resilient Agriculture
   - (a) Sustainability and institutional capacity development
   - (b) Maharashtra Climate Innovation Centre
   - (c) Knowledge and policies

Input data required for our scope of the project primarily comprises of-

Sr No	Data	Source
1	Cluster Boundary	MRSAC
2	LULC	MRSAC
3	Soil	MRSAC
4	Cadastral Map	MRSAC
5	Cluster Boundary with zones	Processing
6	Slope	Processing
7	Rainfall	maharain.gov.in
8	DEM	SRTM,earthexplorer.usgs.gov

Table 2.1: Data Requirement for PoCRA

2.5 My Work

Figure 2.4 represents the adopted system architecture for PoCRA project. The goal is to understand and refine if required the water budget model and datasets while collaborating with different agencies like MRSAC and Skymet for improved data availability and integrate those in the current water budget framework. This will enable more accurate spatial and temporal measurements of crop deficits and regional supply for better planning. The two primary components which I am part of are Zone Creation and Farm-Based Application. It can be seen in the architecture that depending on various inputs like LULC, Soil, Slope the zones are created and respective zone wise budget is generated. The creation of zones to capture the spatial variations thus is the crucial activity in the water budgeting framework. Using the SWAT based soil water balance model the Farm based application is built giving outputs at the granularity of farm. We will see in further chapters in detail the need for zoning and the farm-based application for water budget computation framework.

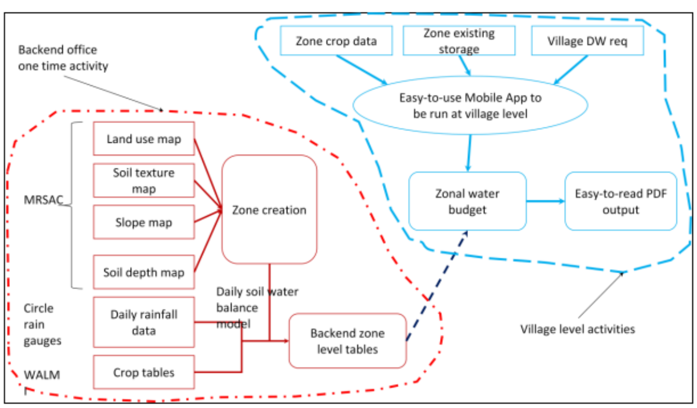


Figure 2.4: Pocra Architecture [23]

2.6 Methodology & Outcomes

The requirement is to design a series of tools to help answer core questions of water availability assessment and water balance using both supply-side analysis (surface water, soil moisture, and groundwater) as well as demand side analysis (PoCRA Objectives). The output of the framework will be fed into the micro watershed-level climate resilient plans development for the targeted 500 micro-watersheds of PoCRA.

Data	Processing	Output
Cluster Boundary	Project the cluster boundary with number of villages.	Cluster Shapefile with required spatial extent.
LULC	Using the cluster shapefile clip the LULC layer	LULC layer with require spatial extent.
Soil	Using the cluster shapefile clip the soil layer	Soil layer with required spatial extent.
Cadastral Map	Using the cluster shapefile clip the Cadastral layer	Cadastral layer with required spatial extent
DEM	Extraction of sub watersheds or zones from Dem	Zone layer with required spatial extent
Cluster Boundary with zones	Intersection of cluster boundary and zone layer	Cluster boundary with number of zones
Slope	Extraction of slope layer from Dem	Slope layer with required spatial extent.
Rainfall	Year rainfall data in CSV format per day	Rainfall CSV file

Table 2.2: Pre-Processing of Data

2.6.1 Pre-Planning

The methodology in below figure is for the plugin built for the water budget computation which is executed over entire zone. The same methodology with a different technical stack is implemented in the Farm level android application. The Farm-level application is basically a boiled down version of the plugin developed with respect to the area covered and outputs delivered. The details of the water balance point model are provided in the next chapter.

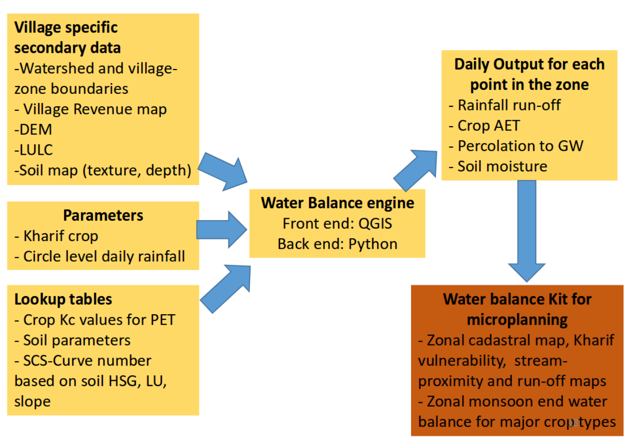


Figure 2.5: Methodology adopted- Pre-Planning [19]

2.6.2 Water budget and Planning

It comprises the use of zone-based vulnerability, proximity and runoff maps to provide the necessary interventions to improve the current farming and water-related scenarios.

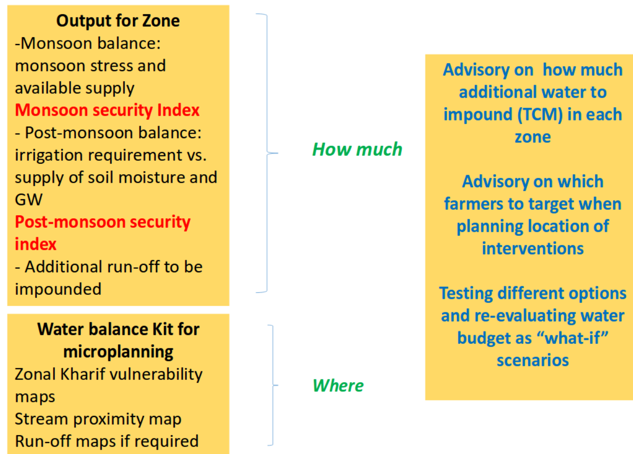


Figure 2.6: Water Budget and Planning [19]

2.7 Proposed Outcomes

1. Identification and targeting of naturally vulnerable farmers
2. Better choice, siting and better utility from interventions
3. Better coverage of the entire village, uniform benefits
4. Focus on assuring protective irrigation to improve yields
5. Better land use and overall water availability including DW (Drinking Water)

Chapter 3

Understanding Water balance

3.1 Objective

The objective is to understand the hydrological cycle. The aim is to assimilate the concepts and tools build to answer core questions of water availability assessment and water balance using both supply-side analysis (surface water, soil moisture, and groundwater) as well as demand side analysis. The Outputs will be fed into watershed development plans for the cluster.

3.2 Water Budget Concepts

The hydrological cycle forms the basis of the water budget. Its key components can be classified in stocks and flows, where the ground water and soil moisture are stocks and precipitation, surface runoff, ground and water discharge, evapotranspiration from vegetation, evaporation from stored surface water are flows. The total amount of water in the hydrological cycle is conserved due to mass balance, which forms the central principle of the water budget.

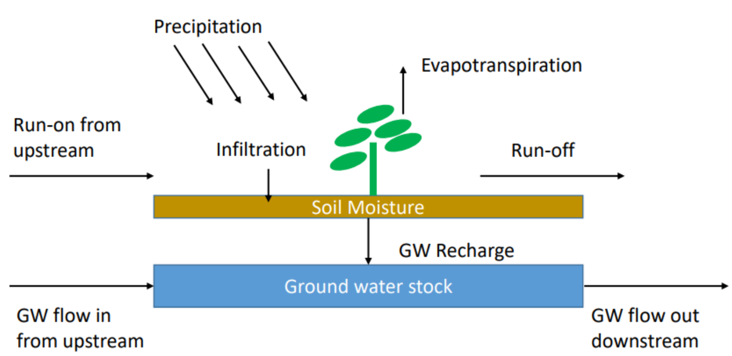


Figure 3.1: Components of water balance [18]

Evapotranspiration or ET
The combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration is referred to as evapotranspiration (ET). Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes.

Reference evapotranspiration or ETo
The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ETo. The reference surface is a hypothetical grass reference crop with specific characteristics. FAO Penman-Monteith method is recommended as the sole standard method for the definition and computation of the reference evapotranspiration.

Reference evapotranspiration surface
The reference surface is a hypothetical grass reference crop. The reference surface closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground.

Crop evapotranspiration (ETc)
The crop evapotranspiration differs distinctly from the reference evapotranspiration (ETo) as the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. The effects of characteristics that distinguish field crops from grass are integrated into the crop coefficient (Kc). In the crop coefficient approach, crop evapotranspiration is calculated by multiplying ETo by Kc.So ETc = Kc * ETo

Single crop coefficient approach (Kc)
The Kc predicts ETc under standard conditions. This represents the upper envelope of crop evapotranspiration and represents conditions where no limitations are placed on crop growth or evapotranspiration due to water shortage, crop density, or disease, weed, insect or salinity pressures. The ETc predicted by Kc is adjusted if necessary to non-standard conditions, ETc adj, where any environmental condition or characteristic is known to have an impact on or to limit ETc.

3.3 Sample Water Balance Model

The below model in Figure 3.2 explains the primary components of the water balance model. It explains how rainfall is converted into evapotranspiration, surface runoff and groundwater flows. In all water balances, there is a chosen boundary and flows across these boundaries need to be estimated. The boundary can be the land surface of the chosen area like farm, village, watershed or it can be soil layer just below the surface or the shallow or unconfined aquifer which starts below the soil layer. There is further division of runoff and groundwater flows into sub-components like runoff impounded, infiltration,base-flows, etc and their respective computation methodologies but the toy model should give a basic idea about how the overall water balance is conserved in the hydrological cycle.

Rainfall	859 mm/yr
Runoff	192 mm/yr
Evapo-transpiration	532mm/yr
Groundwater flows	135mm/yr

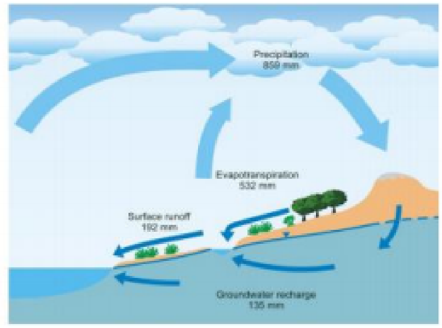


Figure 3.2: Simple Toy Model Germany [23]

3.4 Methodology of water Budgeting

Kharif vulnerability analysis:

As Figure 3.1 shows, the main components of the water balance for Kharif season are: Precipitation, runoff, soil moisture content, crop evapotranspiration, and groundwater percolation. An important component of the water balance model is surface runoff which needs to be computed based on the land use and rainfall data. Based on the inputs of daily rainfall, LULC for the watershed, cropping pattern, soil texture, soil thickness, and slope, we identify Kharif stress zones within the agricultural farmland and compute the extent of crop stress as defined by the difference (in mm/day) between its potential evapotranspiration load and the actual evapotranspiration (PET minus AET). The Kharif stress zones are identified assuming a default cropping pattern that is standard for the region and not based on actual Kharif cropping pattern since that would reinforce existing conditions (social or material) in Kharif demand. This exercise will help identify which zone within the village are most impacted during Kharif dry spells and the estimated extent of protective irrigation that may be required depending on the rainfall pattern. To compute the baseline Kharif water balance, the actual spatial cropping pattern is used which is done using a spatial land use input file that differentiates between single cropped, double cropped and perennial cropped areas as separate zones.

The Kharif vulnerable zone model:

The Kharif vulnerable zone model estimates various flows and crop water requirement at a given point on a daily basis during the Kharif growing season.

The Kharif point model is the core of the framework. Its role is to conduct a daily water balance for a point location with given soil properties and land use input. Given daily rainfall data, this tool models run-off, soil moisture level, actual crop evapotranspiration (AET) and groundwater percolation on a daily time-step. There are two classes of models which may be used for such a model. The first option is a step-wise model where the first run-off is calculated, and then evapotranspiration and then finally, groundwater infiltration. The second is a composite model where all are calculated at once with dependence on one another. Most models differ in their input requirements and their focus on either of the flows. We have adopted a daily composite model which is implemented as a spreadsheet and which is an adaptation of SWAT 2009 [7].

Following is a description of how various flows are computed in the model:-

Run-off calculation

The Kharif model works at a daily time step. Daily rainfall input is given. A daily curve number and retention factor is computed based on fixed parameters (soil HSG, slope, and land-use type) and a variable parameter (soil moisture at the start of the day) [Ref: USDA TR-55, SWAT theoretical documentation 2009]. This is used to compute daily surface run-off. The methodology being used for run-off calculation is the SCS curve number method wherein a daily curve number is computed based on the daily soil moisture levels. The methodology used is the same as that used by SWAT. The methodology also incorporates slope. The SCS Curve number methodology based on the calculation of daily curve number is the preferred method used by standard software such as SWAT. They are applicable to Indian condition when we customize the input values for parameters such as soil profile (clay content, sand content, organic matter etc.), crop PET requirement etc. [10,11]

Crop evapotranspiration calculation

Once the run-off is calculated, the remaining water content infiltrates the soil. The actual crop evapotranspiration (AET) for the day is computed based on the available soil moisture at the start of the day and the crop's potential evapotranspiration (PET) requirement. PET is the potential evapotranspiration load of the crop. There are many methods experimental as well as theoretical that are used to estimate the crop PET for a given crop and climate conditions. The Pan evaporation method is an experimental method used to calculate the evapotranspiration load of a reference crop (grass) under monitored climatic conditions. The Penman-Monteith equation uses daily temperature, humidity, radiation, wind speed etc [12].

Also, Blaney-Criddle is a simplified method which used the only temperature and sunshine hours as input. However, this method too has its limitations and may not be too accurate. None of these methods appear to be a good approximation for the PoCRA target districts. This is because the total crop ET load appears to be in excess of the crop ET load published by WALMI [13,14] for crops sown in Maharashtra. Hence, our model is based on the modified Blaney-Criddle method (altered to match WALMI crop ET load) which may be updated with experimental data when obtained through SAUs. To calculate the AET, it is first assessed whether the crop is under water-stressed conditions or not. A crop stress factor is calculated on a daily basis which is dependent on the soil moisture levels at the start of the day and soil properties of field capacity, wilting point and crop factors such as root zone depth and depletion factor. The standard methodology as described in the FAO crop evapotranspiration report is used to calculate AET [12].

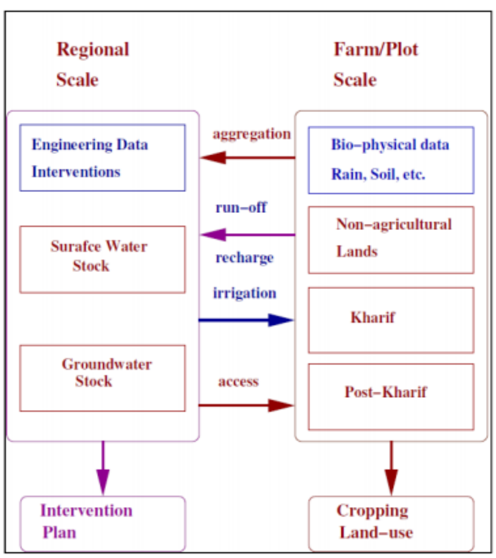
Percolation to ground water

Percolation from the soil layer to the vadose zone is calculated at the end of each day based on the soil moisture level. There is no percolation if the soil moisture is below field capacity. If the soil moisture exceeds field capacity, then the amount of percolation depends on the water available for percolation (soil moisture – field capacity) and a percolation factor that is a function of soil conductivity. The method being used is as used by SWAT [7]. The vadose zone is the unsaturated zone between the soil profile and the aquifer. For simplicity, this zone is not modeled. A time delay factor is used to estimate the change in groundwater levels due to the water percolated from the soil layer. The final soil moisture levels for the end of the day is calculated after accounting for the increase due to any rainfall and decrease due to crop AET and percolation. The end-of-day soil moisture level is then considered as the start-of-day soil moisture for the following day. This exercise is repeated for the entire Kharif season. The output is daily soil moisture levels, crop AET, and percolation to groundwater for the Kharif season.

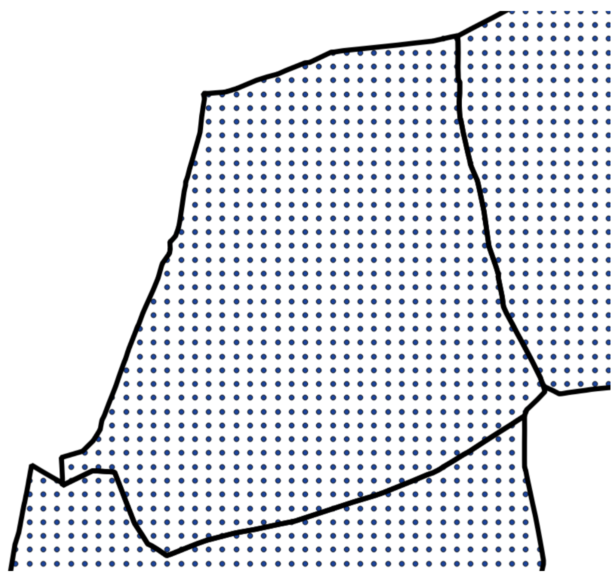
3.5 GIS as an Aggregation Tool

The demands at the farm level are about assuring Kharif crop, stabilizing and increasing crop productivity, increasing area under agriculture (rabbi and summer crops), shifting to more remunerative crops and so on. On the other side, there are climatic, geographical and other natural factors which control the supply side, like rainfall, its daily distribution, soils, geology, topography etc. which can be clubbed together as the biophysical supply side.

The budget is a combination, primarily of the farm-level soil water balance, and the run-off utilization at the zonal/regional level. In Figure 3.3a on its right side are farms and land parcels clubbed by land-use and biophysical attributes such as soil-types, daily rainfall data. This data is to be used to run the farm-level water balance wherein run-off, recharge as well as AET are estimated at the farm level which is where GIS comes into the picture. The GIS also helps in computing the aggregation of farm level results at 100m interval sampling points as shown in fig.3.3b. GIS helps in computation and representation of the farm-level stress and the protective irrigation demand. On the left are the key stocks of surface water and groundwater, which are essentially regional, and the engineering structures which harvest run-off and make these stocks available to the farmer. Thus GIS clubs all the computation outcomes and provide it at the granularity of required level in order to ascertain various allocation and location of interventions in the form of advisories.



(a) Farm and Regional level water balance planning [23]



(b) Sampling Points on GIS for aggregation

3.6 Outcomes

Below are the key parameters computed from the above-discussed water budget model:-

Summary Values

Parameter	Monsoon End	Crop End
Rainfall	509 mm	428 mm
Runoff	62 mm	27 mm
Total Crop AET	329 mm	329 mm
Soil Moisture	66 mm	47 mm
GW Recharge	41 mm	28 mm
Total Deficit	56 mm	56 mm

Figure 3.4: Parameters Computed From the Model

Chapter 4

Point Model Water Budgeting Android Application

4.1 Objective

Can we look at the farm and correctly predict it's status concerning its soil and crop requirement and other related features? Here, comes the need of an android application which takes minimal inputs like Farm location, cropping pattern, irrigation done(if any) and delivers results about the farm status in the form of values like Water Deficit, Rainfall, Runoff, AET, Soil Moisture, etc. The output results are given for both Crop and Monsoon End. It is likely to be beneficial for Krishi-Sahayak and to the administrators for village level planning. The Use-Cases of the Farm based Application can be seen in Section 4.5. How one can look at the farm and correctly predict it's status concerning its soil and crop requirement and related features? What if the same has to be done over the entire village and accordingly, decisions are supposed to be made? Here, comes the need of an android application which takes minimal inputs like Farm location, cropping pattern, irrigation done(if any) and delivers results about the farm status in the form of values like Water Deficit, Rainfall, Runoff, AET, Soil Moisture, etc. The output results are given for both Crop and Monsoon End. It is likely to be beneficial for Krishi-Sahayak and to the administrators for village level planning. The Use-Cases of the Farm based Application can be seen in Section 4.5.

4.2 Android Software Design

Figure 4.1 represents the approach used for developing the Android application and their corresponding needs are taken into account at various stages of development.

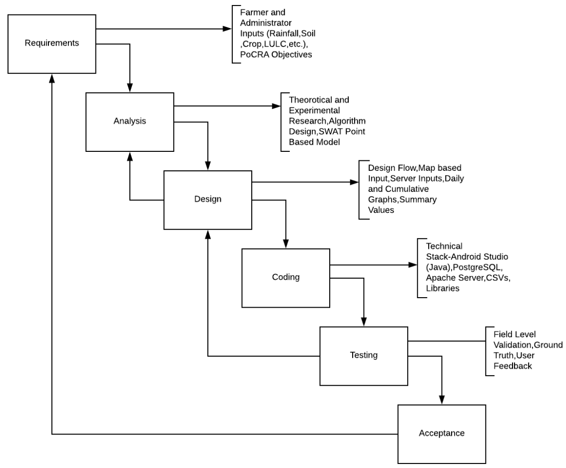


Figure 4.1: Software Design for Android Application

4.3 Context Flow Diagram

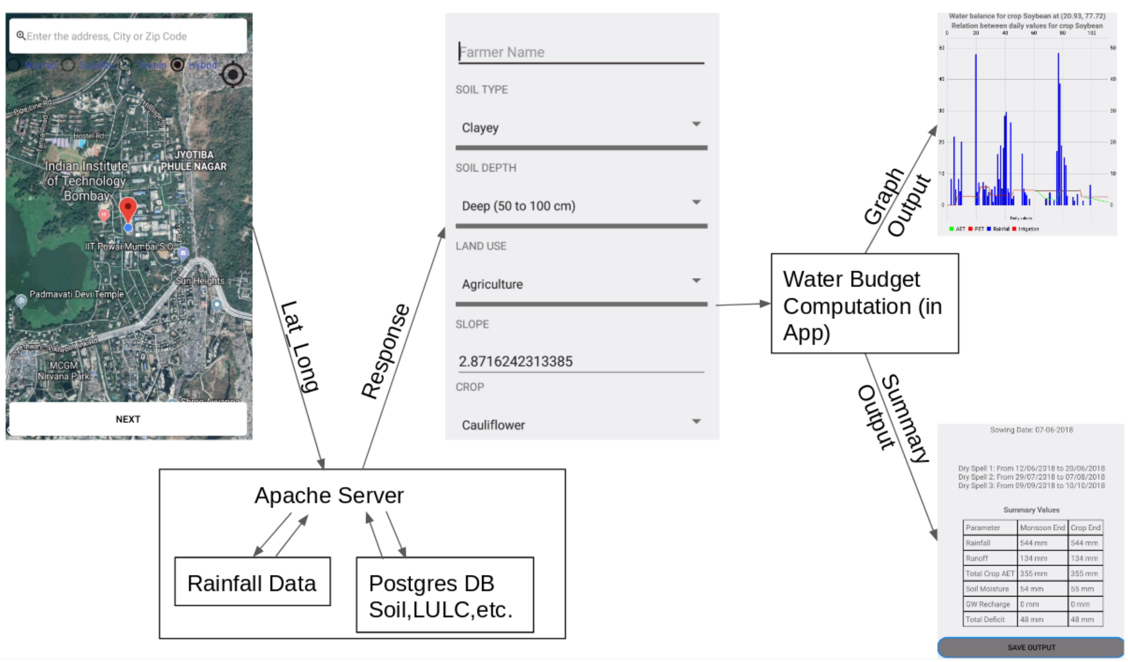


Figure 4.2: System Architecture and Context Flow

The Figure 4.2 represents the flow in which the outputs are generated based on given agriculture-related inputs. Initially, farm location is taken as input from the user (can be Krishi-Mitra, administrator, etc) with Google map/satellite as a reference. This location in terms of latitude and longitude is fed as input to the server and respective values for that corresponding farm are fetched from the server. Those values comprise of Soil Type, Soil Depth, Land Use, and Slope. Then additional information like farmer name, Crop, Irrigation count and amount of irrigation is taken as input from the user. This set of input is then fed to the water budget model calculator in the android application and respective graphs and summary values are computed for both monsoon and crop end. The output value primarily comprises of AET, Water Deficit, Rainfall, Runoff, Soil Moisture, and Ground Water Recharge. The visualization of the discussed steps can be found in the next section.

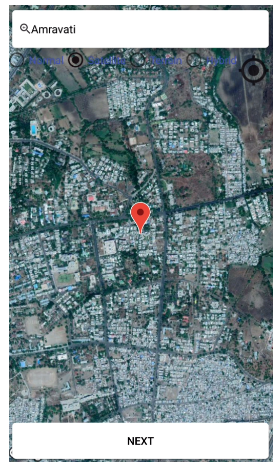
Sr. No.	**Parameter**	**Source**	**Data Source**	**Storage**
1	Soil Type	Server	MRSAC	Database
2	Soil Depth	Server	MRSAC	Database
3	Land Use	Server	MRSAC	Database
4	Slope	Server	MRSAC	Database
5	Crop	User	Farmer	Variable Input
6	Rainfall Year	User	Farmer	Variable Input
7	Rainfall Data	Server	Maharain	CSVs on Server
8	Farmer Name	User	Farmer	Variable Input
9	Irrigation Amount	User	Farmer	Variable Input
10	Number of Irrigation	User	Farmer	Variable Input
11	Farm Location	User	Farmer	Variable Input

Table 4.1: Organisation of key data

4.4 Core Utility Features of Android App

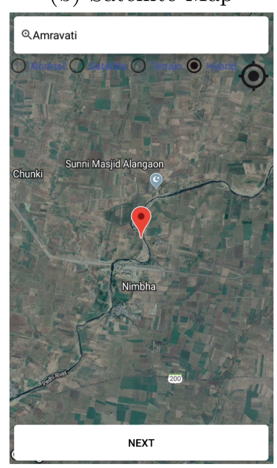
4.4.1 Map Based Input

(a) Normal Map



(b) Satellite Map

(c) Terrain map

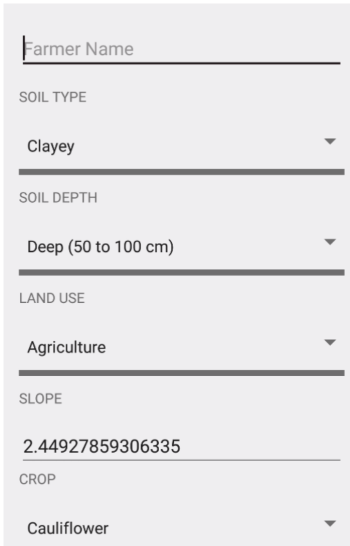


(d) Hybrid Map

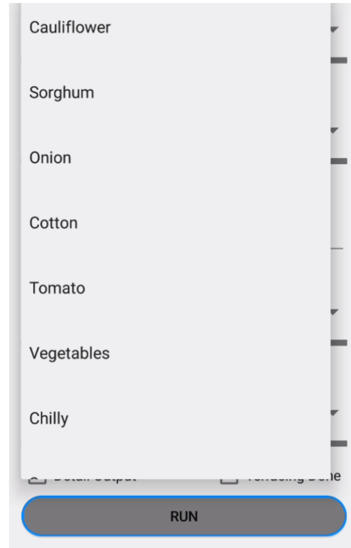
Figure 4.3: Different Maps for Farm Location Input

4.4.2 User Inputs

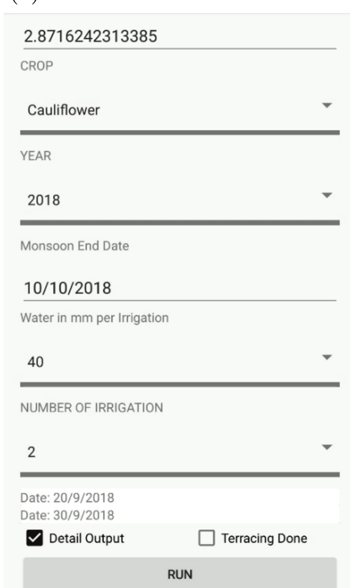
Below Figure 4.4 represents the option of having flexible inputs in-case the values fetched from server do not match with the ground truth or has to be altered for testing purposes. All the values fetched from the server can be changed and the model can be computed over the changed values. One option of terracing is added which basically means a sloping piece of land that has had flat areas like steps built on it so that people can grow crops there. If the given "Terracing Done" option is checked the slope value is set to zero for that model.



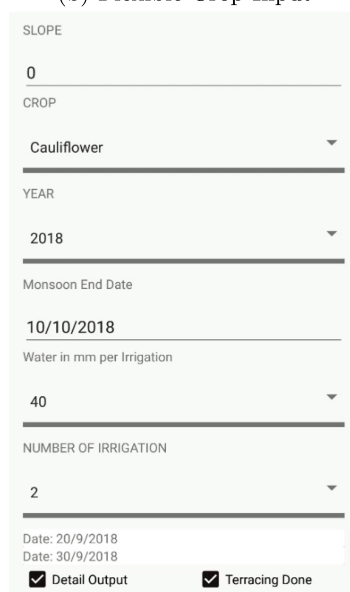
(a) Fetched Values From Server



(b) Flexible Crop Input



(c) Irrigation Count and Date Input

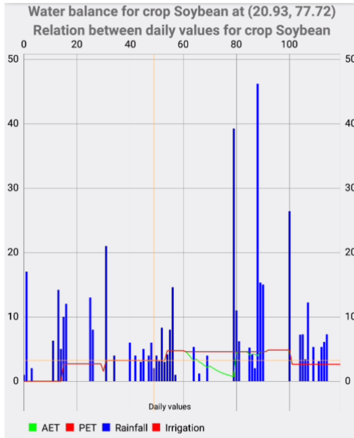


(d) Terracing and Monsoon End Date input

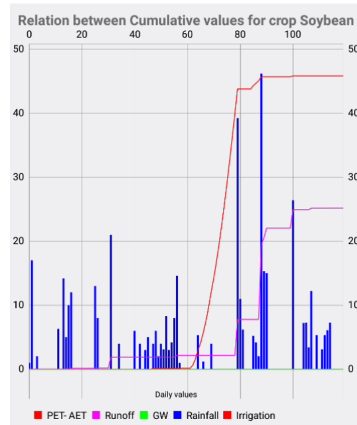
Figure 4.4: Flexible User and Server Based Inputs

4.4.3 Output graphs

Below Figure 4.5 indicates the daily and cumulative values for the Soybean crop. The attribute of interest is the difference in AET and PET representing the water deficit for that particular crop accounting to that many numbers of dry spells. The blue bars in Figure 4.5 represent the daily rainfall events. The red line represent the PET for the crop which is the daily demand of the crop. The green line represent the AET of the crop which is the actual water absorbed by the crop . The gap between the red line and green line is the water deficit.



(a) Daily Values For Soyabean Crop



(b) Cumulative Values For Soyabean Crop

Figure 4.5: Output graph Generated based on User & Server Inputs

4.4.4 Summary Values

Figure 4.6 represents the crop end and monsoon end summary values and respective dry spells. Dry Spell basically is a period having no availability of water for the agriculture. It is during the dry spell period that the other water storage measures like wells, farm ponds are to be utilized for continuing the agricultural processes.

Summary Values

Parameter	Monsoon End	Crop End
Rainfall	509 mm	428 mm
Runoff	58 mm	25 mm
Total Crop AET	339 mm	339 mm
Soil Moisture	93 mm	66 mm
GW Recharge	0 mm	0 mm
Total Deficit	46 mm	46 mm

(a) Monsoon and Crop End Values

Sowing Date: 15-06-2017

Dry Spell 1: From 18/06/2017 to 25/06/2017
Dry Spell 2: From 10/08/2017 to 18/08/2017
Dry Spell 3: From 31/08/2017 to 08/09/2017
Dry Spell 4: From 24/09/2017 to 05/10/2017

(b) Dry Spell Dates

Figure 4.6: Summary Output Generated based on User & Server Inputs

4.5 Improvements in Android Application

4.5.1 GPS Issue

When the GPS is made ON, it has some delay depending upon the location to fetch the GPS co-ordinates which may result in a crash of Android application in the previous version. This issue is now fixed in the current version with a workaround as, instead of crashing the application due to unavailability of the latitude and longitude, it restarts itself without any human intervention and crash messages, resulting into the smooth working flow of the android application and its related computations.

4.5.2 New Crops

The earlier water budget application did not consider the lands which are uncultivated. These include the wastelands, uncultivated agricultural lands and the lands with forests, shrubs, scrub and so on. A significant amount of the water infiltrated by these lands is available as groundwater and hence are important assets of a village as far as water availability is concerned. Below are the new crops added:-

(a) Rice

(b) Current Fallow Crop

(c) Forest

(d) Wasteland

(e) Scrub

4.5.3 Cumulative Groundwater Recharge

The cumulative output graph in the Android application now also displays the groundwater recharge done during the course of time in which the application is executed.

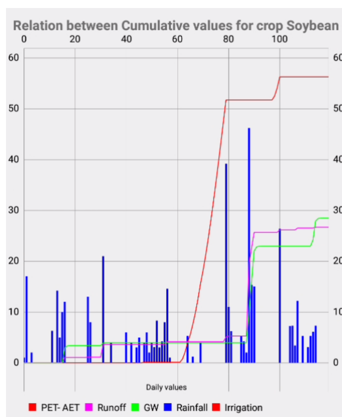


Figure 4.7: Ground Water Recharge for Soyabean

4.5.4 Crop End Summary Values

The output now also displays the crop end summary values which give us the fair idea of the status of the crop at the crop end period. Following are the values displayed for Crop End:-

1. Rainfall
2. Runoff
3. Total Crop AET
4. Soil Moisture
5. GW Recharge
6. Total Deficit

Summary Values

Parameter	Monsoon End	Crop End
Rainfall	509 mm	428 mm
Runoff	62 mm	27 mm
Total Crop AET	329 mm	329 mm
Soil Moisture	66 mm	47 mm
GW Recharge	41 mm	28 mm
Total Deficit	56 mm	56 mm

Figure 4.8: Crop End Values

4.5.5 Change of Sowing threshold

Initially, the code logic for sowing date was to set the date on which the 30mm rainfall is achieved but, it has been observed that in some areas it takes considerable time to reach 30mm sowing threshold which ideally should not exceed 15th of June else the crop and it's status is supposed to be declared as failed or unpredictable.

So, the change was made to set the sowing date and it's related computations to have the minimum of 15th June or date on which the 30mm rainfall is achieved. The given logic was incorporated in the existing Android application.

4.5.6 Satellite View

The need was felt to provide better views to the user for input of the location of the farm(s) to run the water budget computation. The terrain map helps to identify the slope of the region and can be used to provide farm input accordingly. The hybrid view helps in providing the satellite and labeled representation of the map so that it will facilitate the user while navigation of the GPS pointer to locate the area of interest easily. Below is the list of views which can be used/referred for providing the accurate input of farm location for water budget computation. Refer to Figure 4.3 for visualization of different maps.

1. Google Map (Default)
2. Google Satellite
3. Google Terrain
4. Google Hybrid

4.5.7 Improved aesthetics

Some minor aesthetic modifications were done to the Android application as given below:-

- App Icon and Name Added
- User Input Display
- Relevant text Representation (Lat - Long)
- Change in Layout of Output Summary Values

4.5.8 Daily Computation Values

The application runs for a particular given period and the corresponding monsoon and crop end values are displayed as a result. But the need was felt to log the daily computation values in order to debug the android application in-case of any discrepancies related to data or computation methodology is found or need to be traced. So a new input (optional) was added to the application to log those daily values in a file. The daily values logging was kept optional as it takes 2-3 seconds of delay for writing the output to the file which is a heavy operation with respect to time and is done only in-case of debugging required.

The following values are logged for daily computation:-

Sr.No	Logged Values
1	Timestamp
2	District
3	Latitude-Longitude
4	Crop
5	Soil Type
6	Depth Value
7	AET
8	PET
9	SM
10	Runoff
11	Rainfall
12	Irrigation
13	GW Recharge

(a) Daily Computation Logged Values

```
Day 62 AET 6.643
Day 62 PET 6.643
Day 62 SM 104.8250732421875
Day 62 Runoff 82.3983154296875
Day 62 Rainfall 94.0
Day 62 Irrigation 0.0
Day 62 Rainfall+Irrigation 94.0
Day 62 Ground Water Recharge
2.12502384185791
Day 63 AET 6.643
Day 63 PET 6.643
Day 63 SM 107.65872192382812
Day 63 Runoff 13.337312698364258
Day 63 Rainfall 22.0
Day 63 Irrigation 0.0
Day 63 Rainfall+Irrigation 22.0
Day 63 Ground Water Recharge
2.3657305240631104
Day 64 AET 6.643
Day 64 PET 6.643
Day 64 SM 107.31268310546875
Day 64 Runoff 6.516720771789551
Day 64 Rainfall 14.0
Day 64 Irrigation 0.0
Day 64 Rainfall+Irrigation 14.0
Day 64 Ground Water Recharge
2.007765054702759
```

(b) Sample Daily Computation Values Logged

Figure 4.9: Daily Computation Values Logged in File for Validation

4.5.9 Summary Report

Need

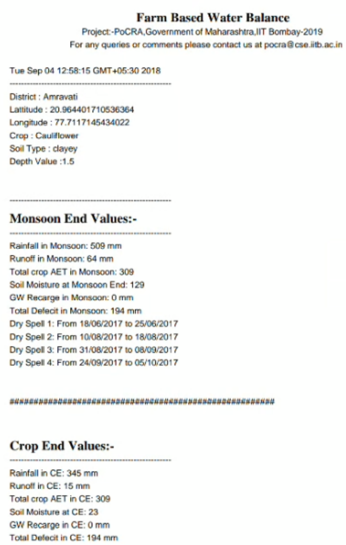
The application is expected to be run by farmers/Krishi-Mitras or the administrators which in-case may not be aware of the currently used computation methodology but by their expertise and experience may observe some conflicts in the results generated. Such cases are required to be thoroughly monitored and analyzed for improving or clarifying the issues raised. With a view to facilitating the above task, an option is added to the Android application to save the current outputs of the application on which the computation was performed in the form of report (PDF) which can be sent to the respective responsible person for further clarification or debugging.

Sample Outputs

Refer Figure 4.10 for the visuals of report content. The report content logs following values as given below:-

Sr.No	Report Content
1	Header
2	Timestamp
3	User Inputs
4	Daily Computation Graph
5	Cumulative Computation Graph
6	Monsoon End Value
7	Crop End Values

Table 4.2: Report Content



Farm Based Water Balance

Project:-PoCRA,Government of Maharashtra,IIT Bombay-2019

For any queries or comments please contact us at pocra@cse.iitb.ac.in

Tue Sep 04 12:58:15 GMT+05:30 2018

District : Amravati

Lattitude : 20.964401710536364

Longitude : 77.7117145434022

Crop : Cauliflower

Soil Type : clayey

Depth Value :1.5

Monsoon End Values:-

Rainfall in Monsoon: 509 mm

Runoff in Monsoon: 64 mm

Total crop AET in Monsoon: 309

Soil Moisture at Monsoon End: 129

GW Recarge in Monsoon: 0 mm

Total Defecit in Monsoon: 194 mm

Dry Spell 1: From 18/06/2017 to 25/06/2017

Dry Spell 2: From 10/08/2017 to 18/08/2017

Dry Spell 3: From 31/08/2017 to 08/09/2017

Dry Spell 4: From 24/09/2017 to 05/10/2017

##

Crop End Values:-

Rainfall in CE: 345 mm

Runoff in CE: 15 mm

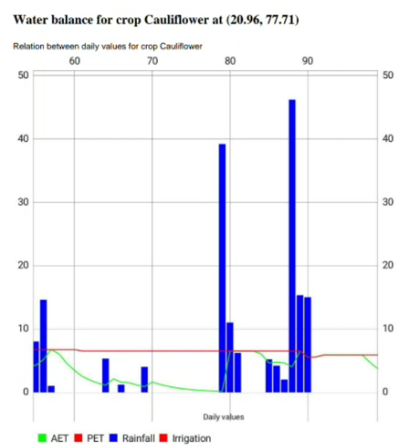
Total crop AET in CE: 309

Soil Moisture at CE: 23

GW Recarge in CE: 0 mm

Total Defecit in CE: 194 mm

(a) User Input,Monsoon & Crop End Values in Report



(b) Graph in Report

Figure 4.10: Report Generated on Clicking Save Output Option

4.5.10 Change of Language

The app is updated to Marathi language. This is done in view of the ease of accessibility for the officials and farmers using the application.

4.5.11 Android App Set for Release

The android application is all set for release. The app is migrated to the server ensuring its all-time availability. The respective set up of PostgreSQL and the required rainfall data was migrated to the server. The app is currently made available on the PoCRA site for downloading it freely. The link is `https://www.cse.iitb.ac.in/~pocra/Android_app/app-debug.apk`

4.6 Use Cases and Extensions

4.6.1 Quick Verification of Farm Status

The application can be of immense help in knowing the current status of the farm while being on the administrative premises for the administrators. Also, it can help farmers to identify the potential threat due to irregular cropping pattern based on previous data.

4.6.2 Facilitating Village Level Planning

The application being run at the granularity of a farm in a village it can be effectively utilized for the planning at the village level. This needs some modifications in the app to deliver different indices like Water deficit, Soil Moisture, Rainfall, etc. for the village to get the overall scenario for those indices in the village. The administrators can identify the status of the farm or nearby areas and can decide upon whether any new water storage constructions or related subsidiaries are supposed to be provided to the respective farmers based on their farm status.

4.6.3 Advisory Support

The Summary values and the output graphs generated out of the application can be used to provide advisory by the administrators related to what is supposed to be planted, how much is the water deficit and the related information which can be used based on experience for the improved productivity of the farm. It can also be used to ensure whether the water requirement is fulfilled and the reasons noted otherwise.

Argument of why farmers may be under watering:

In dry land agriculture, farmers tend to focus on productivity per unit of water instead of productivity per unit of land. This often results in over-cropping. Farmer rations the available water in such a way that high value and remunerative crops (vegetables, soybean, horticulture etc.) get adequate irrigation whereas traditional crops like Jowar, Bajri etc. are left to survive on soil moisture and remain under-watered. Such rationing of water between crops or even within the same crop was observed in many villages during the drought year. For example, in Pedgaon, a farmer with 3 acres of cotton managed water through drip irrigation for only one acre while left the other 2 acres of cotton as rainfed. In watershed plans, it is important to account such farmer level irrigation practices and its impact on yields and farmer incomes while estimating demands and planning interventions at the village level.

4.7 Future Scope

4.7.1 Gat Level Farmer Data Inputs

It has been planned to get the farmer data at the granularity of "Gat" so that it can be incorporated in the water budget computation and can provide respective personalized outputs to the farmer. The data input will be taken (if feasible) with the help of overlay-ed shapefile/KML having the file on the Google map. The file will be the cadastral Gat number file having the primary attribute as Gat number. On clicking particular Gat the information questionnaire form will appear for that farmer to fill which then will be used for the further personalized water budget computation.

4.7.2 Aggregate Farm Output

It has been observed that some farmers do have multiple farms and it is expected to have a consolidated water budget and/or advisory support for those farmers which can be done by the integration of such Gat level data in the android application.

4.7.3 Additional Information at Farm Level

Detail information regarding soil textures, profits, yields, beneficiary information, can be collected to strengthen the app results and deliver better insights into the same.

Chapter 5

Water Budget Components

5.1 Background

The agricultural data for village water balance is fed into the MLP app by micro-planning team during the micro-planning process,conducted in PoCRA villages. The generated water balance provides the seasonal details of supply and demand in the village along with runoff available for impounding. This serves as a guidance in preparation of village intervention plan,as a conclusion to the micro planning process. The micro plan will basically involve profiling of cluster with respect to socio economic conditions, agricultural scenario, constraint analysis wrt soil, crop and water status. It also involves resource mapping and is a seven day long procedure to generate a village summary plan.

To enable knowledge creation for participatory intervention and crop planning a simplified visual representation of village water balance,to be displayed and discussed in the village during finalization of the village intervention plan is designed. A Postgres database has been created as a pilot representation for implementation of water balance.

5.2 Need of Water Budget Analysis

Procedure to prepare village level water balance charts using plugin water balance data and village specific agricultural data available from MLP(Micro_Planning) app is to be formulated.

This describes the overall structural framework of the database along with functional requirements and queries. The schema and fields used for water balance computation are illustrated here and this document is referable as a guidance while actual implementation of water balance component in the MLP app.

The outcome of this exercise is -

1. Database compilation and sample schema design
2. Identifying data and schema issues
3. Output Tables - Village water balance chart table, zone and village level water balance table for actual, proposed structures and proposed crop state

The input database is created at PMU before beginning the microplanning process. This input database is uploaded on server to create login credentials for village and conveyed to field team. After this the field process starts on MLP app. The water budget data for uploaded villages is feeded into app by field team. This data is currently stored at backend on salesforce server after online submission to the server. Once the data is submitted water budget is generated on salesforce server and made available as a 'pdf' file on MLP app. Currently this data from server has been downloaded in csv format and loaded into Postgress for generation of chart table. In new development of the MLP app this data must be stored in postgress database on server, where all computation must take place.

5.3 Approach

Pilot implementation in Postgress was to be done for 106 phase I villages to generate village charts attribute table for year 2018. This was to be done on existing dataset already submitted by the field team. For this purpose the existing MLP dataset was downloaded from salesforce server and loaded into Postgress. Since, there were multiple issues in existing data, as a one time process following steps were taken and based on issues faced solutions are proposed for future implementation.

1. Run QGIS plugin for last 6 years (2013-2018) for all villages and load into Postgres year-wise tables
2. Keep printable zone maps for all villages ready
3. Get MLP database from sales-force and load into Postgres
4. Finding data issues and Data Cleaning for one time (to be taken care of and automated in future by implementing agency)
5. Reporting issues in data to PMU(Project Management Unit) for correction
6. Building queries for chart table generation - village-wise year-wise for last 6 years
7. Validation of queries

5.3.1 Attributes Involved

Following types of attributes are involved in the Water Budget Computation:-

1. Structure Data
2. Population Data
3. Crop Data
4. Plugin Outputs
5. Zone Level Attributes
6. Village Level Attributes
7. Structure Based Water Budget

5.4 Database Schema

The output of this exercise is queries to generate table for village charts, water balance actual and proposed state for last 6 years. It will also provide summary of MLP data issues from plugin and MLP water balance data loaded into database. The tables in database their data source, generation timeline and their use as input or output is illustrated in Table 1.

Sr. No	**Data Table**	**Data source**	**Generated/ Timeline**	**Input/output**
1	Zonal water balance (for last 6 years 2013 – 2018) for the villages in the project area	QGIS plugin output	Before microplanning	Input - in Postgres from plugin
2	Village zone map in pdf/jpeg format at 300 dpi resolution	PoCRA PMU	Before microplanning	Input - On cloud/drive from PMU
3	Current zone wise cropping pattern data	Water Budget data - MLP app	After water budget data submission in the MLP app during microplanning.	Input - required to be stored in Postgres from MLP app as per given schema
4	Current zone wise soil and water conservation structures data	Water Budget data - MLP app	After water budget data submission in the MLP app during microplanning.	Input - required to be stored in Postgres from MLP app as per given schema
5	Proposed zone wise soil and water conservation structures data	Water Budget data - MLP app	After water budget data submission in the MLP app during microplanning.	Input - required to be stored in Postgres from MLP app as per given schema
6	Population data	Water Budget data - MLP app	After water budget data submission in the MLP app during microplanning.	Input - required to be stored in Postgres from MLP app as per given schema
7	Zone level water balance	Query in Postgres	After Microplanning	Output - generated in Postgres on request (from input no. 1 and 2)

Table 5.1 continued from previous page

Sr. No.	Data Table	Data source	Generated/ Timeline	Input/output
8	Village charts water balance data	Query in Postgres	After Microplanning	Output - generated in Postgres on request (from input no. 1 and 2)

Table 5.1: Data Framework

Along with this, there are other supporting data-sets (Master tables) included in the database. Table 2 lists all data tables in the database along with their data source, primary key attributes and fixed or variable data. The Master lists such as village list, crop list, structure list is fixed. The Data from Plugin is uploaded continuously from PMU side while the MLP database should also keep updating continuously depending on the micro-planning schedule.

Sr. No.	Database Table Name	Data Source	Fixed/-Variable data	Primary key attributes	Generation Sequence
1	master_village_list	PMU	Fixed	census_code	I
2	master_crop_list	IITB-PMU	Fixed	crop_id, crop_name_in_english	I
3	master_structure_list	IITB-PMU	Fixed	Structure_id, structure_name_english	I
4	rainfall_data_updated	IITB-PMU	Fixed-Variable (appended yearly)	district_name, taluka_name, circle_name_maharain, year	I
5	kharif_model_zonewise_budget_2013	Plugin	Variable (will get appended)	Census_code, zone_number, crops_in_english	II

Table 5.2 continued from previous page

Sr. No.	**Database Table Name**	**Data Source**	**Fixed/-Variable data**	**Primary key attributes**	**Generation Sequence**
6	kharif_model_zonewise_budget_2014	Plugin	Variable (will get appended)	Census_code, zone_number, crops_in_english	II
7	kharif_model_zonewise_budget_2015	Plugin	Variable (will get appended)	Census_code, zone_number, crops_in_english	II
8	kharif_model_zonewise_budget_2016	Plugin	Variable (will get appended)	Census_code, zone_number, crops_in_english	II
9	kharif_model_zonewise_budget_2017	Plugin	Variable (will get appended)	Census_code, zone_number, crops_in_english	II
10	kharif_model_zonewise_budget_2018	Plugin	Variable (will get appended)	Census_code, zone_number, crops_in_english	II
11	mlp_input_crop_data	MLP_App	Variable (will get appended)	census_code, zone_number, status, crop_id	III
12	mlp_input_population_data	MLP_App	Variable (will get appended)	census_code	III
13	mlp_structure_data	MLP_App	Variable (will get appended)	Census_code, zone_number, status, structure_id	III

Table 5.2 continued from previous page

Sr. No.	**Database Table Name**	**Data Source**	**Fixed/-Variable data**	**Primary key attributes**	**Generation Sequence**
14	water_balance _zone_level	Postgress query	Variable (will get appended)	census_code, water_balance _year, zone_number, date_created	IV
15	master_output _attributes_chart	Postgress query	Variable (will get appended)	census_code, chart_year, date_created	V

Table 5.2: Database Tables and Meta-data

The main outputs from this database are -

1. Water balance - zone level for actual state (for all years 2013 - 2018) table named 'water_balance_zone_level'
2. Water balance - zone level for proposed structures state (for all years 2013 - 2018) table named 'water_balance_zone_level_proposed_structures'
3. Water balance - zone level for proposed structures and proposed crop state (for all years 2013 - 2018) table named 'water_balance_zone_level_proposed_struct_crop'
4. Water Balance - Village level (for all years 2013 - 2018) table named 'water_balance_village_level'
5. Water Balance Charts attributes - Village level (for all years (2013 - 2018) table named 'master_output_attributes_chart'
6. Issues in MLP data - Village level named 'village_data_issues_all' for 459 villages whose data was downloaded from server

Queries have been implemented for this and current level of functionalities and issues are given in next section.

5.5 Data Issues and Cleaning

The data-set was validated while implementing in Postgres and following summary table provides a glimpse of issues in the current database. The steps taken to resolve this and probable solution for MLP is also given in the Table 3.

Sr. no	**Issue**	**Number of villages**	**Step taken**	**Probable solution**
1	Null census code	12	Deleted from 'master_villag_table'	Will add later once data is available from PMU
2	Duplicate population data for village	3	Deleted the duplicate null entries	Single entry should be allowed (previous should be updated instead of new entry) in app on resubmission of data
3	Only marathi crop names in MLP crop data table	All entries	Added english crop names and crop id from' master crop list' lookup table	Keep english crop names entry required for analysis in newly designed backend schema
4	Crop season and landuse not present in MLP crop data	All entries	Added from ' master crop list' lookup table	Needed for analysis purpose - should be included in newly designed backend schema
5	Duplicate crop entries in MLP crop data	400	Summed entries with duplicate primary key after validating that cropping pattern and non-ag land summed up to village area	Single entry per crop should be allowed to maintain 'unique entries'

Table 5.3 continued from previous page

Sr. no	**Issue**	**Number of villages**	**Step taken**	**Probable solution**
6	Structure name in marathi present, english not present in MLP structure data table	All entries	Added english structure names and structure id from look up table 'master structure list'	Keep in backend schema as english names are needed for analysis
7	Unique structure id not present in MLP structure data table	All entries	Added structure id from from look up table 'master structure list'	Needed for analysis as multiple marathi names are mapped to single english name in some cases.
8	Duplicate structures data	65	Eg: multiple CNB entry with same or different capacity.Considered each entry separately. Primary key was not set for this table.	Additional field or appropriate naming (like CNB1, CNB2) for structures will be required to set primary key for this field.
9	Null crop area or null zone number in MLP input crop data	-	Handled in postgres query using Coalese function	-
10	Incorrect zone naming in zone shapefile and plugin output - not giving integer for zone number in final table	-	Split part was used to fetch integer. But text may get fetched due to incorrect naming giving error in running chart query later	Not handled here because - split part was used after population plugin output on the run.

Table 5.3 continued from previous page

Sr. no	Issue	Number of villages	Step taken	Probable solution

Table 5.3: Data Issues and Cleaning

Other Issues and Corrections done

1. Handling null values in database: Null values in MLP data were replaced with zero to avoid computation error. Handling of null values in database must be decided and implemented during new development of MLP
2. Zone number format: Zone number from plugin is in format 'zone-villagename-number' whereas that in MLP app is in format 'number'. These formats must be decided and proper handling would be needed for post processing of MLP data. Currently only the number part is picked from plugin format for utility.
3. Crop season and Landuse field for all crops was added to MLP crop database to allow easy post processing. This field must be included in MLP crop database schema during new design.
4. Structures name in english field was added to MLP structures database. This field must also be included in schema of MLP structures data for new design
5. Required attributes from Master list: Crop list has now been given crop id's but crop id's are not there in plugin output. Matching fields must be incorporated in MLP database schema to be maintained at backend so as to allow easy post processing. Schema for pilot database must be referred for this and discussions must be conducted with IITB team and PMU for finalization.
6. Primary keys and duplicate data: Based on primary keys duplicate data entry in MLP app, where needed, must be handled by incorporating additional attributes in schema. Eg - structures data will need duplicate entry due to varying storage capacity. This can be handled by adding additional attributes in schema like CNB1, CNB2 or by post processing of data by summing up duplicate entries before entry into database.
7. Handling data issues at entry level: Data issues like null entries in population, current structures, proposed structures, current cropping pattern and proposed cropping pattern must preferably be handled at the entry level.
8. Backed reports and timeline:Viewable report formats must be pre-decided and implemented for monitoring purpose.

MLP Data Issues

Following issues were identified in input data which result in incorrect water budget.

1. Null population data
2. Null cropping pattern (Actual or planned)
3. Null structures (Actual or planned)
4. Mismatch in cropping pattern and village area

Below table provides a summary for these issues.

Parameter for data issues	Total	Phase I	Phase II
No. of villages in MLP data	459	58	401
No population data	67	10	57
No current structures data	75	4	71
No planned structures data	25	4	21
No current cropping data	5	0	5
No proposed cropping data	44	9	35
Incorrect current cropping data	5	1	4
Incorrect planned cropping data	3	0	3

Table 5.4: Summary of MLP data issues

5.5.1 Cleaning

Sequence of steps for data cleaning in MLP

1. Crop data table -'mlp _input_crop_data_updated'
   - Add crop season and landuse field to 'mlp_input_crop_data_updated' table by matching with 'master_crop_list'.
   - duplicate crop entries summed
   - added '0' in place of blank entries
2. Population table - 'mlp_input_population_data'
   - duplicate null entries removed.
   - added '0' in place of blank entries.
3. Structures table - 'mlp_structure_data'
   - Adding structures name in english attribute field by matching with 'master_structure_list'
   - added '0' in place of blank entries
   - kept duplicate entries to allow variations

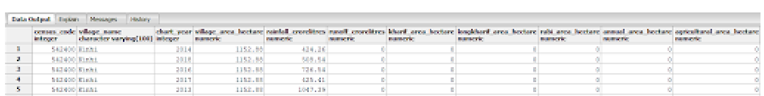
5.6 Validation

1. The chart attribute table query output is validated for 2018 data on below villages-
   - Gunja , Washim
   - Kubhephal , Aurangabad
   - Pandaw Umra , Aurangabad
   - Paradgaon , Jalna

2. The zone level water balance output table (Actual state) has been validated on below villages -
   - Zalta - 548851
   - Gunja - 530632
3. The zone level water balance output table (all states Actual and Proposed) has been validated on below villages -
   - Ghusarwadi - 530039
   - Alasna - 528447
4. Data issues table 'village_data_issues' was validated on below villages for presence of issues:
   - Apoti Kh.-530035
   - Apoti Bk.-530042
   - Shelgi - 560819
   - Kasali Kh -530528
   - Warkhed -528653
5. The 'village_data_issues_all' table for 459 villages was validated on below villages for actual presence of issues -
   - Malpur -532754
   - Visapur - 527722
   - Hiwarkhede Kh -527563

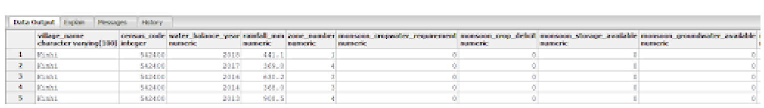
5.7 Sample Results

5.7.1 Database Results



	census_code integer	village_name character varying(100)	chart_year integer	village_area_hectare numeric	rainfall_crorelitres numeric	runoff_crorelitres numeric	kharif_area_hectare numeric	longkharif_area_hectare numeric	rabi_area_hectare numeric	annual_area_hectare numeric	agricultural_area_hectare numeric
1	542400	Kinhi	2014	1152.88	424.26	0	0	0	0	0	0
2	542400	Kinhi	2018	1152.88	569.54	0	0	0	0	0	0
3	542400	Kinhi	2016	1152.88	726.54	0	0	0	0	0	0
4	542400	Kinhi	2017	1152.88	425.41	0	0	0	0	0	0
5	542400	Kinhi	2013	1152.88	1047.39	0	0	0	0	0	0
6	542400	Kinhi	2015	1152.88	566.11	0	0	0	0	0	0

Figure 5.1: Sample entries in chart attributes



	village_name character varying(100)	census_code integer	water_balance_year numeric	rainfall_mm numeric	zone_number numeric	monsoon_cropwater_requirement numeric	monsoon_crop_deficit numeric	monsoon_storage_available numeric	monsoon_groundwater_available numeric
1	Kinhi	542400	2018	441.1	3	0	0	0	0
2	Kinhi	542400	2017	569.0	4	0	0	0	0
3	Kinhi	542400	2016	630.2	3	0	0	0	0
4	Kinhi	542400	2014	368.0	3	0	0	0	0
5	Kinhi	542400	2013	968.5	4	0	0	0	0

Figure 5.2: Sample entries in water balance table

5.7.2 Expected Graphs

1. Rainfall-Runoff graph for last 6 years - based on current year cropping pattern fed into the MLP app by microplanning team.

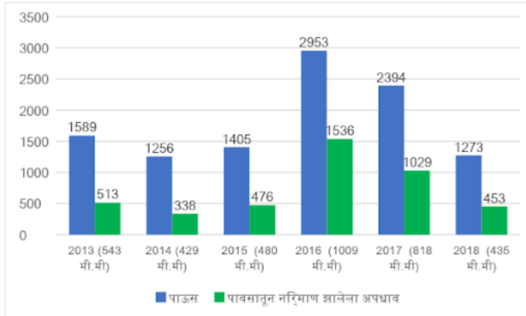


Figure 5.3: Rainfall Runoff Graph for 6yrs

2. Village Cropping Pattern – Area in hectare for different crop types namely Kharif (Kharif_Main and Kharif_Vegetables as naming convention used in plugin output excel), Long Kharif, Annual and Rabi crops in village.

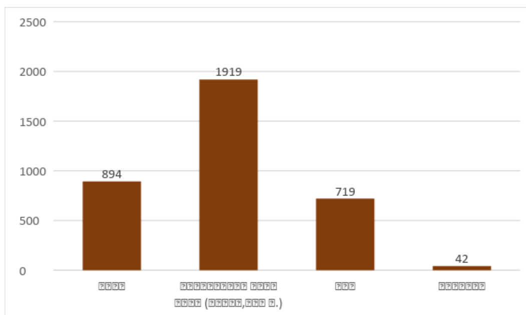


Figure 5.4: Village Cropping Pattern

3. Village water demand and supply graph – Rainfall, Agricultural PET (Total crop water requirement) and Drinking water demand.

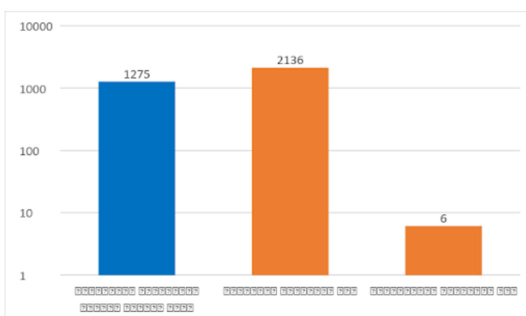


Figure 5.5: Village Water Demand and Supply Graph

4. Agricultural crop water demand and supply in monsoon – PET, AET, Deficit

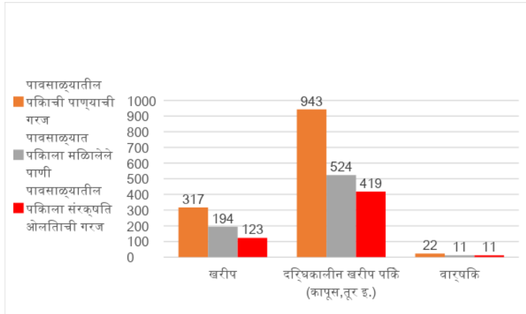


Figure 5.6: Agricultural crop water demand and supply in monsoon

5. Agricultural crop water demand and supply in post monsoon – PET, AET, Deficit

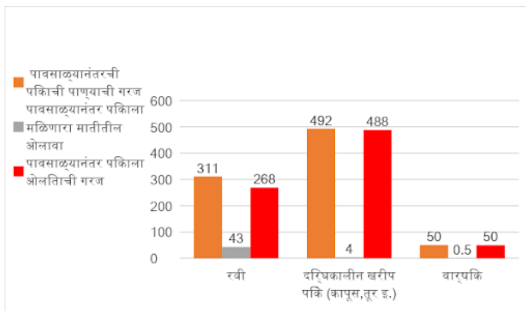


Figure 5.7: Agricultural crop water demand and supply in post monsoon

6. Final summary water balance table showing water balance in current and proposed state.

पावसाच्या पाण्याचे गणित			
१	गावाचे एकूण क्षेत्र (हेक्टर)	२९२७	
२	पावसाचे पाणी (कोटी लिटर)	१२७३	
३	पावसाळ्यात पिकाने घेतलेले पाणी (कोटी लिटर)	७४०	
४	भूजल पुनर्भरण (कोटी लिटर)	१२.०	
५	मातीतील ओलावा (कोटी लिटर)	६७	
६	गाव शिवारातून निर्माण झालेला अपधाव (कोटी लिटर)	४५६	
७	गाव शिवारात अडविण्यासाठी उपलब्ध अपधाव (कोटी लिटर)	२२८	
८	गाव शिवारात आतापर्यंत अडवलेला अपधाव (कोटी लिटर)	८५	
९	अडविण्यासाठी शिल्लक अपधाव (कोटी लिटर)	१४३	
१०	प्रस्तावित कामांनंतर अडणारा एकूण अपधाव (कोटी लिटर)	१२४	
	पिकाची पाण्याची गरज आणि उपलब्धता	पावसाळ्यातील	पावसाळ्यानंतर
११	पिकाची पाण्याची गरज (कोटी लिटर)	१२८३	८५३
१२	पिकाला मिळालेले पाणी (कोटी लिटर)	७२९	४७
१३	पिकाला ओलिताची गरज (कोटी लिटर)	५५३	८०६
१४	अडवलेला अपधाव (कोटी लिटर)	४३	४३
१५	उपलब्ध भूजल (कोटी लिटर)	४.०	८.०
१६	सध्यस्थितीत पाण्याचा ताळेबंद	-५०६	-७५५
१७	एकूण तुट (कोटी लिटर)	१२६२	
प्रस्तावित कामांनंतर पाण्याचा ताळेबंद			
१८	सध्याच्या पिकपद्धतीनुसार प्रस्तावित कामे केल्यानंतरची तुट (कोटी लिटर)	१२२३.२२	

Figure 5.8: Final summary water balance table showing water balance in current and proposed state.

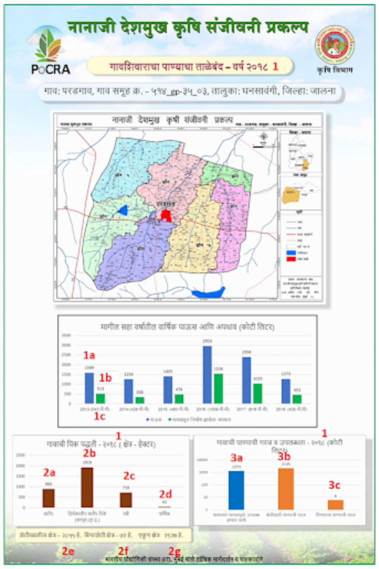


Figure 5.9: Display Chart 1

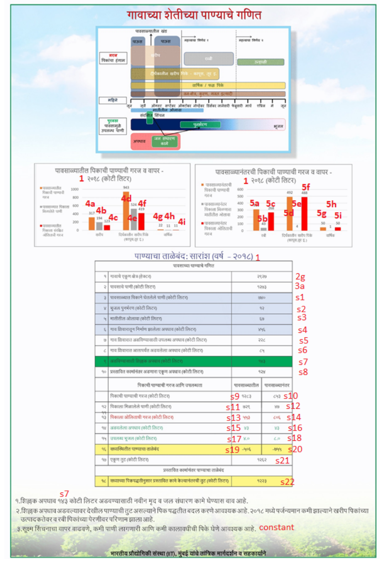


Figure 5.10: Display Chart 2

Deliverable:

The following is submitted to PMU:-

1. Chart MLP Queries and results for 2013-2018 for first 106 villages
2. Constraints Primary Key Queries
3. Data Issues Queries And Results
4. Populating Plugin Output To Database Scripts
5. Status Table Queries
6. Water Budget Queries (zone and village level) for actual, proposed structures and proposed structures and proposed crop state with results for 2013 - 2018 rainfall for first 106 villages
7. MLP Database Backup

5.8 Conclusion

Village level awareness by displaying such charts at village proceedings will not only help the farmers to understand the overall scenario in their village but will also make a way to community based farming practices. This will also help the officials to take better decisions and provide appropriate interventions wherever required in a timely manner.

Chapter 6

Zoning

6.1 Objective

Usually, due to the spatial variations in many factors like soil, GW-availability, SM-availability, social-economic make-up, etc., a single water+crop management regime cannot be applied to the entire village. Consequently, the village has to be partitioned into zones on each of which a single management regime may be applied distinctly from other zones. If the variations are effectively captured, then the location of intervention(s) can be identified, and it can be ensured that the program benefits are reaching to all the parts of the village in all the conditions. So it can be said that zones help to group the areas with similar problems.

- Given limitations of budget, it is to ensure that watershed works and spread evenly across the village.
- How to go about creating these zones depends on the spatial distribution of the above factors and the time-scale for which the management regime is to be applied. This is the zoning problem.
- The solution to this problem, the zoning algorithm, will require automation in the absence of skilled manpower.

Here, we focus on zones w.r.t. stream and watersheds. The stream and watershed zones represent the actual water flow and availability which is were the actual habitation exists. So, it is of interest to identify such zones to consider the water available in the respective water budget.

6.2 Need of zoning

The zonal planning framework is expected to consider the variations within the village such as soil type, soil depth, slope, and nearness to streams and to be used as a planning unit. These factors influence the water balance and, this is visible through the differences in water balance for the same crop in different zones. So each zone has a different vulnerability, runoff, soil moisture, and groundwater recharge compared to other zones. In order to take these factors into account, it becomes important that planning is done at zone level to meet varying zonal requirements and thus ensure coverage of village area and maximum farmers.

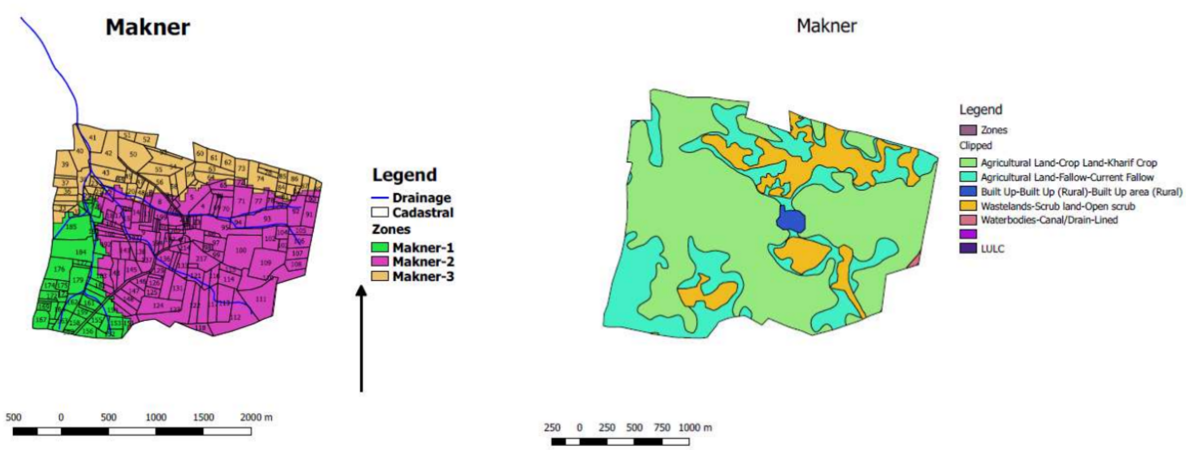
Consider the zoning of Makner village as shown in Fig.6.1. From the Land Use map in Fig. 6.1b and water balance Table 6.1 it can be seen that zone 1 has considerable current fallow land and zone 3 has considerable wasteland. The impact of these factors can be seen in the runoff of zone 1 and zone 3 which is comparatively higher concerning zone 2 having negligible wasteland or fallow land by comparing soil moisture and groundwater in zone 1 and zone 3 concerning zone 2. These values are lower for zone 1 and zone 3 due to the presence of fallow and wasteland, which leads to higher runoff and lower infiltration. This also means that the zones will have different set of interventions.

The differences in the runoff, groundwater and soil moisture between the zones are based on land along with other geophysical factors, and this is evident from the Land Use map, Zonal Map and table 6.1. Hence water balance table 6.1 validates the need for zonal planning and calls for a planning process (land management, area treatment, drain line treatment) considering land use in the zone.

Following table shows the water balance for Kharif crops in three zones of Makner:-

Village Zones	Crop	Rainfall (mm)	Runoff (mm)	Ground Water (mm)	Soil Moisture (mm)	PET (mm)	AET (mm)	Deficit (mm)
Makner-1		823	393	28	107	453	293	160
Makner-2	Soyabean	823	361	39	113	453	308	145
Makner-3		823	385	26	113	453	297	157
Makner-1		823	507	17	138	292	162	130
Makner-2	Bajra	823	482	12	162	292	166	127
Makner-3		823	425	11	230	290	157	134
Makner-1		823	401	6	18	626	398	228
Makner-2	Tur	823	372	12	28	626	411	215
Makner-3		823	392	7	18	626	407	219

Table 6.1: Water Balance for Kharif Crops



(a) Zonal Makner Map (b) Land Use Land Cover Makner Map

Figure 6.1: Zone Based Planning Framework Map Analysis

Various other factors like difference in storage capacity of each zone and its relation to cropping pattern can be used for zone wise planning taking into account the availability of surface water sources in the zone, and through identification of appropriate interventions.

So, with a view of having a zone based model we have formulated a procedure for zoning based on mini-watershed on which the water budget will be computed. The formulated procedure is discussed in the next section.

Watershed

A watershed is the total land and water area, from where the rainfall runoff drains into any water body, be it a stream, river, lake or ocean. It may be a nearly flat area or include hills or mountains. It is considered to be synonymous with drainage basin and catchment area. Watersheds are separated from each other and the boundaries are called as watershed boundaries.

Size for watershed varies as per the topography of the land. Smaller watersheds drain into streams and just as several streams form a river, several small watersheds group to form a larger watershed or river basin with its own defined ridge-line. Ridge-line is the line joining the points of higher elevation in a particular watershed. Ridge-line always divides different watersheds. Below table 6.2 shows the area covered by different watershed types [31]. In fig.6.2 area marked in red (35 ha) is small watershed and the area marked in blue (344 ha) is medium watershed. The concept of differential watershed is explained in section 8.4.

Sr.No.	**Type of Watershed**	**Area Covered**
1	Micro Watershed	0 to 10 ha
2	Small Watershed	10 to 40 ha
3	Mini Watershed	40 to 200 ha
4	Sub Watershed	200 to 400 ha
5	Macro Watershed	400 to 1000 ha
6	River basin	above 1000 ha

Table 6.2: Watershed Types

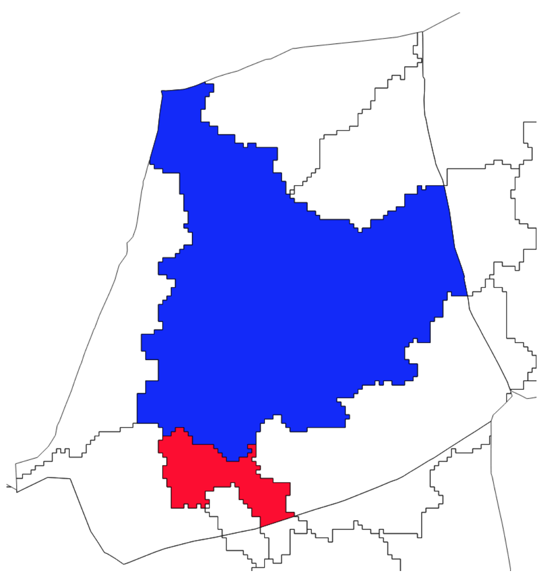


Figure 6.2: Small and Medium Watershed

The main function of watershed is to receive the incoming precipitation and then dispose it off. It's major functions are as:

Hydrological functions: Collect rainfall water, Store water in various amounts and for different periods, Release water as runoff.

Ecological Functions: Provide conditions and sites for various bio-chemical reactions to take place, Provide habitat to flora and fauna of various kinds.

6.3 Detail Zoning Methodology

6.3.1 Input-Output parameters and Algorithms applied

Sr.No	Input	Output	Algorithms
1	Village Boundary	Watershed	r.watershed,r.to.vect
2	DEM	Stream	Eliminate Sliver Polygons,v.clean
3	Cluster Layer	Zone Layer	Intersection,Clip

Table 6.3: Input-Output parameters and Algorithms applied for Zoning

DEM
A Digital Elevation Model (DEM) is a specialized database that represents the relief of a surface between points of known elevation. By interpolating known elevation data from sources such as ground surveys and photogrammetric data capture, a rectangular digital elevation model grid can be created[15].GIS software can use digital elevation models for 3D surface visualization, generating contours, and performing view-shed visibility analysis.

Watershed
A watershed is an area of high ground which divides two or more river systems so that all streams on one side flow into one river and those on the other side flow into a different river as shown in fig.6.5. The "r.watershed" algorithm is used to generate the watershed and stream outputs. Detail explanation of the algorithm is given in section 6.4.1.

Stream
A stream is a small narrow river as shown in fig.6.5.

Cluster Boundary
A cluster comprises 3-4 villages. The villages are merged and the combines boundary represents the cluster boundary as shown in fig.6.5.

6.3.2 Design Approach for Zoning

Figure 6.3 represents the methodology adopted for designing zoning algorithm. Each block is accompanied with the requirements or approaches taken into account at that particular hierarchy of the block. Note that, not all the inputs like soil, LULC, slope were used throughout in the zoning process but were used as reference in case of conflicts and to generate or merge zones manually.

The basic principle of zoning is to identify zones based on mapping of administrative and natural watershed boundary. To achieve it , we clip each village from the combined layer of cluster and watershed boundary. After clipping we clean i.e. eliminate the smaller polygons i.e. those having area less than 50 ha . This is done to have limited number of zones and to run the water budget on zones with considerable size. We again merge the clipped villages to form a cluster with limited number of zones as the output.

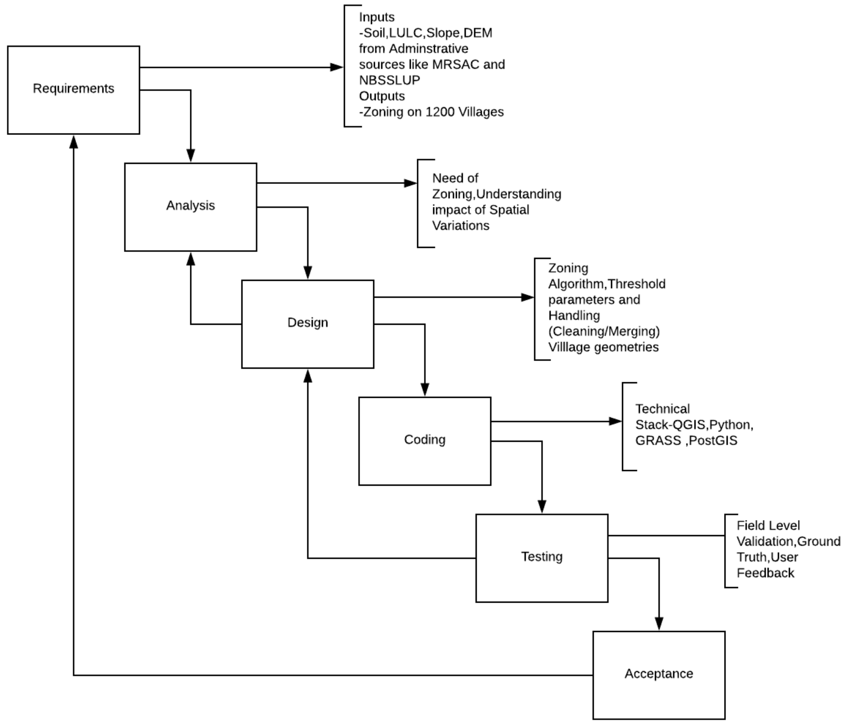


Figure 6.3: Design for Zoning Methodology

6.3.3 Zoning Steps

Zoning Principle and Algo

We take the DEM and cluster boundary as input then we intersect the watershed and cluster polygons. The intersection results small size polygons which are eliminated by using appropriate cleaning algorithms. Some of comparatively larger polygons (50 ha) are merged with adjacent larger polygons based on area parameter which is 50 hectare. For merging, we clip each village separately and then apply the area based merging algorithm and then again combine the clipped villages. We merge this polygons because the water budget computation is to be performed on relatively larger size polygons for proper advisory support. Generally, there are 2-3 zones per village, where the typical village is about 500ha. Below are the detailed steps:-

1. Generate Stream and Watershed from DEM
2. Load Village and Watershed Layer
    (a) Add zone_area attribute to watershed layer
    (b) Apply Eliminate Sliver Polygons algorithm with an appropriate threshold to watershed layer
3. Intersect Village and Cleaned Watershed Layer
4. Clip the Intersected layer to generate separate polygons for each village
    (a) Update the zone_area attribute of each Clipped layer

5. Clean the separated polygons individually
   (a) Use v.clean with appropriate threshold for each layer
6. Merge all the Cleaned Layers
   (a) Update the zone_area attribute of the merged layer

6.3.4 Visualization of steps

1. Generate Stream & Watershed from DEM

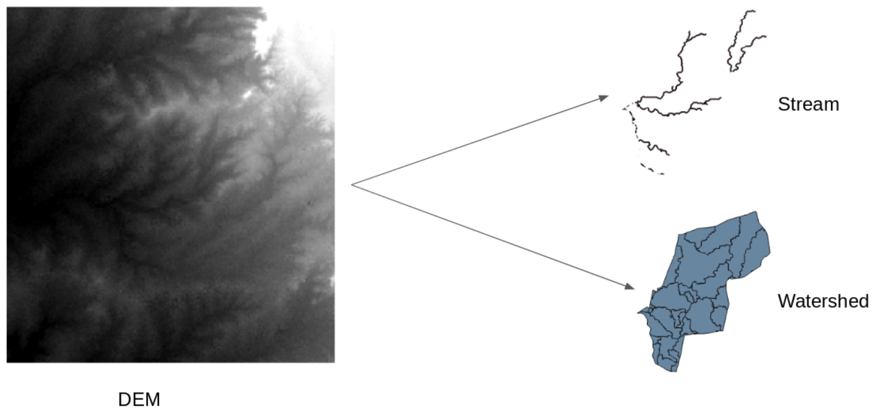


Figure 6.4: Watershed and Stream Delineated from DEM

2. Load Village and Watershed Layer

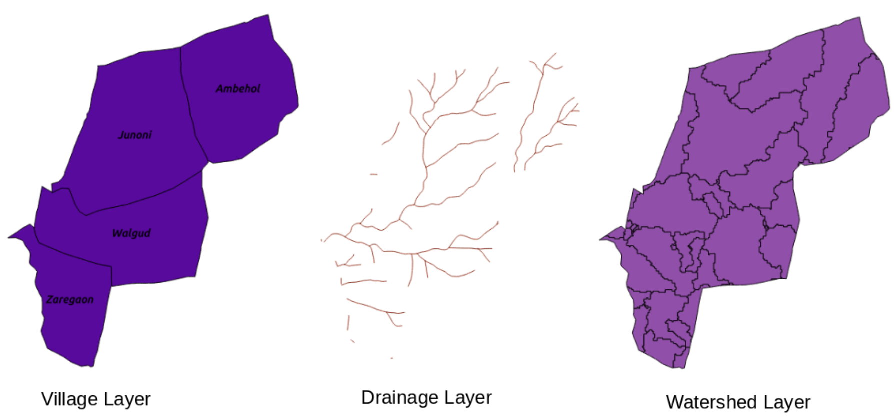


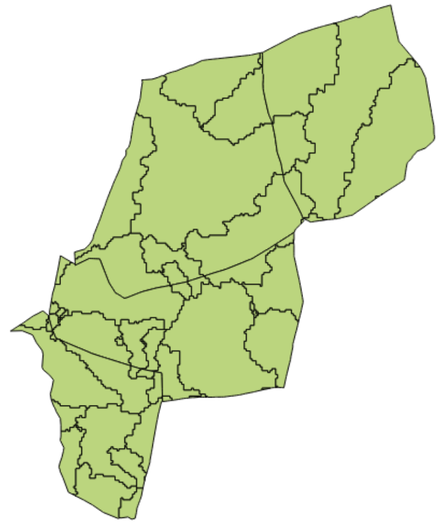
Figure 6.5: Village,Drainage and Watershed Layer

3. Intersect Village & Cleaned Watershed Layer

   ESP is to be applied to watershed with threshold 0.1 hectares and then intersected with the village. A new attribute to the clipped layer named zone_area is added and its value is set as zone_area=$area / 10000 and then v.clean is applied with break tool as ”rmarea” and threshold according to the size of village (5lac or 1lac) during the algorithm formulation (manual runs) which was accordingly incorporated in the zoning algorithm.

	value	label	zone_area	OBJECTID_1	STNCODE	DVNCODE	DTNCODE	THNCODE	VINCODE	VIL_NAME
1	158		2547190.1...	9733	27	2704	525	04240	561463	Ambehol
2	126		847750.55...	2523	27	2704	525	04240	561462	Junoni
3	128		1878206.1...	2523	27	2704	525	04240	561462	Junoni
4	128		1878206.1...	9733	27	2704	525	04240	561463	Ambehol
5	124		3826745.0...	2523	27	2704	525	04240	561462	Junoni
6	124		3826745.0...	9733	27	2704	525	04240	561463	Ambehol
7	162		1818309.1...	9733	27	2704	525	04240	561463	Ambehol
8	124		900.00000...	2523	27	2704	525	04240	561462	Junoni
9	114		866949.28...	2523	27	2704	525	04240	561462	Junoni
10	114		866949.28...	2526	27	2704	525	04240	561464	Walgud
11	164		1080.0250...	9733	27	2704	525	04240	561463	Ambehol
12	130		1667224.8...	2523	27	2704	525	04240	561462	Junoni

(a) Zone_area Attribute Updated



(b) Intersected Layer

Figure 6.6: Applied ESP and Intersection Algorithm

4. Clip the Intersected layer to generate separate polygons. Village Unicode from attribute table is used for clipping and cluster id attribute is further used for merging.

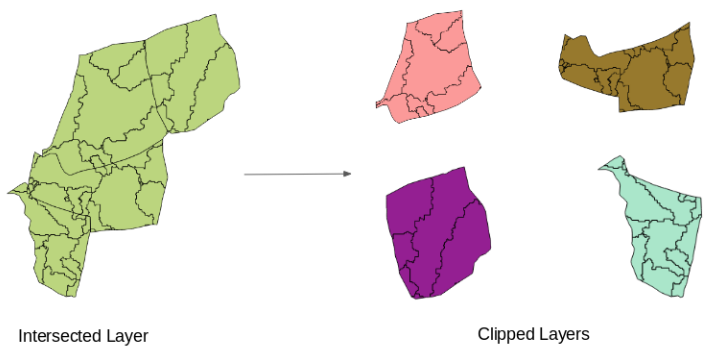


Figure 6.7: Polygons Clipped for Cleaning

5. Clean the separated polygons individually

   We cannot ignore the cleaning step after the intersection, even for small villages, since intersection may generate very small fragments and so a village-area dependent threshold is incorporated in the zoning process.

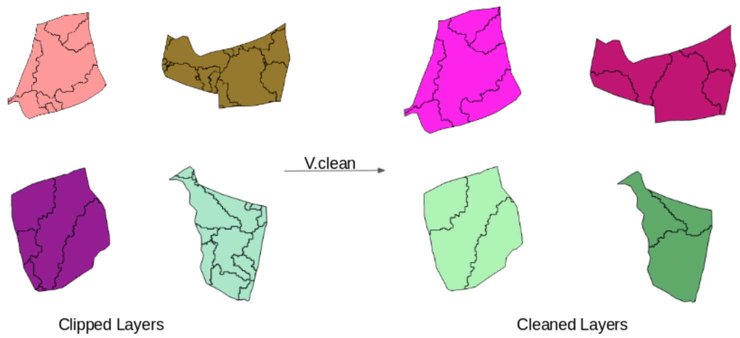


Figure 6.8: Polygons Cleaned Separately

6. Merge all the Cleaned Layers

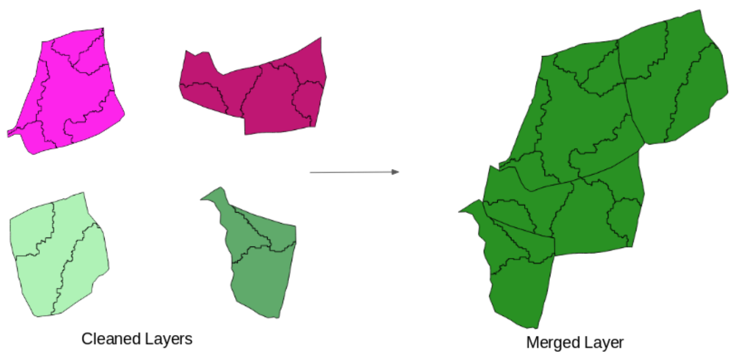


Figure 6.9: Cleaned Polygons Merged

6.4 Algorithms Involved

Identifying stream network and watershed forms a critical part of regional decomposition, zoning, etc. Below is the procedure to extract the stream network and the catchment area from a Digital Elevation Model (DEM). The below section 9.8.1 is taken from ”Drainage Pattern and Catchment Area Delineation” report [28].

6.4.1 Drainage Pattern Extraction from DEM

Generally, there are sinks and flat-areas as errors in the DEM. This errors are required to be cleaned for generating continuous stream network. Such cleaned DEMs which are free from sinks are called depression-less DEM, and those free from flat-areas and sinks are called as modified DEM. This DEMs can be used to obtain better results.

The steps for delineating watershed from the cleaned DEM are as below:

1. Identification of the flow direction for each grid
2. Determination of the flow network
3. Calculation of flow accumulation at each grid

4. Stream network delineation
5. Delineation of the stream links

Identification of the flow direction for each grid

Elevation value is associated with each grid cell as shown in fig.6.10. The direction of the cell having steepest downward slope is accordingly determined. The D8 algorithm is used to identify the direction of the flow where, D8 refers to deterministic eight-neighbors representing the directions. In order to identify the direction, the D8 estimates the difference of elevation between the current cell and its neighboring cells.

The calculation is as follow:-

For first cell with value 78 the direction is identified as the one towards the cell having maximum slope. So, (78-72)/1 , (78-74)/1, (78-67)/$\sqrt{2}$ of which cell with value 67 has the maximum slope and so is the associated direction. Similarly for all other cells the flow vectors are computed. All the cells are square. So, while finding slope between left/right/up/down cells, the center to center distance is unit, as all the cells are square, one can assume unit side of square to simplify the calculation because we are only interested to compare the slopes of all 8 directions. When we need to find slope with the diagonal cells, the center to center distance becomes $\sqrt{2}$, by Pythagoras theorem, diagonal line joining the centres of the diagonal cells will be $\sqrt{2}$.

Determination of flow vectors

The flow direction vectors fo the input DEM are as shown in fig.6.11. There are numerical values assigned to each direction which are 2 power x, with x numbered counter-clockwise starting from 0 in east direction as shown in fig.6.12.

78	72	69	71	58
74	67	56	49	46
69	53	44	37	38
64	58	55	22	31
68	61	47	21	16

Figure 6.10: A Sample DEM

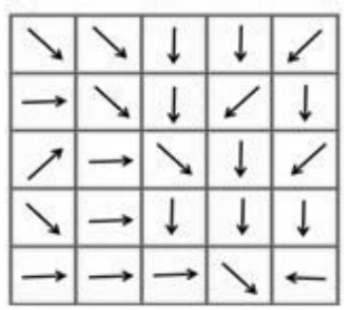


Figure 6.11: Flow Direction Grid

2	2	4	4	8
1	2	4	8	4
128	1	2	4	8
2	1	4	4	4
1	1	1	2	16

Figure 6.12: Flow Direction Matrix with numerical values for each direction

Flow network

From the flow direction grid having flow vectors in each cell, the flow network can be computed by extending the flow vectors of the steepest descent beyond each cell as shown in fig.6.14.

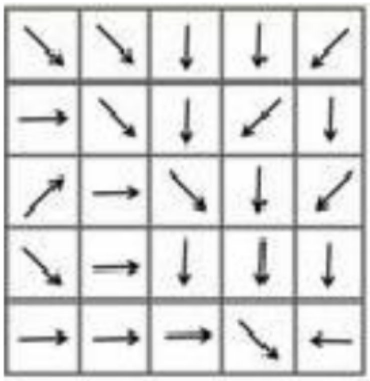


Figure 6.13: Flow directions

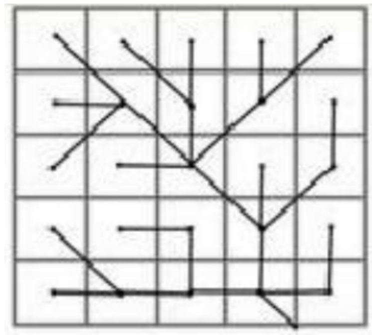


Figure 6.14: Flow Network

Flow accumulation grid

From the flow directions, the contribution of each grid in the outlet of watershed can be computed. A counter is maintained to keep the count of number of cells contributing to the given cell which is incremented as the flow passes through the grid cell. The flow accumulation grid is computed based on the counter value which has the count of upstream grids flowing into each of the grid. So, the cell in flow accumulation grid represents the count of cells flowing into that particular cell as shown in fig.6.16.

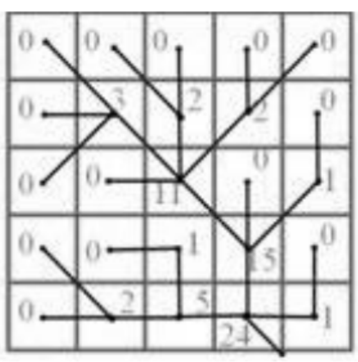


Figure 6.15: Flow Network

0	0	0	0	0
0	3	2	2	0
0	0	11	0	1
0	0	1	15	0
0	2	5	24	1

Figure 6.16: Flow Accumulation grid

Delineation of the stream network

Flow accumulation matrix is used to obtain the stream network. A parameter called "threshold flow accumulation" is to be set which depicts the minimum value of flow accumulation, for which that particular grid is to be considered, contributing to the stream network and so is the part of it. The cells having value of grids greater that the parameter value are considered as part of the stream as shown is fig.6.17 and rest are treated as the overland flows. Higher the value of parameter, the stream length and spread is reduced depicting the concrete stream having more grids contributing and lesser value depicts the wider network with less contributing grids.

0	0	0	0	0
0	3	2	2	0
0	0	11	0	1
0	0	1	15	0
0	2	5	24	1

Figure 6.17: Grids with threshold flow accumulation of 5-cells

Delineation of the stream links

Flow network grid can then be used to identify the stream links as per the threshold as shown in fig.6.18. Knowing the stream links, the grids contributing flow to any point on the stream can be identified, which can be used to delineate the sub-watersheds.

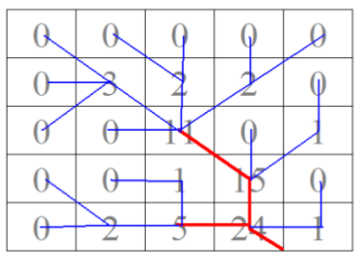


Figure 6.18: Stream network for a 5-cell threshold flow accumulation (shown in red color)

6.4.2 v.clean

"v.clean" allows the user to automatically fix topology of vector maps. An error map is optionally written which stores the erroneous geometries. Null area generated after merging also get cleaned up while using v.clean.

Removes small areas
tool=**rmarea**

The "rmarea" tool removes all areas <= thresh. The longest boundary with an adjacent area is removed or all boundaries if there is no adjacent area. Area categories are not combined when a small area is merged with a larger area. The threshold must always be in square meters, also for latitude-longitude locations or locations with units other than meters [21].

6.4.3 r.watershed

Calculates hydrological parameters and RUSLE factors. "r.watershed" generates a set of maps indicating: flow accumulation, drainage direction, the location of streams and watershed basins

Output accumulation map contains the absolute value of each cell in this output map is the amount of overland flow that traverses the cell.

Output drainage raster map contains drainage direction. Multiplying positive values by 45 will give the direction in degrees that the surface runoff will travel from that cell. The value 0 (zero) indicates that the cell is a depression area (defined by the depression input map). Negative values indicate that surface runoff is leaving the boundaries of the current geographic region. The absolute value of these negative cells indicates the direction of flow.

6.4.4 Intersection

Finds the intersection between two layers and makes a new layer with respective intersecting attributes appended to the attribute table.

6.4.5 Clip

Clips any OGR-supported vector layer by a polygon. The algorithm is derived from the ogr2ogr utility.

6.4.6 Merge

Merging data can be necessary when you obtain vector data from multiple sources. Each layer should be the same underlying projection (check the layer properties, since difference won't be visible in the Project's Map Canvas panel). This Merge algorithm converts the input layers (of same geometry) into one merged layer.

6.4.7 Eliminate Sliver Polygons

Used to select the problematic polygons and merge them to adjacent polygons based on a common boundary or area portion.ESP removes small spaces (slivers) between polygons where the polygons should be touching.

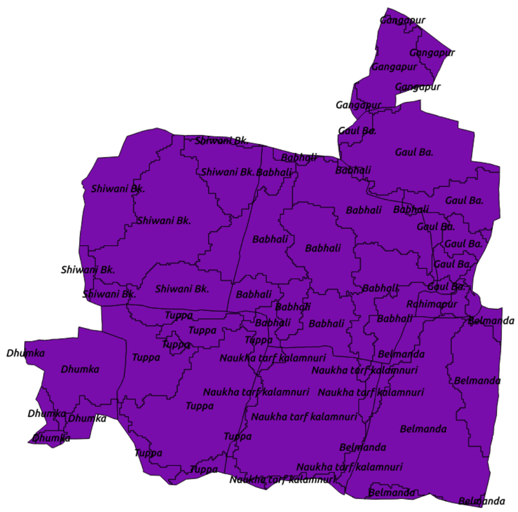
6.5 Automating the zoning process

The above-discussed procedure seems to be time-consuming and prone to errors if done manually. It was required to execute the zoning process on more than 1200 villages. So the process was automated which was to be run on several clusters. We have used 50 ha threshold for cleaning villages above 200 ha and 10 ha threshold for those below 200 ha.

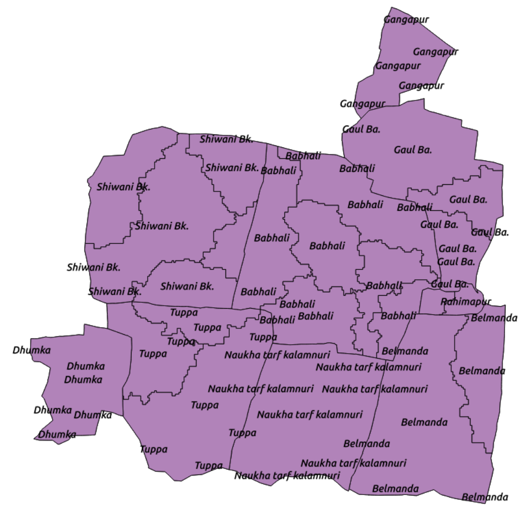
6.5.1 Time estimate of zoning

Depending on the cluster size it takes time to create zones. On an average, it takes 25-30 seconds to generate the final zonal output. After that, it needs to be manually inspected and updated accordingly if required. Drainage, Land use Land Cover map, soil attributes (texture) are used for further inspection of zones formed. So it is safe to assume that the final zones need at max 5 min to be generated from scratch which took 30 minutes earlier during manual process.

Below are some results when zoning is applied on a complete cluster:-



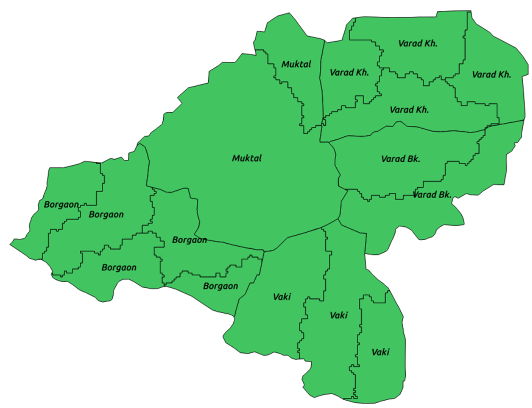
(a) Cluster Before Zoning



(b) Cluster After Zoning

Figure 6.19: Final Results of Zoning Automation

(a) Jalgaon Cluster Before Zoning



(b) Jalgaon Cluster After Zoning

Figure 6.20: Final Jalgaon Cluster Results of Zoning Automation

6.6 Issues in zoning methodology and outputs

6.6.1 Conflicting Zone Results Issue

As the geometries are irregular, the common approach for all the clusters did not work for a few geometries(clusters) causing errors in the various stages of zoning like merge, intersection, etc. Invalid geometry, in some cases, resulted in errors during computation. Such cases needed manual inspection and modification while in some cases it was possible to get correct results by using the alternate algorithms for the same task.

Below is one such case:-

While working on Jalgaon 499_te-24_02 cluster, found the following issue - using "v.clean" on cleaned watershed non-sliver with 50 ha threshold. There were two villages disjoint from the main cluster Vishnapur - 37 ha and Malapur 5 ha, as shown below. These villages disappeared on using v.clean with 50 ha threshold and were causing an error on merging.

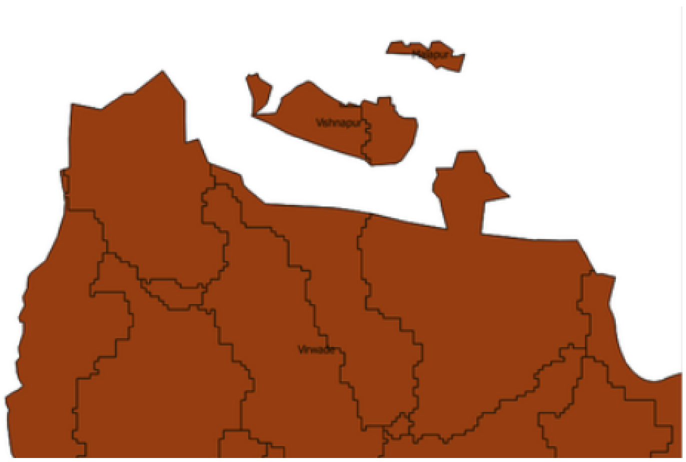


Figure 6.21: Conflicting Cluster

Why was merging causing an error?

Village with Unicode 526663 was converted to Line-string instead of polygon after applying v.clean and during merging due to conflicting types (Line-string vs. Polygon) the merging was not possible. It was converted to Line-string may be due to it has very less area. One can see the smallest polygon at the top of the watershed image, which is eliminated during merging in Figure 6.22a for the successful merge as shown. So the alternative mechanism tried was to use the ESP algorithm for cleaning, which worked quite well as can be seen in Figure 6.22b.

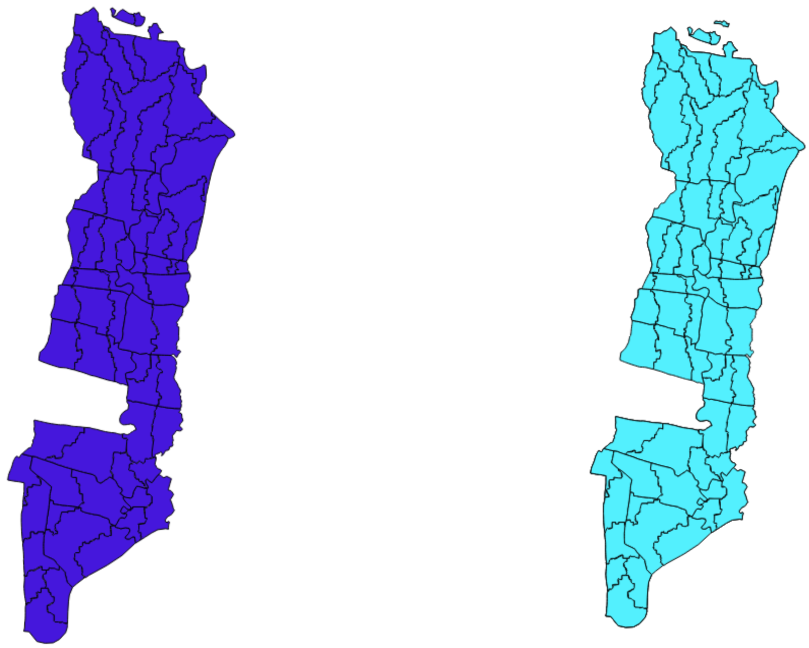
6.6.2 Solution to Conflicting Zones

On applying ESP on the intermediately generated esp_cleaned file (instead of applying on watershed.shp) of the Jalgaon conflicting village, the polygon is preserved including its attributes after cleaning. Also, the null geometries were already eliminated in the esp_cleaned input files. Applying ESP instead of v.clean on the merge conflicting polygon the above results were generated. It was able to preserve the polygon and did not get converted to Line-string.

Parameters used for ESP and its output:-

Selection attribute: Zone_area
Comparison: <=
Value : 10
Merge selection with : Largest area

Similarly, other cases were noted and updated either based on modification in zoning procedure for such cases or manually based on the extent of updating required.



(a) Cluster with conflicts on applying v.clean

(b) ESP Applied

Figure 6.22: Modified Cluster Results

6.6.3 Incorrect Merging of small size polygons

The merging of smaller watershed zones to the adjacent bigger watershed zone based on area as the parameter has certain drawbacks. The watershed whose water is draining into some watershed zone is merged with the watershed zone which is bigger watershed but not the draining watershed zone. Below visual representation will clear the issue in detail.

We have a cluster layer, watershed layer, and drainage layer. Now when three of these layers are overlapped, we can see that in fig.6.26 there are five zones in the Ambehol village. Now according to the merging logic, the smaller area-wise zones will merge into the larger zones as in below fig.6.27.

But if we carefully observe in fig.6.27 the merging of zone 124 which is part of Ambehol village, it can be seen that it is merged with zone number 158 which is area-wise larger adjacent zone beside zone 162. But the stream network depicts that the water from the 124th zone is going into the 128th zone and so should be so logically merged with the 128th zone instead of 158th zone number. This is because while calculating the water budget it happens that the water available in watershed zone 124 is considered in watershed zone 158 and may show the good condition of that zone but actually the water is flowing into the 128th watershed zone whose water budget should take this water into account while computation. The next section will discuss the solution methodology for the same.

Figure 6.23: Cluster Layer

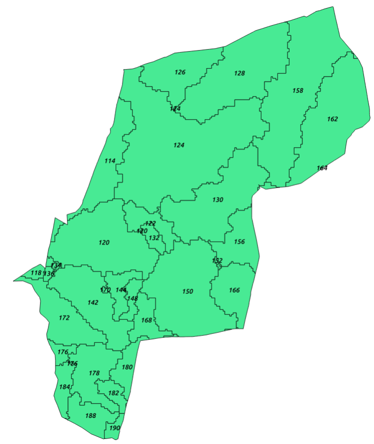


Figure 6.24: Watershed Layer

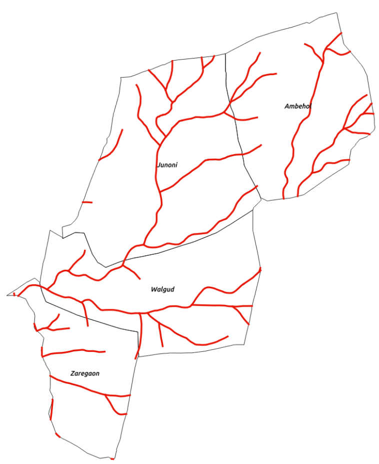


Figure 6.25: Drainage Network in Cluster

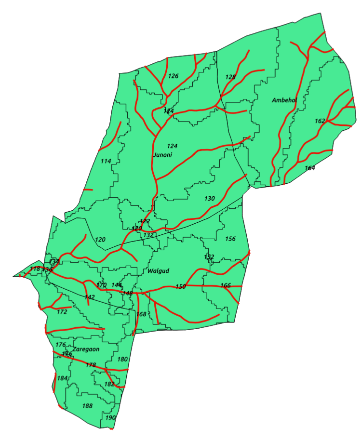


Figure 6.26: Drainage Watershed Cluster Overlapped

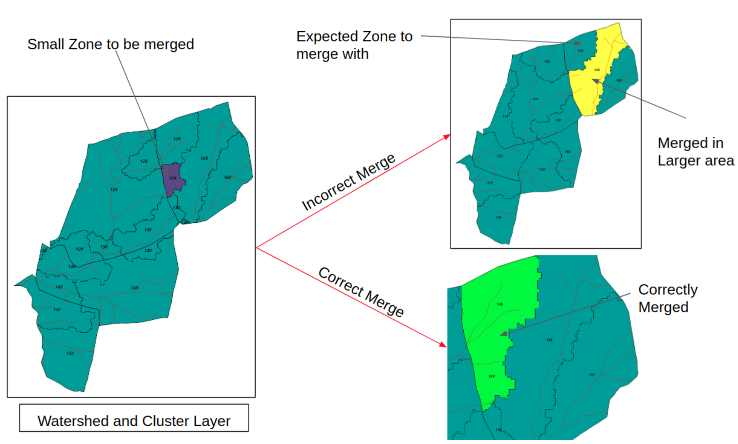


Figure 6.27: Zoning Conflicts

6.6.4 Solution to Incorrect Merging of small size polygons

The merging logic of zones needs to be updated as the water draining in the relevant watershed zones need to be accounted in the respective water budget computations. The factors like groundwater recharge, runoff, soil moisture are drastically impacted by the availability of the water in the individual zones. An API to identify the meeting point of two drain points of the zone will be helpful. Below is the brief merging methodology with the visualization of steps.

Improved Graph Model

The graph model will have the set of edges and vertices of the stream network. Based on the two input drain points provided the merging point will be identified. The green points in fig.6.29 are the input drain points. To find the merging point the direction of the respective stream segment is to be found. The merging point in fig.6.29 is the red point below the two green points which is to be found based on the minimum distance of all adjacent drain merge points. This is the primary API required for the zoning logic. Further, the same merging API can be used to find all the merging points of the adjacent zones and their respective distances can be computed. Below are the detailed steps:-

Updated Merging Methodology

Steps for Merging of Watershed based Zones:

1. Find the drain points for each Watershed Zone.
2. Now while merging of smaller zones find the watershed zones adjacent to the smaller zone.
3. For each adjacent zone, find a new point where the drain point of adjacent and small size zone meet.
4. The zone having the least distance between the drain point of small size zone and the point found in the previous step is the zone to be merged with.
5. If there are multiple drain points for a single zone, choose the zone with minimum drain point distance.

Visualization of Steps

In fig.6.29 the points colored green are the drain points of the zone. The merging point of those green points is the red-point below it and is minimum concerning other drain points. In fig.6.30 it can be seen that zone 124 is merged with zone 128 instead of zone 158.

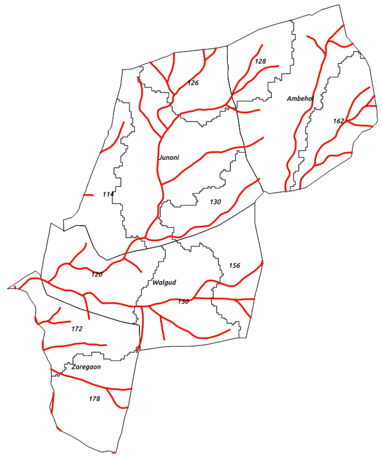


Figure 6.28: Incorrect Zoning Result

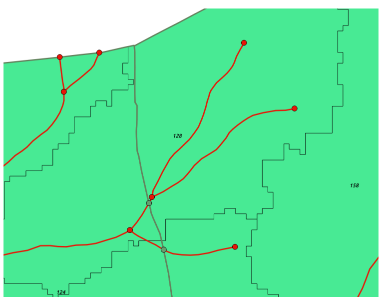


Figure 6.29: Merging of Drain Points

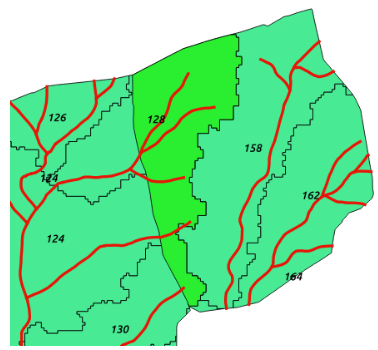


Figure 6.30: Merging Logic Applied

6.7 Future scope

Formulating and implementing zoning based on other criteria like slopes, soil type, stream proximity, etc., suiting the geography and resource availability within the village. Also, formulating a procedure to identify the natural zones within the village such that the access and availability of water is depicted more correctly which matches the cropping patterns within the zone.

6.7.1 Stream Proximity Maps

We need to gain more insight into how stream proximity maps can be incorporated into the zoning methodology for better intervention. In short, stream proximity deals with forming separate zones in the proximity (surrounding) of the streams having the high influence of streams and others with having a relatively lesser impact of flows as shown in fig.6.31. The order of the stream segment can be identified and it is multiplied with appropriate constant to form the buffer. It will be also helpful in providing advisory support like location and allocation of wells in the respective zones. Stream Proximity concept and approach is explained in chapter 10.

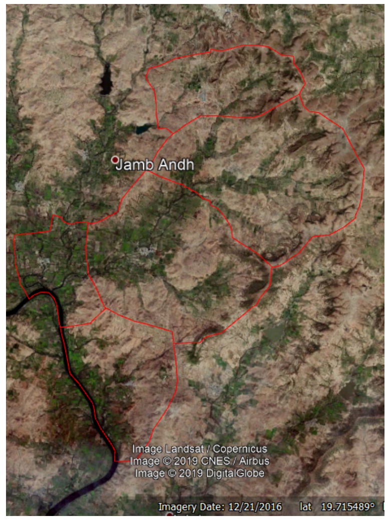
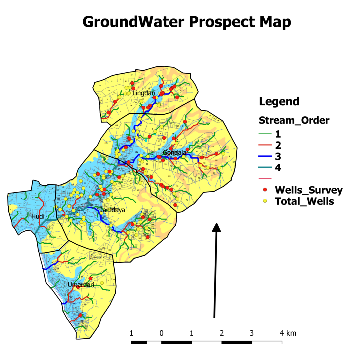


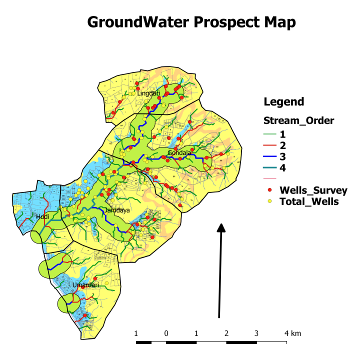
Figure 6.31: Green part is the Buffer around the Stream Segment

6.7.2 GSDA Maps

National Remote Sensing Agency has built a methodology for preparing the 'groundwater prospects maps' under Rajiv Gandhi National Drinking Water Mission (RGNDWM), project. The maps form a comprehensive database on groundwater and are useful for narrowing down the target areas for selection of sites for drilling new wells and prioritization of zones and identification of areas for planning recharge structures to improve the sustainability of drinking water sources[22]. These maps as shown in fig.6.32 and their methodology is required to be thoroughly studied and if found feasible, should be incorporated in the current zoning process.



(a) Groundwater GSDA Map



(b) Groundwater GSDA Map with Buffer

Figure 6.32: Stream Flow and Groundwater

Chapter 7

Data Analysis for Water Budget Improvement

7.1 Background

PoCRA, in technical partnership with IIT Bombay, has developed a framework to assess the water balance in the project villages. Land Resource Inventory (including soil characteristics viz. soil texture, soil depth, Field Capacity (FC), Wilting Point (WP), and erosion vulnerability) along with other data like weather parameters, crop characteristics, etc. form the core database for calculating the water balance and subsequent project planning. Currently, available land resource data is either insufficient or is available at a coarse scale. This leads to suboptimal results in water availability. So, a need has aroused to identify the integration of cropping pattern and soil data from various sources like Mahabhulekh, NBSS&LUP, MRSAC, etc. The cropping pattern data will help in providing the advisory support for the current cropping pattern and also can propose cropping pattern based on water availability.

7.2 Cropping pattern data analysis

7.2.1 Objective

To analyze the Cropping pattern data provided by Mahabhulekh with respect to its suitability for use in zoning, completeness, and consistency. The data primarily has information about the farmer, farm area and cropping pattern and farm divisions if any. The data can be utilized for water budget computation.

7.2.2 Need for Cropping pattern data

1. Cropping pattern data is critical for water budget computation as it is representative of the actual pattern in the zone and the same can be used to evaluate the modified zoning criteria.

2. Currently we are running cropping pattern over the entire region and then aggregating over the entire agricultural region of the zone. If we get the cropping data consistent with the cadastral maps then it can be used to compute the water budget of the region with respect to its cropping pattern.

7.2.3 Understanding data from sources like Mahabhulekh and MRSAC

Mahabhulekh Data Primarily Comprises:-

1. Village Info and its Survey Numbers
2. Cropping Pattern
3. Farmer's Info
4. Farm Area Info

The attribute of interest in MRSAC data Comprises:-

1. Village Info
2. Gat Numbers

ccode character(18)	village_name character varying(50)	survey_number text	area_vf7 numeric(18,4)	land_type text	jirayat_area_h numeric(18,4)	bagayat_area_h numeric(18,4)
270500040050140000	अंबिकापुर	100/3	0.8100	जिरायत	0.8100	0.0000
270500040050140000	अंबिकापुर	2	1.9200	जिरायत	1.8600	0.0000
270500040050970000	अन्वी	17/2	1.7800	जिरायत	1.7800	0.0000
270500040050970000	अन्वी	19/4	0.8900	जिरायत	0.8900	0.0000
270500040050970000	अन्वी	19/4	0.8900	जिरायत	0.8900	0.0000
270500040050970000	अन्वी	31/2	2.5100	जिरायत	2.5100	0.0000
270500040050970000	अन्वी	31/2	2.5100	जिरायत	2.5100	0.0000
270500040050970000	अन्वी	31/2	2.5100	जिरायत	2.5100	0.0000
270500040050970000	अन्वी	31/2	2.5100	जिरायत	2.5100	0.0000
270500040050970000	अन्वी	31/2	2.5100	जिरायत	2.5100	0.0000
270500040050970000	अन्वी	31/2	2.5100	जिरायत	2.5100	0.0000
270500040050970000	अन्वी	31/2	2.5100	जिरायत	2.5100	0.0000
270500040050970000	अन्वी	31/2	2.5100	जिरायत	2.5100	0.0000

Figure 7.1: Mahabhulekh Farmer Area Information

fullname text	khata_no character varying(7)	khata_area numeric	season_name character varying(50)	const_crop_name character varying(50)	pure_crop_name character varying(50)	pure_irr_area_h numeric	pure_unirr_area_h numeric
रामदास जानराव गावंडे	139	0.8100	खरीप	मुग		0	0
रामदास काशीराम इंगळे	130	1.9200	खरीप	कापूस		0	0
उमेश बंडुजी गाढगे	1757	1.7800	खरीप		सोयाबीन	0	1.7800
शे.नसीर शे.कदीर बागवान	152	0.8900	खरीप		ज्वारी	0	0.4000
शे.नसीर शे.कदीर बागवान	152	0.8900	खरीप		सोयाबीन	0	0.4900
सै. आवेज सै. मीरनफीस	1744	1.6200	खरीप		कापूस	0	0.8000
सै. आवेज सै. मीरनफीस	1744	1.6200	खरीप		ज्वारी	0	0.8000
सै. आवेज सै. मीरनफीस	1744	1.6200	खरीप		ज्वारी	0.4000	0
सै. आवेज सै. मीरनफीस	1744	1.6200	खरीप		पेरु	0.4500	0
सै बुशरा सै.मिरनफीस	1821	0.8900	खरीप		कापूस	0	0.8000
सै बुशरा सै.मिरनफीस	1821	0.8900	खरीप		ज्वारी	0	0.8000
सै बुशरा सै.मिरनफीस	1821	0.8900	खरीप		ज्वारी	0.4000	0
सै बुशरा सै.मिरनफीस	1821	0.8900	खरीप		पेरु	0.4500	0

Figure 7.2: Mahabhulekh Farmer's Information

7.2.4 Hierarchy and Observations in Mahabhulekh Data

The Mahabhulekh data has a particular hierarchy for land ownership and representation. For a particular Village, it can have multiple survey number including duplicates, each survey/Gat number may have further "khata_no." which represents the further division of land.

There is no inconsistency in the data with respect to cropping pattern. The cropping pattern is according to key as "KhateNumber_OwnerName", it means that the cropping pattern of all the keys across given Survey number is same. It means, for example, for Survey Number 274, cropping pattern of key1 in 274 survey number is same as that of cropping pattern in key2 in same survey number representing the consistency which was verified programmatically.

7.2.5 Comparative Results

For a given district and taluka, the ccode(state census code for village), Location/Village name and Gat number count for both Mahabhulekh and Cadastral data can be obtained for all the villages.

Below is one such sample (Yavatmal-Kalamb):-

		Mahabhu_Gat_no_count	MRSAC_Gat_no_count
ccode	location	gat_no_count	p_gat
271400030171660000	चापर्डा	30	121
271400030171670000	बेलोना	44	136
271400030171680000	घोटी	37	170
271400030171690000	कळंब (खंड 1)	61	Kalamb=993
271400030171690000	कळंब खंड2	152	Kalamb=993
271400030171700000	मलकापुर	31	54
271400030171770000	जोंधळणी	28	29
271400030171780000	दत्तापुर	10	73
271400030171810000	औरंगपुर	5	15
271400030171850000	सातेफळ	13	59

Figure 7.3: Mahabhulekh and MRSAC Gat Number Count

```
mhrorako_akt_gat_count.csv----6
mhrorako_tel_gat_count.csv----4
mhrorako_pat_gat_count.csv----3
mhrorako_bar_gat_count.csv----4
mhrorako_mur_gat_count.csv----2
mhrorako_bal_gat_count.csv----2
mhrorako_ako_gat_count.csv----19
Total Villages= 40
```

```
akola_akot_gat_count.csv----180
akola_akola_gat_count.csv----199
akola_telhara_gat_count.csv----106
akola_murtijapur_gat_count.csv----162
akola_barshitakli_gat_count.csv----159
akola_balapur_gat_count.csv----103
akola_patur_gat_count.csv----96
Total Villages= 1005
```

Figure 7.4: Village Count in Mahabhulekh and MRSAC Data

7.2.6 Discrepancies in Mahabhulekh Data

1. Missing Survey numbers in villages
2. Non-Standard formats for survey number representation
3. Number of villages covered is significantly less than known number of villages present in taluka (Village count given in folder of each district taluka-wise)
4. Some districts are missing (Hingoli, Parbhani, Washim)

   Similar, taluka wise analysis for cadastral(MRSAC) data is provided to cross-check the count of Talukas, Districts, Gat_nos, etc. including missing data for Mahabhulekh. Also, Wardha does not have location info in cadastral data so its comparative data is missing in both sources.

7.2.7 Action plan

Analysis of the cadastral data (PoCRA) is performed to figure out "what" and "how much" is missing. The same is forwarded to the concerned authorities for validation and getting the complete consistent data which can then be used to improve the zoning results.

7.2.8 Future Scope

1. Efficient Zone based Water Budgeting
2. Reduced Computation Time
3. Advisory Support
4. Enable Predictions

7.3 Soil Data Analysis

7.3.1 Objective

We need to characterize the regions within villages as per soil characteristics along with other features. However, the data for soil characteristics is not available for the whole state at sufficiently fine resolution. Also, the sources of soil data are different and have different parameters to measure. The challenge is to identify such correlations between parameters of one source with the other so that the data can be used to approximate better the main characteristics of our interest i.e.soil texture and soil depth.

Need of Soil Analysis

The NBSSLUP data is available at finer granularity i.e. at the scale of 1:10 while the MRSAC (cadastral) data is available at a granularity of 1:50. Also, the number of samples of NBSSLUP data is more than that of MRSAC data. So the integration of NBSSLUP data is to be done in order to improve the existing model with respect to its soil properties.

7.3.2 Methodology for Soil Analysis

We have adopted the following approach:

We were given shapefile from NBSSLUP source and we had shapefile from MRSAC source for the same area i.e. Yavatmal. We divided the shapefile in a grid format and for a point in each grid in one shapefile was compared to the corresponding grid in another shapefile. The results were noted in the form of a table having the dimension of n * m where n and m are the types of attributes in the NBSSLUP and MRSAC data sources respectively.

Procedure in brief:-

(a) We make a grid across the region in both maps.

(b) We have values of parameters in each grid cell in each map.

(c) We match the values in each cell in one table with that in the other.

(d) We then compute the frequency of matches.

(e) We choose the match as per frequency of match.

(f) The match is not a simple one to one but one to many.

(g) The matches are thus ranked in order of frequency.

(h) Thus the same parameter may occur multiple times on right-hand side.

Detail Procedure Adopted to find the results:-

(a) Load Yavatmal MRSAC shape-file in QGIS

(b) Find its extent (bounding box)

(c) Generate the vector grid as per bounding box

(d) Find the centroid of each grid in the vector

(e) Convert the centroid layer to a database

(f) For each centroid find the polygon enclosing it (Make a separate table)

(g) Append attributes of interest to the Centroid-polygon data generated

(h) Repeat the same procedure for NBSSLUP data

(i) Compare both the tables with a common column as grid_id for generating the final grid by a separate script

7.3.3 Evaluation of Results for Surface Texture

Results

Sr.No	Short Form	Surface Texture
1	CL	Clay Loam
2	C	Clayey
3	GC	Gravelly Clay
4	GCL	Gravelly Clay Loam
5	GL	Gravelly Loam
6	GSCL	Gravelly Sandy Clay loam
7	GSL	Gravelly Sandy Loam
8	LS	Loamy Sand
9	SCL	Sandy Clay Loam
10	SL	Sandy Loam
11	SiL	Silty Loam
12	HM	Habitattion Mask
13	WM	Waterbody Mask
14	M	Mining

Table 7.1: Surface Texture Attribute Types

	MRSAC Data														
	*	LS	C	HM	SL	SiL	GSCL	M	GCL	GC	CL	GL	SCL	WM	GSL
NBSSLUP Data	i	0	1	0	0	0	0	0	0	1	0	0	0	0	0
	m	38	5461	118	113	96	823	6	2101	194	1099	15	54	274	634
	k	0	440	3	27	14	28	11	146	3	62	2	2	7	52
	h	0	16	0	13	0	7	0	41	2	56	5	1	0	23
	f	1	253	5	9	0	152	0	381	39	163	10	25	26	558

Figure 7.5: Surface Texture Attribute Type's Count

Maximum Value in Row
Maximum Value in Column
Maximum Value in both Row & Column

Figure 7.6: Surface Texture Attribute Type Count Coloring

It can be seen from Table 7.5 the distribution of attribute's count is not uniform even after approximation. Most of the mapping can be seen with "m" type attribute from NBSSLUP data which may be a mixed type of multiple MRSAC attributes.

Observations/Mapping

The below table shows the top 3 matching MRSAC attribute types for each NBSSLUP attribute type. A distinct (approx.) mapping would have concluded the soundness of the data.

Sr.No	NBSSLUP Data	MRSAC Data
1	i	GC ,C
2	m	C,GCL,CL
3	k	C,GCL
4	h	CL,GCL
5	f	GSL,GCL,C

Table 7.2: Mapping of Surface Texture of NBSLLUP Data to MRSAC Data

Validating by database

Figure 6.7: Soil Depth Attribute Type's Count A total of 12000 (approximately) points were evaluated for generating the results. The below table can be used to validate the count of corresponding attribute types in the table 7.5.

Sr. No	Surface tex	Count
1	i	2
2	m	10372
3	k	747
4	h	163
5	f	1568

Table 7.3: NBSSLUP Query Result for Surface Texture

Sr.No.	Soil Texture	Count
1	Waterbody Mask	315
2	Clay Loam	1378
3	Gravelly Clay Loam	2670
4	Clayey	6157
5	Gravelly Sandy Clayey Loam	1009
6	Gravelly Clay	235
7	Habitation Mask	126
8	Gravelly Sandy Loam	1267
9	Loamy Sandy	39
10	Mining	17
11	Silty Loam	109
12	Gravelly Loam	32
13	Sandy Loam	162
14	Sandy Clay Loam	82

Table 7.4: MRSAC Query Result for Surface Texture

7.3.4 Evaluation of Results for Soil Depth

Results

Sr.No.	Short Form	Soil Depth
1	VD	Very deep (>100 cm)
2	DTVD	Deep to very deep (>50 cm)
3	D	Deep (50 to 100 cm)
4	MD	Moderately deep (25 to 50 cm)
5	STVS	Shallow to very shallow (<25 cm)
6	S	Shallow (10 to 25 cm)
7	VS	Very shallow (<10 cm)
8	HM	Habitation Mask
9	WM	Waterbody Mask
10	M	Mining

Table 7.5: Soil Depth Attribute Types

	MRSAC Data										
NBSSLUP Data	*	D	VS	DTVD	HM	S	M	WM	MD	VD	STVS
	0	12	4	0	91	130	14	220	34	231	23
	1	101	55	0	8	2080	0	8	698	489	297
	2	67	178	0	5	1002	0	8	405	690	147
	3	87	3	1	5	354	0	21	255	823	79
	4	22	0	1	1	216	0	0	143	453	44
	5	0	0	0	0	72	0	0	29	78	6
	6	138	15	3	16	627	3	50	395	2579	95

Figure 7.7: Soil Depth Attribute Type's Count

Maximum Value in Row
Maximum Value in Column
Maximum Value in both Row & Column

Figure 7.8: Soil Depth Attribute Type's Count Coloring

It can be seen from table 7.7 that there is bit randomness in the mapping and which is better in comparison to surface texture mapping. So the soil depth data can be said to be consistent with the MRSAC data.

Observations/Mapping

Sr.No.	NBSSLUP Data	MRSAC Data
1	0	VD,WM,S
2	1	S,MD
3	2	S,VD
4	3	VD
5	4	VD,S
6	5	VD,S
7	6	VD,S

Table 7.6: Mapping Soil Depth of NBSLLUP Data to MRSAC Data

Validating by database

Approximately 13000 points were used for mapping in both the shapefiles which can be seen in below tables and the respective counts can be validated for the table 7.7 from the same.

Sr.No.	Soil Depth	Count
1	6	3921
2	4	880
3	5	185
4	1	3736
5	2	2502
6	3	1628
7	0	759

Table 7.7: NBSSLUP Query Result for Soil Depth

Sr.No	Soil Depth	Count
1	Very deep (>100 cm)	5332
2	Deep to very deep (>50 cm)	5
3	Deep (50 to 100 cm)	425
4	Moderately deep (25 to 50 cm)	1955
5	Shallow to very shallow (<25 cm)	690
6	Shallow (10 to 25 cm)	4479
7	Very shallow (<10 cm)	254
8	Habitation Mask	126
9	Waterbody Mask	315
10	Mining	17

Table 7.8: MRSAC Query Result for Soil Depth

7.3.5 Action Plan

We have asked NBSSLUP department for the clarification as below:-

"Regarding shapefiles of two districts, Yavatmal and Wardha provided by NBSSLUP. We would like to know the information of these two attributes Soil Depth (0,1,2,3,4,5,6) and Surface Tex (f, h, i, k, m) in case of Yavatmal and Wardha. What do we mean by numbers and alphabets in brackets of these two attributes? Kindly, also provide the percentage of composition like clay, sand, and silt used for above texture classification. This will be important while running the water budget."

7.3.6 Future Scope

Further collaboration possibilities with NBSSLUP and MRSAC for refinement of soil and other data will be undertaken and the validation may be carried out using NBSSLUP data as per feasibility. This validation will enable refinement of soil input parameters to the plugin so that it generates water balance closer to ground reality. The data if found suitable and consistent can be used in the current water budget framework ensuring better results with respect to soil attributes like depth and textures.

7.4 Soil Sampling Background

PoCRA - IITB phase 1 project has involved the development and delivery of a scientific village level water budgeting and planning framework based on a water balance approach. Phase 1 was envisaged to promote optimum intervention and crop planning within the village through water balance exercise. To do this, generic GIS tools, datasets, and scientific procedures were developed and transferred to PMU, PoCRA. These tools provide zone level water balance outputs for micro-watershed zones within the village which measure seasonal agricultural water deficit, water availability in the form of various water balance components - soil moisture, groundwater, and runoff to enable demand-supply based zonal planning methodology.

Zone and village level water budgeting framework was developed based on these outputs and deployed to the field through PoCRA micro planning app. This water budgeting framework enables understanding of the current situation of the village in terms of water supply and demand parameters, based on its cropping pattern and existing interventions. It also enables scientific planning by allowing the user to plan only for available runoff.

The next step is translating the water budgeting into policy planning objectives, advisories, technical refinements in the model, and process automation. This chapter focuses on the technical refinement of soil input shapefile and based upon those soil properties being used to measure seasonal agricultural water deficit and other water balance components like soil moisture, groundwater, and runoff.

7.4.1 Objective

Compare texture results obtained from the field and its comparison with the texture results obtained from the MRSAC shapefile. Also, we will discuss the impact of texture values on the model output.

7.4.2 Need of Soil Sampling

MRSAC has provided the soil shapefile for the project area, which is at 1:50000 scale. This contains various physical and chemical soil properties, including soil texture and soil composition. We want to compare the soil texture values obtained from the soil series database with the values being tested at a few locations in the project region.

7.4.3 Soil Sampling Methodology

Within Paradgaon, various soil polygons from MRSAC shapefile were analyzed carefully by PoCRA team, and from different types of soil polygons, some soil samples were collected randomly in such a way that whole village and different soil types were covered completely.

Table 8.1 gives us the result of values tested in the laboratory and extracted from the soil series data for the locations where the sample has been collected. From the samples, one conclusion can be made that clay content is very less as compared to the MRSAC values and soils are high in silt content.

E.g., gat number 462 shows sandy loam, which is opposite from clayey given in MRSAC shapefile. The same thing is observed for gat number 24.

7.4.4 Impact of Texture Water Budget

The plugin was run at locations where soil sample has been tested. This was done to analyze the impact of texture values on model output. In Paradgaon village, survey number 328 with cotton plot is selected for analysis. At the locations, the model was run for tested soil texture and texture obtained from MRSAC value.

The model was run for two years, 2017 and 2018 at location 328. According to MRSAC shapefile soil is very deep, and its texture is clay. But, soil depth at the location is 0.5m and texture is sandy loam or silty loam. The model was run for all the scenarios, and the result is given in table 9. In 2018, there is less rainfall whereas in 2017 there is more rainfall. In clay texture obtained from MRSAC shapefile, there is hardly any groundwater recharge. This is tested for two depths, 1.5m, and actual depth 0.5m when depth is more, more water is being stored in the clay soil and is available to plants as it has high water holding capacity. Due to less depth, the soil is completely saturated and recharge through it is very slow as it tries to hold water; this does not allow much groundwater recharge. This causes high runoff and more deficit. The model was run for tested texture and actual depth as well, which is sandy loam or silty loam. In the case of sandy loam, there is more groundwater recharge, and the crop has taken less water due to which deficit is more. In the case of silt loam, groundwater recharge is less as compared to sandy loam and crop has taken more water. Silty loam situation matches the ground scenario. The same kind of trend has been observed in model output for the year 2018.

Cotton_328_2017				
	Test		**MRSAC**	
2017	**Sandy_loam _0.5**	**Silty_loam _0.5**	**Clay_0.5**	**Clay_1.5**
Rain-fall_Monsoon_End	777	777	777	777
Runoff_Monsoon_End	229	230	376	268
AET_Monsoon_End	372	452	386	483
Soil Mois-ture_Monsoon_End	4	13	6	31
GW_Monsoon_End	172	83	11	0
Deficit_Monsoon_End	131	50	117	20
AET_Crop_End	413	497	425	539
Soil Moisture_Crop_End	4	9	6	11
Deficit_Crop_End	361	227	348	234
Cotton_328_2018				
Rain-fall_Monsoon_End	436	436	436	436
Runoff_Monsoon_End	116	93	162	134

Table 7.9 continued from previous page

Cotton_328_2017				
AET_Monsoon_End	253	292	260	301
Soil Moisture_Monsoon_End	4	9	6	1
GW_Monsoon_End	62	41	7	0
Deficit_Monsoon_End	283	244	275	235
AET_Crop_End	253	292	260	301
Soil Moisture_Crop_End	4	9	6	0
Deficit_Crop_End	525	485	517	476

Table 7.9: Model output for cotton plot 328 in paradgaon for year 2017 and 2018

7.4.5 Field Visits and Soil Sampling Results

Comparative Analysis of Soil Samples in Android Application:-

1. As per below graphs fig.7.9 and fig.7.13, it can be seen that when the soil type was clayey the runoff was 374mm and the groundwater recharge is just 1 mm due to the property of clayey soil that it holds more water and does not let the water percolate in groundwater and so the water runoff is more.

2. We are trying to validate over a larger area and in detail considering the two or three layers of soil and then validating them with MRSAC data for better results.

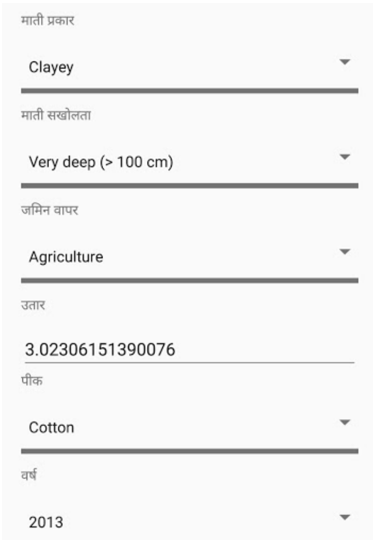


Figure 7.9: MRSAC Inputs

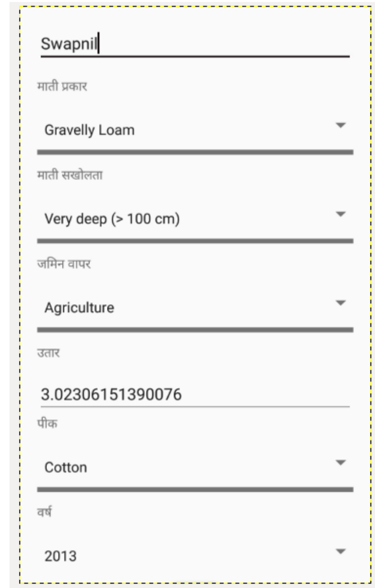


Figure 7.10: Actual Inputs

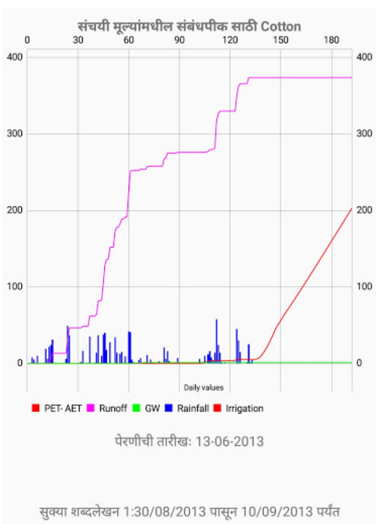


Figure 7.11: MRSAC Soil Cumulative Values

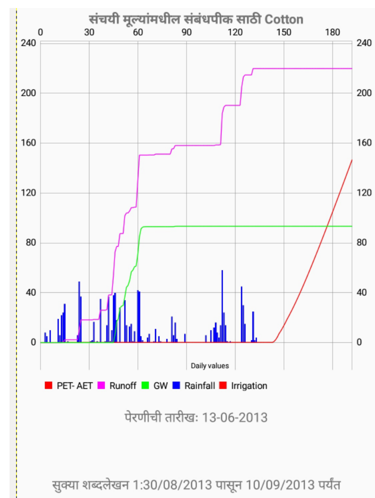


Figure 7.12: Cumulative Values for Actual Data

सुक्या शब्दलेखन 1:30/08/2013 पासून 10/09/2013 पर्यंत

सारांश मूल्ये

परिमापक	मान्सून एन्ड	पीक समाप्त
पाऊस	1007 mm	1013 mm
रनऑफ	374 mm	374 mm
एकूण पीक एईटी	504 mm	571 mm
मातीचा ओलावा	117 mm	67 mm
जीडब्ल्यू रिचार्ज	1 mm	1 mm
एकूण तूट	5 mm	203 mm

Figure 7.13: MRSAC Summary Values

सारांश मूल्ये

परिमापक	मान्सून एन्ड	पीक समाप्त
पाऊस	1007 mm	1013 mm
रनऑफ	220 mm	220 mm
एकूण पीक एईटी	509 mm	627 mm
मातीचा ओलावा	171 mm	72 mm
जीडब्ल्यू रिचार्ज	93 mm	93 mm
एकूण तूट	0 mm	147 mm

Figure 7.14: Summary Values For Actual Data

	Lab Results			**MRSAC Data**		
Gat No.	**Sand%**	**Silt%**	**Clay%**	**Sand%**	**Silt%**	**Clay%**
12	28	40	32	39	22	39
12	53	36	11	33	27	40
12	80	18	2	33	27	40
40	50	46	4	8	28	64
40	10	82	8	7	29	64
40	44	52	4	7	29	64
79	11	85	4	24	22	54
79	3	66	31	24	22	54
88	37	51	12	39	22	39
88	74	24	2	33	27	40
88	82	16	2	33	27	40
110	50	35	15	17	27	56
110	48	40	12	24	22	54

Table 7.10: Sample lab results and their comparison

More clay can be seen in MRSAC (Maharashtra Remote Sensing Application Centre) data than that of actual ground values.

7.4.6 Conclusion

Currently, soil maps being used are at 1:50000 scale and soil texture results for five villages show that there is the scope of improvement. Model output results at five locations show that there is a difference in texture values being used directly from the shapefile and field-tested results. The soils have more silt content as compared to clay content. Due to this difference model output results varies significantly. At some places, there are huge variations in runoff, groundwater recharge, soil moisture values, and hence in crop deficit. Improved input data to any model will result in better output. Soil maps can be brought down to 1:10000 scale. This will improve land-based planning as well as farm-level water budget results. Efforts should be made towards bringing the down the scale of the map.

Outcomes

Memorandum Of Understanding Between Maharashtra Project On Climate Resilient Agriculture, Government Of Maharashtra And National Bureau Of Soil Survey And Land Use Planning, Nagpur: For High-Resolution Land Resource Inventory and Land Use Planning for Climate Resilient Agriculture

NBSS&LUP is an apex national organization for soil survey and land use planning in India with the mandate to undertake soil survey and mapping of soils (land resource inventory) of the country to promote scientific and optimal land-use programs in collaboration with relevant institutions and agencies.

This assignment aims at inventory mapping of land resources of selected villages in 15 project districts to facilitate optimum utilization of soil and water resources. During the period of the assignment, soil, water, and crop interaction will be carefully studied, analyzed, and solutions based on this analysis will be implemented at the farm level[30].

The broad objectives of the project are (taken from the MOU) [30]:-

- Characterization and Mapping of soil resources on 1:10000 scale for their optimum utilization and conservation.
- To create Soil Atlas of the project villages depicting different characteristics and generate advisories for adaptation to climate change and optimum, sustainable use of land resources.
- Development of abiotic stress management plan to enhance the resilience of farming communities
- Capacity building of the project functionaries

7.5 Soil Sampling Application

7.5.1 Need

There is a mismatch between the MRSAC data and actual field data. This leads to incorrect results for runoff, groundwater recharge, and other related attributes in the water budget calculation. The parameters obtained from the soil sampling application will help the to validate the results generated from the NBSS&LUP. Validation of primary data from NBSS&LUP will be done by the secondary data obtained from the application. The android application is in Marathi to ease the personnel responsible for data collection.

NBSS&LUP has been given the task to prepare an inventory of land resources in the project villages. The False Color composites are visually interpreted using image interpretation elements along with all the collateral data available for the area for delineation of physiographic boundaries.

Then intensive traversing of each physiographic unit like hills, uplands and lowlands is carried out. Based on the soil variability observed on the surface, transects are selected across the slope covering all the physiographic units identified in the village/watershed. In the selected transect soil profiles are located at closely spaced intervals to take care of any change in the land features like a break in slope, erosion, gravel, stones, saline/alkali etc. Apart from the transect study, soil profiles are also studied at random, almost like in a grid pattern outside the transect areas to validate the soil map unit boundaries. However, it is not possible to cover all the area with transect walk and dig soil profiles everywhere. To supplement the validation process survey-based information about soil type, depth, its characteristics, and the dominant crop is gathered on cadastral scale.

7.5.2 Objective

To collect soil, farm, and farmer related information to analyze and improve the existing soil database.

7.5.3 Android Application Design

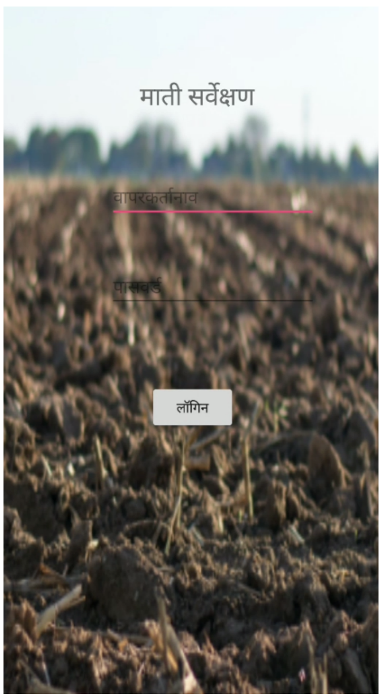


Figure 7.15: Login Soil

Figure 7.16: User Input 1

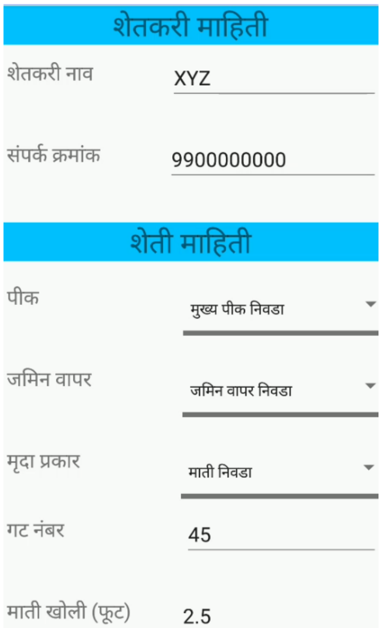


Figure 7.17: User Input 2

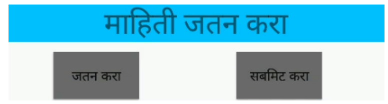


Figure 7.18: Save Submit Options

7.5.4 Core Utility Features of Android Application

Login

Currently, the application has a single login credential set. The credentials can be added later as per the requirement.

Farmer Input Attributes

The android application collects the soil information as per below categories:-

1. **Location Information**
   (a) District Name
   (b) Taluka Name
   (c) Village Name
   (d) Latitude
   (e) Longitude
   (f) Timestamp
2. **Farmer Information**
   (a) Farmer Name
   (b) Farmer Contact Number
3. **Farm Information**
   (a) Gat Number
   (b) Crop Name
   (c) Land Use
   (d) Soil Type
   (e) Soil Depth (In Foot)

Click Based Location and Timestamp

The timestamp and Lat-Long information can be added on a single click of the button. The lat-long information then dynamically changes as the user moves.

Local Input Storage

The inputs fed by the user can be stored (and are supposed to be) stored locally if the internet connection is weak or not available.

Input Storage at Server and Database Schema

The application checks if the internet connection is available and then updates the inputs saved locally to the Postgres database on the server.

Storage at Server Side:

Below attributes get updated to the database server once the submit option is clicked.

Database Table:- soil_info

district_name character varying(100),
taluka_name character varying(100),
village_name character varying(100),
farmer_name character varying(100),
contact_no character varying(100),
gat_no character varying(100),
crop_name character varying(100),
landuse character varying(100),
soil_type character varying(100),
soil_depth numeric,
latitude numeric,
longitude numeric,
time_info character varying(100),
year character varying(100),
yield numeric,
watering numeric,
watering_type character varying(100)

district_name character varying(100)	taluka_name character varying(100)	village_name character varying(100)	farmer_name character varying(100)	contact_no character varying(100)	gat_no characte
अमरावती	अकोला	अगासखेड	Swapnil	7709405270	54

Figure 7.19: Snapshot of database entry

7.6 Future Scope

7.6.1 Additional Section of Farmer Inputs

Other parameters like soil type from second and third layer can be also be taken. Parameters related to cropping pattern, cropping area, irrigation can also be asked and analyzed in the respective farm level water budget outputs.

Chapter 8

Regional Decomposition for Water Budgeting Purpose

8.1 Background

The current water accounting framework computes the water budget indices at the point(farm) level, and then those indices are aggregated over zones. But this framework does not take into account the amount of water flowing within zones, movements of water across zones and the respective flows associated with it. A considerable amount of runoff can be made available to the adjacent villages from the current village, which can be used to tackle the crop water deficit more effectively. The availability of ground water and surface water in upstream villages is for less time as it flows to the downstream villages. This problem is with respect to the temporal and spatial characteristics of the area. This issue can be addressed by mapping the administrative and watershed boundary and then establishing a relationship between the water available in each watershed and the water passing drain points of the administrative boundary. If we can evaluate the amount of water available at drain points and also at the points within the village on stream network, then we will be able to propose locations for water storage structures to achieve equal distribution and availability of water within the area. The runoff harvesting structures if built, will be useful to farmers to use the impounded water in dry seasons. This work aims to create a water accounting framework which will roughly answer how much water is available to the village from external sources, how much was used and percolated within the village and how much water is flowing out of the village or is made available to other neighboring villages.

8.2 Motivation for Regional Decomposition

1. Integrated analysis of Administrative and Natural boundaries
   (a) Establishing a relationship between Village and Watershed boundaries
2. Regional or Village level Irrigation Planning
   (a) Understanding stream flows and water availability
3. Better analysis of surface water flows and water availability within administrative units.

8.3 Regional Decomposition Methodology

8.3.1 Objective

Given a DEM and administrative boundary (henceforth referred as village/cluster boundary), dividing the village area into zones such that either each zone represents the whole or part of the watershed for each drain point in the village or it represents a part of village boundary where water is flowing IN or OUT of the village.

So, it basically means to obtain the partitions of a region into zones given DEM, administrative boundary and list of points on the stream network as the input as shown in fig.8.1. Here, drain point refers to a point on the administrative boundary through which either water enters or leaves the boundary. The primary aim of this exercise is to have an idea about the overall water accounting within the administrative boundary.

In below fig.8.1, R is the cluster boundary or total area under consideration, V is the village boundary, S1 is the stream network within the village V and S2 is the stream network outside village V, D is the set of points (D1,D2,...Dn) on village V and stream network S1, L is the part of village area V not in the watershed area of the village, P1,P2,...P5 are the partitions of the village area V based on the differential watersheds of input points D. D1 is the exit point of water for the village and D2,D3 are the entry points of water for the village. D4,D5 are the points within the village V and on stream network S1 representing the potential water storage structures.

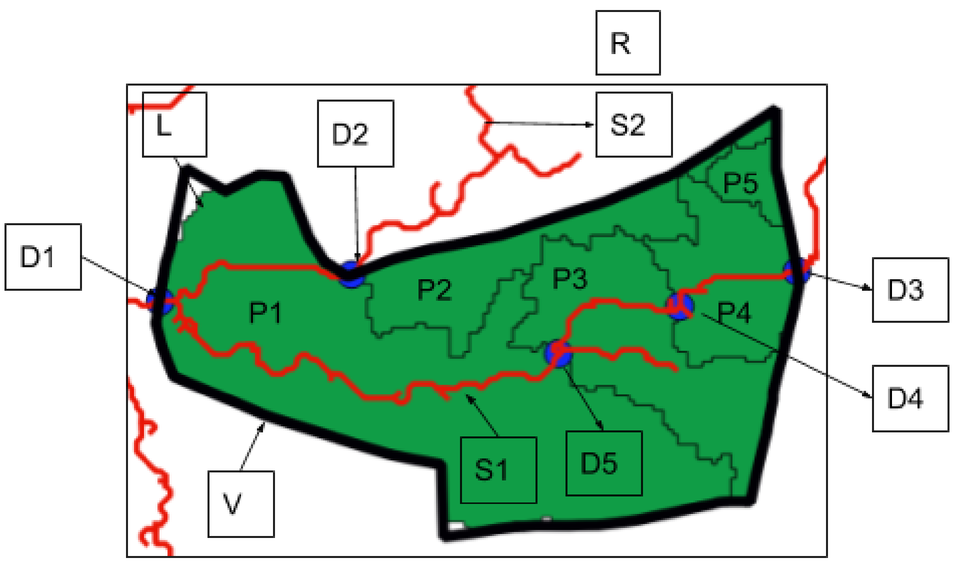


Figure 8.1: Regional Decomposition Problem

8.3.2 Input Output Parameters

Input:

1. DEM (Digital Elevation Model)
   (a) Used for generating Stream Network
2. Set of Points
   (a) Intersection of Administrative Boundary and Stream Network called drain points
   (b) Other points representing Water Storage Structures on stream network

Output:

1. Zones
   (a) Division of Administrative boundary into regions called as zones, based on a watershed basis
2. Differential Watershed for each input point
3. IN or OUT notion representing the flow with respect to the administrative boundary
   (a) Represents water flow within or OUT of the administrative boundary
   (b) IN and OUT notion of water flow is also applicable to points taken in input which is represented as a label in the output decomposition table

8.4 Visualization of Differential Watershed

A watershed describes an area of land that contains a common set of streams and rivers that all drain into a single larger body of water, such as a larger river, a lake or an ocean. It is any surface area from which runoff resulting from rainfall is collected and drained through a common point. The differential of a watershed is that part of the watershed which is the new water accumulating at that point which may be the subset of the actual watershed of that point. Here, 'new' is with respect to the water accumulated at predecessor points. This accounting gives us the idea of how much new water has arrived at that particular point which can be used to conceptualize a water accounting framework representing how much of water is coming IN the village and how much of water is going OUT of the village. The concept of differential water helps us to identify the amount of water which will be available even if no water is allowed to transcend from the surrounding points either through runoff or groundwater, etc.

Partially Ordered Set of Points on Stream Network

We need to understand the concept of partial ordering of points on the stream network before identifying the differential watershed for those points. The partial order helps to identify the new water that is contributed at that particular point by eliminating the watershed of points of all the predecessor points in the sequence. In below fig.8.2 I_i is the part of the stream network contained in differential watershed of that point. We define a partial order on the collection of channels I_i and reservoirs R_j as $X_i \leqslant X_j$ if the drain point d_i is downstream of d_j in S, where X_i , X_j are either channels or reservoirs. The sample partial order is shown below in fig.8.2. Note that I7 is not a single segment but a collection of stream segments merging and draining at d7. The below partial order states that the obtained sequence should be followed while calculating the watershed for all the points. The partial order for stream network given in fig.8.3 is 48-49-47-50-46-51-45.

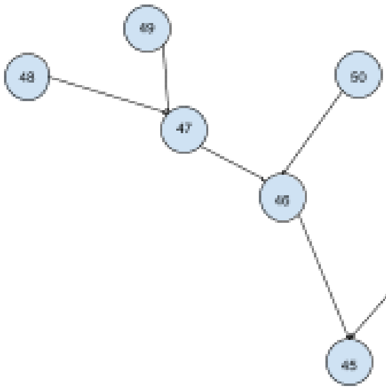


Figure 8.2: Partial Order on Stream Network

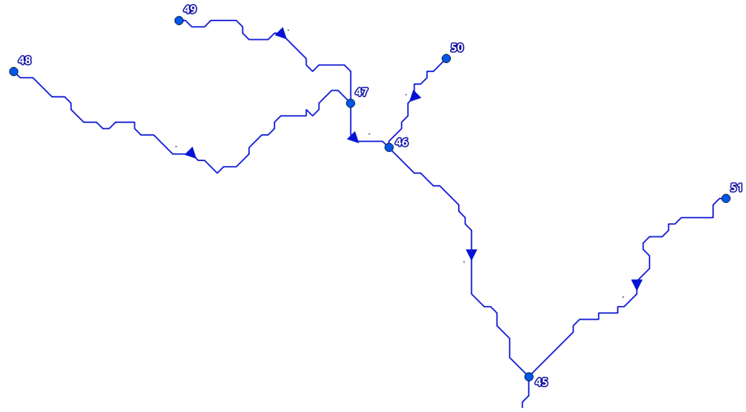


Figure 8.3: Partial Order on Stream Segments

Example of Differential Watershed:

Let's visualize and understand the concept of the differential watershed through example. Consider the below administrative boundary and the respective stream segments generated from the watershed, which is a natural boundary. The points on the stream network represent the drain points and the potential water storage structure points.

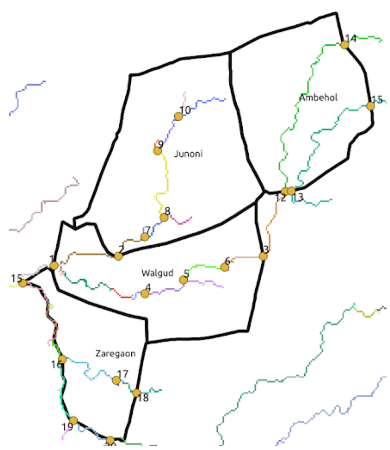


Figure 8.4: Intersection of Cluster Boundary and Stream Segments

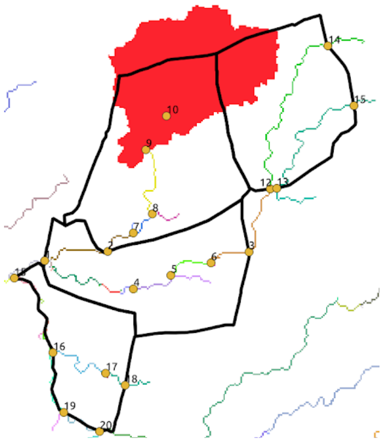


Figure 8.5: Watershed For Point 10

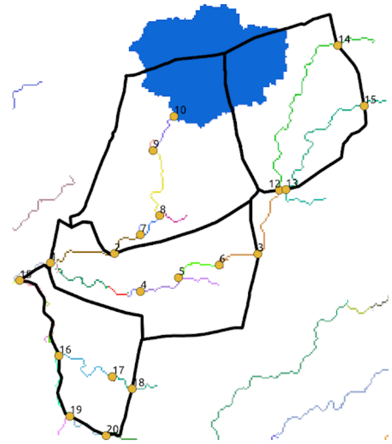


Figure 8.6: Watershed For Point 9

Now, the differential watershed for point 9 is the amount of water accumulating at point 9 and is not part of the watershed for point 10 or any of its predecessor points. In below fig.8.7 the area marked in green represents the differential watershed for point 9. Let's say "X" amount of water is available in the watershed for point 10, and "Y" amount of water is available in the watershed for point 9. Then the differential watershed for point 9 will comprise of "Y-X" amount of water, given that they are in partial order hierarchy. Now, if there is significant extraction of water at point 10, then the availability of water at point 9 is impacted causing the shift of farming practices in the area dependent on the water at point 9.

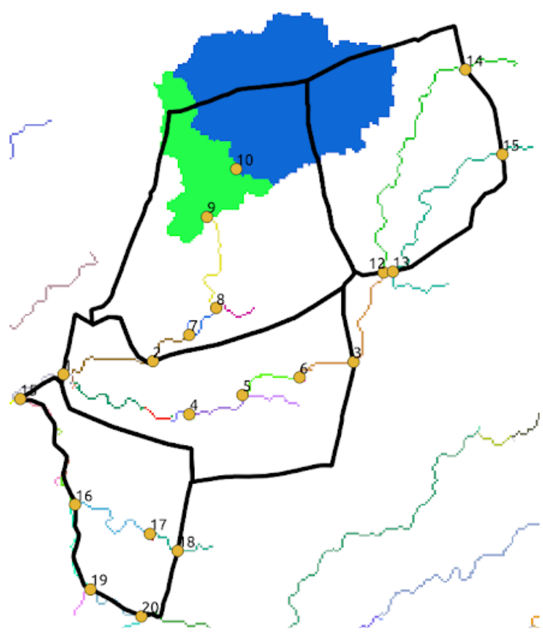


Figure 8.7: Differential Watershed For Point 9 and 10

8.4.1 Regional Decomposition Problem

Let us consider a cluster area given by a region Y, and attempt to create a framework for hydrological analysis, which is informative as well as extendable to the areas around the region Y. The framework begins with a stream network S and a DEM for the region Y, along with other hydro-geological parameters as inputs. Here, hydro-geological parameters refers to water related attributes on and beneath the earth's surface. The major part of mathematical model used here is obtained from "GIS Framework for Regional Flows" document [27].

Sr.No.	**Representation**	**Explanation**
1	Y	Cluster Boundary
2	S	Stream Network
3	D$\{d_1, d_2..d_n\}$	Set of Points on Administrative Boundary and Stream Network
4	V	Village Boundary
5	WS(d)	Watershed of Point d
6	DWS(d)	Differential Watershed of Point d
7	d'	Predecessor Points for Point d
8	Z_i	Differential watershed DWS(d_i)
9	L	Area within administrative boundary not covered by watershed
10	I_i	$Z_i \cap$ S, part of the stream network contained in Z_i,called as Channel in Z_i
11	R	Reservoir

Table 8.1: Regional Decomposition Terminologies

Zones, Watershed and Differential Watershed

The partition of region Y into administrative boundary as village denoted as $\{V_1, V_2...V_n\}$. Our first step is to identify a special set of points D = $\{d_1, d_2...d_n\}$ within Y and on the stream network S. These points may be chosen to include reservoir discharge points, key infrastructure locations, e.g., as KT weirs, and points where, e.g., the soil, the topography or cropping practice makes a transition. Geographically these points will be the points obtained from the intersection of administrative boundary and stream network, points on the stream network within the administrative boundary denoting potential location for water storage structures.

The problem is to arrive at zones Z_{ij} such that they follow $\cup_i Z_{ij} = V_i$ which means union of all zones should constitute village area and $\cup_i Z_{ij}$ = DW(d_j) + L_j means union of all zones is the sum of all the differential watersheds and the part not in watershed area ,where L_j is the area not in watershed.The area L can be defined as $L_i = V_i$ - DW(d_i).

Meaning of Differential Watershed

There exists a partial order on D given by S, the stream network, viz., $d_i \leqslant d_j$ if d_j drains into d_i in S which there exists a hierarchy of points such that the higher elevation point drains into lower elevation point based on the partial order. The differential watershed DWS(d) for a drain point is given as the difference of WS(d) $- \cup_{d<d'}$WS(d'), of the watershed of d and the watersheds of all its predecessor points.All run-off in Z_i will discharge into the channel I_i.Note that Z = $\cup_i Z_i$ may be different from Y. See for example the fig. 8.8, where the zones Z_i (not restricted to Y) are coloured, while the region in white belongs to zone not part of watershed area. We define an extension Z_i' as the union of Z_i with a suitable sub-area of the area of Y not covered by Z which is L_i.

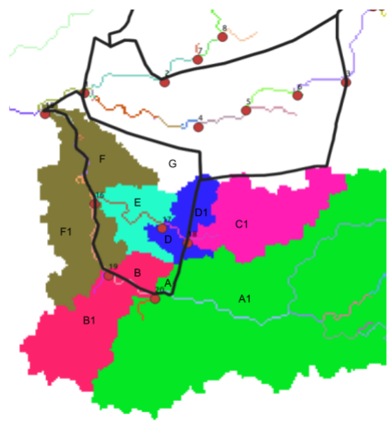


Figure 8.8: Zonal Decomposition with Village area in Watershed area and Non-watershed zones

8.4.2 Regional Decomposition Steps

1. Derive Stream Network from DEM.
2. Convert Administrative boundary polygons into a line layer.
3. Intersect Stream network and Administrative boundary for drain points.
4. Include additional stream points representing water storage structures.
5. Find differential watershed for each point as per the partial order.
6. Allocate zones to differential watershed areas.
7. Identify and assign zones to areas not covered in any watershed boundary.

8.4.3 Visualization of Steps

1. Derive Stream Network from DEM.

   Using "r.watershed" in QGIS we can obtain the required stream segments. The only parameter to set to obtain stream segments is "Minimum size of exterior watershed basin".It is basically the number of cells to consider while deriving the stream network. The value set to this parameter is 300. Results for both values 300 and 150 are shown in below figures 8.10 and 8.11. It gives raster files are output which to be converted to vector using "r.to.vect" command.

Figure 8.9: Input DEM for cluster 525_sa-33_04

Figure 8.10: Stream segments 300 raster

Figure 8.11: Stream segments 150 raster

Figure 8.12: Stream segments 300 vector

Figure 8.13: Stream segments 150 vector

2. Convert Administrative boundary polygons into a line layer.

   "Polygon to line" feature in QGIS is used to achieve the same.

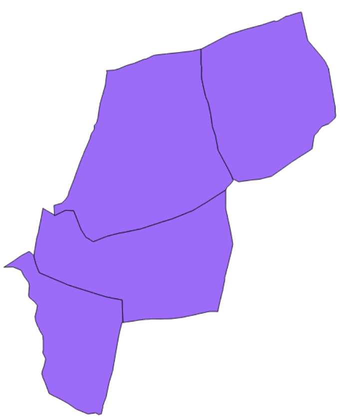


Figure 8.14: Administrative Boundary Polygon Layer

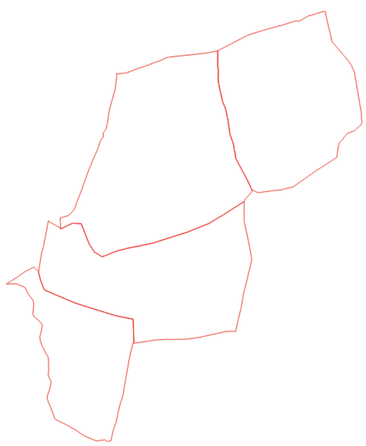


Figure 8.15: Administrative Boundary Line Layer

3. Intersect Stream network and Administrative boundary for drain points.

   Line intersection feature in QGIS is used to intersect the stream and administrative boundary.

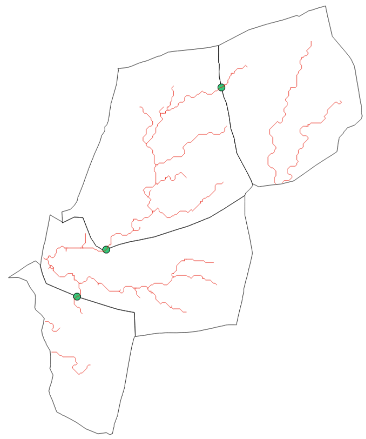


Figure 8.16: Drain Points

4. Include additional stream points representing water storage structures.

   We can have additional points within the village, i.e., the points which are not in the intersection set of village boundary and stream network. This points may represent the location of current or proposed water storage structures, and hence, the analysis of such points will be useful. Let's take a sample set of points. In the below-given image, we have taken a total 6 points out of which three are on the village boundary, and 3 points are within the village on stream network.

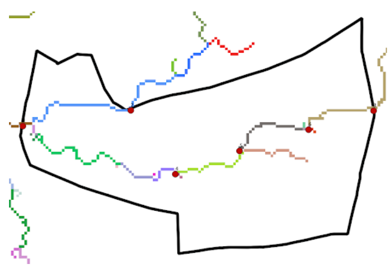


Figure 8.17: Points within and on Village Boundary

5. Find differential watershed for each point.

   The command "r.water.outlet" available in GRASS is used to obtain the watershed for each input point in the network. It takes drainage raster layer as input.

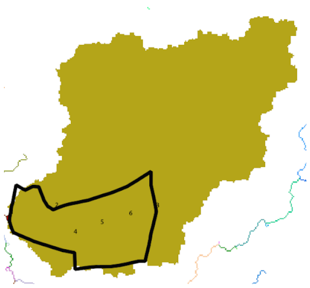


Figure 8.18: Watershed for point 1

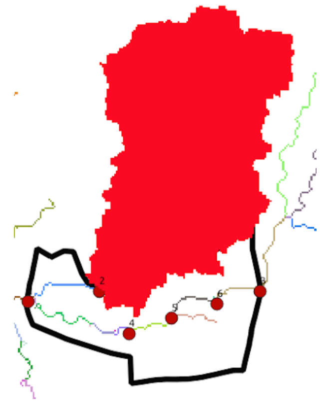


Figure 8.19: Watershed for point 2

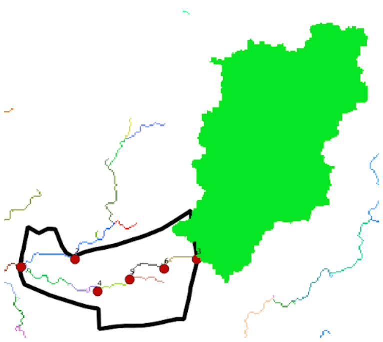


Figure 8.20: Watershed for point 3

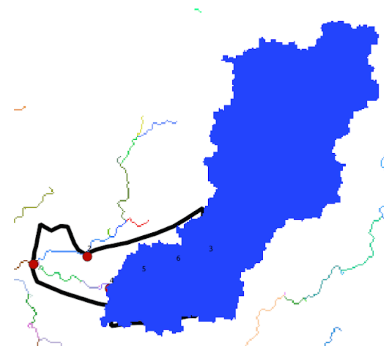


Figure 8.21: Watershed for point 4

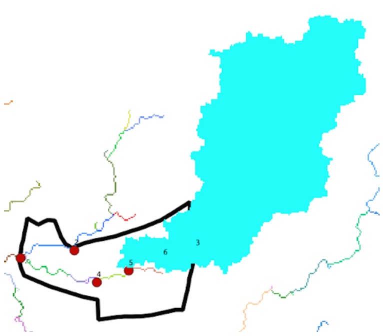


Figure 8.22: Watershed for point 5

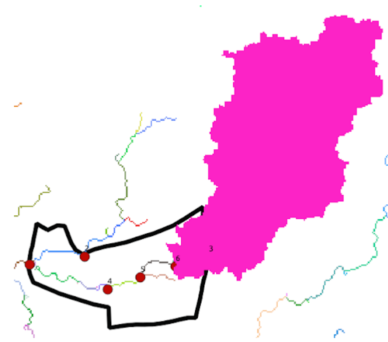


Figure 8.23: Watershed for point 6

6. Allocate zones to differential watershed areas.

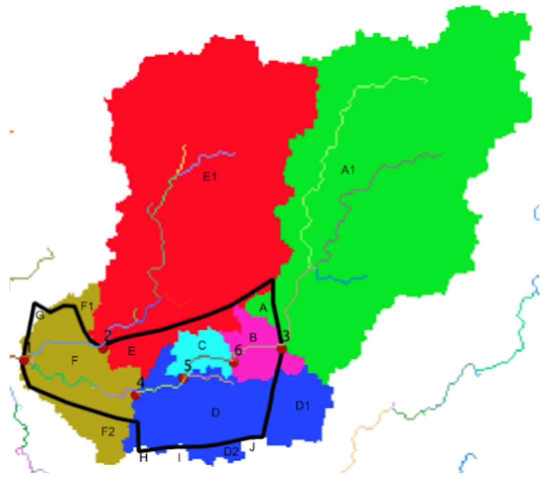


Figure 8.24: Zonal Decomposition for Water Accumulation of Walgud Village

7. Identify and assign zones to areas not covered in any watershed boundary.

Point No.	Contributing Inner Zones	Contributing Outer Zones	Label
1	F	F1,F2	-1
2	E	E1	+1
3	A	A1	+1
4	D	D1,D2	0
5	C	-	0
6	B	-	0

Table 8.2: Zonal Decomposition Table for Water Accumulation of Walgud Village

Label: "0" is for a point within the village, "+1" for water entering the village and "-1" for water leaving out of the village for that point.

The attribute "Contributing Inner Zones" represents the division of administrative boundary, which is a village. The union of points F, E, A, D, C, B may not constitute a complete village area. It is because there is some part of the village which is not part of any watershed. The areas marked as H, I, J, G are such polygons which are not part of any watershed boundary. The attribute "Contributing Inner Zones" represents the differential watershed for a particular point. The attribute "Contributing Outer Zones" represents the part of the watershed which lies outside the village boundary and is also part of differential watershed for respective point of interest. The attribute "Label" indicates whether the water is flowing IN or OUT of that particular point.
The identification of the flow direction of water is made through visualization of stream segments by checking if the stream segments are merging depicting the flow in the merging direction. The more concrete conclusion of direction flow can be accomplished through contours generated from the DEM (Digital Elevation Model). The contours represent the elevation values for each point. The flow is generally considered to be flowing from the point of higher elevation to the point of

lower elevation. So, if the stream segments and points of intersection are overlapped with the contour layer, then the direction flow can be verified as shown in below fig.8.25.

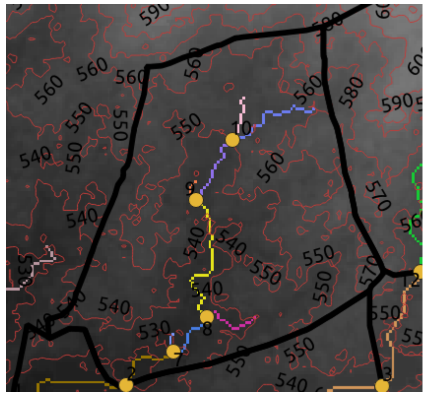


Figure 8.25: Contour Layer Overlapped With Stream Segments

In the above figure, for point 7 the elevation value from contour map is 530, and for point 10 it is 550. It can be concluded that the water is flowing from point 10 to point 7. Similarly, for other locations, the contour values will be useful to derive the flow.

8.4.4 Sample Outputs

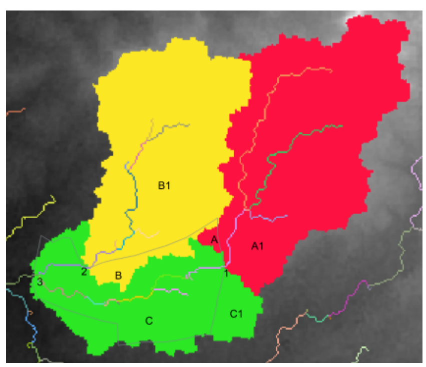


Figure 8.26: Zonal Decomposition of Walgud Village

Point No.	Zones	Outside Zones
1	A	A1
2	B	B1
3	C	C1

Table 8.3: Zones for each drain point of the village

Decisions:

1. The decision needs to be taken on merging and assigning zones having a comparatively smaller area than that of the village area.In fig.8.27 zones E, F, G, D, have a comparatively smaller area than total village area. These areas accounted for in the area not contained in any of the watersheds within the village.
2. There is some part of the watershed for point 18 seen in the Walgud village as in fig.8.30, i.e., above the village of point 18. The water in that part has to be either accounted in the Walgud or Zaregaon village. It is preferred to account that part in the Zaregaon village itself treating the Walgud's village boundary updated not to accommodate the watershed part.

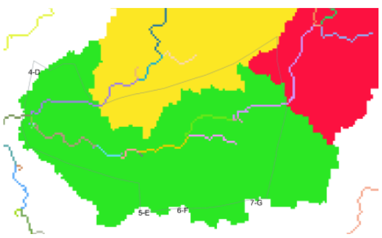


Figure 8.27: Part of Village area not in Watershed area of the village

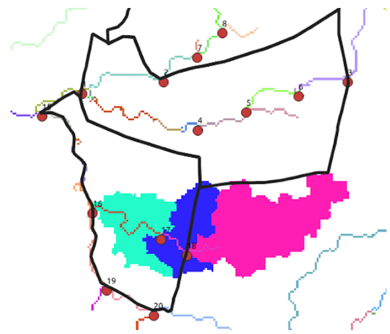


Figure 8.28: Part of Differential Watershed for Point 18 in another village

Zonal Decomposition of nearby villages (Cluster):

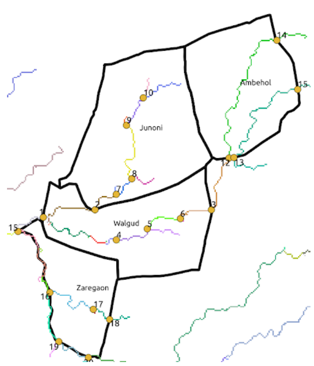


Figure 8.29: Cluster Boundary

Watershed for each point in Zaregaon village (Lowermost in Cluster):

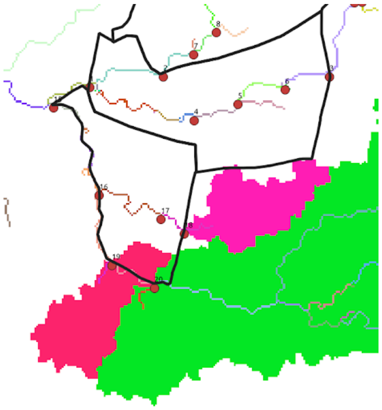


Figure 8.30: Differential Watershed for Point 18

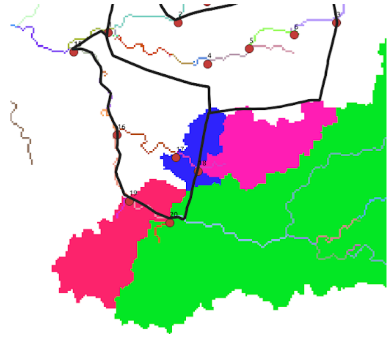


Figure 8.31: Differential Watershed for Point 17

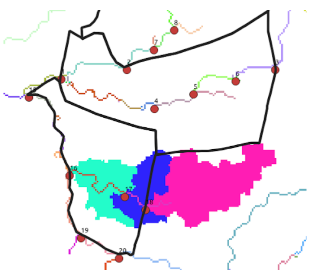


Figure 8.32: Differential Watershed for Point 16

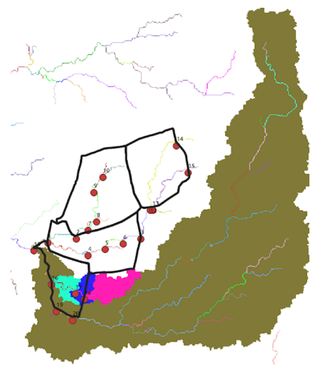


Figure 8.33: Differential Watershed for Point 15

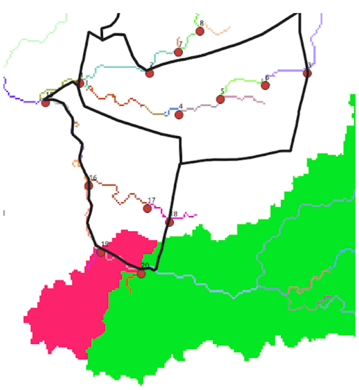


Figure 8.34: Differential Watershed for Point 19

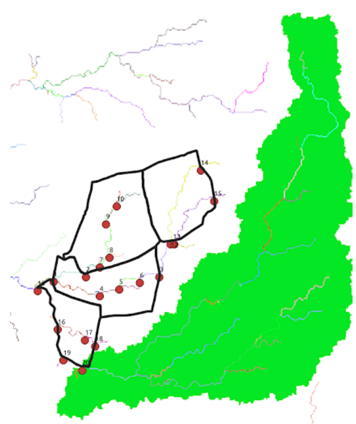


Figure 8.35: Differential Watershed for Point 20

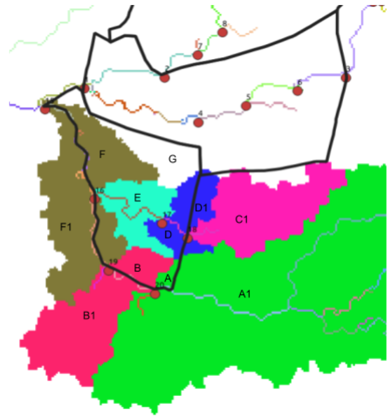


Figure 8.36: Zonal Decomposition of Zaregaon Village

Point No.	Contributing Inner Zones	Contributing Outer Zones	Label
15	F	F1	-1
16	E	-	+1
17	D	D1	0
18	-	C1	+1
19	B	B1	+1
20	A	A1	+1

Table 8.4: Zonal Decomposition Table for Zaregaon Village

The F, E, D, B, A are the zones formed by watershed boundary, and zone G is the part not in any watershed. All the inner and outer zones represent whole or part of the respective differential watershed.

8.5 Comparative Analysis of Intra Cluster Water Accounting

In below fig.8.37, the zone G has no water coming IN from the points within its village boundary. The water contributing to the zone G then has to come from one (or more) of the adjacent villages. In fig.8.38, it can be seen that F2 zone (and some part by H zone) is the watershed part which is contributing to the zone G from the left side. This type of water accounting brings more conceptual clarity of the contributing water based on watershed zones, the flow of water, and the overall mapping of the natural and administrative boundaries. Similar accounting can be established for each part of the village concerning its adjacent villages.

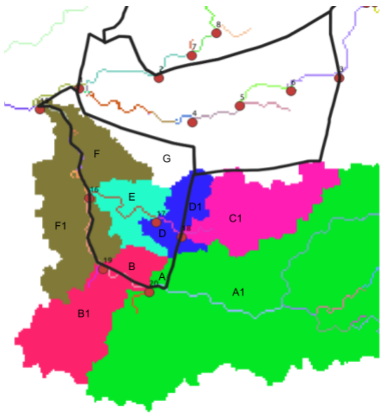


Figure 8.37: Complete Zonal Decomposition of Zoregaon Village

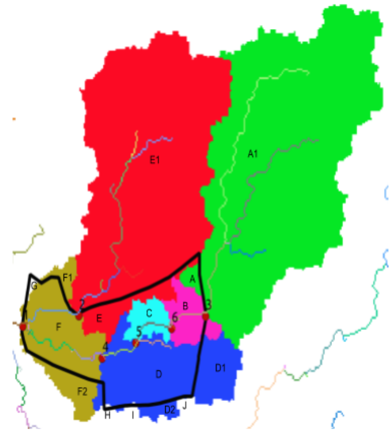


Figure 8.38: Contributing Water from Adjacent Village

8.6 Area Analysis for Junoni Village

Village area: 804.751 ha
Total Watershed Area (including watershed outside the village): 1144.290 ha
Total Watershed Area (excluding watershed outside the village): 701.379 ha
Village area not in any Watershed: 103.373 ha

Village Area = Total Watershed Area (excluding watershed outside the village) + Village area not in any Watershed

Total Watershed Area (excluding watershed outside the village) = Sum of the area of all the differential watersheds within the village.

8.7 Applications

1. **Water Accounting Framework**

   This framework can be widely extended to answer core questions of water consumption and availability. The usage and flow of the water within administrative premises will help to plan the water budgeting more accurately.

2. **Stream Flow Simulation**

   The availability of water in the water storage structures is always uncertain and is dependent on the overall geographical hierarchy and consumption at various points in the regime. This model will, in a way provide a way to simulate the stream flows across the administrative boundary.

3. **Integration with existing Water Balance plugin**

   The framework can be integrated with the existing water budget tool to provide advisory at more finer granularity and accuracy. This will also help to consider other factors like cropping pattern, soil, and land-use parameters for better intervention planning.

8.8 Algorithms Involved

8.8.1 Processing on Stream Network

Objective

Given a stream network convert into a set of edges and vertices such that each edge represents one independent stream segment and each vertex is either a degree one or degree three vertex. The degree is the total amount of incoming or outgoing edges in the network.

Issue in Stream Network

We have a stream network, and the problem is to convert it in a graph like data structure, for which we need to have or generate a precise set of FROM and TO vertices. But, the given geometry of the stream network is not correct, i.e., the stream segments are not split at meeting points on the stream network.Meeting points are those points where stream segments cross each other. So, we have to merge the edges with degree two nodes in the network so that the network will have only one and three degree vertices (degree with vertices greater than three is not expected). The labels to the vertices in the below fig.8.39 represent the stream vertex id and degree of the vertex, i.e., ID-Degree pair. We have two shape-files, one is point layer having attributes as vertex ID and degree of the vertex, and other is stream network having TO and FROM attributes for each edge but with degree 2 vertex to be eliminated.

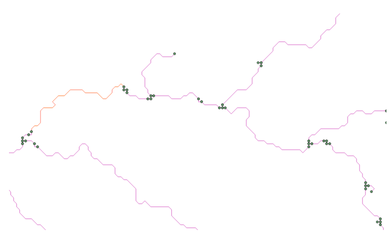


Figure 8.39: Issue of broken Stream Segments (Sample marked in red)

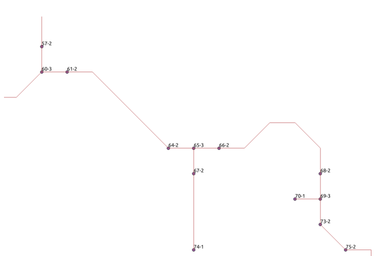


Figure 8.40: Degree with Vertices 1,2,3 in Stream Network

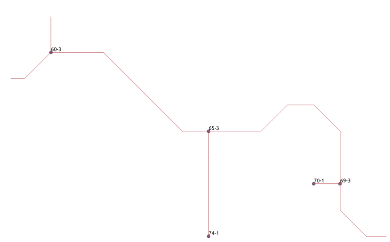


Figure 8.41: Expected Stream Network

Attempt at cleaning the Stream Network

For each edge, we will check the degree of the associated vertices (assuming any starting vertex), and if the degree is not either 1 or 3 (degree greater than three is not expected) then the respective edge is merged, and the iteration continues else the next vertex pair is considered. For this, we need to identify the degree two vertices and the edges associated with them. When the above approach was implemented it was found that all the edges are not preserved in the resultant stream network as the merging logic of edges took two edges as input, and in next iteration if the adjacent edge is to be merged with an already merged edge (whose edge id is changed) then the network gets disconnected at that point. The solution to this is to reconstruct the network after merging of each edge which is a time-consuming process.

The better approach of tackling this problem was found in the logic of identifying the stream order where each stream segment is assigned a number based on the relative size of the stream.For this, we need to use r.stream.order in GRASS tool. It assigns a number to a stream segment till the current stream segment merges with a new stream segment. This way, it keeps on combining the stream segment until it meets a new stream segment at some merging point. Also, it gives us the concrete set of edges and vertices to be represented as the graph-like structure.

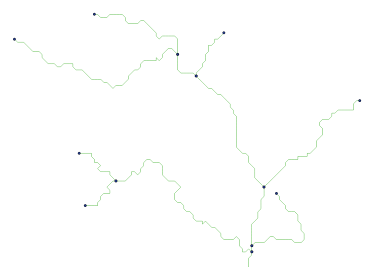


Figure 8.42: Stream Network with vertices having degree 3 and 1 only

8.8.2 Assigning direction to Stream Network

Once the stream network is cleaned by keeping only the edges between vertices with degree 3 and degree 1, then it is crucial to identify the flow of the water within the stream network. To achieve water directionality, means to assign a direction to each stream segment. The direction algorithm D-8 explained earlier in section 9.8.1 is applied internally to the stream network via ”RIVERGIS” plugin available in QGIS. Below is one such sample result. The stream directions generated by this exercise is validated on the field in Suleman-Deola by PoCRA-IITB team and is found to be matching the actual stream flow.

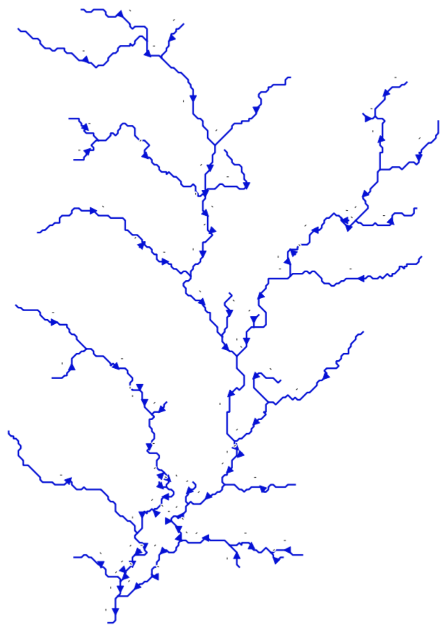


Figure 8.43: Direction assigned to Stream Network

8.9 Future Scope

8.9.1 Integration of Ground-Water Flows

The model discussed can be extended to include sub-surface water flows. The consideration of ground water and recharge will help to answers questions related to water storage structures like well, farm-ponds and their levels at various intervals of time. This will also help to consider the stream proximity at a much broader level concerning runoff and zonal planning.

Chapter 9

Stream Flow Simulation

9.1 Objective

To calculate the amount of water flowing from one point of the stream to another having intermediate points representing water storage structures like Cement Nala Bund (CNB). The aim is also to identify the number of times those intermediate structures get filled and the water harvested and recharged in the stream network in the respective time period. To obtain relevant geographic attributes from given data.

9.2 Need of Stream Flow Simulation

We need a model which will give us the idea of how much water is available at what point and also the period when the respective storage structures will get filled. This will not only help in identifying the potential locations for water storage structures but will also help to analyze the impact of such storage structures on the water availability of the villages down the hierarchy.

Once the water availability at a particular point is known and respective attributes like daily and cumulative groundwater recharge, runoff is available then the water flow across other stream points can be computed. Runoff from the first CNB point can be made available to the second CNB point based on the effective stream length, effective stream width, etc. We will also need to consider the amount of water percolated or used before reaching the next CNB point. This will give us better analysis of surface water flows and water availability within administrative units.

9.2.1 Stream Flow Simulation Representation

Below fig.9.1 represents the cluster layer overlapped with a drainage network. The points represent the stream start point and location of water storage structure CNB. The model currently assumes that the first CNB is located at point 1, and it will compute its water level every day. The point 2 on the stream network represents the second CNB point for which the runoff from previous CNB point that is point 1 will also be available other than it's own area runoff.

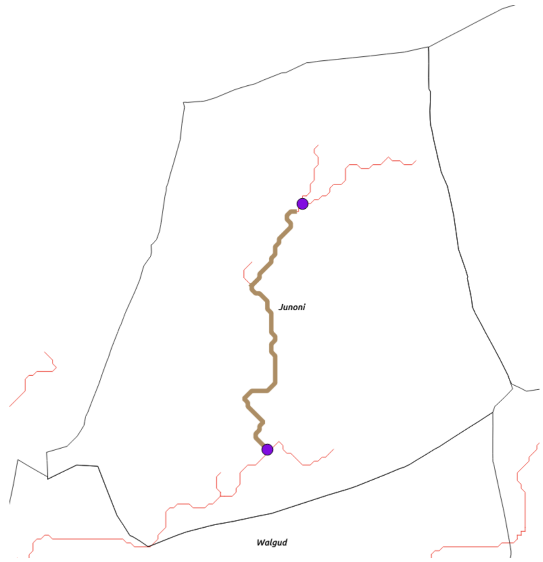


Figure 9.1: Cluster Layer Overlapped with Drainage Network with CNB points

For this, we need to consider the differential watershed for both of the points and then calculate runoff respectively. The concept and need of differential watershed is already explained in previous chapter.

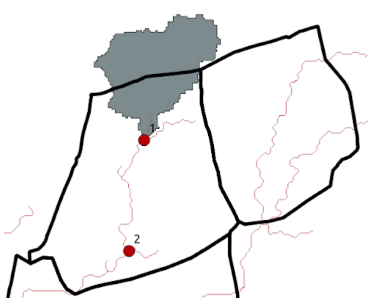


Figure 9.2: Differential Watershed of Point 1

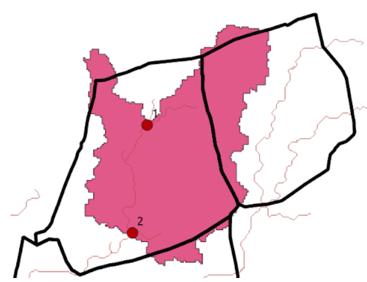


Figure 9.3: Differential Watershed of Point 2

9.3 Simulation Methodology

9.3.1 Stream Flow Simulation Problem

Consider the following representation for the problem:-

Sr.No.	Representation	Explanation
1	n	Point location of CNB
2	I(n)	Inflow of water at point 'n' from it's differential watershed
3	O(n)	Outflow of water from point 'n'

Table 9.1 continued from previous page

Sr.No.	Representation	Explanation
4	V(n)	Volume of Channel between point 'n' and 'n-1'
5	α	Percolation Factor
6	β	Ground Water Recharge factor
7	C(n)	Capacity of CNB at point 'n'
8	G(n)	Ground Water Recharge in TCM at point 'n'
9	t	time (daily)
10	DW(n)	Differential Watershed of point 'n'
10	R(n)	Runoff in mm at point 'n'
11	GW(n)	Ground Water Recharge in mm at point 'n'
12	CR(n)	Cumulative Runoff in TCM at point 'n'
13	CGW(n)	Cumulative Ground Water Recharge in TCM at point 'n'
14	P(n)	Percolation Volume in TCM at point 'n'

Table 9.1: Mathematical Representation for Stream Flow Simulation

Model Elaboration and Assumptions:-

1. The inflow of water is considered concerning the differential watershed of the point which means the watershed area of the predecessor points is subtracted from the current point's watershed.
2. It is assumed in the model that if the runoff is greater than the daily groundwater recharge, then the groundwater percolation will be treated as zero, i.e., will be filled by the available runoff.
3. Percolation factor (α) is considered as 50% of the volume of the channel network.
4. Ground Water Recharge factor (β) is considered as 10% of previous day CNB water availability.

9.3.2 Sample Model Calculation and Flow

Some of the model parameters are computed through QGIS and values for some parameters are assumed.The model calculation is restricted to two CNB points but it can be re-used to compute for further CNB points.For re-using the model only "Runoff_TCM_From_Previous_CNB" is required to be fed in the next CNB point input.

Parameter	Value	Remarks/Source
Total Watershed area for Point 1	238.709 ha	Computed
Differential Watershed area for Point 1	238.709 ha	Computed
First CNB capacity	12 TCM	Assumed
Groundwater recharge percent	10 Percent	Assumed
Total Watershed area for Point 2	1017.236 ha	Computed
Differential Watershed area for Point 2	778.527 ha	Computed
Second CNB capacity	20 TCM	Assumed
Length between two CNBs (L)	2371.376 m	Computed
Width of the Nala (W)	5 m	Assumed
Depth of the intermediate Nala (D)	3 m	Assumed
Percolation from First CNB to Second CNB	15 TCM	(L * W * D) / 1000

Table 9.2: Model Calculation Values

9.3.3 Attributes and Formulae in the Model

1. **Runoff_TCM_CNB**
   $I(n,t) = (R(n,t) * DW(n))/ 100$
   here, DW(n) is the differential watershed area for that particular point.

2. **GW_Recharge_TCM_CNB**
   $G(n,t) = (GW(n,t) * DW(n))/ 100$
   here, DW(n) is the differential watershed area for that particular point.

3. **Cumulative_Runoff_TCM_CNB**
   $CR(n,t) = CR(n,t-1) + R(n,t)$

4. **Cumulative_GW_Recharge_TCM_CNB**
   $CGW(n,t) = CGW(n,t-1) + G(n,t)$

5. **Capacity_TCM_CNB**
   $C(n) = 15$ and 20 for each CNB which is constant in the current model.

6. **Percolation_factor_CNB**
   $\beta = 0.5$, fifty percent is percolated and rest is allowed to flow further.

7. **Percolation_Volume_TCM_CNB**
   $P(n,t) =((l*w*d)/1000) * \beta$, where l, d , w is the length, depth and width of the channel.

8. **Runoff_TCM_from_Previous_CNB_to_CNB**
   $RP(n,t)= WSA(n-1,t)$

9. **Total_Available_Runoff_from_CNB**
   $TAR(n,t) = IF (RP(n,t) + I(n,t)) < P(n,t), 0 , (RP(n,t) + I(n,t)) - P(n,t))$

10. **GroundWater_Recharge_Factor_CNB**
GRF(n) = 0.1 , 10 percent is taken as constant.

11. **Water_Lost_in_GW_and_Extraction_CNB**
WL(n,t) = WIN (n,t-1) * GRF(n,t)

12. **Amount_that_can_be_added_in_CNB**
AAC(n,t) = IF (TAR(n,t) > WL(n,t) , IF (TAR(n,t) > (C(n) - (WIN(n,t-1) - WL(n,t))),(C(n) - (WIN(n,t-1) - WL(n,t))), TAR(n,t) - WL(n,t)) , 0)

13. **Water_in_CNB1**
WIN(n,t) = IF (AAC(n,t) > 0, WIN(n,t-1) + AAC(n,t) - WL(n,t) , WIN(n,t-1) - WL(n,t))

14. **Water_Sent_Ahead_from_CNB**
WSA(n,t) = IF (AAC(n,t) > 0 ,TAC(n,t) - AAC(n,t), 0)

15. **Cross_check_Sum_CNB**
CCS(n,t) = AAC(n,t) + WSA(n,t)

9.4 Approach

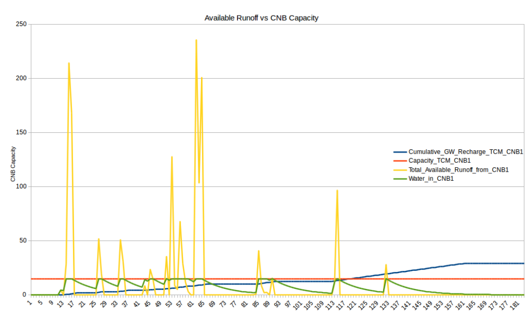
1. Initially daily runoff, groundwater recharge was computed from existing point-based water budget model.
2. Runoff and ground water recharge are to be computed in TCM based their respective differential watershed.
3. Then the water in CNB and water sent ahead are the two primary parameters to be computed. The detailed calculation formulae of the attributes in the model can be seen in the excel sheet.
4. Next, the percolation volume is computed based on the length width and depth of the connecting nala or channel.
5. After subtracting the percolation losses multiplied by percolation factor, the CNB runoff was added to current CNB's daily runoff.
6. The amount that can be added in CNB is computed based on available runoff and CNB capacity.
7. Based on the amount that can be added in CNB, the actual storage is computed eliminating the groundwater recharge of daily 10 percent.
8. The remaining water is treated as "water sent ahead" and can be made available to next CNB in the stream network.

9.5 Result Graphs

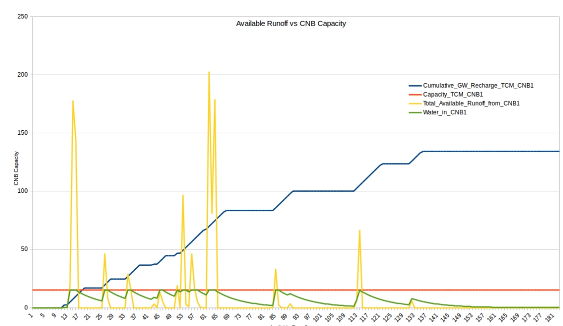
In below fig.9.4 it can be seen that the change of soil type from Clayey to Gravelly Sandy Loam leads to increase in ground water recharge and decrease in runoff. This is due to the soil characteristics where Clayey soil holds more water and does not let the water percolate in groundwater and so the water runoff is more than that of Gravelly Sandy Loam soil. Also, from fig.9.6 it can be seen that the runoff available for second CNB is greater than the first CNB point. This is because the part of runoff from first CNB point is also available to the second CNB point. Such hierarchy helps us to plan and analyze the water consumption and utilization problems effectively within the administrative premises. All the units of the subsequent graphs are in TCM.

	Clayey Soil		Gravelly Sandy Loam Soil	
Parameter	**Monsoon End**	**Crop End**	**Monsoon End**	**Crop End**
Crop	**Soybean**			
Rainfall	777	707	777	707
SM	106.75	84.18	39.5	20.96
Runoff	372.21	341.66	276.80	259.13
Infiltration	404.78	365.33	500.19	447.86
PET	418.63	418.63	418.63	418.63
AET	344.653	344.653	342.85	342.85
GW Recharge	29.129	12.53	134.09	100.20

Table 9.3: Summary Values of both Soil Types

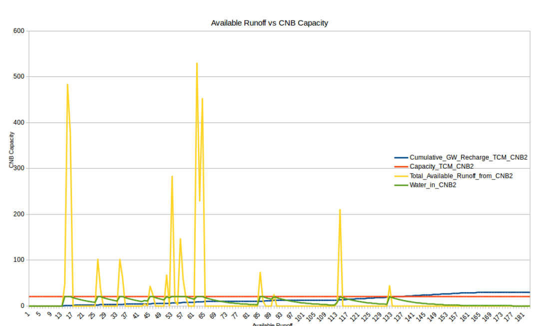


(a) CNB_1 Capacity vs Available Runoff-Clayey Soil

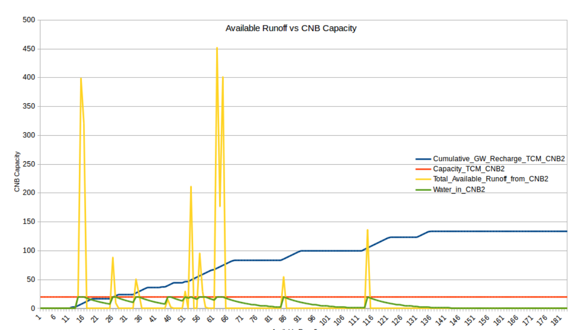


(b) CNB_1 Capacity vs Available Runoff-Gravelly Soil

Figure 9.4: Available Runoff vs CNB Capacity for CNB_1



(a) CNB_2 Capacity vs Available Runoff-Clayey Soil



(b) CNB_2 Capacity vs Available Runoff-Gravelly Soil

Figure 9.5: Available Runoff vs CNB Capacity for CNB_2

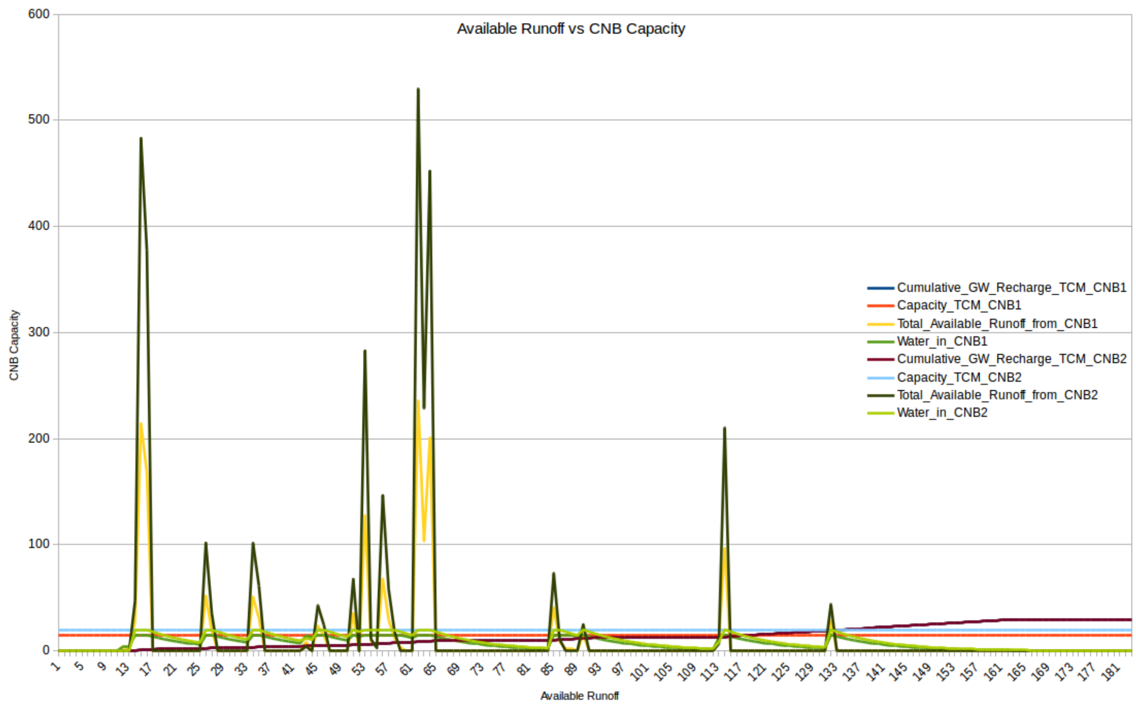


Figure 9.6: Comparative Results for CNB Capacity vs Available Runoff for Clayey Soil

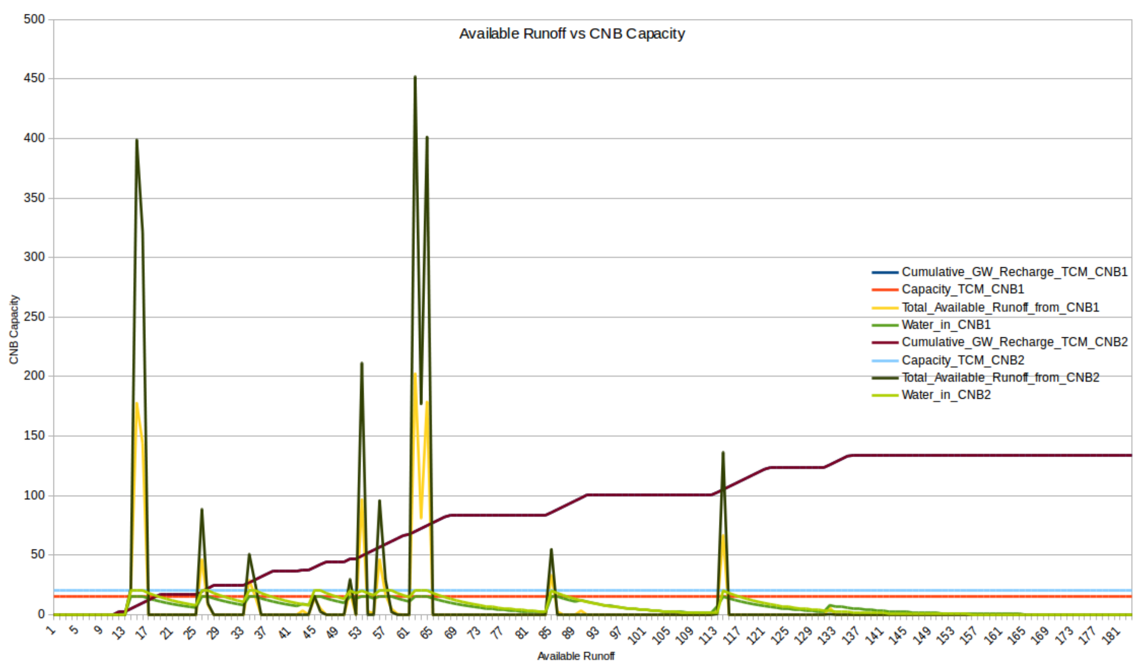


Figure 9.7: Comparative Results for CNB Capacity vs Available Runoff for Gravelly Soil

9.6 Future Scope

The current model provides a basic framework of simulating the stream flow. The assumed values can be computed or derived by considering additional parameters like slope, CNB dimensions,etc. The model can also be updated to integrate more complex scenarios with respect to the CNB locations like multiple CNB points contributing runoff to a common CNB point. This can also be implemented as a QGIS plugin. The model can serve as a effective tool to provide advisory support and community awareness in water planning.

Generalization of Model

In order to generalize the model for other complex inputs like fig.9.8 of CNB locations the parameter "Water_Sent_Ahead_from_CNBX" is to be provided to the next point CNB inputs. The parameters which need to be configured include percolation factor, ground water recharge factor, percolation volume including width,depth and height parameter, runoff and ground water recharge in TCM by multiplying it with a factor of its differential watershed area. For below fig.9.8 the partial order is A-B-C-D-E-F.

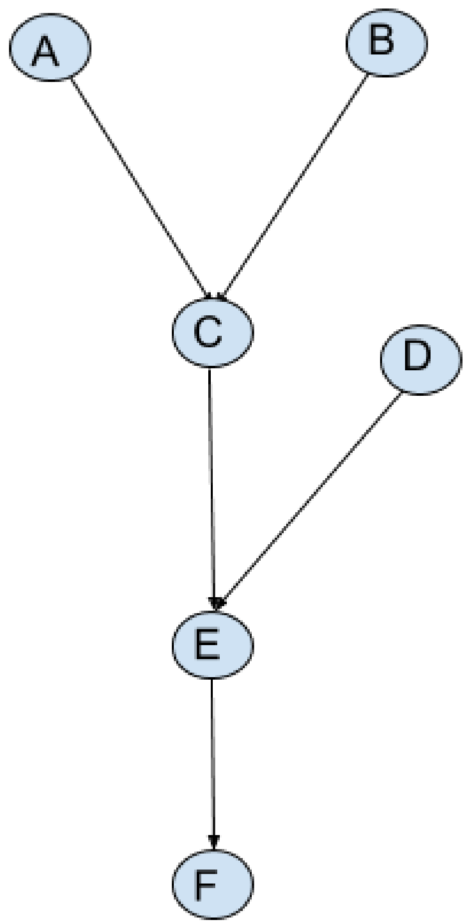


Figure 9.8: Stream Flow Complex Scenarios

Chapter 10

Stream Proximity

10.1 Background

For sustainable and equitable agriculture, there is a need to differentiate areas with the differential natural propensity to access to water. Streams define an essential natural feature that divides the landscape into two types of zones. Identifying the zone of influence depending upon the type and order of stream impacting the water budget in its proximity. A buffer area is found out with respect to the order of the stream and such zones are formed resulting into two classes i.e. stream zones and non-stream zones, which will lead to enhancing the zoning and water budget computation results.

10.2 Relevant Concepts

Stream

A stream is a path of water that has surface water flowing within the bed and banks of a channel. The stream encompasses surface and groundwater fluxes that respond to geological, geomorphological, hydrological and biotic conditions.

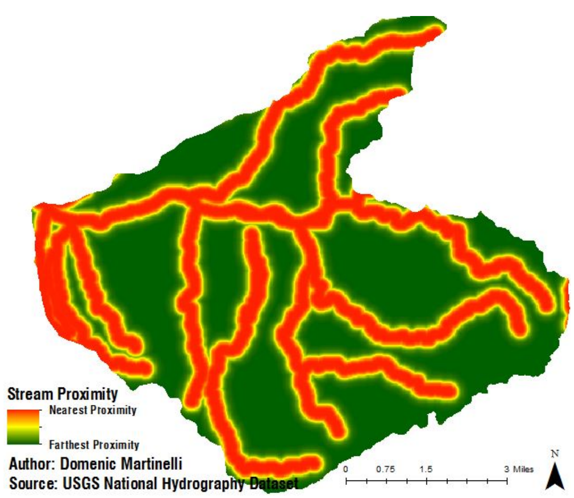


Figure 10.1: Stream Proximity Map [17]

Stream Order

The stream order or water-body order is a positive whole number used in geomorphology and hydrology to indicate the level of branching in a river system. The assignment of the number to stream segment representing its order will be explained in detail in the subsequent sections.

Stream Proximity

Stream proximity is basically defined as the area surrounding the stream which is likely to be influenced with respect to water and soil conditions than that of the area far from the proximity of the stream.

Elevation

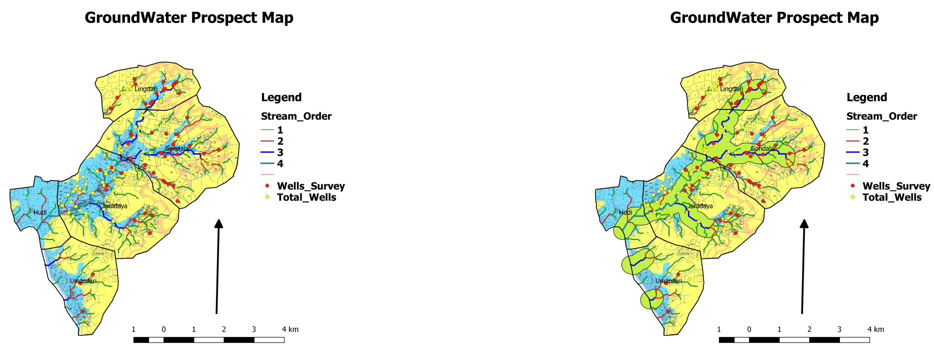
The elevation of a geographic location is its height above or below a fixed reference point, most commonly a reference geoid, a mathematical model of the Earth's sea level as an equipotential gravitational surface.

10.3 Need of Stream Proximity Maps

The area nearby streams are likely to have more water. So if such zones having more water nearby streams are identified, then the construction and allocation of wells can be effectively done. We have a rough idea of groundwater recharge at a particular point, and if the extraction in wells is identified, then appropriate water balance can be tracked and maintained accordingly with relevant interventions.

It can be logically concluded from the water budgeting process that the area having stream(s) is likely to have better outputs than that of the area not having streams nearby. Parameters like soil quality, water holding capacity, i.e., water availability are likely to be positively influenced near the stream proximity zones than that of non-stream proximity zones. So, it becomes the primary need to understand and formulate a methodology to derive such proximity based maps for better capturing the essential factors determining or influencing cropping patterns and water management.

Below fig.10.2b represents the GSDA (Groundwater Surveys & Development Agency) map with buffer made around the stream network. This buffer will depict the impact of stream on the soil, land and crop characteristics around the stream. The fig.10.3 shows the crops taken around the stream from google map. This is sufficient to infer that the water availability is high in that region for which buffer is to be found. This water availability buffer is actually what we are trying to achieve considering parameters like stream order, elevation, etc.



(a) Groundwater GSDA Map (b) Groundwater GSDA Map with Buffer

Figure 10.2: Stream Flow and Groundwater

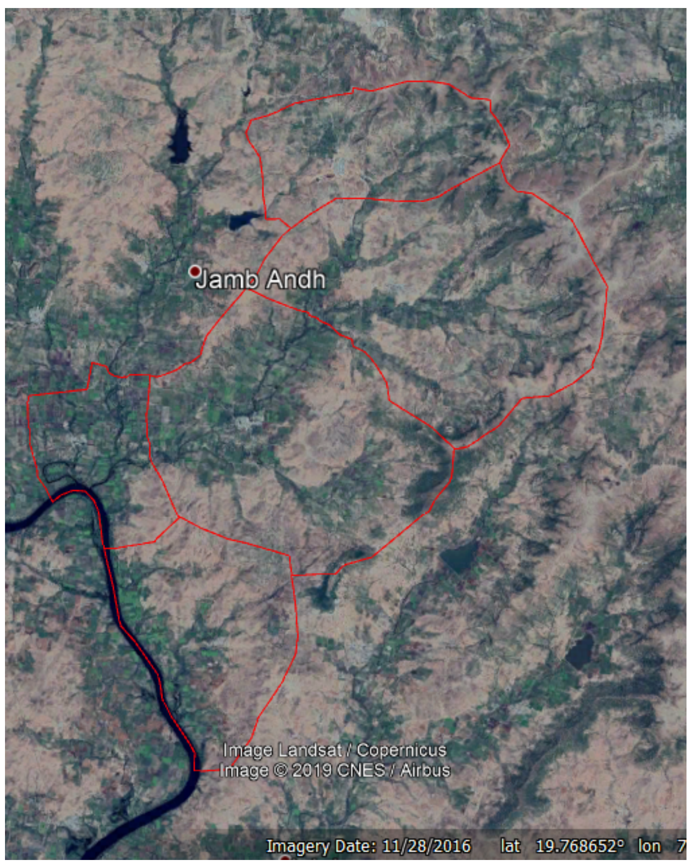


Figure 10.3: Crops in November 2016

From the stream map, we can identify the cadastral numbers through which the stream passes as below shown in below fig.10.4, and then we can assign the respective buffer to the stream network. Then we can identify the distance of the cadastral centroid to the particular order of the stream to evaluate the water accessibility in the respective village.

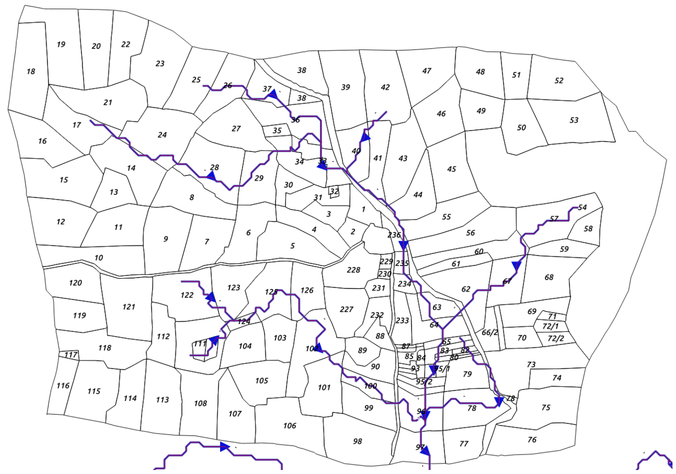


Figure 10.4: Stream passing through Cadastral

10.4 Stream Proximity Map Generation Process

10.4.1 Stream Order Based Proximity

Generation of proximity-based maps is formulated as below:-

Inputs:- DEM (Digital elevation model)

Intermediate Outputs:-Raster of Accumulation, Drainage Direction, Stream Segment & Order

Final Output:-Proximity Stream Map

Approach

Steps:-

1. Load DEM of interest in QGIS
2. Run r.watershed command from processing toolbox to generate Drainage Direction, Accumulation, Stream Segment raster files.
3. Give appropriate value for the minimum size of an exterior watershed basin(200-330 for small village area)
4. Use the above-generated output in GRASS to generate stream order
5. Before you use "r.stream.order" it is expected to run "g.region" over the input DEM in GRASS itself to make it align with region settings.
6. Then the r.stream.order command can be used to generate the required stream order vector and/or raster file
7. Load the stream order output of GRASS in QGIS
8. Add an additional attribute to the loaded stream order layer as “buffer”.

9. Depending upon the requirement of buffer size the values of the attribute is accordingly updated.
10. The layer with updated attribute values is given as input to the Variable distance buffer function available in QGIS with attribute value set as "buffer".
11. The required stream proximity map is generated.
12. The map is further inspected manually and updated accordingly if required.

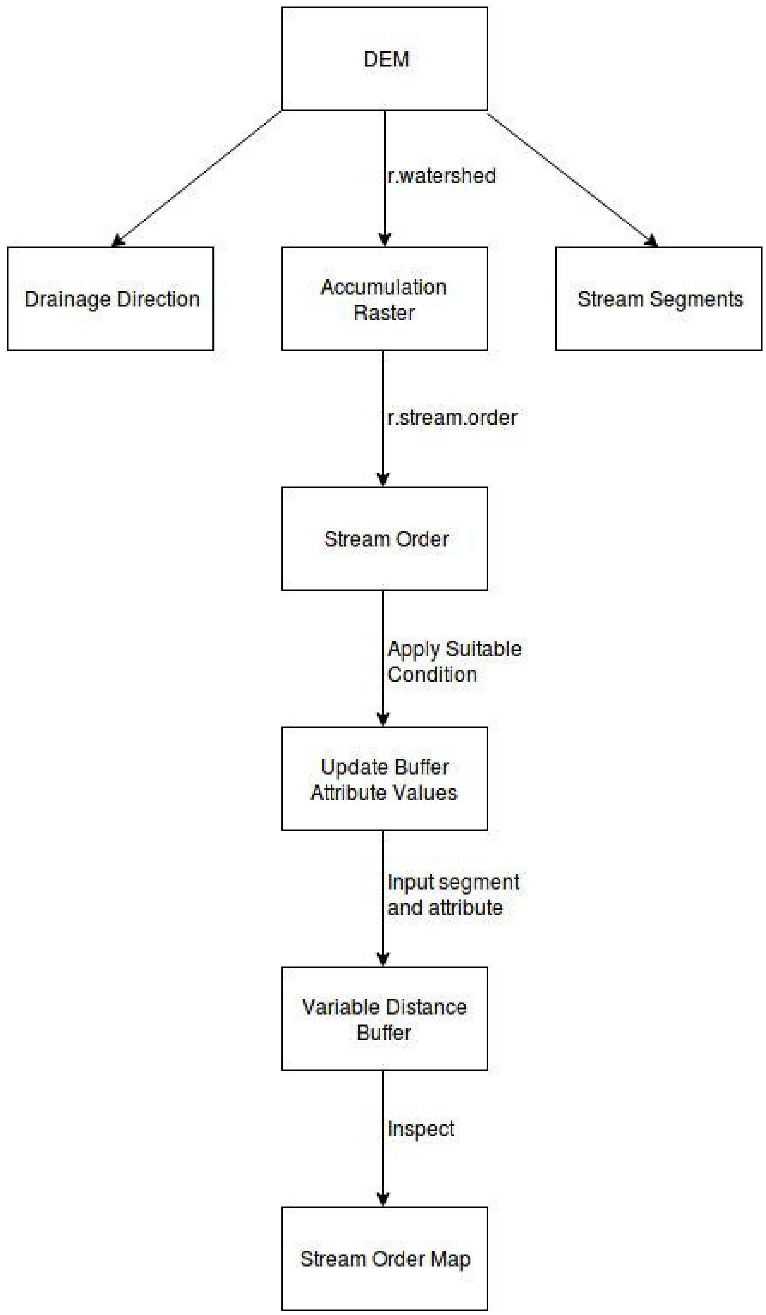


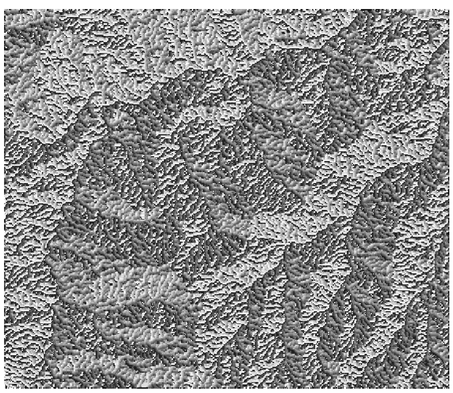
Figure 10.5: Stream Proximity Map

Visualisation of Steps

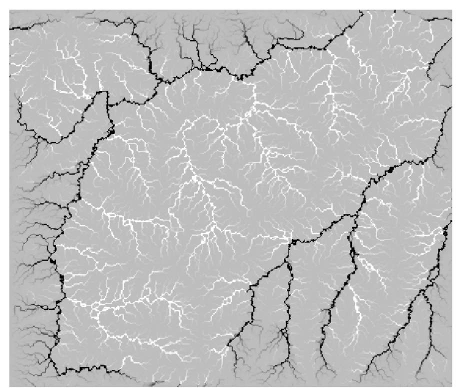
1. Input DEM (Latur_Shelgi Village)

Figure 10.6: Digital Elevation Model

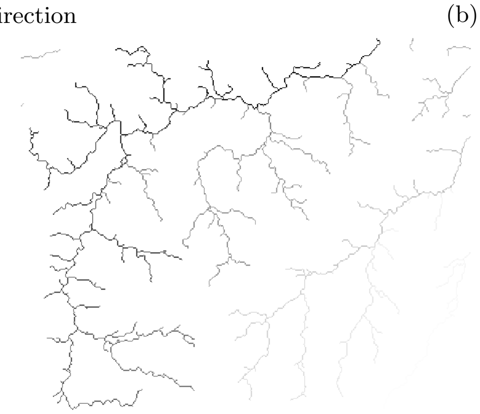
2. Run r.watershed command to generate below raster files:-



(a) Drainage Direction



(b) Accumulation



(c) Stream Segment

Figure 10.7: Output from "r.watershed" command

3. Use the above-generated output in GRASS to generate stream order

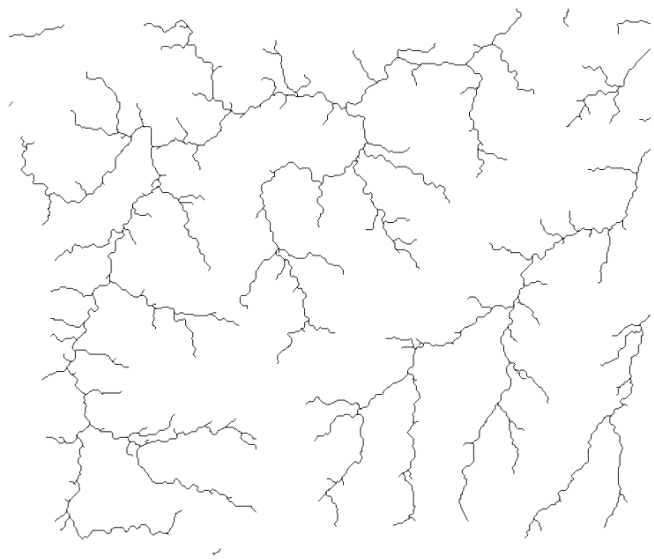


Figure 10.8: Stream Order Output

Its attribute table before update:-

cat	stream	prev_str01	prev_str02	prev_str03	strahler	horton	shreve	hack	topo_dim	drwal_old
2	2	4	406	0	4	4	103	1	1	7
4	4	6	8	0	4	4	102	1	2	7
6	6	0	0	0	1	1	1	2	3	1
8	8	10	388	0	4	4	101	1	3	7
10	10	12	386	0	4	4	96	1	4	7
12	12	14	16	0	4	4	95	1	5	7
14	14	0	0	0	1	1	1	2	6	1
16	16	18	20	0	4	4	94	1	6	7
18	18	0	0	0	1	1	1	2	7	1

Figure 10.9: Attribute Table before Updation

length	stright	sinosoid	cum_length	flow_accum	out_dist	elev_drop	out_drop	gradient
1132.5265...	933.25987...	1.2135170...	24962.420...	101732.59...	1132.5265...	0.0000000...	0.0000000...	0.0000000...
245.26848...	265.46970...	0.9239040...	23829.894...	75775.917...	1377.7950...	0.0000000...	0.0000000...	0.0000000...
202.72340...	186.85695...	1.0849120...	202.72340...	82733.384...	1580.5184...	8.0000000...	0.0000000...	0.0394630...
503.21436...	510.54418...	0.9856430...	23584.625...	98693.410...	1881.0093...	5.0000000...	0.0000000...	0.0099360...
1033.0405...	970.98037...	1.0639150...	23081.411...	71111.070...	2914.0499...	2.0000000...	1.0000000...	0.0019360...
506.81568...	495.01477...	1.0238390...	22048.371...	86292.505...	3420.8656...	0.0000000...	-1.0000000...	0.0000000...
1133.4644...	796.90630...	1.4223310...	1133.4644...	13183.268...	4554.3301...	6.0000000...	1.0000000...	0.0052940...
905.35080...	726.40918...	1.2463370...	21541.555...	78427.028...	4326.2164...	0.0000000...	1.0000000...	0.0000000...
947.43211...	841.09907...	1.1264220...	947.43211...	1361.5894...	5273.6485...	6.0000000...	1.0000000...	0.0063330...
1069.7416...	873.96273...	1.2240130...	20636.204...	88621.009...	5395.9580...	4.0000000...	-1.0000000...	0.0037390...

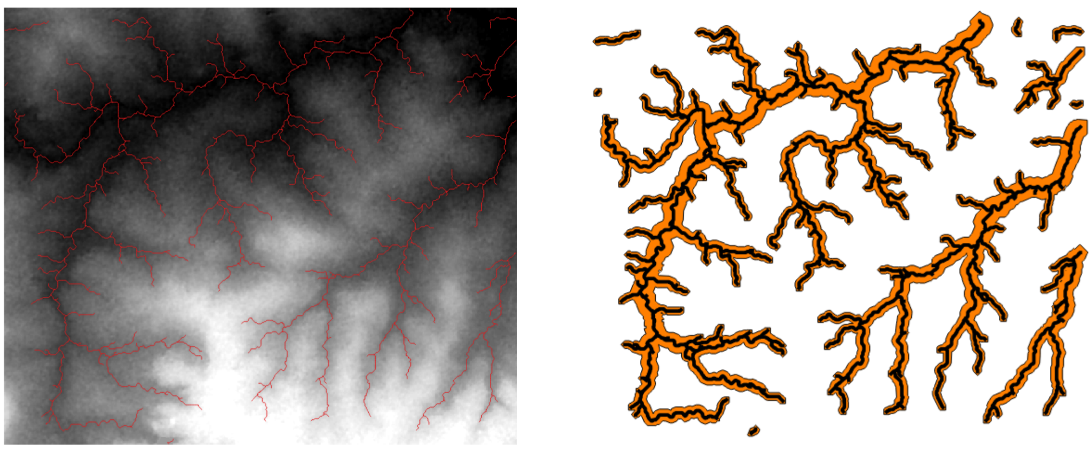
Figure 10.10: Attribute Table before Updation

4. Add an additional attribute to the loaded stream order layer as “buffer” (Last Attribute).

length	stright	sinosoid	cum_length	flow_accum	out_dist	elev_drop	out_drop	gradient	buffer
1132.5265...	933.25987...	1.2135170...	24962.420...	101732.59...	1132.5265...	0.0000000...	0.0000000...	0.0000000...	0.00250
245.26848...	265.46970...	0.9239040...	23829.894...	75775.917...	1377.7950...	0.0000000...	0.0000000...	0.0000000...	0.00250
202.72340...	186.85695...	1.0849120...	202.72340...	82733.384...	1580.5184...	8.0000000...	0.0000000...	0.0394630...	0.00100
503.21436...	510.54418...	0.9856430...	23584.625...	98693.410...	1881.0093...	5.0000000...	0.0000000...	0.0099360...	0.00250
1033.0405...	970.98037...	1.0639150...	23081.411...	71111.070...	2914.0499...	2.0000000...	1.0000000...	0.0019360...	0.00250
506.81568...	495.01477...	1.0238390...	22048.371...	86292.505...	3420.8656...	0.0000000...	-1.0000000...	0.0000000...	0.00250
1133.4644...	796.90630...	1.4223310...	1133.4644...	13183.268...	4554.3301...	6.0000000...	1.0000000...	0.0052940...	0.00100
905.35080...	726.40918...	1.2463370...	21541.555...	78427.028...	4326.2164...	0.0000000...	1.0000000...	0.0000000...	0.00250
947.43211...	841.09907...	1.1264220...	947.43211...	1361.5894...	5273.6485...	6.0000000...	1.0000000...	0.0063330...	0.00100
1069.7416...	873.96273...	1.2240130...	20636.204...	88621.009...	5395.9580...	4.0000000...	-1.0000000...	0.0037390...	0.00250

Figure 10.11: Attribute Table Updated

5. The layer with updated attribute values is given as input to the Variable distance buffer function available in QGIS with attribute value set as "buffer" for proximity map generation.
   So, in short, it is as below:-

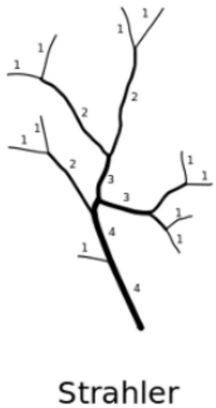


(a) Input DEM (b) Output Stream Proximity Map

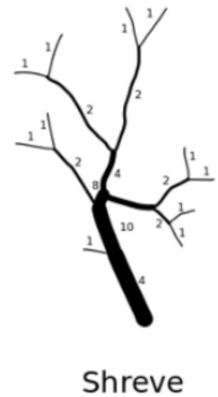
Figure 10.12: Stream Proximity Map Generation Overview

Evaluating Proximity Maps

It can be observed from the stream network that the ordering followed for the stream order evaluation keeps the buffer almost same even if new streams are added. It is expected that the stream width should increase in size and so it's ordering resulting in an increase in the size of the buffer or proximity around the streams. The argument follows from the logic that as the stream flows and other streams are merged with the stream the zone of influence will be more than that of the consistent (non-significant) buffer size. The disadvantage of this method is the lack of distinguishing the main channel which may interfere with the analytical process in highly elongated catchments[16]. The stream order basically used here is that of Strahler's which can be seen below:-



(a) Strahler Stream Order



(b) Shreve Stream Order

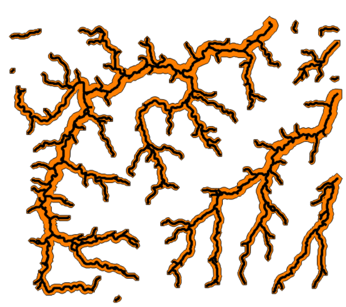
Figure 10.13: Comparative Results of Stream Order[16]

So in order to increase the buffer size or stream proximity, we make use of different stream order called as Shreve stream magnitude which assigns the stream ordering based on the number of streams merging the respective stream as per table10.1.

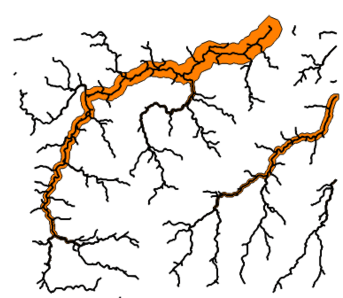
Stream Order	**Width**
1	0.001
2	0.0015
3	0.002
4	0.0025
5	0.003

Table 10.1: Stream Order Proximity Factor

The modified results can be seen below:-



(a) Strahler Stream Order Based Proximity map



(b) Shreve Stream Order Based Proximity map

Figure 10.14: Stream Order Comparison

10.4.2 Elevation Based Proximity

Here, we generate the modified buffer based on elevation approach. The elevation value is taken as 5 metres. The elevation is important factor because higher the elevation less is the water flowing capacity in that region and in the flat slope there is high possibility of water availability in the nearby area. The approach and results are given in subsequent sections.

Problem Definition

Given a region R, Stream S and a depth d in metres. We have DEM say F, which when queried as F(x,y) gives elevation e as output in metres , were x and y are the coordinates of the point.

For a point p, we define D(p,S) = q , where q is the closest point in S to P. This means that point p is at a distance d from q and the segment [p,q] is perpendicular to S at q.

Also, we define Proximity function as,

$$Prox(S,d) = \{p|\, f(p) - f(D(s,p)) <= d\}$$

"We assume for simplicity that if $p \in Prox(S,d)$ and q is the closest point to p on S, then the segment $[p,q] \subseteq Prox(S,d)$ as well".

Approach

1. Load Stream Network
2. Generate Equidistant point on the stream network (Locate Points along the line)
3. Find the elevation of those equidistant points (Point Sampling tool plugin)
4. Draw perpendicular to each stream segment from the equidistant point (Cross Profiles in Processing Toolbox)
5. Generate Equidistant point on the perpendicular line
6. Find the elevation of those perpendicular points
7. For each point on stream network find the corresponding point on perpendicular line having 5m (or close) of elevation (Manually)
8. Enclose all such intersected point on perpendicular point into a polygon representing a buffer. The buffers are to be generated separately for each division of the stream segment and then can be merged later (Point2shape plugin)
9. Dissolve the individual buffers (Dissolve tool)
10. Fill the gaps and form a continuous buffer

Visualisation of Steps

1. Load Stream Network

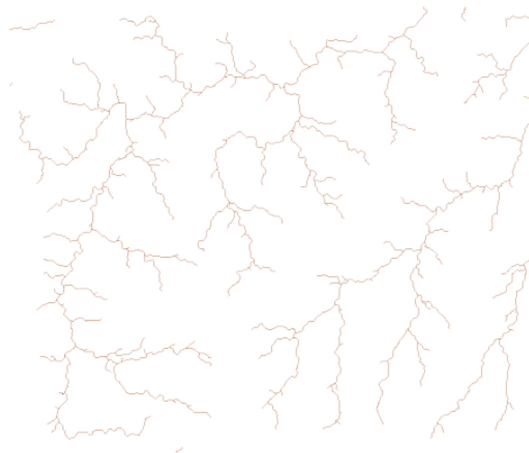


Figure 10.16: Sample Stream Network

Figure 10.17: Stream Segment

2. Generate Equidistant point on the stream network (Locate Points along the line)

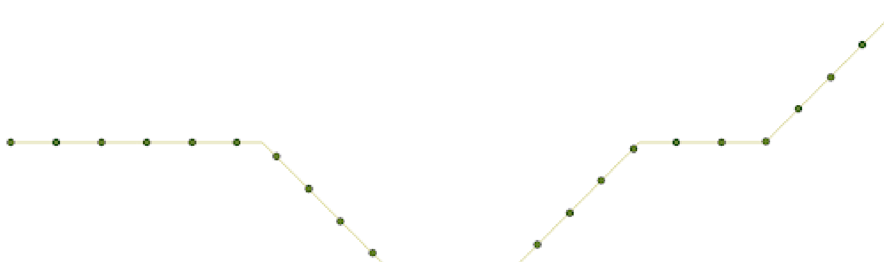


Figure 10.18: Equidistant Points on Stream Segment

3. Find the elevation of those equidistant points (Point Sampling tool plugin)

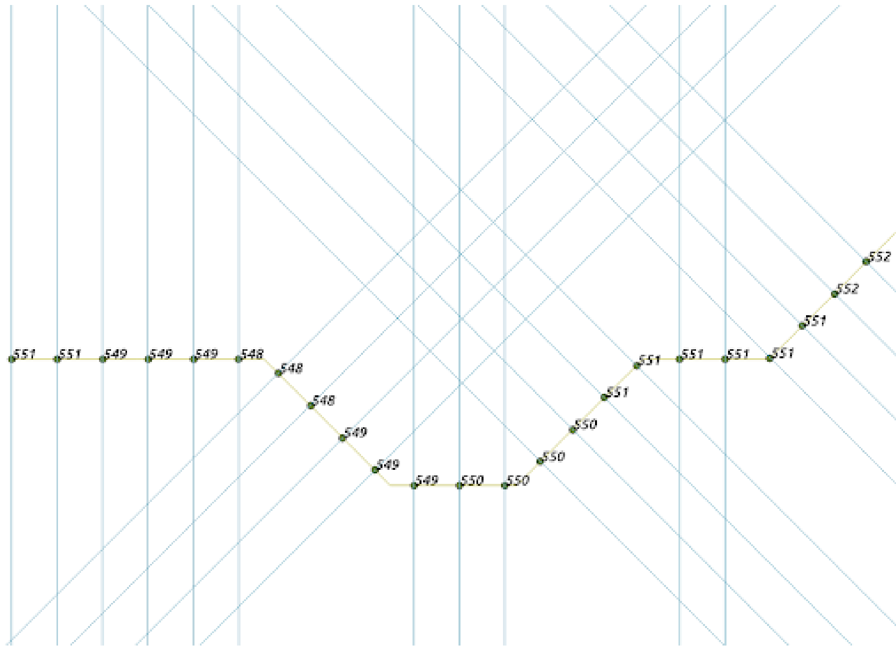


Figure 10.19: Elevation Assigned to Equidistant Points

4. Draw perpendicular to each stream segment from the equidistant point (Cross Profiles in Processing Toolbox)

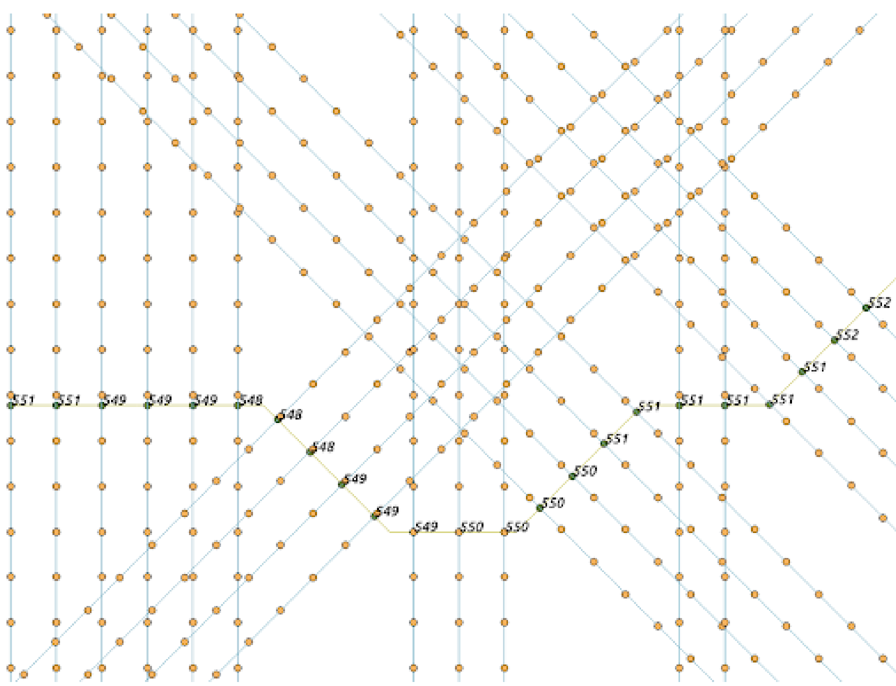


Figure 10.20: Perpendicular to Stream Segment

5. Generate Equidistant point on the perpendicular line

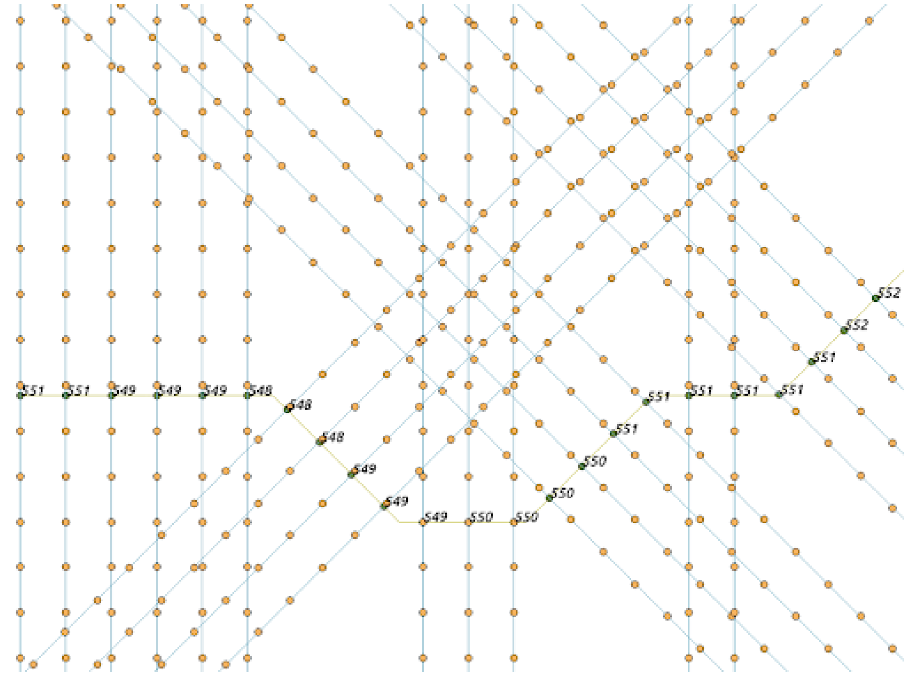


Figure 10.21: Equidistant Points on Perpendicular Line

6. Find elevation of those perpendicular points

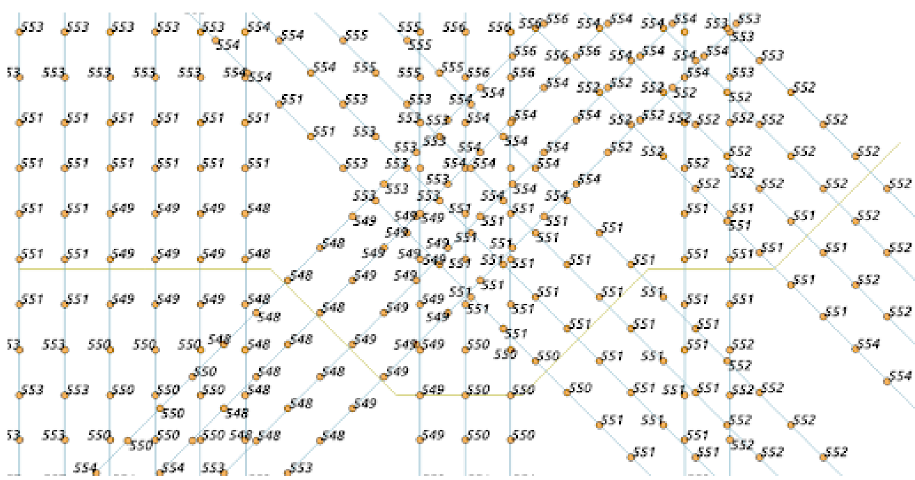


Figure 10.22: Elevation Assigned to Equidistant Points on Perpendicular Lines

7. For each point on stream network find the corresponding point on perpendicular line having 5m (or close) of elevation (Manually)

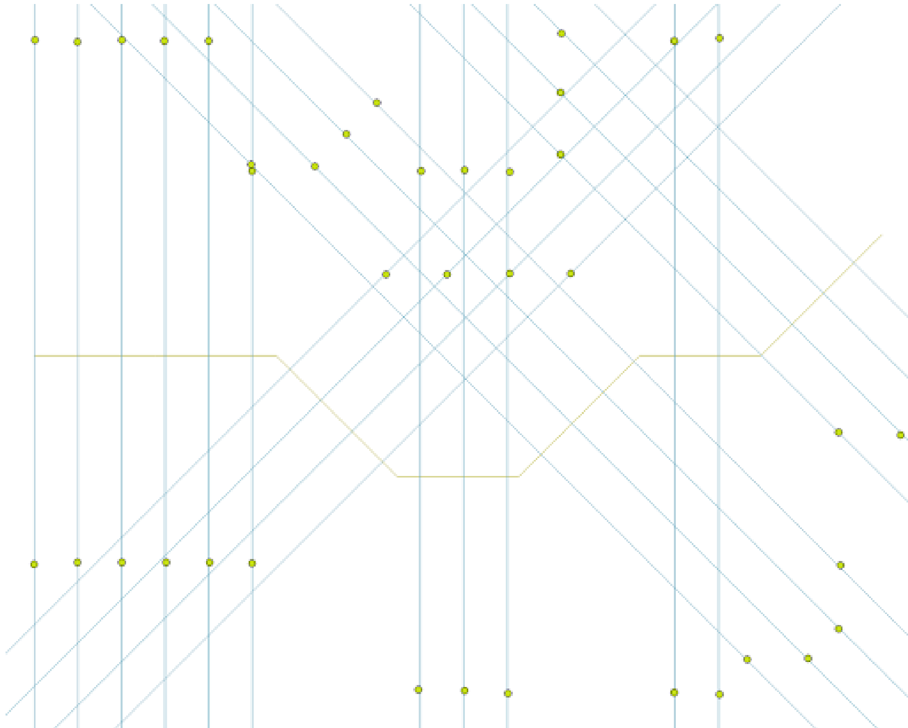


Figure 10.23: Five meter Elevation Points

8. Enclose all such intersected point on perpendicular point into a polygon representing a buffer. The buffers are to be generated separately for each division of stream segment and then can be merged later (Point2shape plugin)

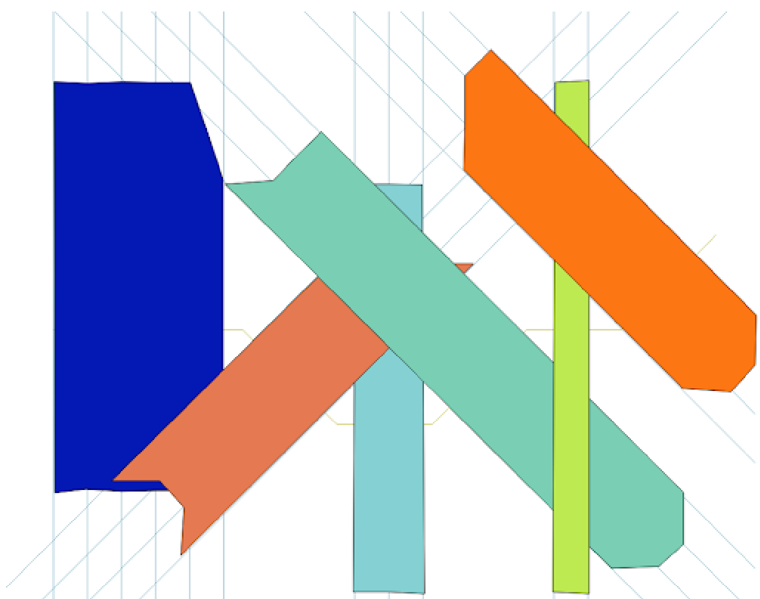


Figure 10.24: Enclosed Elevation Polygons for each Sub-Segment

9. Dissolve the individual buffers (Dissolve tool)

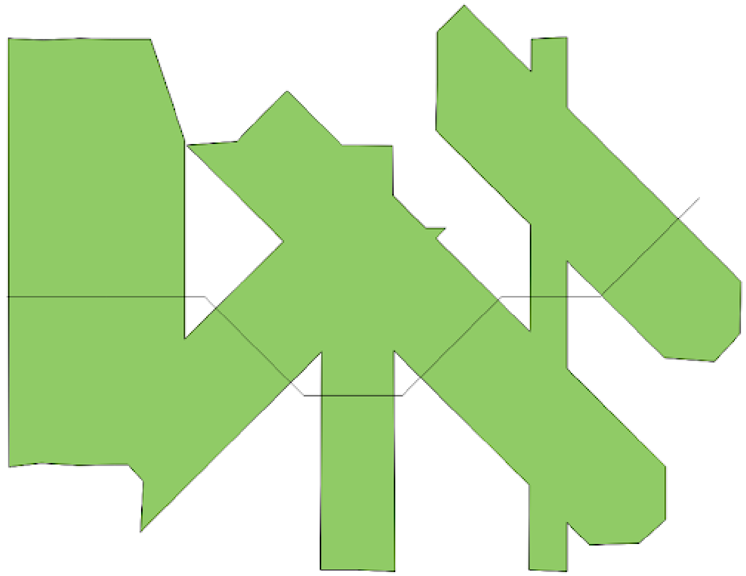


Figure 10.25: Elevation Polygons Dissolved

10. Fill the gaps and form a continuous buffer

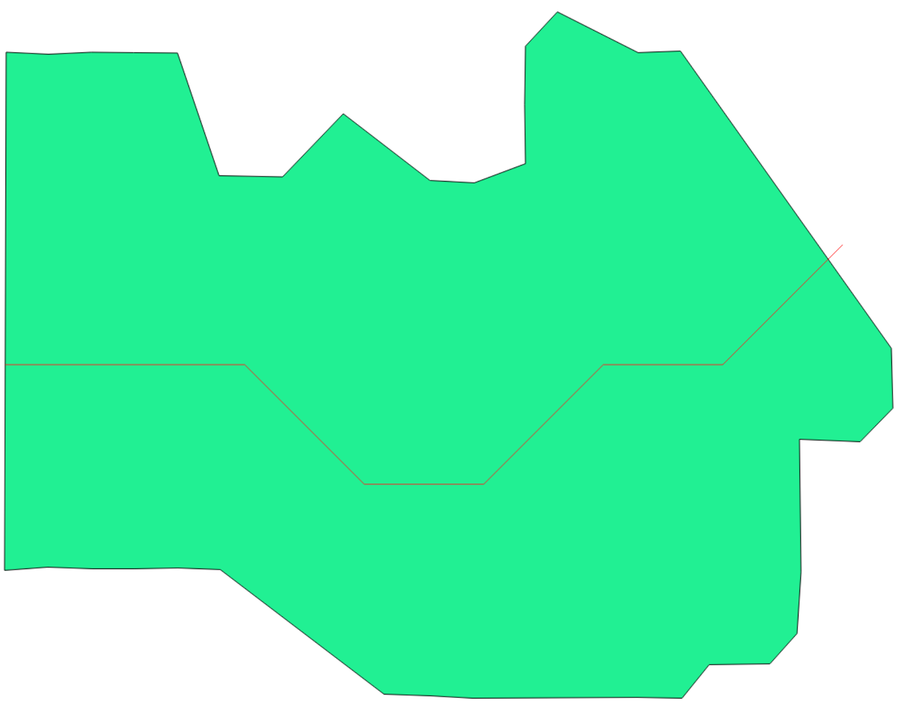


Figure 10.26: Buffers Merged

Evaluating Elevation based Proximity Maps

The elevation based proximity results were not considered satisfactory. This is because there is much variation in elevation values for individual stream segment generating uneven buffer areas.This is problem is likely to get more severe as the elevation value is increased to 10m. This approach can be used in future with integration of additional parameters like soil type, runoff,etc.

10.5 Future Scope

10.5.1 Runoff Based Proximity

Further additional parameters like groundwater recharge, soil type, slope, etc. can be used to form zones in-order to correctly reflect the cropping scenarios and form better zones for water budget modeling. Increasing the buffer size, i.e., the area surrounding the streams was to explore the possibility of having control over the proximity of streams. The more logical attempt is to modify the proximity based on the runoff at that particular point which is planned as a part of the next phase of the project. The variable size buffer based on hydro-geological parameters is likely to match the actual stream proximity.

Chapter 11

Conclusion and Future Work

The purpose of planning across the region for equitable development will be better served by factoring in, the zones of natural bias of water access. There is still a lot to explore, like various factors impacting the water availability and cropping patterns, which are also required to be backed up by validation through ground results. Village or zone level rain-gauges will increase model accuracy significantly. The model can be integrated with yield and economic parameters to allow for cropping pattern advisory. Integration of groundwater flows and improved zoning based on aquifer properties can be done. An attempt has been made towards the given objectives and a lot is possible and to be explored.

Future Work Summarized

1. Android Application for Water Budgeting
2. Asset Marking Application
3. Integration of Regional Flows
4. Complex Stream Flow Model Simulation with complete GIS Integration
5. Zoning based on combined parameters
6. Stream Proximity based on combined parameters
7. Soil Sampling Application Detailed Info and Analysis
8. Integration of Cropping Pattern Data

Chapter 12

Annexure

12.1 Appendix I : Database Schema Water Budget

1. Master village list - schema

```
CREATE TABLE master_village_list
(
village_name character varying(100) ,
census_code integer NOT NULL ,
village_name_marathi character varying(100) ,
district_code numeric ,
district_name character varying(100) ,
taluka_name character varying(100) ,
cluster_code character varying(100) ,
chart_status integer ,
CONSTRAINT master_village_list_pkey PRIMARY KEY (census_code)
)
```

2. Master Crop List schema

```
CREATE TABLE master_crop_list (
crop_id character varying(100) NOT NULL ,
crop_name_in_english character varying(100) NOT NULL ,
crop_name_in_marathi character varying(100) ,
crop_season_and_landuse character varying(100) ,
CONSTRAINT master_crop_list_pkey PRIMARY KEY (crop_id , crop_name_in_english) )
```

3. Master Structure list schema

```
CREATE TABLE master_structure_list (
structure_id character varying(100) NOT NULL ,
structure_name_english character varying(100) NOT NULL ,
structure_name_marathi character varying(100) ,
storage_capacity_unit character varying(100) ,
storage_capacity_per_unit numeric ,
```

evaporation_percent numeric ,
structure_type character varying(100) ,
CONSTRAINT master_structure_list_pkey PRIMARY KEY (structure_id , structure_name_english))

4. Plugin output schema

CREATE TABLE kharif_model_zonewise_budget_2018 (
village_name character varying(100) ,
census_code numeric NOT NULL ,
date_of_creation character varying(100) ,
rainfall_circle character varying(100) ,
zone_number character varying(100) NOT NULL ,
zone_area_ha numeric ,
crops_in_english character varying(100) NOT NULL ,
crops_in_marathi character varying(100) ,
crop_season_and_landuse character varying(100) ,
rainfall_mm numeric ,
pet_monsoon_end numeric ,
aet_monsoon_end numeric ,
monsoon_deficit numeric ,
gw_recharge_in_monsoon numeric ,
runoff_in_monsoon numeric ,
soil_moisture_monsoon_end numeric ,
post_monsoon_pet numeric ,
infil_monsoon_mm numeric ,
soil_moisture_crop_end numeric ,
aet_crop_end numeric ,
pet_crop_end numeric ,
crop_deficit_duration numeric ,
post_monsson_ground_water numeric ,
post_monsoon_runoff numeric ,
rainfall_year numeric ,
CONSTRAINT kharif_model_zonewise_budget_2018_pkey PRIMARY KEY (census_code , zone_number
, crops_in_english)
)

5. MLP crop data schema

CREATE TABLE mlp_input_crop_data_updated (
village_name character varying(100) ,
census_code numeric NOT NULL ,
crop_area_count numeric ,
crop_name character varying(100) ,
zone_number numeric NOT NULL ,
zone_area numeric ,
status character varying(100) NOT NULL ,
date_of_creation character varying(100) ,
crop_id character varying(100) NOT NULL ,
crop_season_and_landuse character varying(100) ,
CONSTRAINT mlp_input_crop_data_updated_pkey PRIMARY KEY (census_code , zone_number

, status , crop_id)
)

6. MLP population data schema

CREATE TABLE mlp_input_population_data (
village_name character varying(100) ,
census_code integer NOT NULL ,
poultry_farming numeric ,
small_animals numeric ,
people numeric ,
cattle numeric ,
CONSTRAINT mlp_input_population_data_pkey PRIMARY KEY (census_code)
)

7. MLP structure data schema

CREATE TABLE mlp_structure_data (
village_name character varying(100) ,
census_code numeric ,
zone_number numeric ,
status character varying(100) ,
total_capacity numeric ,
total_water numeric ,
structure_name character varying(100) ,
strcuture_count numeric ,
structure_name_english character varying(100) ,
structure_id character varying(100)
)

8. Rainfall_data schema

CREATE TABLE rainfall_data (
district_name character varying(100) ,
taluka_name character varying(100) ,
circle_name_maharain character varying(100) ,
year integer ,
day_1 numeric ,
day_2 numeric ,
day_3 numeric ,
. . day_364 numeric ,
day_365 numeric
)

9. Data Issues schema

CREATE TABLE village_data_issues_all (
census_code numeric NOT NULL ,

village_name character varying(100) ,
drinking_water_crorelitres_status numeric ,
currently_impounded_runoff_status numeric ,
runoff_impounded_after_proposed_structures_status numeric ,
agricultural_area_hectare_status numeric ,
agricultural_area_hectare_planned numeric ,
CONSTRAINT village_data_issues_all_pkey PRIMARY KEY (census_code)
)

10. Chart attributes schema

CREATE TABLE master_ouput_attributes_chart (
census_code integer NOT NULL ,
village_name character varying(100) ,
chart_year integer NOT NULL ,
village_area_hectare numeric ,
rainfall_crorelitres numeric ,
runoff_crorelitres numeric ,
kharif_area_hectare numeric ,
longkharif_area_hectare numeric ,
rabi_area_hectare numeric ,
annual_area_hectare numeric ,
agricultural_area_hectare numeric ,
non_agricultural_area_hectare numeric ,
agricultural_pet_crorelitres numeric ,
drinking_water_crorelitres numeric ,
kharif_pet_monsoonend_crorelitres numeric ,
longkharif_pet_monsoonend_crorelitres numeric ,
annual_pet_monsoonend_crorelitres numeric ,
kharif_aet_monsoonend_crorelitres numeric ,
longkharif_aet_monsoonend_crorelitres numeric ,
annual_aet_monsoonend_crorelitres numeric ,
kharif_deficit_monsoonend_crorelitres numeric ,
longkharif_deficit_monsoonend_crorelitres numeric ,
annual_deficit_monsoonend_crorelitres numeric ,
rabi_pet_postmonsoon_crorelitres numeric ,
longkharif_pet_postmonsoon_crorelitres numeric ,
annual_pet_postmonsoon_crorelitres numeric ,
rabi_aet_postmonsoon_crorelitres numeric ,
longkharif_aet_postmonsoon_crorelitres numeric ,
annual_aet_postmonsoon_crorelitres numeric ,
rabi_deficit_postmonsoon_crorelitres numeric ,
longkharif_deficit_postmonsoon_crorelitres numeric ,
annual_deficit_postmonsoon_crorelitres numeric ,
monsoon_aet numeric ,
ground_water_recharge numeric ,
soil_moisture numeric ,
runoff numeric ,
available_runoff numeric ,
currently_impounded_runoff numeric ,
runoff_available_for_impounding numeric ,

runoff_impounded_after_proposed_structures numeric ,
pet_monsoon numeric ,
pet_post_monsoon numeric ,
aet_monsoon numeric ,
aet_post_monsoon numeric ,
deficit_monsoon numeric ,
deficit_post_monsoon numeric ,
impounded_runoff_monsoon numeric ,
impounded_runoff_post_monsoon numeric ,
available_ground_water_monsoon numeric ,
available_ground_water_post_monsoon numeric ,
water_balance_current_state_monsoon numeric ,
water_balance_current_state_post_monsoon numeric ,
total_deficit_or_extra numeric ,
water_cropping_and_proposed_structures numeric ,
date_created character varying(100) ,
rainfall_mm integer ,
CONSTRAINT master_ouput_attributes_chart_pkey PRIMARY KEY (census_code ,
chart_year)
)

11. Water balance actual state - zone level schema

CREATE TABLE water_balance_zone_level (
village_name character varying(100) ,
census_code integer NOT NULL ,
water_balance_year numeric NOT NULL ,
rainfall_mm numeric ,
zone_number numeric NOT NULL ,
monsoon_cropwater_requirement numeric ,
monsoon_crop_deficit numeric ,
monsoon_storage_available numeric ,
monsoon_groundwater_available numeric ,
monsoon_balance numeric ,
monsoon_index numeric ,
post_monsoon_crop_water_requirement numeric ,
post_monsoon_drinking_water_requirement numeric ,
post_monsoon_storage_available numeric ,
post_monsoon_groundwater_available numeric ,
post_monsoon_soil_moisture_available numeric ,
post_monsoon_balance numeric ,
post_monsoon_index numeric ,
runoff_generated numeric ,
runoff_available numeric ,
runoff_available_for_impounding numeric ,
zone_area numeric ,
kharif_area_hectare numeric ,
rabi_area_hectare numeric ,
soil_moisture_monsoon_end_kharif numeric ,
soil_moisture_monsoon_end_lk_a numeric ,
CONSTRAINT water_balance_zone_level_pkey PRIMARY KEY (census_code ,

water_balance_year , zone_number)
)

12. Water balance zone level proposed structures

CREATE TABLE water_balance_zone_level_proposed_structures (
village_name character varying(100) ,
census_code integer NOT NULL ,
water_balance_year numeric NOT NULL ,
rainfall_mm numeric ,
zone_number numeric NOT NULL ,
monsoon_cropwater_requirement numeric ,
monsoon_crop_deficit numeric ,
monsoon_storage_available numeric ,
monsoon_groundwater_available numeric ,
monsoon_balance numeric ,
monsoon_index numeric ,
post_monsoon_crop_water_requirement numeric ,
post_monsoon_drinking_water_requirement numeric ,
post_monsoon_storage_available numeric ,
post_monsoon_groundwater_available numeric ,
post_monsoon_soil_moisture_available numeric ,
post_monsoon_balance numeric ,
post_monsoon_index numeric ,
runoff_generated numeric ,
runoff_available numeric ,
runoff_available_for_impounding numeric ,
zone_area numeric ,
kharif_area_hectare numeric ,
rabi_area_hectare numeric ,
soil_moisture_monsoon_end_kharif numeric ,
soil_moisture_monsoon_end_lk_a numeric ,
CONSTRAINT water_balance_zone_level_proposed_structures_pkey PRIMARY KEY (census_code
, water_balance_year , zone_number)
)

13. Water balance proposed structures and cropstate - zone level schema

CREATE TABLE water_balance_zone_level_proposed_struct_crop (
village_name character varying(100) ,
census_code integer NOT NULL ,
water_balance_year numeric NOT NULL ,
rainfall_mm numeric ,
zone_number numeric NOT NULL ,
monsoon_cropwater_requirement numeric ,
monsoon_crop_deficit numeric ,
monsoon_storage_available numeric ,
monsoon_groundwater_available numeric ,
monsoon_balance numeric ,
monsoon_index numeric ,

post_monsoon_crop_water_requirement numeric ,
post_monsoon_drinking_water_requirement numeric ,
post_monsoon_storage_available numeric ,
post_monsoon_groundwater_available numeric ,
post_monsoon_soil_moisture_available numeric ,
post_monsoon_balance numeric ,
post_monsoon_index numeric ,
runoff_generated numeric ,
runoff_available numeric ,
runoff_available_for_impounding numeric ,
zone_area numeric ,
kharif_area_hectare numeric ,
rabi_area_hectare numeric ,
soil_moisture_monsoon_end_kharif numeric ,
soil_moisture_monsoon_end_lk_a numeric ,
CONSTRAINT water_balance_zone_level_proposed_struct_crop_pkey PRIMARY KEY (census_code , water_balance_year , zone_number)
)

14. Water Balance - All states - Village Level (state is specified by status field)

CREATE TABLE water_balance_village_level (
village_name character varying(100) ,
census_code integer NOT NULL ,
water_balance_year numeric NOT NULL ,
status character varying(100) NOT NULL ,
rainfall_mm numeric ,
monsoon_cropwater_requirement numeric ,
monsoon_crop_deficit numeric ,
monsoon_storage_available numeric ,
monsoon_groundwater_available numeric ,
monsoon_balance numeric ,
monsoon_index numeric ,
post_monsoon_crop_water_requirement numeric ,
post_monsoon_drinking_water_requirement numeric ,
post_monsoon_storage_available numeric ,
post_monsoon_groundwater_available numeric ,
post_monsoon_soil_moisture_available numeric ,
post_monsoon_balance numeric ,
post_monsoon_index numeric ,
runoff_generated numeric ,
runoff_available numeric ,
runoff_available_for_impounding numeric ,
CONSTRAINT water_balance_village_level_pkey PRIMARY KEY (census_code , water_balance_year , status)
)

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