IITB-GoM PoCRA MoU-I Completion Report

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Date: 8th October 2018

1 Introduction

The Maharashtra Project On Climate Resilient Agriculture (PoCRA) is a World Bank aided project being implemented by Government of Maharashtra in 15 drought prone districts of Maharashtra. The project development objectives are to enhance climate-resilience and profitability of small-holder farming systems in project districts of Maharashtra. The project aims to achieve the objective through promotion of climate resilient technologies and commodity value chain across approximately 4,000 drought-prone villages in 15 districts, namely, Jalgaon, Aurangabad, Jalna, Beed, Parbhani, Hingoli, Osmanabad, Latur, Nanded, Buldana, Washim, Akola, Amravati, Yavatmal, and Wardha and approximately 1000 salinity affected villages in the basin of Purna river spread across Akola, Amaravati, Buldana and Jalgaon districts.

One of the important aspects of ensuring resilience is to assure availability of soil moisture at the critical stages of the crops. Since most of the project clusters are in rainfed areas, management of rainwater becomes critical. A host of factors like rainfall pattern, total rainfall, geomorphology of the watersheds, groundwater recharge potential, surface water and soil moisture management and cropping pattern have impact on the resilience of farmers against climate vulnerability and change. The long-term climate change projections indicate increased moisture stress on agriculture sector. Therefore, a scientific planning of this critical resource with stakeholder engagement is the key to ensure enhanced water and crop productivity.

The IITB-PoCRA collaboration has been done to undertake the development of such water balance based scientific planning methodology. This document provides the details of the deliverables transferred to PoCRA PMU as a part of MoU-I between IIT Bombay and PoCRA signed on 16th August 2017 and for the period 16th August 2017 to 15th August 2018.

1.1 Objectives

This project was taken up with the objective of providing guidance at the village level on the seasonal availability of water so that key decisions on crop choice could be made in a climate resilient manner. The basic strategy was to promote water budgeting and participatory planning approach at micro watershed and village level. To do this it was envisaged to design a water balance computation procedure and to carry it out at the village and the cluster level. This exercise would require a generic framework, that is, a series of tools and analysis designed to help answer core questions of water availability, assessment and water balance using both supply side analysis of surface and groundwater resources and demand side analysis of current water use at the village and the cluster level.

The outputs of these framework will enable visualization of current agricultural water balance status at micro watershed zone/village level thereby providing planning support for cropping pattern and new engineering interventions. These outputs framework would feed into village and watershed level climate resilient plans development.

The methodology would enable measurement of spatial and seasonal water availability in village along with identification of vulnerable farms and micro watershed zones with respect to extra irrigation requirement based on crop water use.

1.2 Deliverables and Methodology

In accordance to the objectives the deliverables were delineated as given below-

Table 1.1 Deliverable stages and components

Stage	**Component**	**Activities**	**Deliverable**
I	**(I)** Building prototype Cluster Water Balance **(CWB-I)** framework	Model Selection, field visit, primary data collection, preparing estimation protocols,	GIS based model with water balance computation
II	**(I)** Testing and fine-tuning of CWB-I framework	Validation of protocols using above model	Validated offline model (CWB-I framework).
III	(II) Adaptation and refinement of CWB-I into CWB-II.	Validation of methodology on new watersheds. Integration. Observation of field practices, stress, etc.	Integration of CWB framework in microplanning.

IV	(II) Transfer of CWB-II to PMU	Preparing thumb rules and guidelines for micro-planners for CWB-II. Training of trainers -I	1.On line tool for water balance. 2. Documentation and user manual
V	(III) Support to PMU	TOT-II, addressing field issues. Incorporating new learning's.	Revisions if required.

These stages have been elaborated separately in deliverables and periodic presentations, deliveries and documentation have been submitted to PoCRA PMU in accordance with each stage. This report summarizes what has been achieved in MoU-I and provide links to more detailed submissions as required by MoU-I.

2 Overall Solution Architecture

The overall solution architecture for PoCRA water balance exercise was designed during the first phase of the project. This consisted of (i) a farm or point-level monsoon season water balance, and (ii) a temporal and spatial integration of these point-level water balance computations to arrive at zonal and regional water availability. GIS technology is used for the second part. One key output is a decomposition of precipitation into its components, viz., run-off, soil moisture, crop uptake and groundwater recharge. Each component was designed based on literature review conducted on existing soil moisture balance models and their adaptability to Indian conditions. A second key output is the identification of dry-spells, i.e., absence of precipitation over long periods, and an estimation of the crop-water deficit. This deficit and its management constitute an important step towards climate resilience. Care was taken to ensure that the outputs were made available in formats which extended existing and familiar frameworks such as Jal Yukta Shivar water balance being used in India and Maharashtra.

The framework was designed keeping in mind the availability of required datasets in the Indian scenario and its implementability in a participatory micro-planning process at the village level. It was developed to provide outputs which would help measurement of seasonal supply, demand and deficit (impact of dry spells / climate resilience) to enable alignment of the planning process towards project objectives. The key outputs of the hydrological framework were (A) Kharif dry spell vulnerable zones, (B) available run-off for stress mitigation (C) Rabi groundwater availability with irrigation requirement for different zones within the village. The first step of a village-level model consisted of development of point or farm level model and extending it spatially using GIS technology for development of the village level model. This is the PoCRA planning unit at the lowest level.

The link to detailed reports on overall solution architecture and model development methods is provided in Chapter 4.

2.1 The Point water-balance model

We now elaborate the development of point level model and its outcome.

Kharif Point/Farm level Model

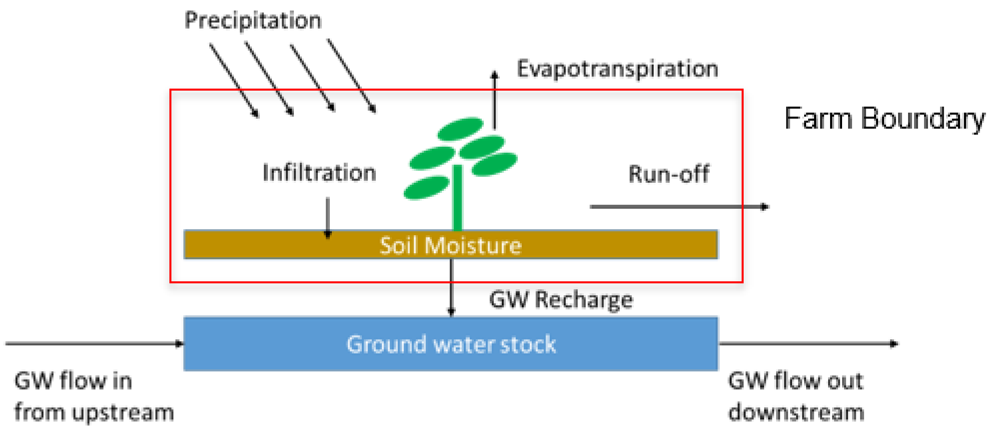


Fig 2.1 Components of water balance

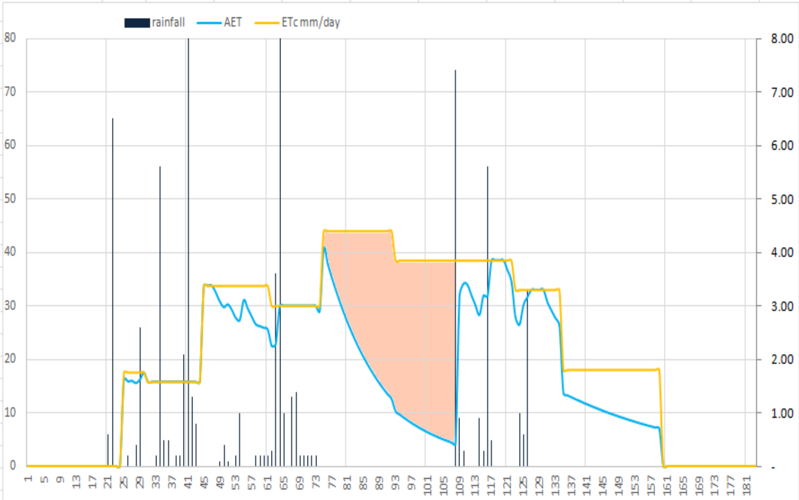


Fig 2.2 Daily water balance

The Kharif point model developed for PoCRA water balance is the core of the hydrological framework. Its role is to compute 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. This allows for the identification of dry spells and estimating the crop water requirements during the dry spell. See Fig. 2.2 above for an analysis of AET vs. precipitation in the village Gondala for the year 2017. On the x-axis, is the number of days from the onset of monsoon. There are two y-axes. On the left is the scale to measure daily rainfall in mm. The rainfall events are shown in the graph as vertical black bars.The right y-axis is to measure soil moisture, i.e., supply (in blue) and ideal crop water requirement, i.e., demand (in yellow), both in mm. One can see that rainfall events cause the blue curve to rise while crop water uptake causes the blue curve to fall. The gap between the demand and supply of soil moisture is the shaded region and is the overall crop water deficit. This deficit is converted into a volumetric water requirement which has to be managed through interventions. This sets up the basic demand, supply, volumetric allocation and enabling access as the key kharif planning framework.

Review of various models

The selection of the point-model is crucial, and we now give a quick summary of various reported models and our choice of model. Considering the variations in accuracy, data requirement and other parameters of reviewed models we have adopted suitable methodologies from different models to develop our point level kharif vulnerability model. Moreover, this model was validated against the "industry-standard" SWAT[32] and other models, as well as in the field.

Our model is a combination of a crop-water model and a run-off model and these are separately described. There exists a range of soil moisture and crop growth models that vary in complexity depending on the vertical discretization of the soil profile and the assumptions made. This includes the one-layer bucket model, the tipping bucket multi-layer models [28][30] The single layer leaky bucket model is too simplified since it overlooks the temporal distribution of rainfall. The other models tend to be too complex for use in the field. The FAO describes a procedure to calculate spreadsheet-based point level crop water balance [33] and this has been the basis of much work [30]. The work that comes closest is that by [30][31] which examines the impact of dry spells on crop yields in rainfed areas of Africa.

As regards run-off, currently, Strange's method or modified Strange-table method and other methods which considers antecedent soil moisture conditions are in common practice. All these methods were explored for their fit with the chosen crop-water/soil-moisture model. SCS curve number methodology was chosen and is used to simulate the runoff in our model.

The simplest crop-water model tried was the single layer soil model. This model had some issues in the generation of runoff and percolation to groundwater, especially in thick soil conditions. Till the complete layer was taken above field capacity, very little runoff was being generated. Another issue was that AET happened at the root zone which is typically the top few centimeters of the soil layer. The entire soil profile as one layer took lot more rainfall for the entire soil column to reach a moisture level that can support full PET. A more refined two-layer model was chosen to overcome the two issues above. The top layer matched with root zone and other was the soil below the root zone. The root zone top layer was to vary with different crops. This partially solved the problem of runoff but there were still some issues observed in shallow soils. The problem here was that the second layer became very thin and became a bottleneck for GW recharge. This issue was resolved by making sure that layer 2 depth is at least 5cm.

Based on the above discussion, we have developed a daily-composite model which is implemented as a spreadsheet and which is an adaptation of SWAT[32]. Table 2.1 outlines the input datasets used and methodology adopted for computation of various components in water budget.

Table 2.1 Water Balance Input Output datasets and Methodology

Water budget component	**Method (Reference)**	**Data source / Input**	**Output**

Surface runoff, Infiltration	SCS Curve number adjusted for slope	SWAT Theory Land use input: LULC maps - MRSAC, slope - DEM.	Runoff model
Rainfall	Input	Maharain.gov.in - Data for last 5 years	Automatic rainfall selection in plugin
Potential Crop ET (PET)	Modified Penman Monteith Method	ET0: WALMI, KC: FAO	Regional crop water requirement (PET) for list of crops
Actual Crop ET (AET)	FAO Methodology	Soil Properties: FC, WP, Crop root depth, soil depth. Soil conductivity function of soil texture input Input: MRSAC Soil, LULC Maps DEM, slope	Estimates of crop AET (farm level vulnerability maps)
Ground Water Recharge	SWAT Methodology		Estimates of ground water recharge
Soil Moisture	Mass balance (based on a two-layer cascading soil water model)		Estimates of soil moisture

Some important differences with SWAT are as follows. First, unlike SWAT this is a simplified spreadsheet-based model that can be run with data that is usually available (or can be collected) in the Indian context. Secondly, for the sake of simplicity, each soil layer is considered to have homogenous properties. These properties are obtained from the MRSAC soil maps which are being validated against field samples in the pilot locations. However, as in SWAT, the computation of the crop AET is limited to the root zone layer which is defined for each crop. It is assumed that moisture below the root zone is not accessible to the crop and water rise due to capillary action is ignored in the model. Also, lateral flows within the soil layer are also considered negligible and ignored in the model.

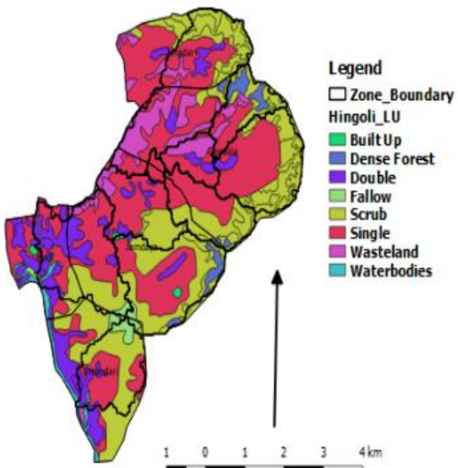
A detailed description of this model with adaptation of input datasets is available in document [2] link, [20] link in Chapter 4.

2.2 Aggregation to village level model

We now summarize the village level water balance model. A detailed description of this model with adaptation of input datasets is available in document [20] link, [2] link in Chapter 4.

As was seen in the last subsection, the point-model needs many geographical attributes such as soil texture, depth and other attributes. Core to the computation the regional water balance is that these are also available as GIS layers. The basic steps are to (i) divide the village into zones, and (ii) to run the point model with a grid of points within the zone, and finally, (iii) to aggregate the various point model outputs and construct the zonal water balance. Each village was divided into zones of size 200-400 Ha., using watershed and sub-watershed boundaries. This was to ensure that upstream and downstream areas in the village were identified, thereby allowing for better analysis of cropping and water requirements and an even distribution of interventions.

The computation is implemented as a QGIS plug-in which resides at the PMU. The inputs and outputs of this plugin are listed below in Table 2.1. Note that while some of the data was provided by MRSAC and obtained by PMU, other data sets (such as rainfall or Kc values) had to suitably arranged. Rainfall was downloaded from Maharain and arranged circle-wise. While computing the village/zone water budget, the plug-in automatically selects the circle, etc., and other relevant datasets.



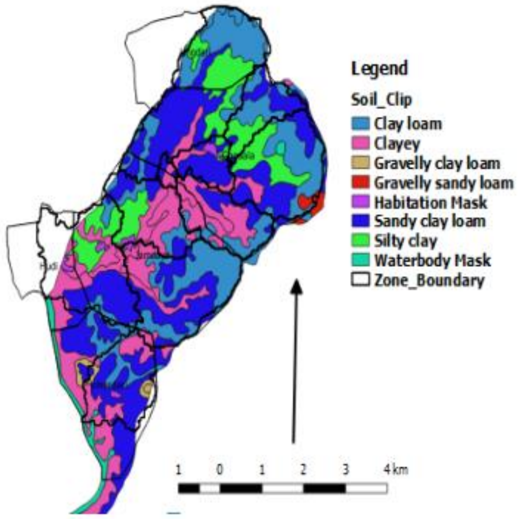


Fig 2.3 Input 1 - Land Use Land Cover

Fig 2.4 Input 2 - Soil Map

The plugin requires five input maps namely – Land Use Land Cover, Soil, Zone, Cadastral and Slope. It also requires daily rainfall file. These inputs are processed to compute the point level water balance which is aggregated at various steps to give farm, zone and village level water balance outputs. Each layer was procured from MRSAC and needed considerable proofing and corrections. For example, in the LULC maps, 65 land-use types were aggregated into 8 types for our purpose. Similarly, for soil texture, median values of the soil texture polygon were used. For soil-depth, the value taken was the maximum of the range. This was after done after matching it with various field locations, see Table 2.4 below.

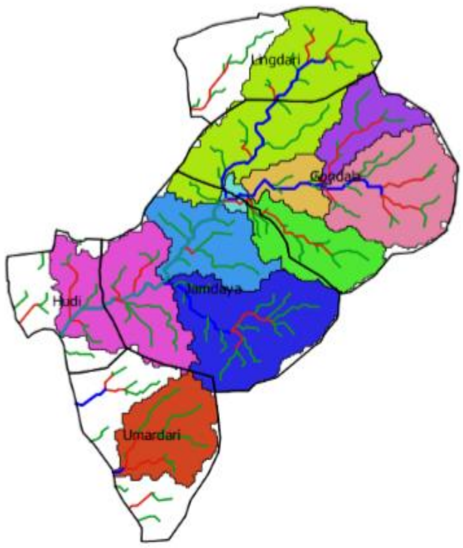


Fig 2.5 Input 3 - Zone Map

Fig 2.6 Input 4 - Cadastral Map

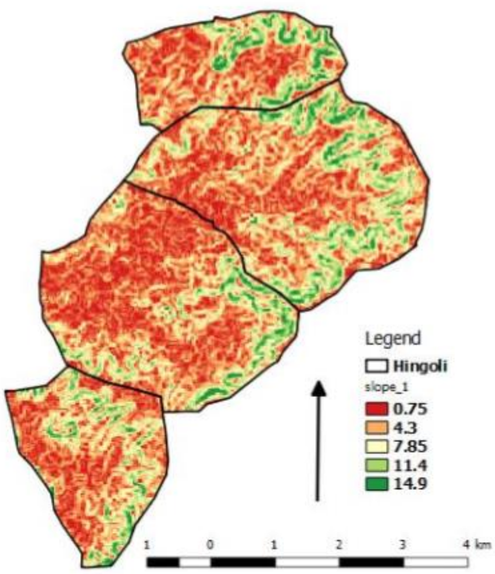


Fig 2.7 Input 5 - Slope Map

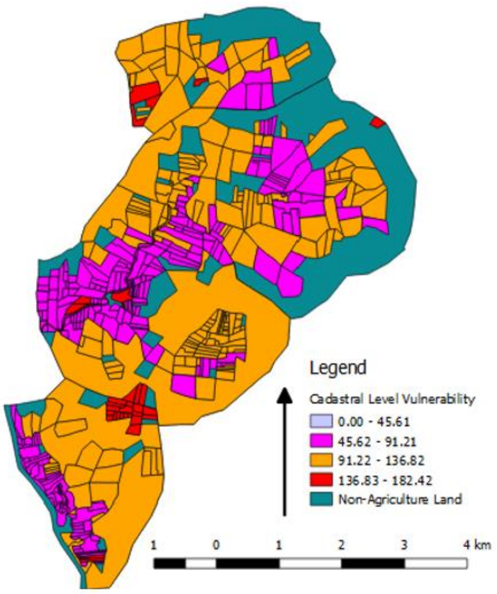


Fig 2.8 Output - Cadastral vulnerability map

Farm-level vulnerability is defined as the typical crop water deficit in a typical (see above Fig. 2.8) monsoon year and is measured in mm of water required (see Fig. 2.2 above) and is an important output of the model. This number depends on the local topography and soil conditions of the land and captures the vulnerability of agriculture at that location. Farm level vulnerability maps for various crop options are available as the output from plugin. This map shows climate vulnerability for each farm by measuring monsoon crop deficit (i.e. protective irrigation requirement) for that farm. The spatial impact of dry spells can be seen through these maps. This enables identification of vulnerable farmers and interventions to help him/her to to meet protective irrigation requirement. In short, these maps provide farm level intervention planning targets.

Table 2.2 Plugin Output: zone wise water balance table

Village Name	Census Code	Zone	Zone Area (ha)	Crops in English	Crops in Marathi	Crop Season and Landuse	Rainfall (mm)	PET Monsoon End	AET Monsoon End
Peth	534587	zone-Peth-1	174.68748	bajra	बाजरी	Kharif_Main	872.0	324.89	287.04
Peth	534587	zone-Peth-1	174.68748	current fallow crop	चालु पड	Landuse	872.0	151.19	144.98
Peth	534587	zone-Peth-1	174.68748	Non Agri	बिगर शेती	Landuse	872.0	151.19	144.98
Peth	534587	zone-Peth-1	174.68748	permanant fallow crop	कायम पड (गावठाणसह)	Landuse	872.0	151.19	144.98
Peth	534587	zone-Peth-1	174.68748	wasteland	पोटखराबा	Landuse	872.0	246.57	231.69
Peth	534587	zone-Peth-1	174.68748	scrub	गायरान	Landuse	872.0	153.32	148.41
Peth	534587	zone-Peth-1	174.68748	forest	वनक्षेत्र	Landuse	872.0	472.45	415.7
Peth	534587	zone-Peth-2	283.85261	bajra	बाजरी	Kharif_Main	872.0	324.89	287.04
Peth	534587	zone-Peth-2	283.85261	current fallow crop	चालु पड	Landuse	872.0	151.19	144.98
Peth	534587	zone-Peth-2	283.85261	Non Agri	बिगर शेती	Landuse	872.0	151.19	144.98
Peth	534587	zone-Peth-2	283.85261	permanant fallow crop	कायम पड (गावठाणसह)	Landuse	872.0	151.19	144.98
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Peth	534587	zone-Peth-2	283.85261	forest	वनक्षेत्र	Landuse	872.0	472.45	415.7

Table 2.2 illustrates yet another output of the plugin which is used for zonal planning. This table indicates for every crop in that region and for a typical monsoon year, the net water availability, deficit, groundwater recharge etc., in mm. The key steps in the planning process are as follows:

(i) The transfer of the crop-wise zonal water tables to the village-level field teams.
(ii) Field level survey to ascertain zonal cropping pattern and the computation of key water demand components (kharif protective irrigation, rabi, long kharif and annual crop water requirements) and supply components (groundwater stock, run-off and soil moisture) in volumetric terms.
(iii) Field assessment of existing watershed interventions and a computation of the village water budget and supply-demand deficits.
(iv) Planning, i.e., locating and dimensioning, of provisional area and drain-line watershed interventions such as bandharas, farm-ponds etc., and access and allocation devices such as wells, lift irrigation infrastructure or delivery systems such as drips and sprinklers.
(v) Recomputation of the village water budget and revision of cropping plan and interventions as required.
This is facilitated by the PoCRA micro-planning app whose sample screens are shown in Fig. 2.9 below. The data of Table 2.2 is integrated by the PoCRA micro-planning app, and specialized to the actual cropping pattern observed (see Fig. 2.9, left panel) and the various interventions which are existing (Fig. 2.9, middle panel) and planned. The output of planning app is zone level water budget for three scenarios – current scenario, post intervention planning and post crop planning (Fig. 2.9, right panel). Finally, the net water budgets are obtained as reports as shown in Table 2.3.

This is how the water budget provides concrete intervention planning targets and aids the planning process.

Fig 2.9 PoCRA MLP app inputs for water budget

Table 2.3 Sample zone level water budget output from MLP app for village Paradgaon Village, Jalna - Current state

2018 Seasonal Water Balance	Rainfall - 435 mm	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**	**Zone 7**	**village**
Monsoon Water Balance (TCM)	Monsoon protective irrigation requirement	606	939	938	213	851	1135	921	5602
	Monsoon storage through existing structures	57	59	73	41	56	87	56	429
	Ground water available to crops in monsoon	0	15	6	0	4	9	4	37
	Water Budget 1: Monsoon	-548	-866	-858	-171	-791	-1039	-861	-5136
	Monsoon protective irrigation index	0	0	0	0	0	0	0	0
Post Monsoon water balance (TCM)	Post Monsoon protective irrigation index	635	1020	1429	517	1266	1680	1513	8061
	Drinking water requirement								159
	Post monsoon storage remaining in existing structures	57	59	73	41	56	87	56	429
	Post monsoon ground water available to crops	0	29	12	1	7	17	7	74
	Soil Moisture	0	36	60	44	64	64	86	354
	Water Budget 2: Post Monsoon	-578	-1054	-1284	-431	-1140	-1512	-1364	-7362
	Post Monsoon water use index	0	0	0	0	0	0	0	0
Planning (TCM)	Available runoff (50% of total runoff from village area)	227	431	370	81	339	446	372	2265

	Runoff available for new planning	112	314	223	0	227	272	261	1407

2.3 Validation Cycle

We now describe various steps taken to validate most of the inputs, outputs and the key computations of the water budget. Since the water balance model is a combination of existing scientific models as reported in literature, the focus was on calibration and gaps in integration. This validation was done by visiting various villages, and farmer and field worker interviews. The process followed, and the questions asked are described below.

Table 2.4 Input parameters collection/verification

Sr.No.	**Input parameter**	**Sampling**	**Methodology used for verification**
1.	Soil texture	Using MRSAC Soil Maps, farms with different soil texture near and away from stream were selected	% clay, % sand, % gravel, % silt for few samples were checked in lab. Soil samples from Gondala, Bajar Wahegaon, Yeulkhed were collected and tested. Visual inspection and farmer interview were also used to verify soil texture.
2.	Soil layer thickness	Using MRSAC Soil Maps, farms with different soil depth were selected	At few locations trial pits were taken. Through interview and visual observations from wells sidewalls soil depth was ascertained.
3.	Validate LULC (esp. type of forest, fallow land, cropping intensity)	Using MRSAC LULC Maps, farms with different LULC type were selected.	Questions were asked for multiple years from farmers regarding their land use and land cover, permanent fallow land, built up areas and forest land in village.
4.	Slope/streams	Through discussion with Farmers, Agri-assistant and field survey spots were identified.	Streams and slope generated from the DEM were verified through interview, field inspection. Drainage generated from Dem and MRSAC were compared with field.

5.	Existing watershed structures	Through discussion with Farmers, Agri-assistant and field survey spots were identified.	Structures were marked on the Map through group discussion with farmers, sarpanch, Agri- assistant and field inspection.
6	Rainfall pattern (how closely does the dry spell match circle level data)	Farmers were selected using soil and LULC maps.	Farmers were shown the circle level rainfall graphs. Questions were asked to verify the dry spells and high rainfall events.

Table 2.5 Model Output validation: Runoff

Sr.No.	Output parameter	Sampling	Methodology used for verification
1.	Runoff collected in structures (accumulated)	Good year/bad year, by different months from different farmers using soil and, drainage and LULC map	Questions were asked related to filing of various structures, full by month, Relevance for Kharif protective irrigation & mapping to Vulnerable zones. It was compared with the output value given by model.
2	Stream flow	Major streams in the village	Questions related to beginning of flow, duration and drying of flows were asked.
3	Run-off for Non-Agricultural LU	Non-Agricultural LUs such as: Forest, scrub, fallow, wasteland obtained from MRSAC	Question related to reduced or increased runoff flows from Non-Agricultural lands and increased GW recharge were asked. Same were verified with model output.

Table 2.6 Model validation: Sowing Date/AET/PET

Sr.No.	Input parameter	Sampling	Methodology used for verification

1.	Kharif cropping pattern	Farmers were selected using MRSAC's LULC and soil Map	Crop sowing report gave the idea of the cropping pattern which was verified with various farmers in the field through interview.
2.	Crop details	Farmers were selected through maps, discussions covering different crop types in village	Questions related to seed variety, sowing date (after how many mm of rainfall), crop duration, root depth, typical irrigation requirement in different soil types. All these details were used to match the crop characteristics being used in the Model.
3.	Initial soil moisture level before first rains	Farmers were selected through maps, discussions covering different crop types in village	Questions related to drying of soil, cracks (how deep), moisture holding capacity of soils were asked. These things helped in checking that the AET is being modelled correctly.

Table 2.7 Model validation: Kharif vulnerable zones: Output validation

Sr.No.	**Output parameter**	**Sampling**	**Methodology used for verification**
1.	Kharif PET-AET zones/ vulnerable zones	Farmers from PET-AET zones output of plugin were selected	Questions related to sowing date, ideal number of irrigations and timing, number of irrigations this year, dry spell decisions, availability and source for irrigation, availability of water in wells, bandharas etc. for Kharif protective irrigation, estimating the volume of water given in each protective irrigation, crop yield and quality (actual or expected), Current well water levels in different PET-AET zones were asked.

Table 2.8 Model validation: GW stock/flow

Sr.No.	**Input parameter**	**Spatial sampling**	**Methodology used for verification**
1.	Kharif GW extraction	Using MRSAC Soil Maps, farms with different soil texture near and	Estimate of kharif extraction by individual farmers during dry spells, number of irrigations given. Pump capacity, duration of pumping etc.

		away from stream were selected	
2.	Rabi fallow land	As per LULC map and discussions with Agri assistant, Sarpanch, farmers many farms were selected	Discussion with farmers on their Rabi fallow this year, situation of land in other year, Kharif crop choice, and availability of water was done.
3.	Rabi crop details	Using MRSAC Soil Maps, farms with different soil texture near and away from stream were selected	Questions related to seed variety, sowing date, crop duration, typical irrigation requirement and timing in different soil types, availability of farm ponds – how they were filled, and which crops are they used for were asked.
4.	Water table level	Using MRSAC Soil Maps, farms with different soil texture near and away from stream were selected	Questions related to well depth, water level at different times of the year, availability of first water for irrigation, availability of last water for irrigation.

Several villages were visited last year and this year to understand the ground level realities and build the model as well as to validate and calibrate our model (see Table 2.4 below). This year too, many villages were visited to check the effectiveness of the model and micro-planning linkages. A set of questions were asked to farmers related to rainfall pattern and its intensity, dry spells, irrigations applied and its sources, soil type, depth, runoff and groundwater recharge based upon its model was validated. This survey format can be found here at [26] link, [27] link. Out of many villages, Example of two villages level runoff analysis is given below.

A. Ghusar Village

Ghusar village from Akola district was visited on 25th January 2018. Procedure used for runoff validation during the visit was interviews of key farmers. In this case, the objective was to match farm-level run-off given by model with water collected in farm-pond. Various gat-numbers were selected through discussion with farmers using secondary data like, MRSAC Soil, LULC Map for validation of model. One of such gat number is shown below (Fig 2.10).

The total size of the selected farm was 4.7 ha (Farm with farm pond number 1 see image below Fig 2.10).

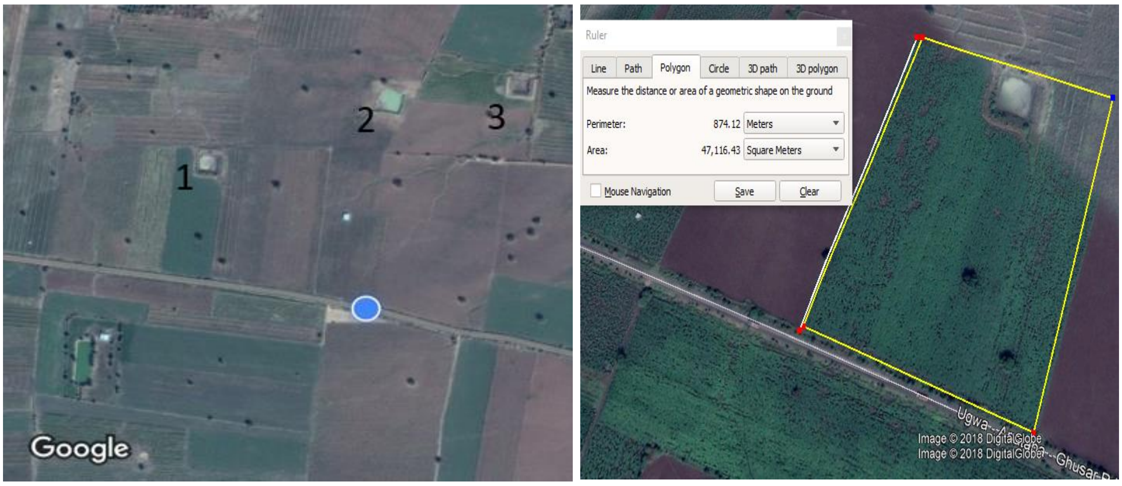


Fig 2.10 Farm with farm pond number 1 (Google Image Date – 22nd October 2017)

Fig 2.11 Farm Pond Number 1 (25th Jan 2018)

The model predicted the runoff amount during the entire season to be 71mm. This generated around 3.3 TCM of runoff water from that farm. The capacity of his farm pond was 2.2 TCM (30*30m). The farmer who had farm pond number 1 was asked if his farm pond filled and overflowed. His response correctly matched with the prediction made by model runoff. Farm pond number 2 was also filled due to enough runoff generation. Farm pond number 3 did not fill at all. The water that overflowed from farm pond number 1 and 2 was not enough to fill the farm pond number 3. This can be clearly seen in the Fig 2.10. Farm pond 2 still had some water left and farm pond 3 did not have any water. All these things were correctly predicted by the model and hence validated on field through various question-answer sessions with the farmer.

Sr. No	Name	Pond Capacity	Farm Runoff generated	Farmer Reply
1	Farm 1	2.2 TCM	3.3 TCM	Pond Filled and overflow

Model output is also given in Fig 2.12. It gave us various values like rainfall runoff, soil moisture at monsoon end, ground water recharge, deficit which were also validated through interviews. Questions were asked related to impact of deficit in terms of yield, availability of soil moisture at the end of monsoon and its impact on post monsoon irrigation. Fig. 2.12 information like rainfall, runoff and deficit is also displayed in graphical form.

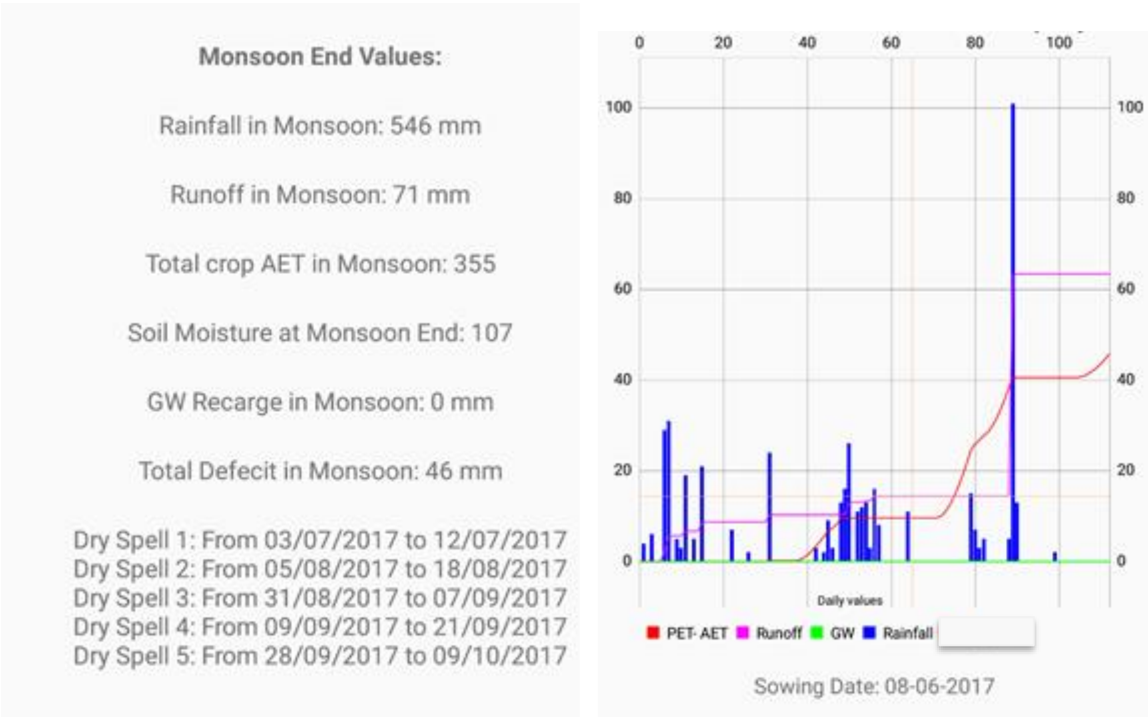


Fig 2.12 Model output for Ghusar location farm with pond no. 1

B. Yeulkhed Village

Another village visited was Yeulkhed on two occasions. This village was visited twice, last year on 17th-18th November 2017 and this year on 18th -19th September 2018. Our model correctly predicted the runoff in this village during both the years. Farm with gat no. 2 was selected whose area is 5 ha see Fig. 2.14. Farmers were asked several questions to validate the model. This year runoff predicted by the model was 86 mm from total rainfall of 424 mm till 18th September 2018 see Fig. 2.17 and 2.18. Farmer was asked when his farm pond was filled completely. His answer at the end of July 2018 matched with the runoff predicted by the model. Till end of July 2018, runoff predicted by model was 47mm. Total runoff generated from his field at that point of time was 2.3 TCM which was enough to fill his farm pond whose capacity is 2.2 TCM. This farmer had utilized water from pond to irrigate the crops during august. This can be observed from the rainfall pattern, there was dry spell of 15 days. Later again in August 2018, between 17th and 22nd there was a rainfall event which led to generation of runoff and filling of his farm pond once again. All model predictions matched very well with the farmer's answers. Last year there was only 38mm of runoff which generated only 1.9 TCM of water which was not enough to fill his farm pond. This can be seen in the images below Fig 2.13. Comparison of results of both the years is given in Table 2.9.

Table 2.9 Comparison of results of two year

Year	Farm size Ha	Pond Capacity (TCM)	Rainfall (mm)	Runoff till End of July (mm)	Runoff Monsson Season (mm)	Total Runoff (TCM)
2018	5	2.2	424	47	86	4.3
2017	5	2.2	486	28	38	1.9

Fig 2.13 Yeulkhed farm pond at Gat No. 2 Year 2018 (Left) and Last year 2017 (Right)

Fig 2.14 Yeulkhed farm validation Gat No. 2

In the images below, enough runoff can be seen in the streams and farm ponds at other places as well during current year. Whereas last year there was hardly any runoff generated to fill the farm ponds. Our model had predicted this quite well.

Fig 2.15 Yeulkhed stream flow current year 2018(Left) and last year 2017(Right) scenario

Fig 2.16 Yeulkhed farm pond current year 2018(Left) and last year 2017(Right) scenario

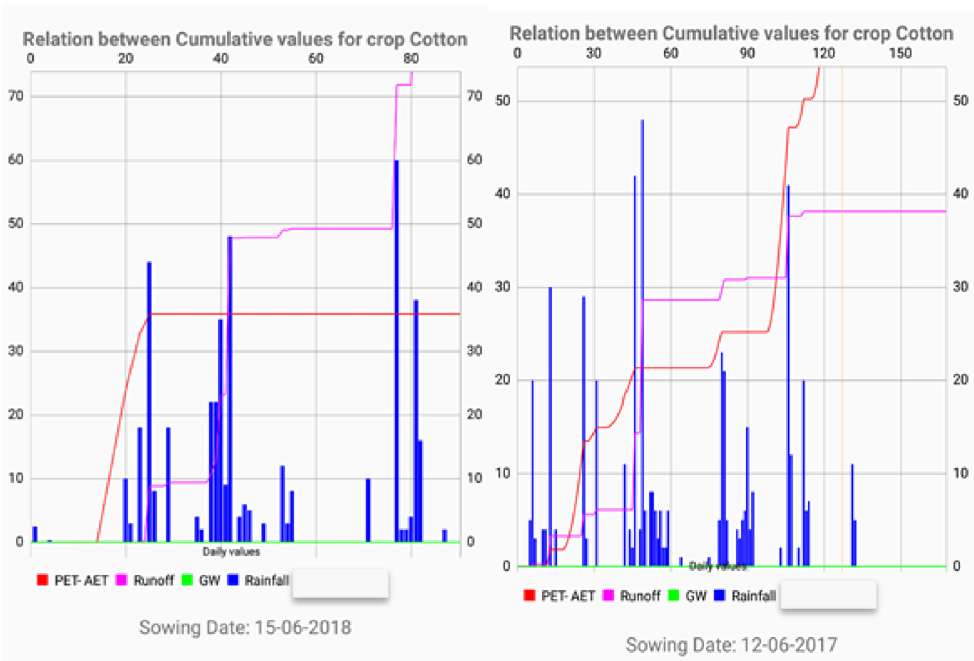


Fig 2.17 Yeulkhed model runoff current year (2018) and last year (2017) scenario

Fig 2.18 Yeulkhed model output current year (2018) and last year (2017) scenario

Rainfall of the circles nearby yeulkhed village for year 2018 is shown below in Fig 2.19. Both the circles depict similar rainfall pattern. From the rainfall pattern one can see there were rainfall events at the end of june which led to the sowing. In the second week of July there were rainfall events which led to generation of enough runoff which filled the farms ponds. Then there was a dry spell of 20 days at the start of August during which people utilized the water from farm ponds for protective irrigation. Later in August there were more rainfall events which led generation of runoff a second time and filled the farm ponds again.

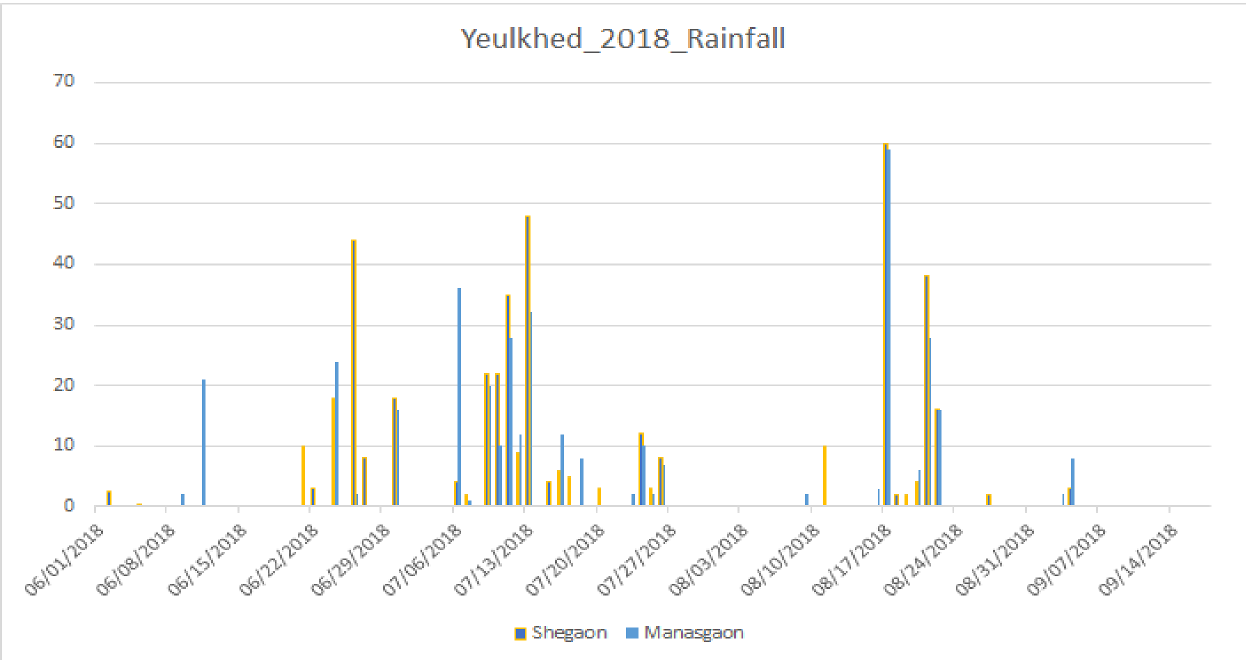


Fig 2.19 Yeulkhed Rainfall 2018

Table 2.10 Field Visit Details

Sr. no	District	Field Visits	Date
1	Hingoli	Gondala, Jamdaya	21st September 2017
2	Jalna	Bajar Wahegaon	23rd September 2017
3	Buldhana	Yeulkhed, Shegaon	17th November 2017
4	Buldhana	Malkapur-Jalamb-Khumgaon	3rd January 2018
5	Washim	Wai, Wadhvi Karanja Cluster	5th January 2018
6	Akola	Ghusar, Akola	25th January 2018
5	Ahmed Nagar	Hiwre Bajar	11th Feb 2018
6	Pune	Baramati Visit	14th March 2018
7	Jalna	Paradgaon, Jalna	21st May 2018
8	Jalna	Paradgaon, Jalna	2nd June 2018
9	Latur	Shelgi, Latur	15th July 2018
10	Bid	Suleman Deola, Beed	22nd June 2018

Description of work done and Deliverables

This section describes in detail the phase-wise work done for formulation and implementation of water balance exercise in PoCRA region. Tasks undertaken, and deliveries made in CWB I, CWB II including model formulation, testing, validation and refinement along with transfer of full package and deployment support are elaborated here.

3.1 Building Prototype Cluster Water Balance Framework (CWB I)

This phase consisted of prototype point-wise model development and aggregation to spatial level using GIS. The process consisted of reviewing existing soil-moisture balance and crop water balance models, incorporating suitable methods to be used in our model, conducting field visits to finalize the estimation protocols and conduct primary verification of model based on field observations.

The point level model developed was translated into aggregated spatial model using MRSAC soil, land use land cover datasets, Digital Elevation Model data available from SRTM and daily rainfall data for last five years available from Maharain website. Village and cadastral shapefiles provided by PoCRA PMU enabled farm level as well as village level implementation of model with respect to the planning unit.

The soil, land-use datasets were adapted based on input parameters required by point level model to enable computation of crop water balance. The adaptation and validation was done based on field observations. For example, the MRSAC database of Land Use Land Cover maps consisted of number of land use types. These land use types were grouped into 7 categories namely – agricultural, non -agricultural, wasteland, scrub, forest, current fallow and permanent fallow. This grouping was done by matching maps with field observations. Similarly, the soil composition (sand, silt and clay percentage) for soil textures in MRSAC map, which determines important soil characteristics was assigned from soil triangle.

Micro watershed zones in village were also introduced during this phase. This was done with an objective to segregate regions with similar biophysical properties in the village as well as enable resource allocation and intervention planning for each zone. Zone creation methodology was finalized and zoning support was provided to PMU throughout this phase. Crop water requirement computation methodology was fixed based on available Walmi and FAO data and list of 10 crops were added to the prototype GIS water balance plugin.

First version of GIS crop water balance model was a preliminary prototype which could be run for a cluster on a single crop at a time. It generated cluster level seasonal water balance outputs in excel sheet. The outputs were generated at zonal level for each village in the same sheet. The inputs required were made available from input shapefiles adapted as per the model. Figure 3.1 below shows a sample output where each column mentions the 'name of village - zone no. - Land use type'. In similar way water balance excel output was generated for each soil type present in zone with a final balance which was weighted average of the water balance for each soil type. The unit of measurement here is mm. The plugin also generated farm level vulnerability map measuring monsoon crop deficit.

	A	B	C	D
1		zone-Pimparkhed-1-Agricultural Total	zone-Pimparkhed-1-scrub open	zone-Pimparkhed-1-overall
2	Rainfall	431	431	431
3	Runoff in Monsoon	84	147	92
4	Infiltration in Monsoon	300	237	292
5	Soil Moisture Crop end	107	14	94
6	Soil Moisture Monsoon end	93	52	88
7	GW Recharge in Monsoon	18	54	23
8	AET Crop End	189	179	187
9	PET Crop End	454	281	454
10	AET Monsoon End	189	131	181
11	PET Monsoon End	454	281	454
12	Monsoon Deficit(PET-AET)	265	20	233
13	Crop duration Deficit(PET-AET)	265	103	244

Fig 3.1 Sample water balance output format for plugin version I

Initial field visits were conducted in Gondala and Wahegaon villages in Hingoli district, which helped finalization of estimation protocols and preliminary validation of plugin. Visit to Yeulkhed cluster in Buldhana district enabled the introduction of zonal approach in microplanning.

In this manner GIS based offline water balance model was developed and validated as a part of phase I and phase II in CWB I, and delivered to PoCRA PMU on 22nd January 2018. Phase II plugin description document ([4] link) provides details of adapted datasets, used inputs and generated outputs.

3.2 Integration with Microplanning Framework and Transfer (CWB II)

This phase consisted of adaptation and refinement of plugin to integrate into microplanning framework. Online water budgeting tool was developed for this purpose and methodology for computation of water budget was set to enable its integration with microplanning framework.

First a simplified version of online water budgeting tool was developed which needed plugin output water balance data for main crops in village to be entered into the app by field staff, along with village cropping pattern and existing interventions data. This version was refined, modified and updated later to enable plugin output data to be fed into the online tool from backend at PMU premises whereas the village level cropping pattern and existing intervention details were to be fed by field staff at front end of online water balance tool. This helped reduce the field level complications and improve the usability of plugin outputs.

At the same time the single crop plugin was modified and refined to multicrop GIS plugin. The multicrop plugin generated village wise water balance outputs for multiple crops in single run on any cluster. The crop set was updated with total of 48 crops as illustrated in crop water requirement calibration document ([13] link). The output formats of multicrop plugin were adapted as per requirements of online water budgeting tool. These outputs would feed into the backend of online water budgeting tool.

An automatic rainfall selection methodology for village (with overwrite facility) was developed to select rainfall circle and rainfall year for water budget computation. This methodology was finalized in consultation with PoCRA PMU. The selection of rainfall circle was based on revenue circle of village and the selection of rainfall year was based on nearest total rainfall to average of last five years.

Project area input database for GIS plugin was compiled consisting of soil, land use land cover, slope, drainage, cadastral, zones and rainfall files for each cluster. This database was delivered to PoCRA PMU. The outcome of this integrated set of offline multicrop plugin and online water budgeting tool was a zone and village level seasonal (monsoon and post-monsoon) water budget. This water budget showed monsoon and post monsoon water deficit and supply components such as runoff available for impounding after current storage, soil moisture available to post monsoon crops and ground water. The offline plugin also gave farm level vulnerability (monsoon crop deficit) maps as output, which were to be used for beneficiary prioritization purpose in village level planning. In consultation with PoCRA PMU it was decided to take up integration of these maps into microplanning process in next phase.

These outcomes enabled zone level planning to ensure consideration of spatial variability and intervention planning for all regions in the village. The online tool generated three scenarios for water budget - one depicting current water budget status, second depicting the water budget status after planning of interventions and third depicting the status after new interventions and new cropping pattern. This package of offline and online tools, input plugin database along with technical documentation and user manual ([10] link, [18] link) in local and official language were delivered and transferred to the PoCRA PMU in this phase. The links to the documents are available in Chapter 4.

This exercise measured climate vulnerability in terms of crop deficit, supply side components of available runoff, ground water recharge and soil moisture available for post monsoon season. This provided concrete intervention planning targets at farm, zone and village level.

3.3 Support to PMU

Technical handholding and support were provided to PMU for a duration of 6 months to enable seamless deployment of water budgeting framework and tools on the ground. Training at various level ranging from DSAO to field level microplanning staff was conducted as per requirements, field issues were addressed and new learnings were incorporated during this phase. The details on this are available in Table 4.3.

Besides technical support and handholding, IIT Bombay also provided routine operational IT support. This consisted of

(i) Responding to queries and questions coming directly from field staff.

(ii) Preparing zones for all the 1200 villages of PoCRA Project phase I and transferring the same to PMU,

(iii) Running our water budget plugin for all the above villages and uploading these on vendor servers.

This support was outside the scope of the MoU and amounted to about 4 man-months.

4 Schedule of Deliverables

This section elaborates the delivery schedule as per various components listed in preceding sections. Current active link to various documents and deliveries is provided in this section.
The work done for building prototype Cluster Water Balance (CWB-I) framework and testing and fine tuning CWB-I framework has been given in Table 4.1

Table 4.1: Overall Hydrological Framework and Prototype GIS tool Delivery

Work done during adaptation and refinement of CWB-I to CWB-II and Transfer of Full package to PoCRA PMU is given in table 4.2

Table 4.2 Delivery of Full Package with Documentation to PoCRA PMU

Sr.no.	**Deliveries**	**Type**	**Date**	**Link**
1	Technical advisory progress presentation on scope for refinement	Presentation and Meeting (Agricultural Committee Meeting) – Mumbai	6th February 2018	[8] link
2	Plugin Refinement - requirements presentation	Presentation and Meeting (Agricultural Committee Meeting) – Mumbai	6th February 2018	[9] link
3	Refined PoCRA water balance computation Manual in local language. (useful for Agri department and field staff)	Report	25th February 2018	[10] link
4	Presentation on village plan analysis steps based on field visit	Presentation - Mumbai	25th February 2018	[11] link
5	PoCRA Vs JYS - Presentation to Agricultural committee on way forward to water budgeting	Presentation and Meeting (Agricultural Committee meeting) - Aurangabad	7th April 2018	[12] link
6	Crop Water Requirement Calibration document	Report	23rd April 2018	[13] link
7	Zoning Process Document	Zoning Process	26th April 2018	[14]link
8	Plugin User Manual	User Manual for PMU	30th April 2018	[15] link

9	PoCRA Water Budget and Planning - Scope for Improvements presentation	Presentation and Meeting – PMU Mumbai	11th May 2018	[16] link
10	Mahabhulekh data analysis presentation	Presentation – PMU Mumbai	11th May 2018	[17] link
11	MLP App user manual in local language	User Manual	15th May 2018	[18] link
12	Plugin Functional Validation Document	Report	25th May 2018	[19] link
13	Multicrop refined plugin report (Technical details, datasets and user instructions)	Report	25th May 2018	[20] link

Table 4.3 Technical Handholding and Support to PoCRA PMU

Sr.no.	Deliveries	Type	Date	Link
1	Presentation - Divisional Officers Orientation Program, Yashada, Pune	Training Presentation	2nd November 2017	[21] link
2	Presentation - Training of Trainers Water Budget – Yashada, Pune	Training Presentation	25th November 2017	[22] link
3	Malkapur- jalamb- khumgaon Cluster	Training water budget	3rd - 6th January 2018	MLP App Water Budget training
4	Training - Karanja Cluster,	Training water budget and online MLP app version 1	6th January 2018	MLP App Water Budget training
5	Training - Ghusar, Akola	Training water budget and online MLP app version 1	27th January 2018	MLP App Water Budget training
6	Presentation - Training VSTF, Pune	Training Presentation	28th March 2018	[23] link
7	Training - Beed, Aurangabad	Training Presentation and MLP App	22nd May 2018	[24] link
8	Training - Jalna, Jalgaon	Online water budget app training	22nd May 2018	MLP App Water Budget training

9	Training - Latur	Online water budget app training	12th June 2018	MLP App Water Budget training
10	Delivery of Zones for 1200 phase I villages – PMU Mumbai	Shapefiles delivered	16th August 2018	
11	DPR Assessment Support - Buldhana	Meeting for DPR finalization based on water budget	19th September 2018	DPR Assessment support
12	Presentation - SDAO level Water Budget, Planning and DPR Assessment - Nagpur	Meeting for DPR finalization based on water budget	10th September 2018	[25] link

Currently the water budget has been successfully deployed and functional in PoCRA region and is being utilized in planning process for approval of no. of interventions.5 Conclusions and future work

The core project objectives of the IITB-GoM PoCRA MOU I were (i) the design and development of a regional water budgeting framework (ii) deployment of this framework as a tool in the village level planning process. These have largely been achieved. Generic GIS tools, datasets, and scientific procedures were developed and transferred to PMU, PoCRA as a part of MoU-I. These tools consisted of single crop water balance plugin (first version of plugin) and multi-crop water balance plugin (refined 2nd version of plugin) respectively. Zone level water budgeting framework was integrated into PoCRA microplanning process and deployed on field through zone level water budgeting applet (PoCRA Microplanning app).

These tools enabled zone level water balance computation to measure seasonal agricultural water deficit and water availability in form of various water balance components - soil moisture, groundwater and runoff. Water budget based zonal planning methodology was introduced based on this. This methodology enabled measurement of water budget for current and post intervention and crop planning scenarios to guide the planning process.

Impact of stream proximity and ground water recharge discharge zones was observed during field visits. Analysis of this and its incorporation into the planning process may be considered in future phases. Field visits conducted during this phase also revealed need for development of water budget-based indices and planning guidelines.

A crop prioritization methodology and water allocation framework based on water budget needs to be set up and integrated with the micro planning process to enable planning guidance at farm, zone and village level. This will lead to informed decision making for planning of new interventions and prioritization of beneficiaries at zone and village level. It would also enable better utilization of the outputs from water balance plugin in planning process and provide direct linkages to critical project outcome measurements.

Refinement of core models should also be taken up. This should be done in two axes. First the validation of secondary data and its refinements, validation of crop and run-off models etc., through regional agencies and universities, such as SAUs, should be undertaken. The second axes is of incorporation of temporal data, both live and legacy, through collaboration with agencies like IMD and Skymet. Development of GIS based dashboard would be useful for real time monitoring and analysis of water balance parameters. This exercise will deliver an integrated Water Budgeting, Planning support and Measurement system consisting of various GIS, models based and apps.

There is scope to provide better estimates of groundwater stocks and flows in a tabular form for various regions in the cluster and for different scenarios, e.g., of Rabi cropping intensity. Each flow/stock or water level needs to estimate for the region as a whole. This may be done by gathering data regarding well behaviour for a limited number of wells in each zone. This will help in better planning of interventions in terms of number of wells to be given.

Annexure I: Zoning Process Document

1 Preamble

This document describes the process of zoning within a village. This is one of the many pre-processing steps required to run the plugin. This document is extension of document "Plugin Description Document (Phase III Deliverable) pdf" available at https://www.cse.iitb.ac.in/~pocra/. Zoning makes an important step of the whole water budgeting exercise and then micro planning exercise. Within the village itself temporal and spatial variation can be found in terms of cropping pattern, availability of water surface or ground, type of storage and conservation structures. The cause of this variation is due to factors like rainfall, variation in type of soils and its depth, topography and slope. Due to this within a village or cluster of villages patches of land can be easily seen with variation in availability of groundwater and surface storage structures and hence variation in cropping pattern. This further leads to inequality in distribution as well utilization of natural resources. The people with high availability of storage structures or groundwater can benefit more than the those with the less. It is highly important to identify such zones. Planning of cropping as well as structures in such zones will depend on such zones.

This document describes the process used for zoning. Description about the steps used in the process is given below. First and foremost, user needs to download the dem and extract watersheds from the dem. In the second step, user needs to intersect the extracted watersheds with the cluster boundary. Before intersecting user needs to clean watershed file. User needs to merge the small polygons with the near ones to avoid any error during intersection process. Third step, user needs to create drainage with basin size of 100-200 to get the extensive drainage network. This will help in zone creation process. Fourth step, user needs to clean the intersected file by splitting the geographically discontinuous but single polygons and merging them with the near ones. The next step is the process of zone creation which requires the understanding of watershed delineation process. Description of same and links to resources for understanding delineation process are provided in this document. Understating this process will help the user in creation of the zones. After creation of zones user needs to add the attribute names for the created zones in the attribute table.

Sr.No	**Summary of Steps**
1	Delineation of Watersheds
2	Intersection process Issues and resolution
3	Drainage Generation
4	Cleaning of intersected file
5	Zone Creation Process
6	Addition of Zone name in attribute table

2 Delineation of watersheds

2.1 Downloading the DEM

User needs to download the DEM for the project area. Current DEM has been downloaded from the USGS earth explorer website (https://earthexplorer.usgs.gov/). The user needs to give the areal extent, name or shapefile of the project area at USGS website for downloading the DEM. The dataset at website contains the number of products like imageries, derived products and digital elevation model generated from various satellites. The user has number of options for the Digital Elevation Model. For the current use SRTM DEM has been used. The following video link describes the process how to download the

DEM and satellite image from USGS and Bhuvan Portal. https://www.youtube.com/watch?v=Vky_2-SZmJI

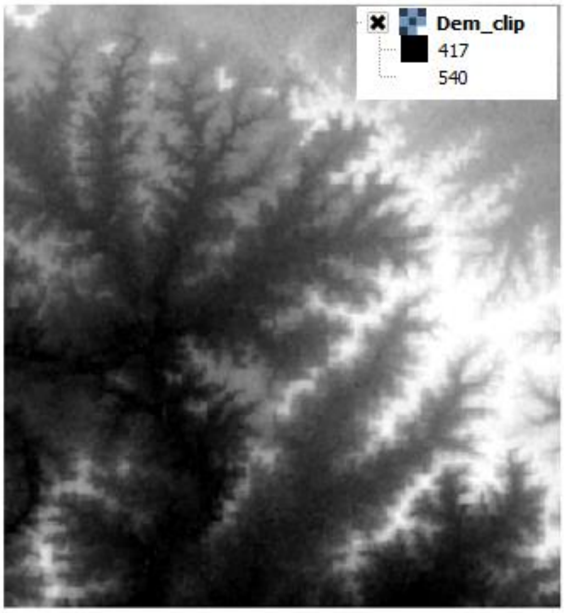


Figure 1 Sample DEM

2.2 Clipping the DEM

After downloading the DEM, we need to load the DEM to our QGIS window. Currently we are using Qgis Version 2.18.12. We also need to load our shapefile of the project area in the Qgis. This can be done through add vector layer command for shapefile and add raster command layer than browsing to your file. User can directly drag and drop the files into Qgis interface as well. After adding both the files user needs to clip the DEM according to the project area. Clipping option can be found from the **Raster->extraction->clipper** as given in the figure below. User has two options of clipping the raster through shapefile(MASK) or by giving or selecting the spatial extent from the Map canvas. A link describing the clipping process has been given below. https://www.youtube.com/watch?v=jE-1_19b5Hs

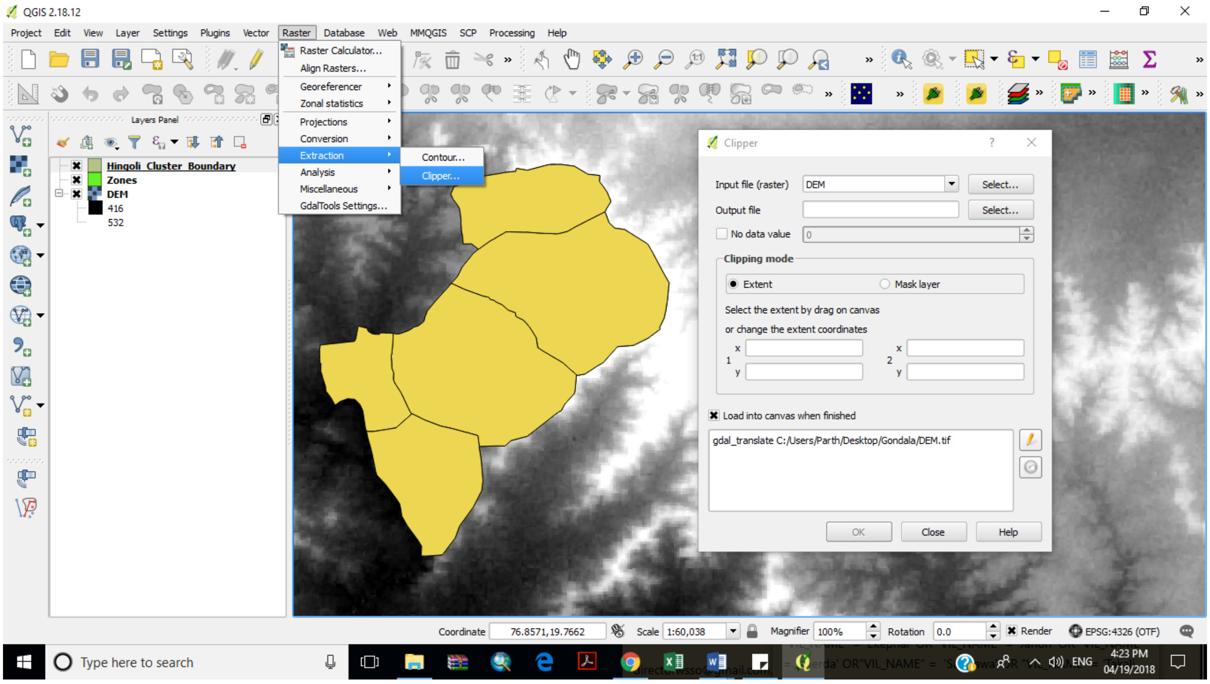


Figure 2 Clipping the DEM

2.3 Extraction of watersheds

After clipping the DEM next step is to delineate watersheds based upon the size. ***"r.watershed"*** command is used to extract sub watersheds from the DEM. This command can be found at the processing toolbox. **Processing->Toolbox->** processing toolbox dialogue will appear. Type the r.Watershed in the search box. Minimum size of exterior watershed basin is selected as 1500 in this case. The threshold basin size (Minimum exterior basin) is the minimum area considered to be a basin. low threshold values will dramatically increase run time and generate difficult to read basin and half basin results. This parameter also controls the level of detail in the **stream** segments map. At DEM resolution of 30x30, each cell has area equal to 900 sq.m. So, a threshold of 1500 means a minimum basin of 1350,000 sq.m or 135 hectares. By default, all the options for various output maps is turned on. We need to select only unique label for watershed basins. After running the command, it will generate the raster map consisting of various watersheds.

To read more about the various options on the dialogue click on the help tab on the dialogue. A link describing the process is given below. https://www.youtube.com/watch?v=UsMTAXrUYok

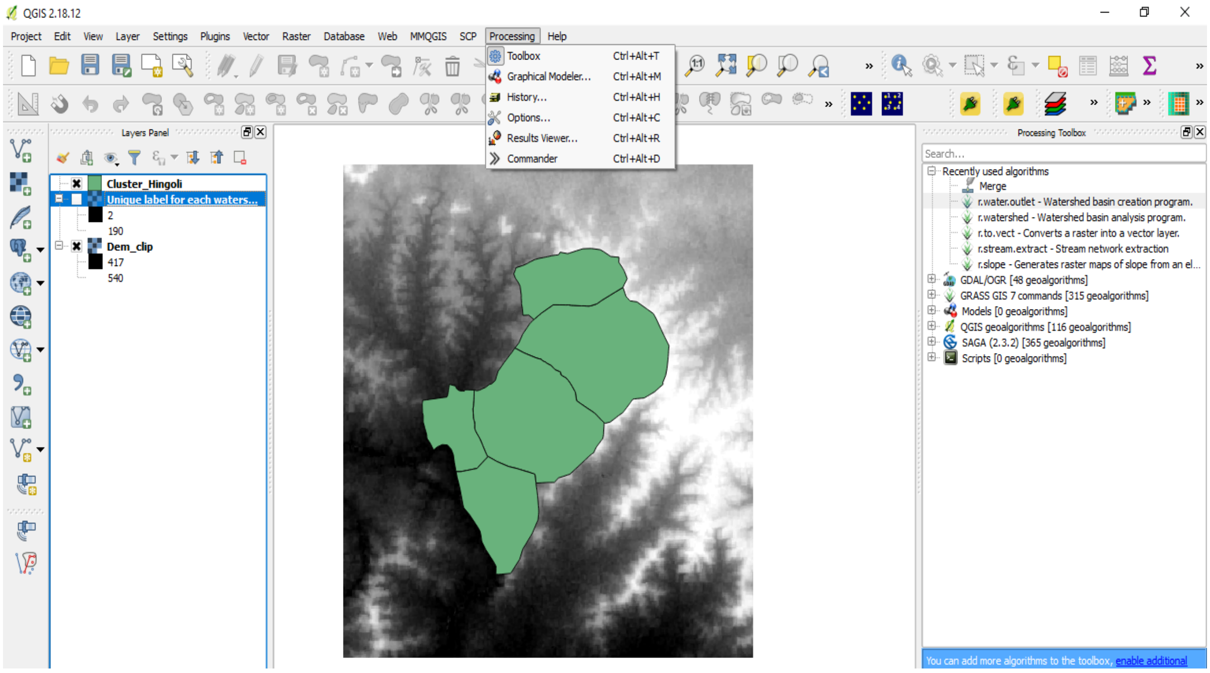


Figure 3 Processing Toolbox

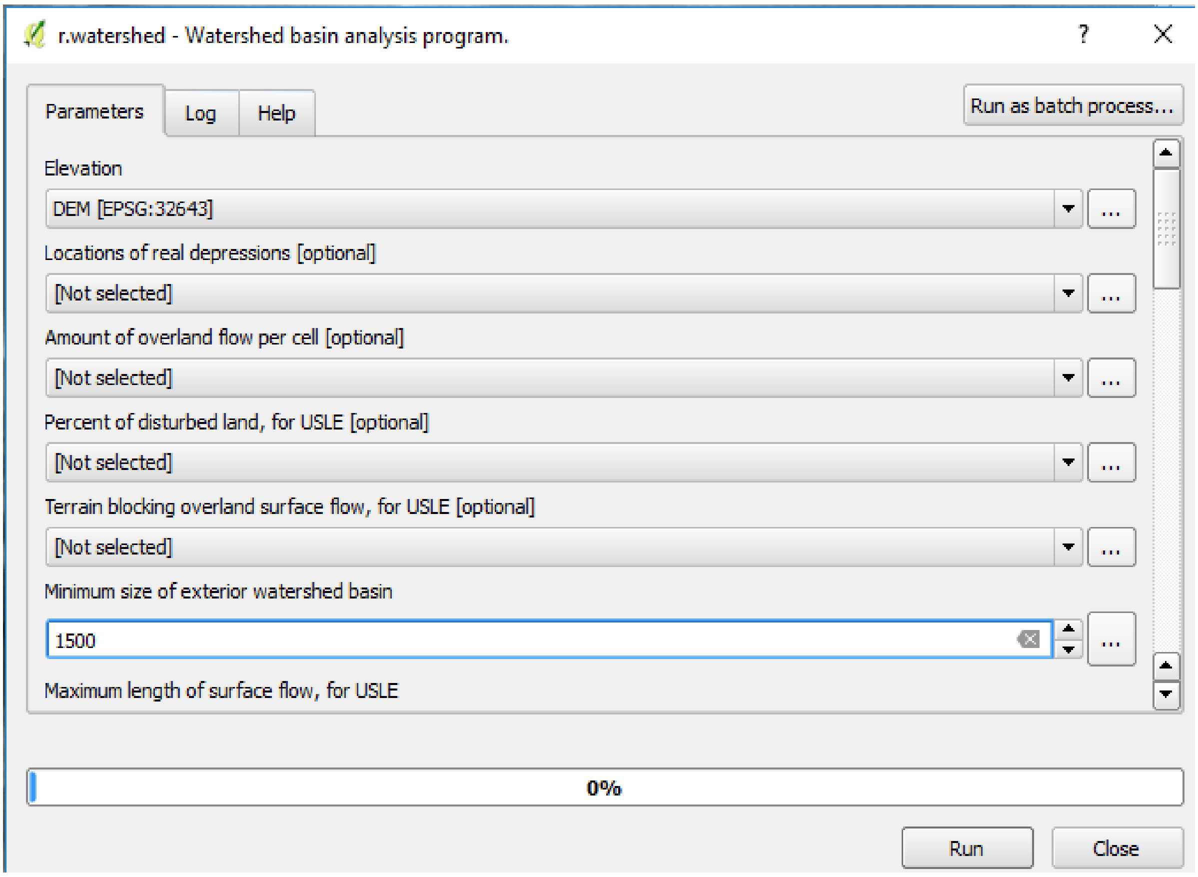


Figure 4 r. Watershed Dialogue Box

Figure 5 Delineated Watershed Raster

2.4 Conversion of raster to vector file

"r.to.vect" is used to convert the sub watersheds raster file into vector file. This command can also be found at processing tool box. User needs to select input raster layer which is the output of r.watershed. The basin map is polygons, so feature type should be area. Help tab can be checked more doubts.

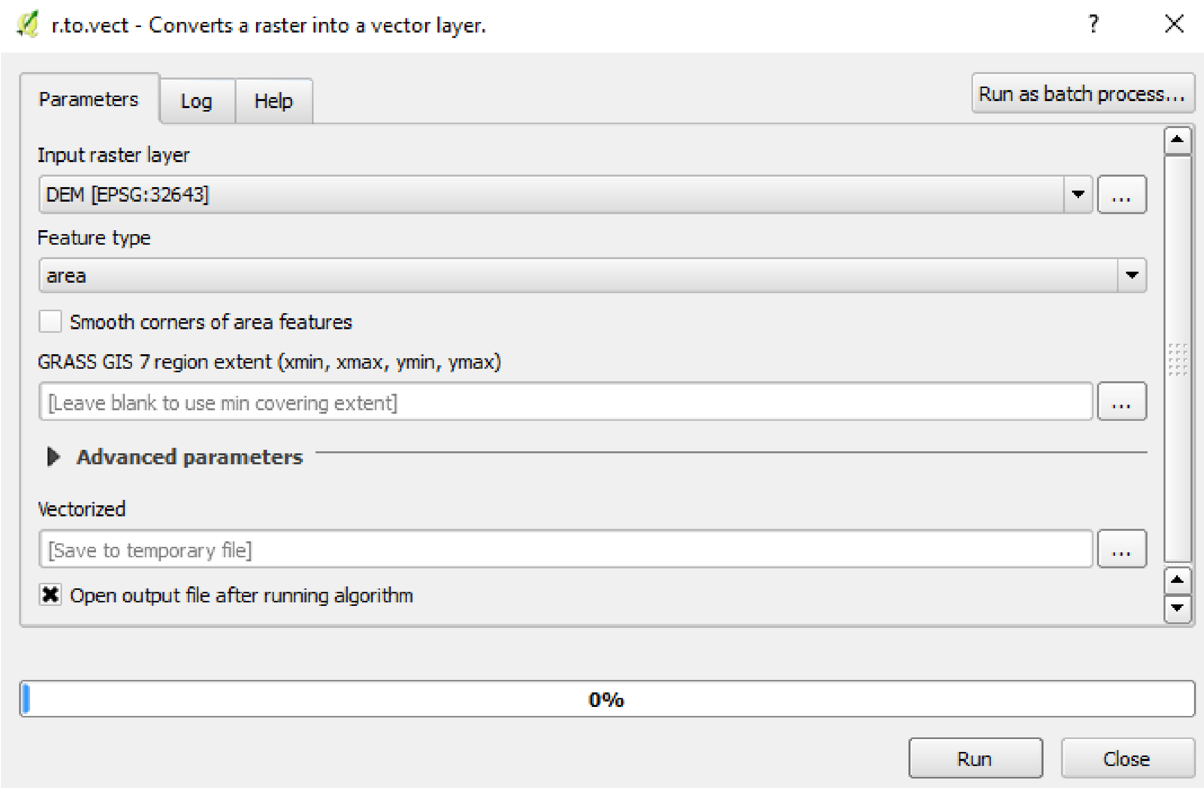


Figure 6 r.to.vect Dialogue Box

3 Intersection process Issues and resolution

3.1 Intersection Command

Intersection command can be found at **Vector->Geoprocessing Tools->Intersection**. The same command can be used from the processing toolbox as well. In the intersection dialogue box select the two layers to be intersected. In this case it will be watersheds file and project area file. Video link for doing the process given below. https://www.youtube.com/watch?v=b2RxI34CiS0

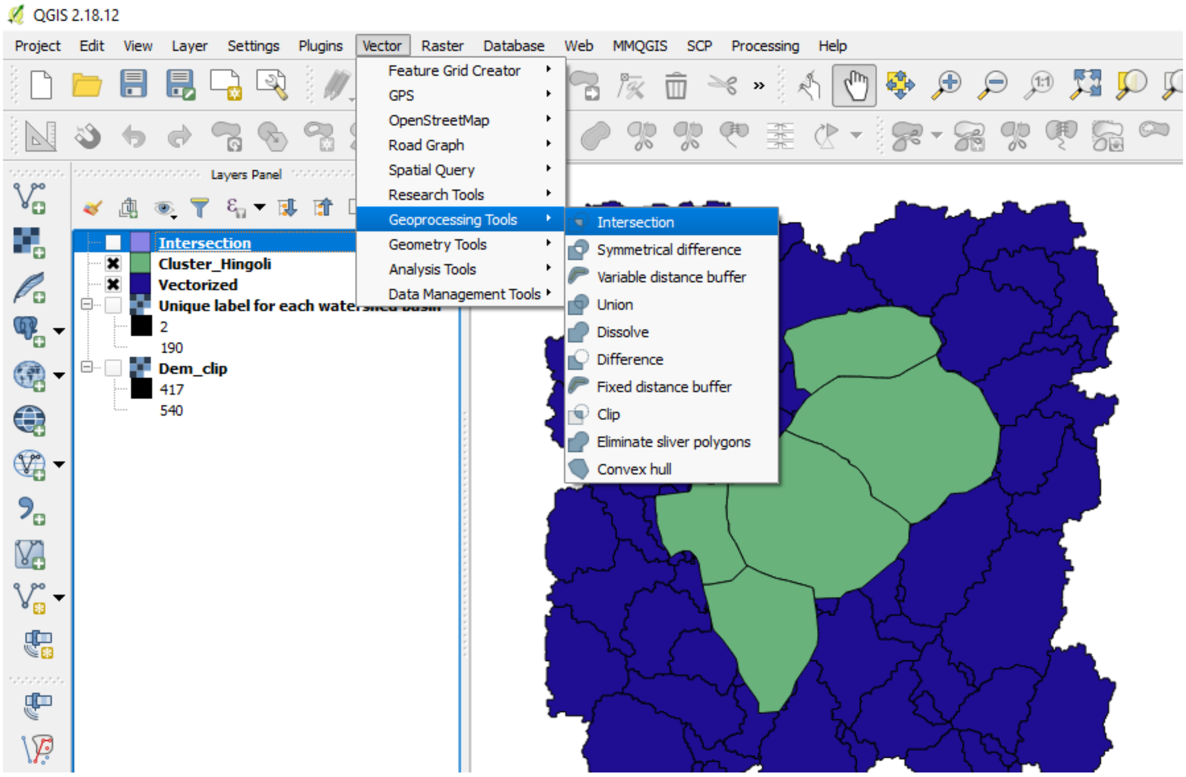


Figure 7 Intersection Command

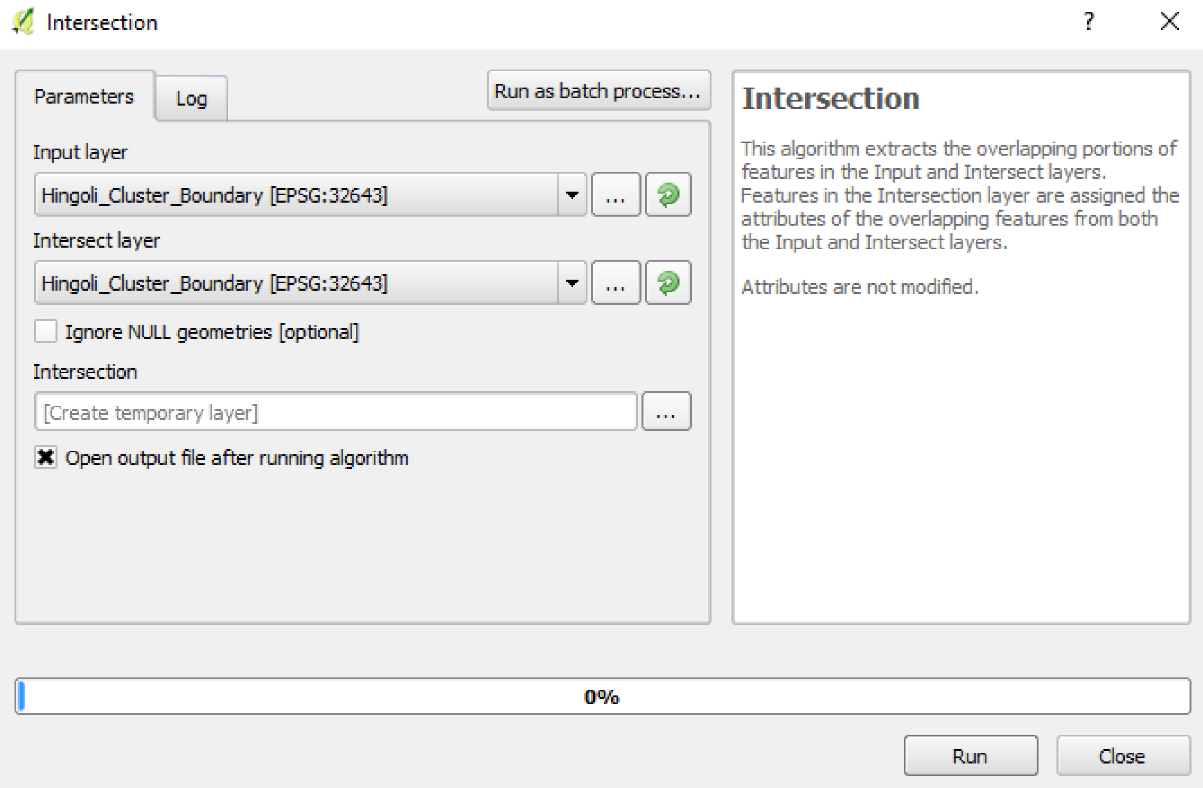


Figure 8 Intersection Dialogue Box

3.2 Error while running intersection algorithm

Sometimes while automatically generating sub watersheds using r. Watershed smaller polygons do form. Such polygons need to be merged with other sub watersheds. User can delete the watersheds lying outside the project shapefile. A dialogue box showing the same has been given below.

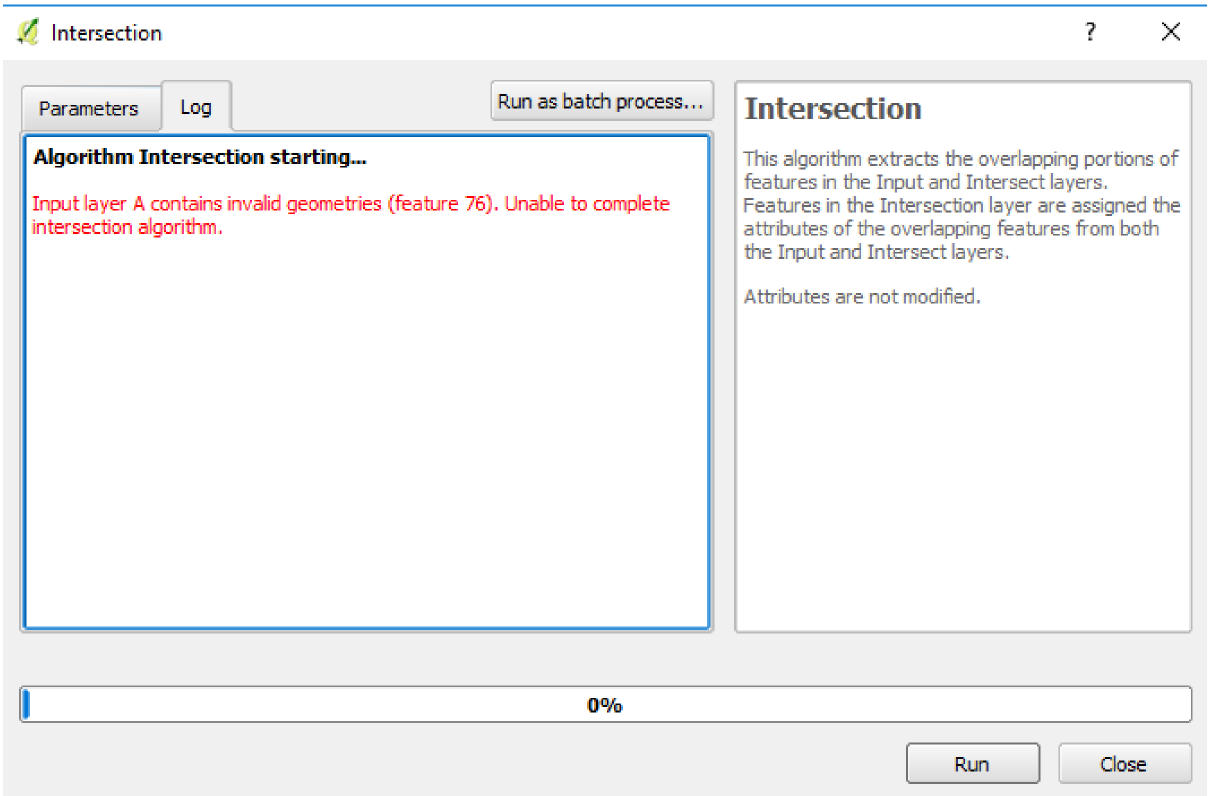


Figure 9 Error during intersection algorithm

3.3 Cause of error

The reason for error is invalid geometry due to which intersection process is remaining incomplete. In the image below, it can be clearly seen some polygons are of very small size. Such polygons are creating problems during intersection process.

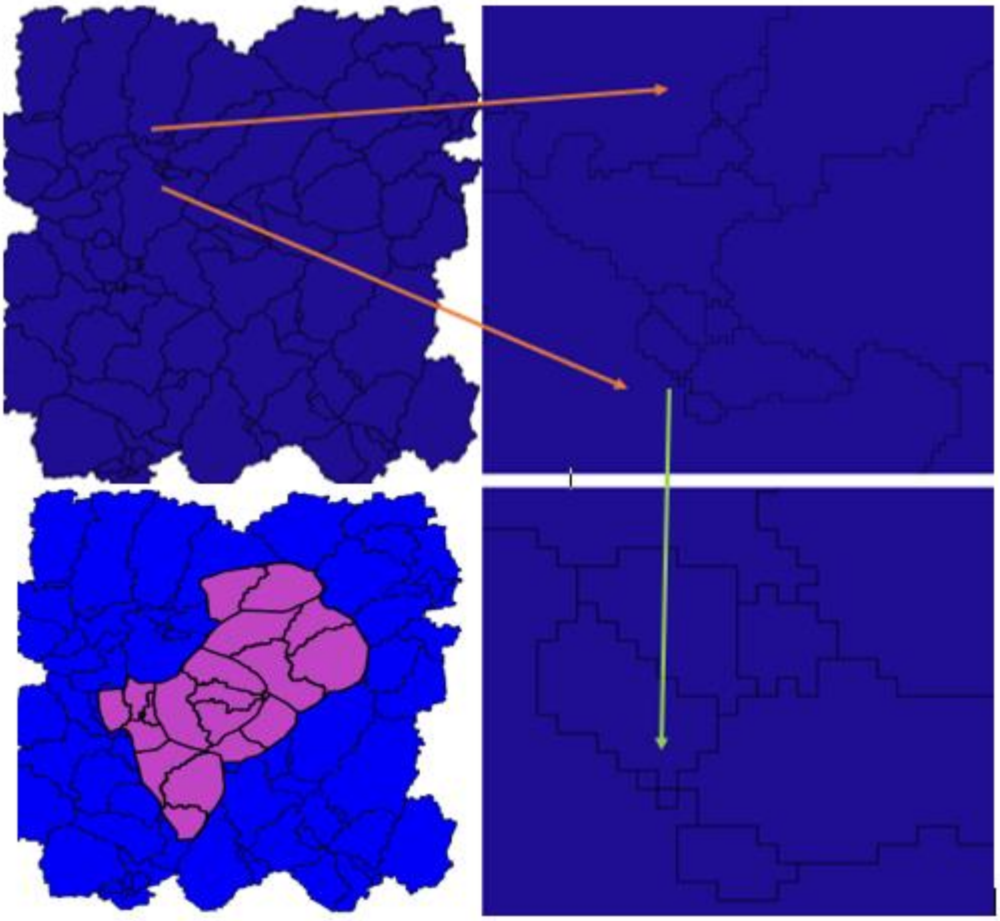


Figure 10 Problem with using r. Watershed command

3.4 Output of Intersection Process

Output of intersection file needs to be carefully analyzed. small watersheds will come in this file as well because one of our input files was sub watersheds file which is output of r.watershed. After finding drainage network and contour map we will start merging these watersheds with nearby watersheds.

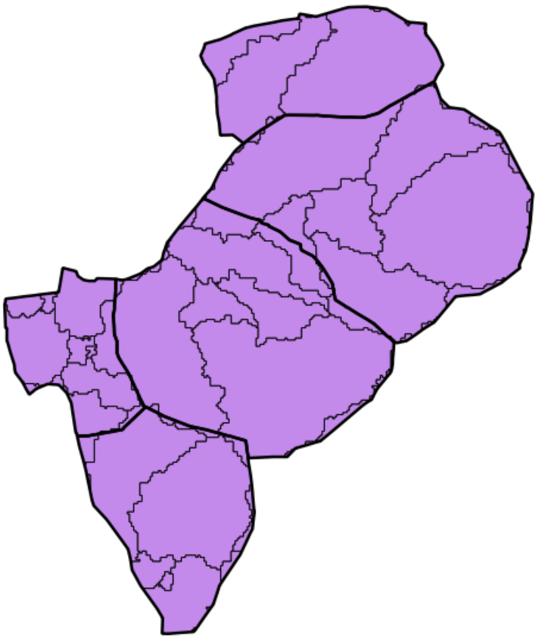


Figure 11 Output of Intersection

4 Drainage Generation

After completing the above process. Run the **r.watershed** again. This time with much lower threshold around 100 or 200. We need to generate the denser drainage network. Select only the stream Map from the dialogue box. This will generate the stream raster. Use the **r.to.vect** command to convert the drainage into vector file. This time select feature type as line.

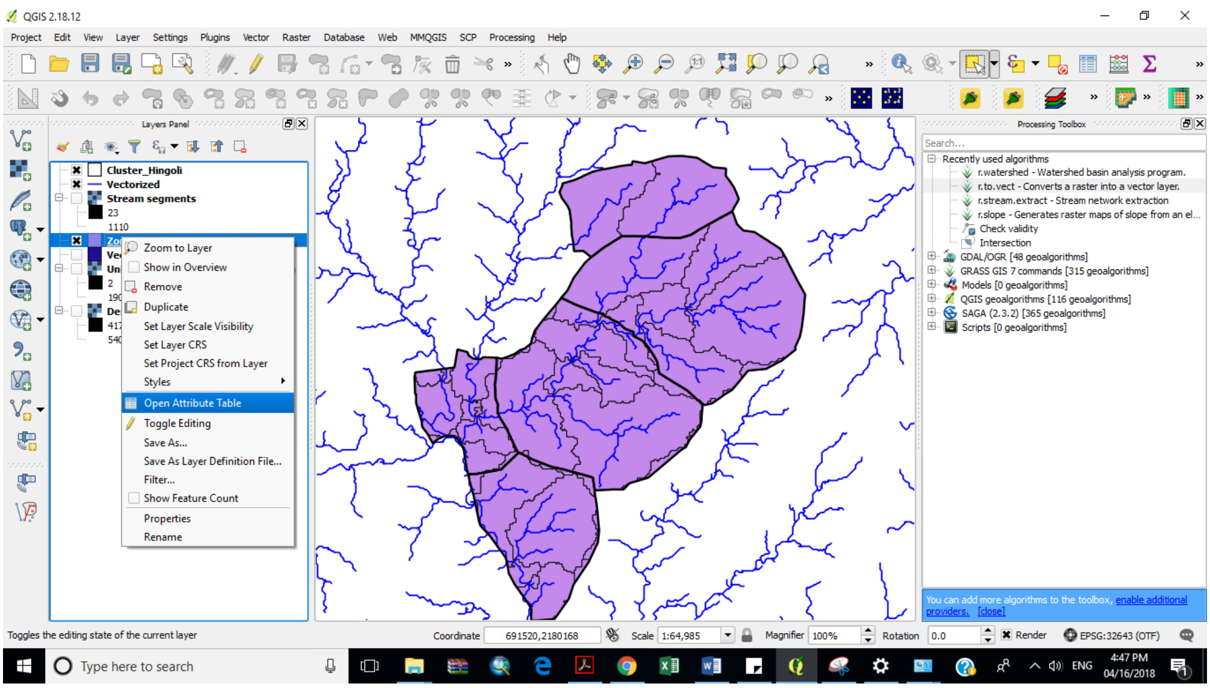


Figure 12 Drainage network

5 Cleaning of intersected file

To clean up the file obtained after intersecting village and watersheds shapefile we need to turn on the editing mode for this file. Select the shapefile in the layer panel. Turn on the editing mode by clicking on toggle editing.

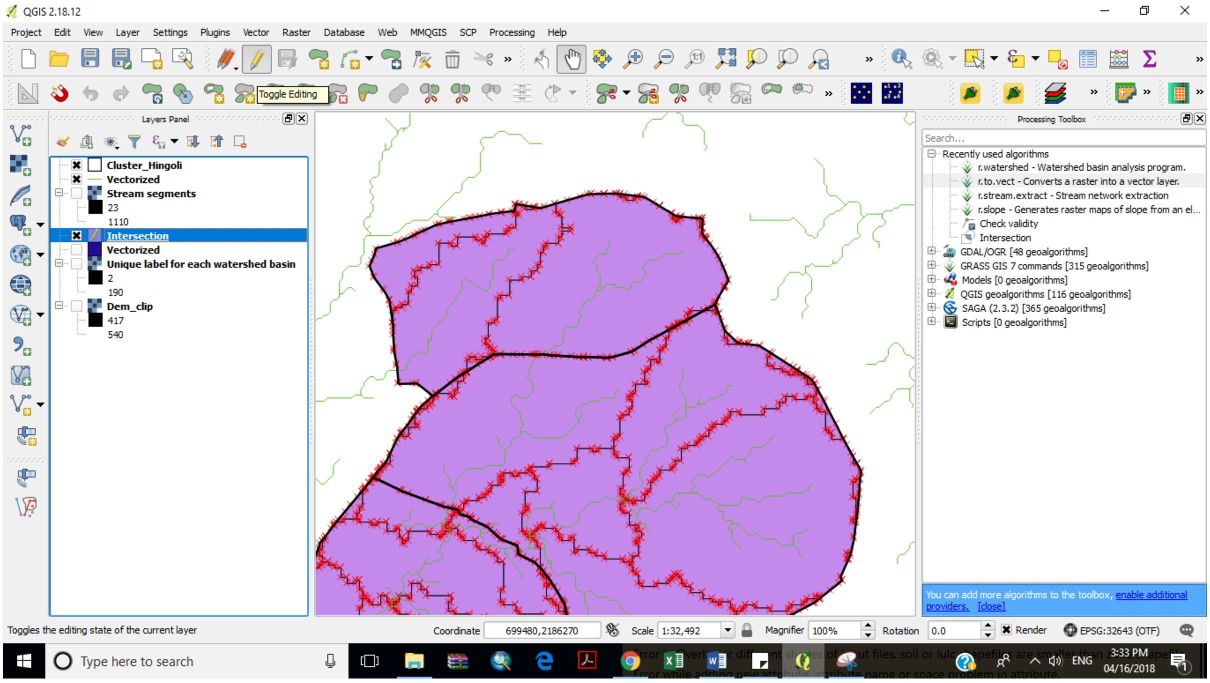
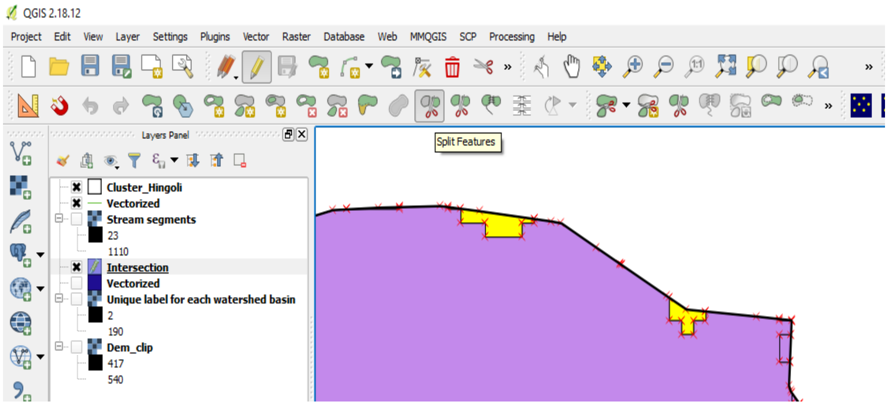


Figure 13 Shapefile in Editing Mode

5.1 Splitting geographically discontinuous but single Polygons

There may be many small interconnected polygons not geographically connected but still acting as one polygon. This may happen when we are automatically generating watersheds. We need to disconnect these polygons by splitting them into separate polygons. To do so select the polygon which needs to be split up in to two parts. After selecting the polygon select the split feature tool. Simply draw a line across the polygons which needs to be split. This will split the polygon in two parts. **Go to settings-> snapping options->** try different options for splitting the polygons. Check which one suits you.



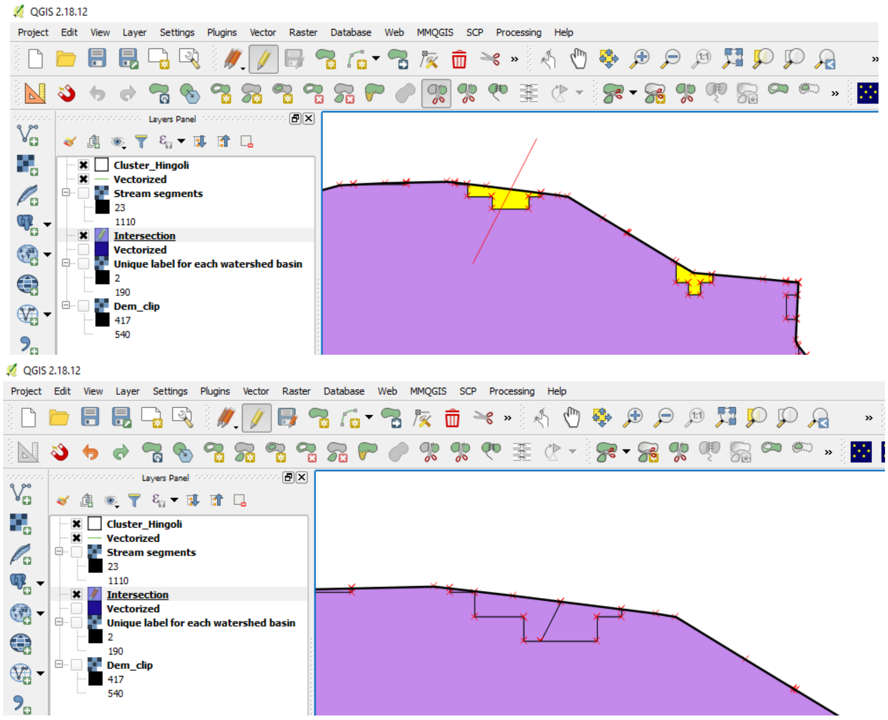
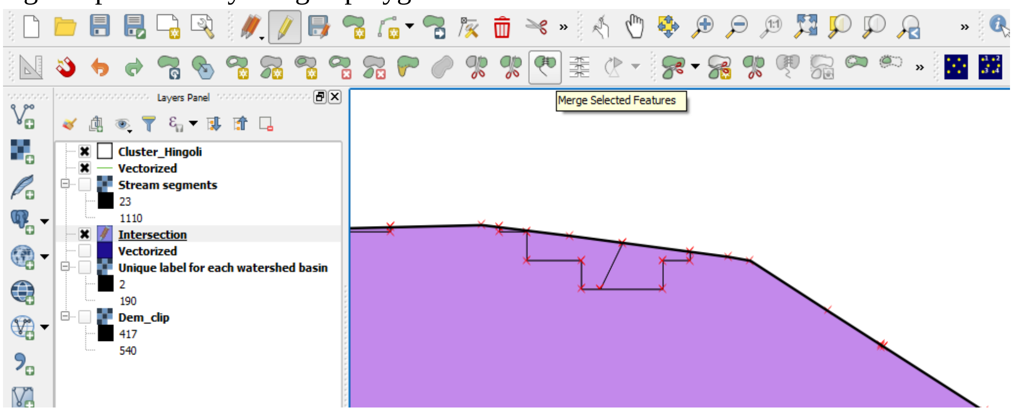
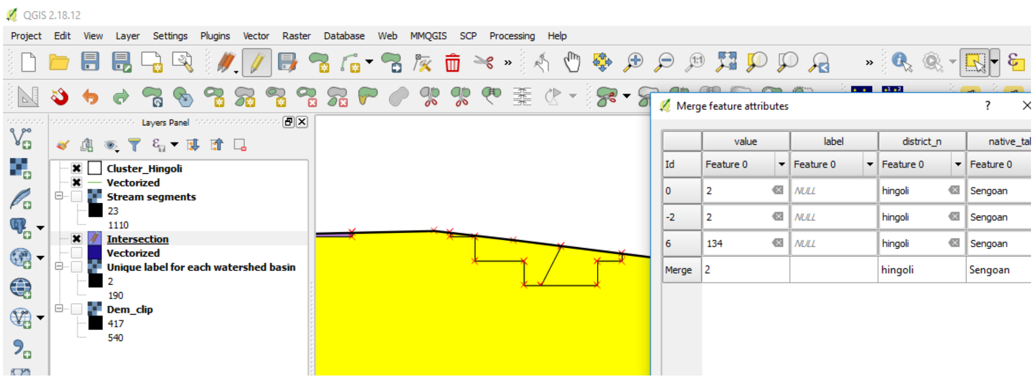


Figure 14 Splitting Discontinuous Polygon

5.2 Merging the output of splitted Polygons

Then select the features which needs to be merged. Select the merge selected feature tool. Both the polygons have separate attribute properties. A table will appear which will ask you to assign the attribute properties for merged feature. You can assign it anyone or bigger polygon attribute values. After completing this process only merged polygon will be there.





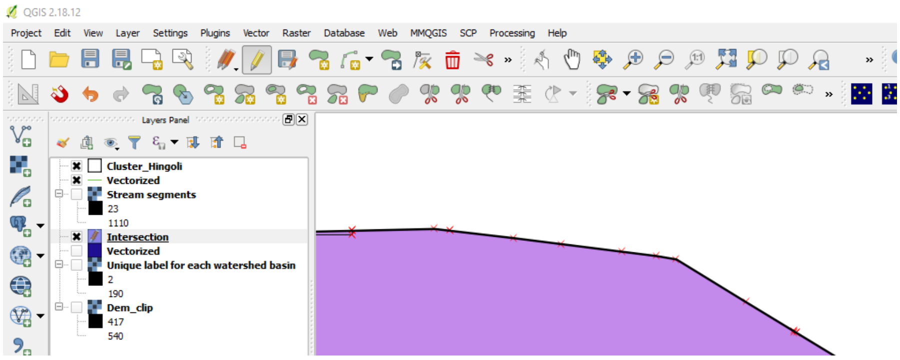


Figure 15 Merging of Splitted Polygon

6 Manual Delineation of watershed

Other way is to carefully analyze the contour map. This requires the understanding of contour maps, ridges valleys, flow lines. One can visually delineate the watershed using common outlet and then delineate the smaller watersheds on first or second order stream. This will also give an idea on which watersheds needs to be merged. While manually delineating watersheds from the contour map following points can be kept in mind.

- The watershed delineation should start from the outlet and you should work your way up on each side.
- Identify valleys and ridges on the map canvas or contour maps. Use google earth also for better understanding
- Simply follow the contours at perpendicular angles until the ridges meet.
- You can do this in the field as well, walking the boundary of the watershed, starting from the outlet and mapping each side until they converge.

A video link describing the above process is given below
https://www.youtube.com/watch?v=pQrfi4jR1Zc

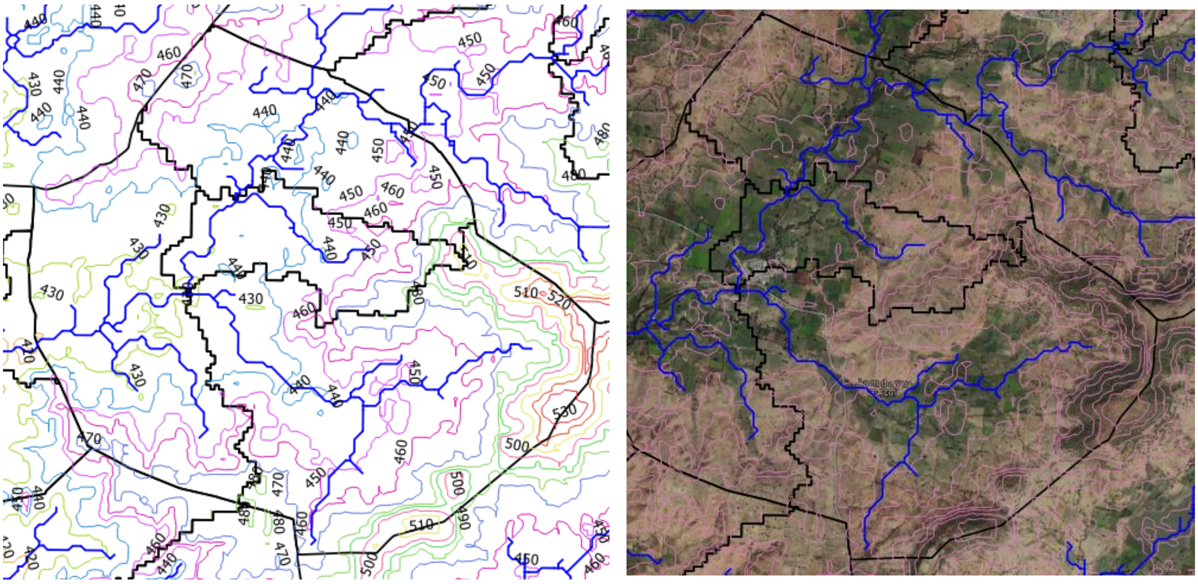


Figure 16 Contour and Google Earth Map

7 Zone Creation Process

7.1 Calculating the area of individual feature

We need to find out the size of polygons so that they can be merged with bigger ones. This step can be skipped with user experience(visually user can estimate the size of polygons). User can add separate attribute in the attribute table for area of each polygon. After this user can select all the polygons with smaller areas from attribute table. By **right clicking the shapefile->Open attribute table->Open Field Calculator**.

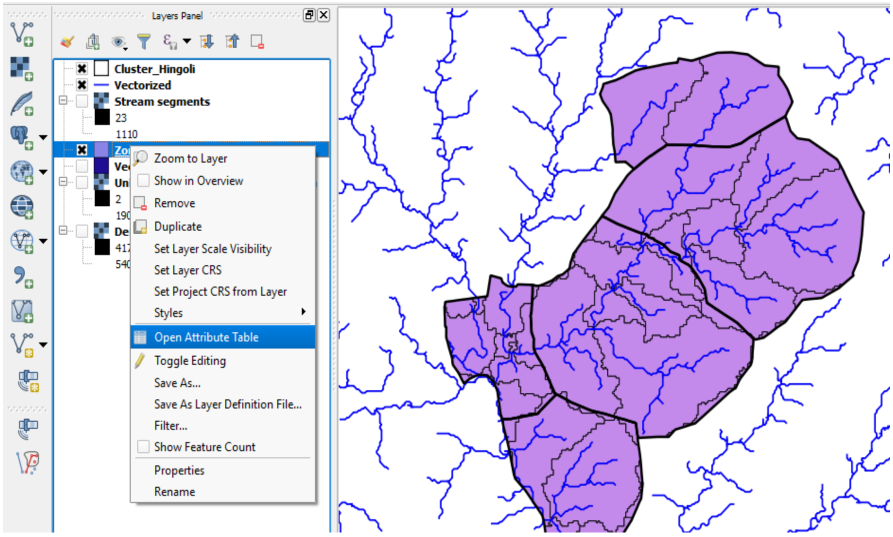


Figure 17 Opening Attribute Table

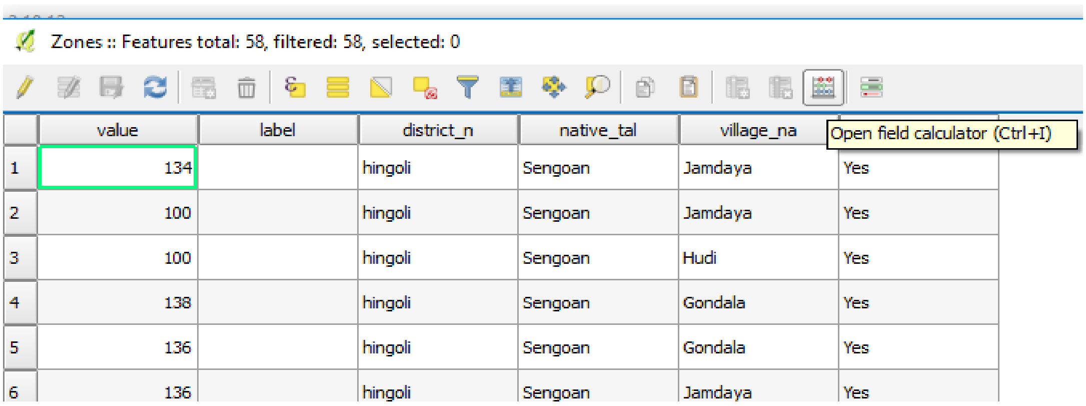


Figure 18 Opening Field Calculator

Once the field calculator is opened user can create new field. User needs to give output field name, output field type and Output field length and precision. In the expression box user needs to write the expression to calculate the area in the desired units. This will add another attribute in attribute table named (given in field name) and area for all the polygons at once.

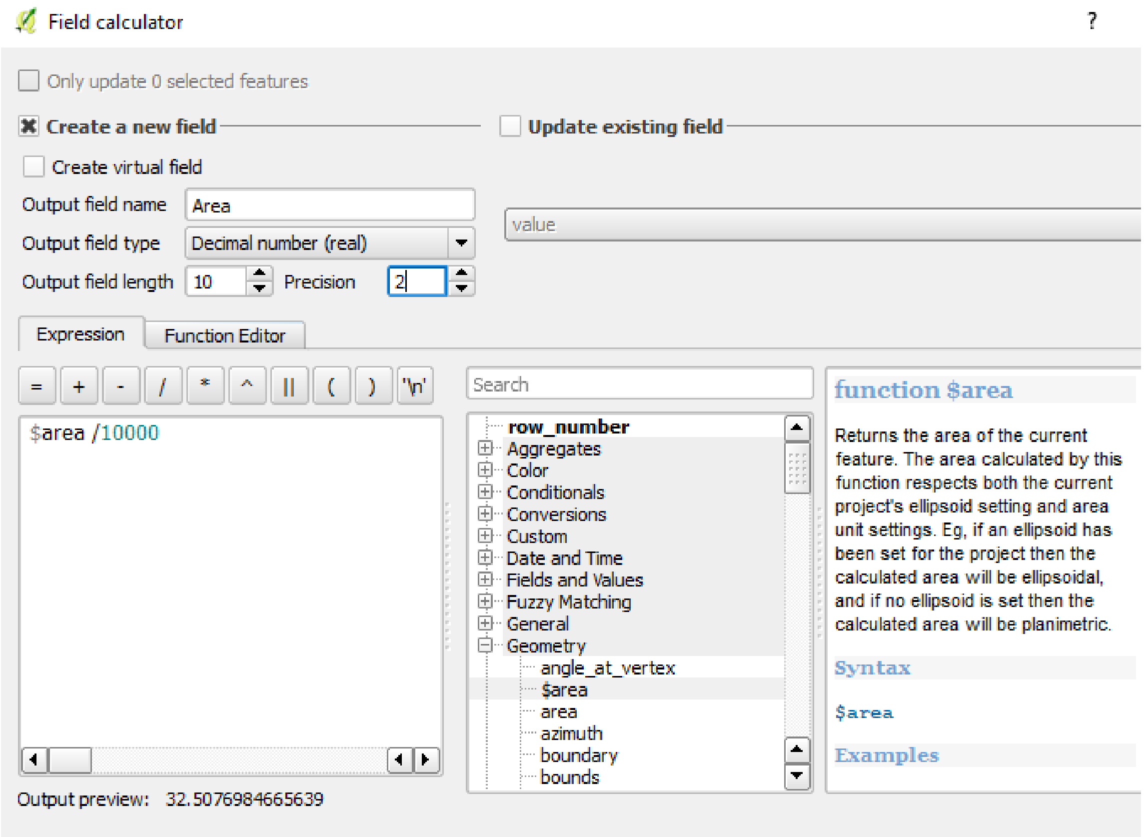
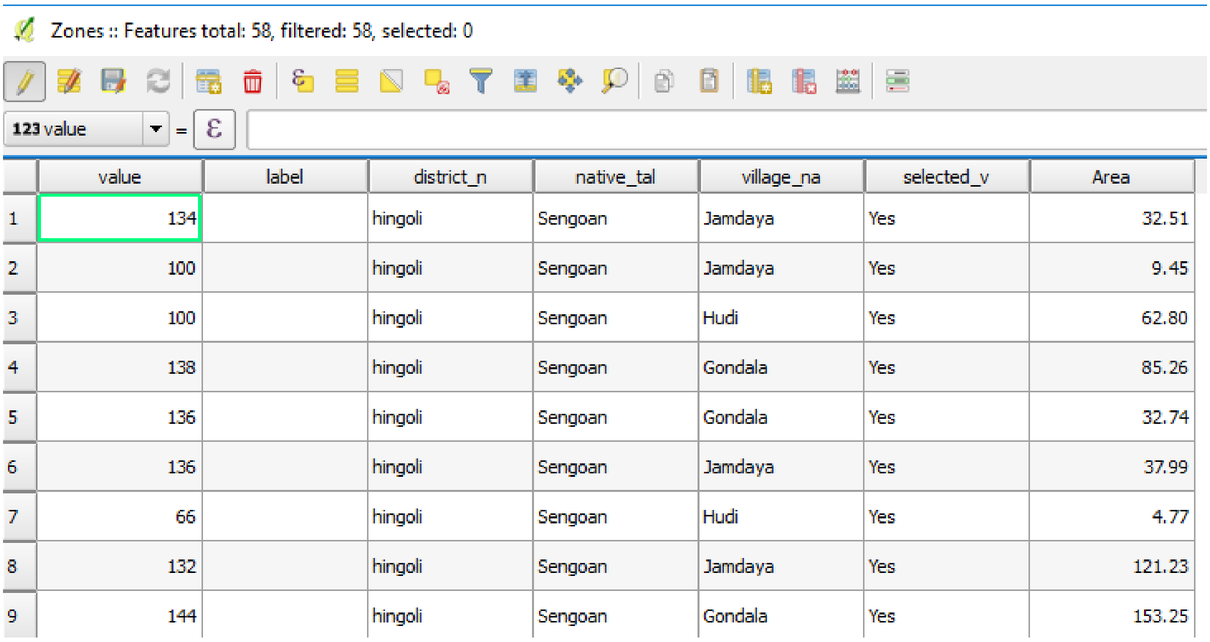


Figure 19 Field Calculator Dialogue Box



	value	label	district_n	native_tal	village_na	selected_v	Area
1	134		hingoli	Sengoan	Jamdaya	Yes	32.51
2	100		hingoli	Sengoan	Jamdaya	Yes	9.45
3	100		hingoli	Sengoan	Hudi	Yes	62.80
4	138		hingoli	Sengoan	Gondala	Yes	85.26
5	136		hingoli	Sengoan	Gondala	Yes	32.74
6	136		hingoli	Sengoan	Jamdaya	Yes	37.99
7	66		hingoli	Sengoan	Hudi	Yes	4.77
8	132		hingoli	Sengoan	Jamdaya	Yes	121.23
9	144		hingoli	Sengoan	Gondala	Yes	153.25

Figure 20 Attribute Table with Area Added

7.2 Identification of Polygons needs to be merged

From the attribute table user can sort the polygons based upon their area from ascending to descending or descending to ascending. After that user can select all the rows below an area to highlight them on map canvas. This will highlight all the polygons selected in the attribute table on the Map canvas.

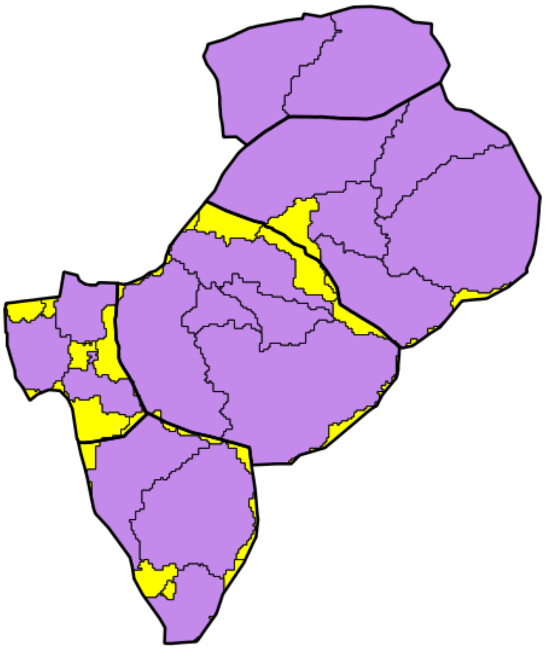


Figure 21 Polygons Need Merging

User can also use the Filter option from the attribute table. This will open the query builder. User can write an expression in the query builder to highlight only those polygons whose area is below particular area.

Query builder can also be used to highlight the polygon who is very small is size and needs to be merged with the other polygon. This polygon is sometimes hard to find, and query builder is easy to use tool to find them.

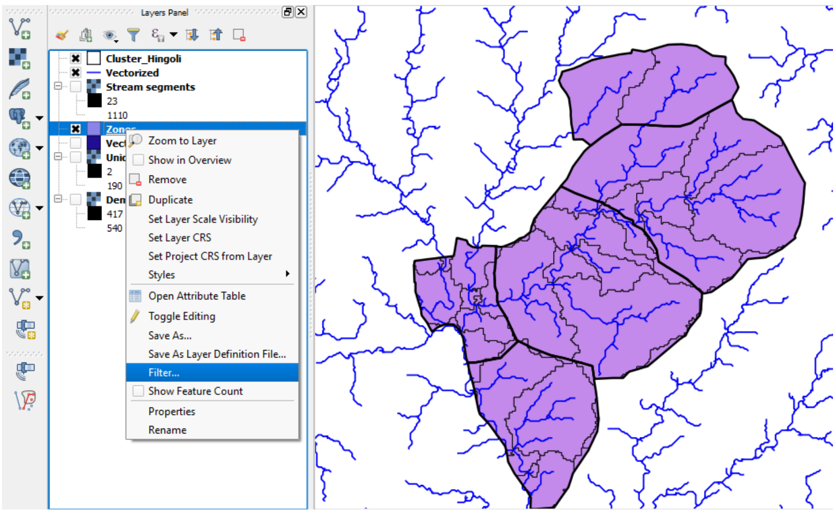


Figure 22 Opening Query Builder

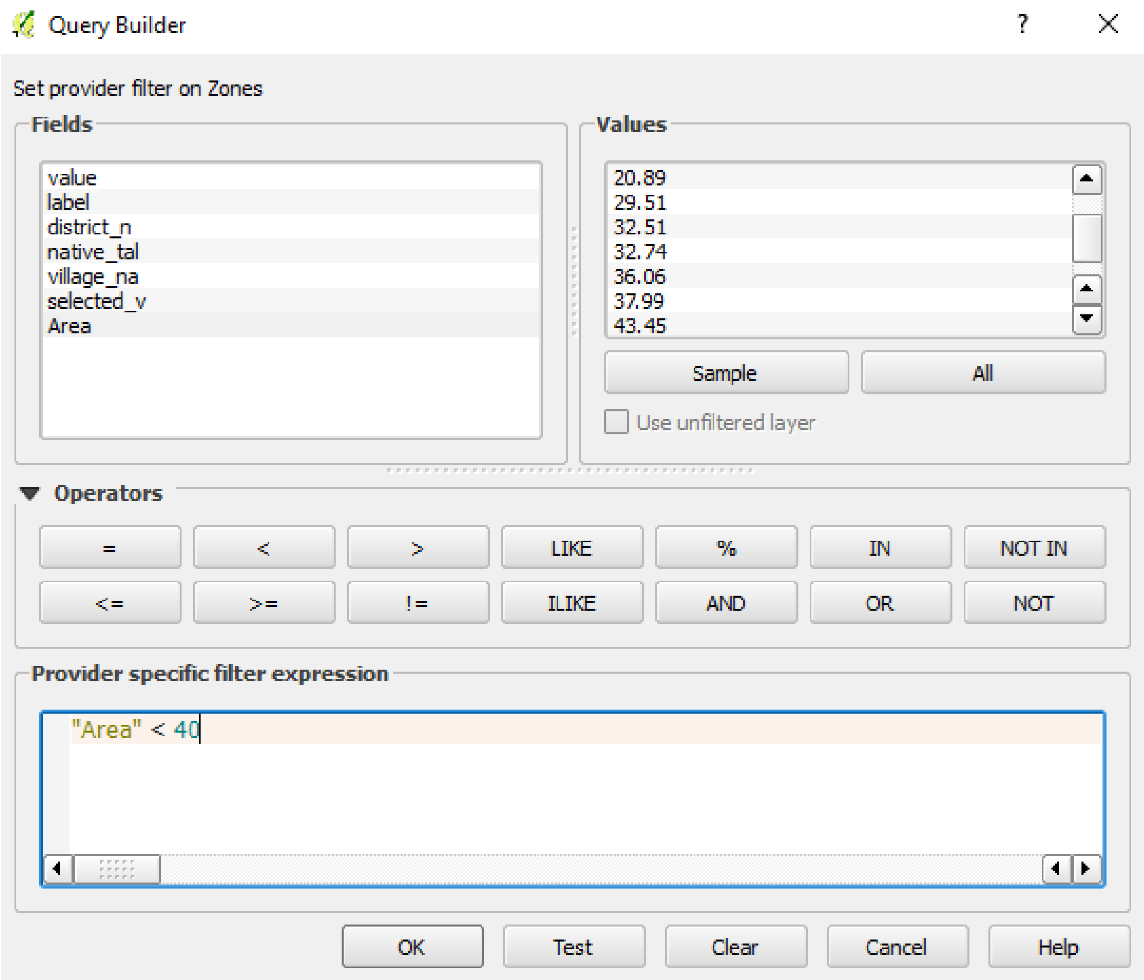


Figure 23 Query Builder Dialogue

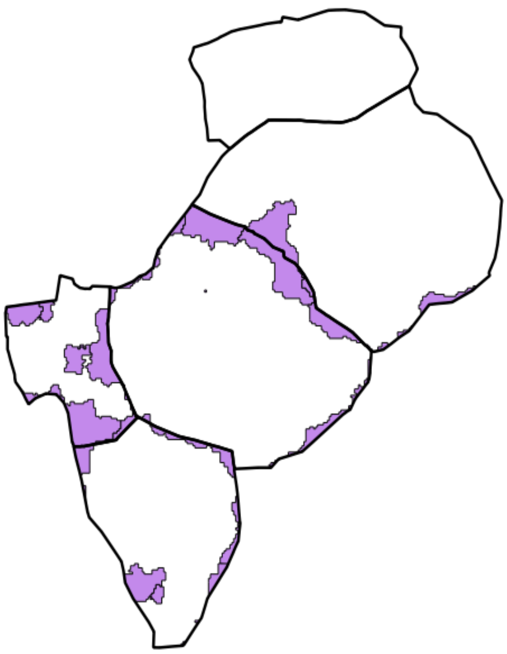


Figure 24 Output of Query

While analyzing the shapefile we can see after intersection of watershed layer with village boundary layer many watersheds which are spread across village boundary gets divided into two. Size of these split watersheds needs to be analyzed. If size is big enough it can be left as separate zone. If size is smaller than it needs to be merged with nearby watersheds.

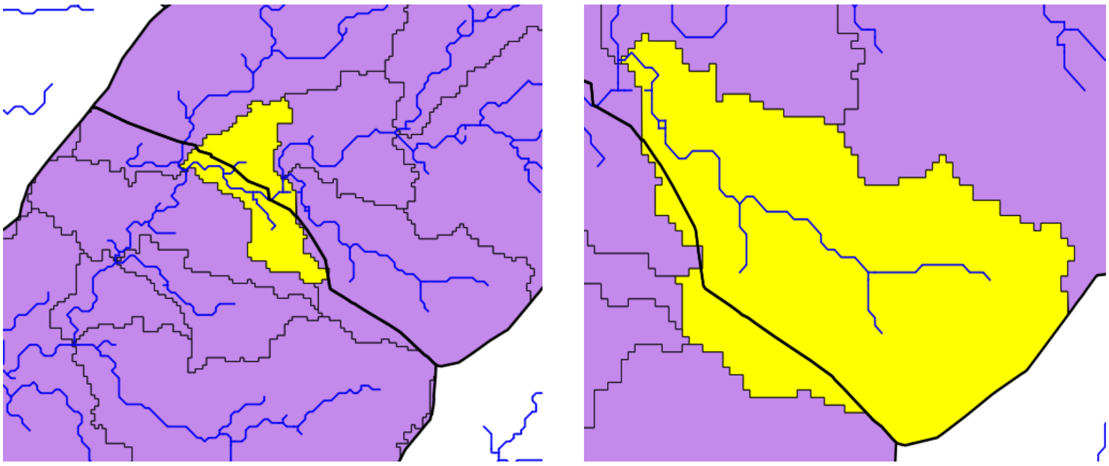


Figure 25 Watersheds Spread Across Village

7.3 Merging of smaller watersheds

Within a village itself there can be smaller watersheds which needs to be merged with other watersheds. This is very important step. It requires careful examination to decide which watershed needs to be merged. This decision can be taken with the help of drainage network layer, contour map and google earth map. Visually a common outlet on the streams can be fixed and its drainage area can be delineated. Based upon that small watersheds can be merged with bigger one.

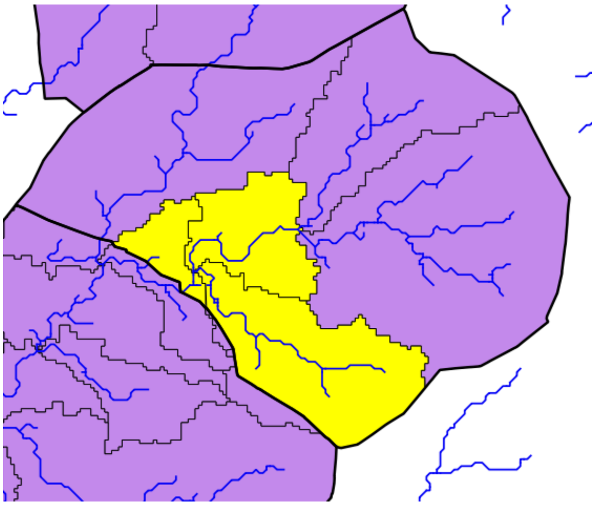


Figure 26 Merging Smaller Watersheds

7.4 Splitting of bigger watersheds

Similarly, bigger watersheds can be split up into smaller watersheds by visually inspecting the contours and streams generated. Watershed below has been divided into three small watersheds.

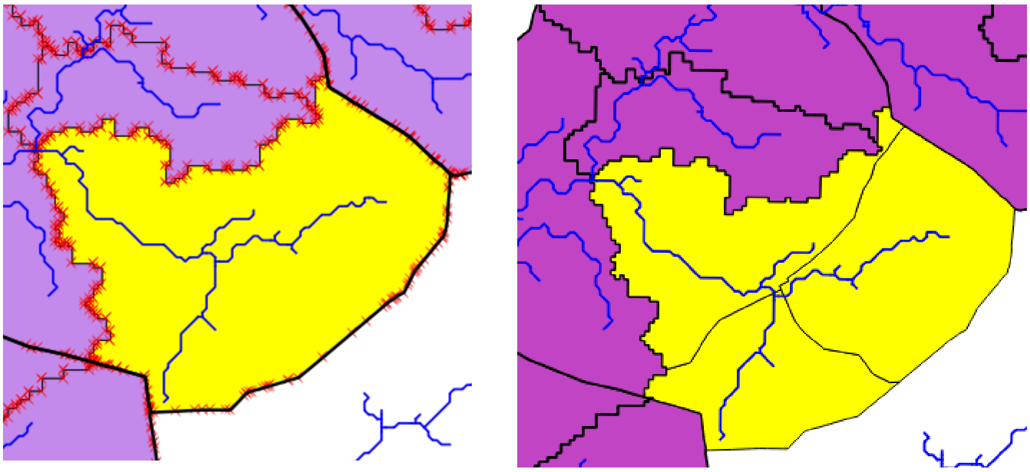


Figure 27 Splitting Bigger Watershed

After cleaning the shapefiles, the zones in the cluster appears as below.

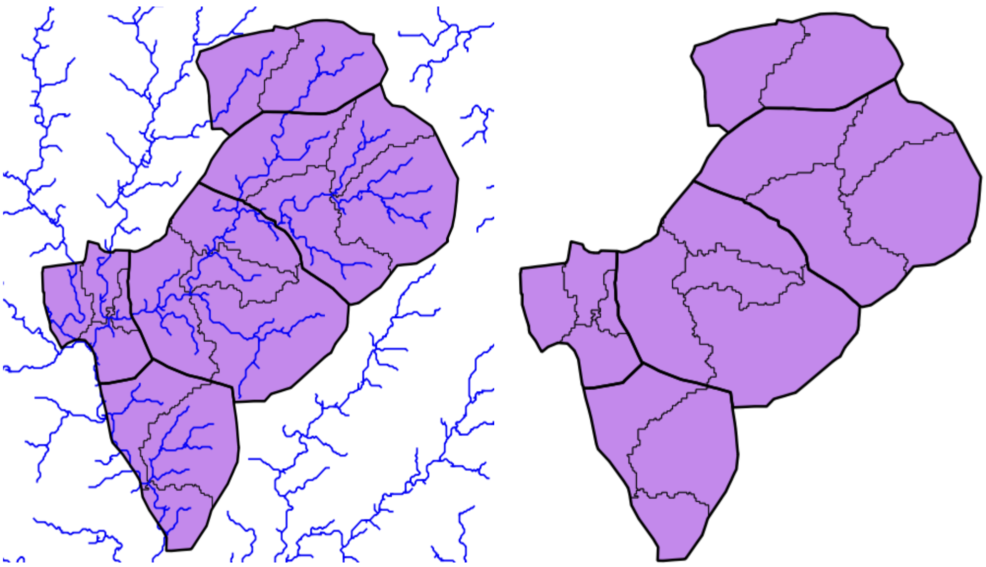
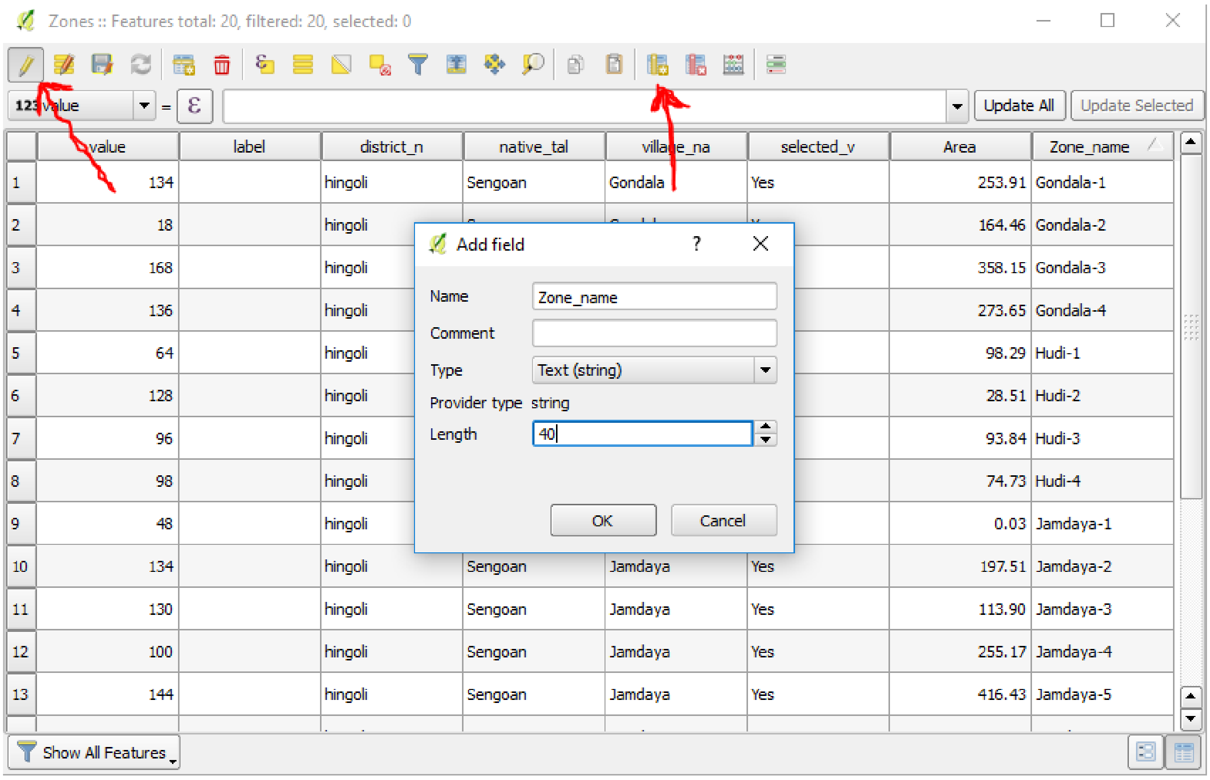


Figure 28 Zone File

8 Addition of Zone name in attribute table

After Zone creation, we need to add the attribute name in the attribute table. First step is to open the attribute table. Second step is to turn on the toggle editing mode. Third step is to add the new field by clicking the add new field. As can be seen in the image below attribute name with “Zone_name” is created. Its data type should be text and length should be equal to maximum number of characters to be given as input. In the following case it is set as 40.


Zones :: Features total: 20, filtered: 20, selected: 0
Update All
Update Selected
value
label
district_n
native_tal
village_na
selected_v
Area
Zone_name
Add field
Name
Zone_name
Comment
Type
Text (string)
Provider type
string
Length
40
OK
Cancel
Show All Features

Annexure II: Multicrop Plugin Technical details and Features

Table of Contents

Objective of the document 50
Computer Requirements 50
Description of Multi Crop plugin 50
Data Requirements and Pre-processing of Data 51
LULC 52
Soil 53
Zones Map of cluster based upon sub watersheds 55
Cadastral Map 56
Slope Map 57
Rainfall Data 57
Stream Buffer Map 58
Running of Plugin 59
Preparation and transfer of database to PMU 60
Output 63
Cadastral Wise Vulnerability Map 63
Vulnerability Map 64
Zone wise table for each Sub watershed 64
Uploading the output to Server 68
Appendix 1 Terminologies Explained 69
Appendix 2 Database used at the back end 72
Appendix 3 Excel Model 77

List of Tables

Table 1 Data requirement 51
Table 2 Pre-processing of Data 51
Table 3 Land Use Land Cover 53
Table 4 Soil Type and Depth 54
Table 5 Database Prepared 61
Table 6 Gat wise vulnerability 67

List of Figures

Figure 1 Description of Plugin 51
Figure 2 LULC Map 53
Figure 3 Soil Type 55
Figure 4 Zone Map 56
Figure 5 Attribute Table of Zone Shapefile 56
Figure 6 Cadastral and Slope Map 57
Figure 7 Format for Rainfall file 58
Figure 8 Stream Buffer 58
Figure 9 Plugin Display 59
Figure 10 Filled Plugin Display 60
Figure 11 district wise Cluster Folders with pre-process files 62
Figure 12 5-year Rainfall File 63
Figure 13 Cadastral Vulnerability Map 64
Figure 14 Point wise Vulnerability Map 64
Figure 15 Computational Data 66

Objective of the document

The objective of this document is to describe the plugin developed and refined for water balance model which will run on desktop PC and eventually be freely available for wider use. This document builds upon the document submitted for single crop plugin available at https://www.cse.iitb.ac.in/~pocra/ModelDocument.pdf .The plugin interface is easy to use and can be operated by the technically skilled but non-specialist user. The document also describes the pre-processing of database required to be done before being fed into the plugin. It describes the various tabular outputs as wells as maps being generated by the plugin to be utilized for cluster water balance exercise during microplanning of cluster.

Computer Requirements

You must have a computer with latest windows operating system, QGIS is known to run on just about any machine with Windows XP+, Any modern Linux (Ubuntu/Debian, Fedora/Red Hat, OpenSUSE, Arch, Gentoo, etc), and Mac OS X. If you can run those OS you can run QGIS. The following programs must be installed for running the plugin.

1 QGIS Desktop version 2.18.12
2 Plugin addon in QGIS

Description of Multi Crop plugin

The figure 1 gives the summary regarding the plugin. The inputs needed for plugin to run are divided into two parts. One which needs to be input by the user and second which are hard coded at the backend and generated from the inputs layer fed by the user to the plugin or QGIS interface. Following Options are provided to the user.

- User are provided with selecting the sowing threshold which means sowing will only happen after the mentioned amount of rainfall.
- User can also select the multiple crops for which it wants to run the plugin
- User can decide the monsoon ending date in the plugin.
- User can also categorize the intervals for the water deficit faced by crop or crop water stress.

Data which has been used at the back end is given in the appendix. Brief description of input and output is described in fig 1.

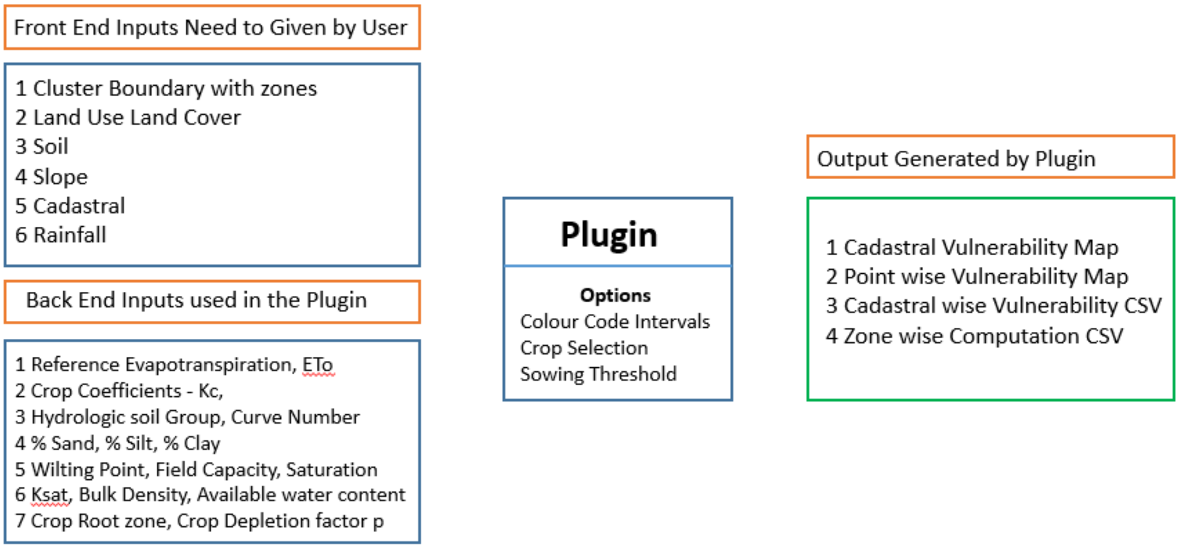


Figure 29 Description of Plugin

Data Requirements and Pre-processing of Data

Table 1 gives the summary of the data used in the plugin with its sources.

Table 1 Data requirement

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, https://earthexplorer.usgs.gov/

Table 2 briefly describes the pre-processing needs to be done on the layers before being fed into the plugin. It also mentions the commands being used in the process.

Table 2 Pre-processing of Data

Sr.No	Input	Processing	Output	Commands Used
1	Cluster Boundary	Project the cluster boundary with number of villages in UTM projection.	Cluster Shapefile with required spatial extent.	Save command is used by selecting required villages
2	LULC	Using the cluster shapefile clip the	LULC layer with require spatial extent.	Qgis Clip Command

		LULC layer in UTM Projection		
3	Soil	Using the cluster shapefile clip the soil layer in UTM Projection	Soil layer with required spatial extent.	Qgis Clip Command
4	Cadastral Map	Using the cluster shapefile clip the Cadastral layer in UTM Projection	Cadastral layer with required spatial extent.	Qgis Clip Command
5	DEM	Extraction of sub watersheds or zones from Dem	Zone layer with required spatial extent.	“r.watershed” , “r.to.vect”
6	Cluster Boundary with zones	Intersection of cluster boundary and zone layer and naming of zones	Cluster boundary with number of zones	Qgis Intersection Command
7	Slope	Extraction of slope layer from Dem	Slope layer with required spatial extent.	"r.slope"
8	Rainfall	Full year rainfall data in CSV format in two columns days and Rainfall	Rainfall CSV file	Excel

LULC

The Land Use Land Cover file obtained from MRSAC by PMU unit contains the 35 types of land use and Land cover given in the table 3. This file has been obtained in the form of shapefile. The user needs to make sure that the file does not contain any other LULC type apart from the types given below in table 3. Otherwise plugin will give error. To remove the error user can add the land use type in the plugin dictionary or can match the land use type with the existing land use type given in the table 3. The user needs to make sure that the shapefile contains the attribute with name “Descriptio” which contains LU type for each polygon. An example of LULC map has given in Figure 2. This is the first file which is required as input for plugin to run. The file needs to be projected in the UTM projection before being fed into the plugin. User also needs to make sure that the spatial extent of this file should be at least equal to the cluster boundary file or the area for which user want to run the plugin. Failing any of the above-mentioned requirements will not allow the plugin to run successfully.

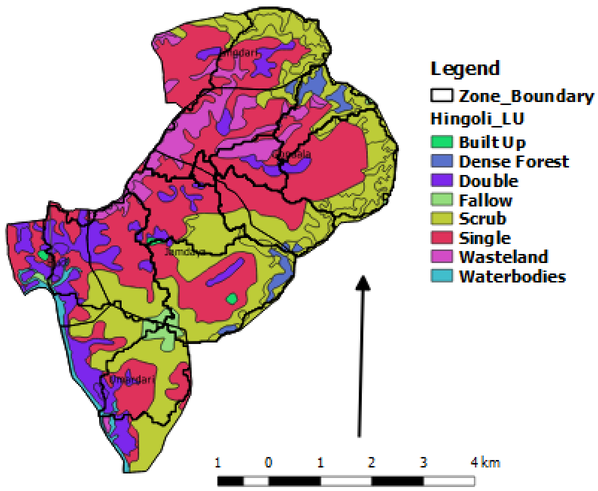


Figure 30 LULC Map

Soil

The Soil map obtained from MRSAC by PMU unit contains the 14 types of soil and depth of the soil has been categorized into 7 types given in the table 4. This file has been obtained in the form of shapefile. The user needs to make sure that the file does not contain any other soil type and depth apart from the types given below in table 4. Plugin uses the TEXTURE and DEPTH attribute from the shapefile, user should make sure that these two attributes exists in shapefile. Otherwise plugin will give error. To remove the error user can add the soil type in the plugin dictionary or can match the soil type with the existing soil types given in the table 4. This is the second file which is required as input to plugin to run. The file needs to be projected in the UTM projection before being fed into the plugin. User also needs to make sure that the spatial extent of this file should be at least equal to the cluster boundary file. Failing any of the above-mentioned requirements will not allow the plugin to run successfully. In figure 3 we can see the soil shapefile does not completely overlay or matches with the cluster boundary in such cases the plugin will not run.

Table 3 Land Use Land Cover

Sr. No	Land Use Land Cover	Class
1	Cropped in more than two seasons	Agriculture
2	Cropped in two seasons	Agriculture
3	Rabi	Agriculture
4	Zaid	Agriculture
5	Kharif	Agriculture
6	Agricultural Plantation	Agriculture
7	Built up - Compact (Continuous)	Build Up
8	Built up - Sparse (Discontinuous)	Build Up
9	Industrial Area	Build Up
10	Rural	Build Up

11	Fallow Land	Fallow
12	Deciduous (Dry/ Moist/ Thorn) - Dense/ Closed	Forest
13	Evergreen/ Semi Evergreen - Dense/ Closed	Forest
14	Forest Plantation	Forest
15	Tree Clad Area - Dense/ Closed	Forest
16	Tree Clad Area - Open	Forest
17	Ash/ Cooling Pond/ Effluent and Other waste	Wastelands
18	Mining - Abandoned	Wastelands
19	Mining - Active	Wastelands
20	Quarry	Wastelands
21	Deciduous (Dry/ Moist/ Thorn) - Open	Scrub Forest
22	Evergreen/ Semi Evergreen - Open	Scrub Forest
23	Scrub Forest	Scrub Forest
24	Barren Rocky	Wastelands
25	Gullied/ Ravinous Land - Gullied	Wastelands
26	Scrub Land - Dense/ Closed	Wastelands
27	Scrub Land - Open	Wastelands
28	Vegetated/ Open Area	Wastelands
29	Reservoir/ Tanks - Permanent	Waterbodies
30	Reservoir/ Tanks - Seasonal	Waterbodies
31	River - Non Perennial	Waterbodies
32	River - Perennial	Waterbodies
33	Canal/ Drain	Waterbodies
34	Lakes/ Ponds - Permanent	Waterbodies
35	Lakes/ Ponds - Seasonal	Waterbodies

Table 4 Soil Type and Depth

Sr. No	TEXTURE	Sr.No	DEPTH
1	Clay loam	1	Very shallow (< 10 cm)
2	Clayey	2	Shallow (10 to 25 cm)
3	Gravelly clay	3	Shallow to very shallow (< 25 cm)
4	Gravelly clay loam	4	Moderately deep (25 to 50 cm)
5	Gravelly loam	5	Deep to very deep (> 50 cm)
6	Gravelly sandy clay loam	6	Deep (50 to 100 cm)
7	Gravelly sandy loam	7	Very deep (> 100 cm)
8	Habitation Mask	8	Habitation Mask
9	Loamy	9	Waterbody Mask
10	Loamy sand		
11	Sandy clay		

12	Sandy clay loam		
13	Sandy loam		
14	Silty clay		
15	Silty loam		
16	Waterbody Mask		

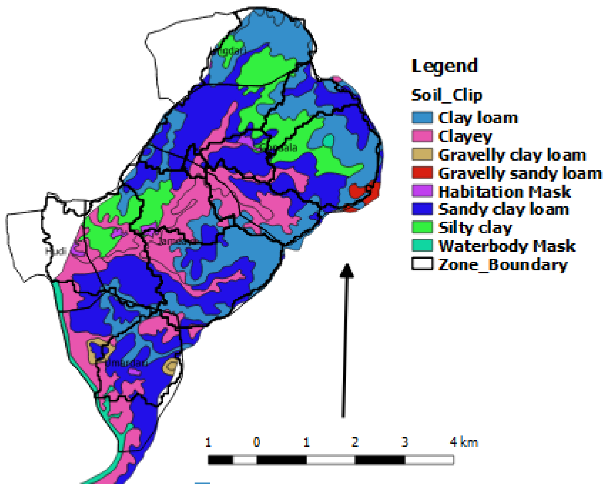


Figure 31 Soil Type

Zones Map of cluster based upon sub watersheds

For the preparation of zones user needs to download the DEM for the required area**.** ***"r.watershed"*** command is used to extract sub watersheds from the DEM. This command can be found at the processing toolbox. Minimum size of exterior watershed basin is selected as 1500 in this case. The threshold basin size (Minimum exterior basin) is the minimum area considered to be a basin. At DEM resolution of 30x30, each cell has area equal to 900 sq.m. So, a threshold of 1500 means a minimum basin of 1350,000 sq.m or 135 hectares. Areas that drain off the map, or into the sea, and are smaller than that are not considered to be a basin. ***"r.to.vect"*** is used to convert the sub watersheds raster file into vector file. Sometimes while automatically generating sub watersheds smaller polygons do form. Such polygons need to be merged with other sub watersheds. This is the third file which needs to be fed into the plugin. The file needs to be projected in the UTM projection before being fed into the plugin. User also needs to make sure that the spatial extent of this file should be equal to the cluster boundary file. For easy pre-processing or to reduce the work zone file should be intersected with the cluster boundary file and all the geometries or features falling outside the cluster boundary should be removed. The images of the same have been given in the figure 4. The user needs to make sure that this file should have following two attributes which are being used for printing the zone name and census code into the final output CSV file. Their name should be kept as it is (UNICODE, Zone_name) as shown in fig 5. The village boundary or cluster boundary shapefile already has UNICODE attribute in it. While intersecting it with zone file this will also become part of intersected file. In this case user only needs to add Zone_name attribute in the final zone shapefile. Document describing the detailed zoning process is available at https://www.cse.iitb.ac.in/~pocra/Zoning%20Process.pdf.

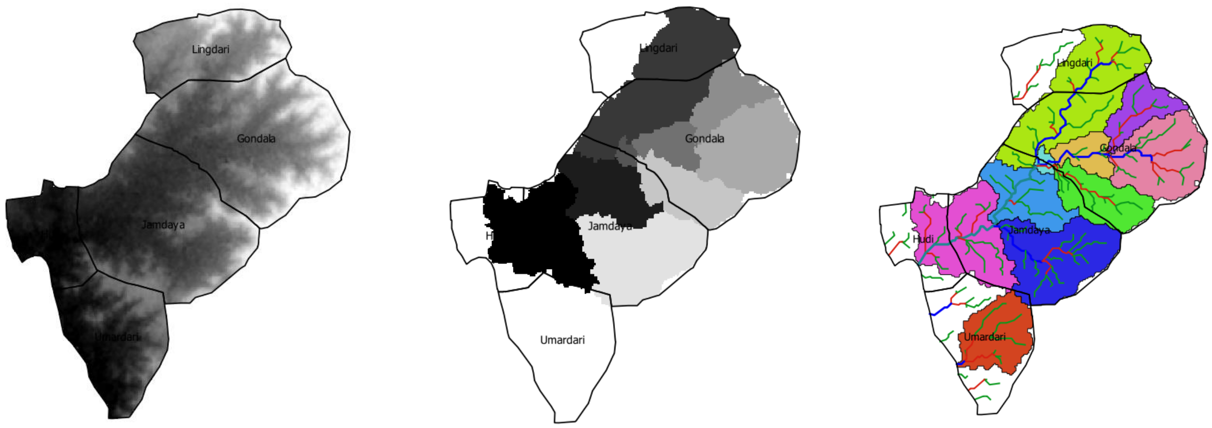
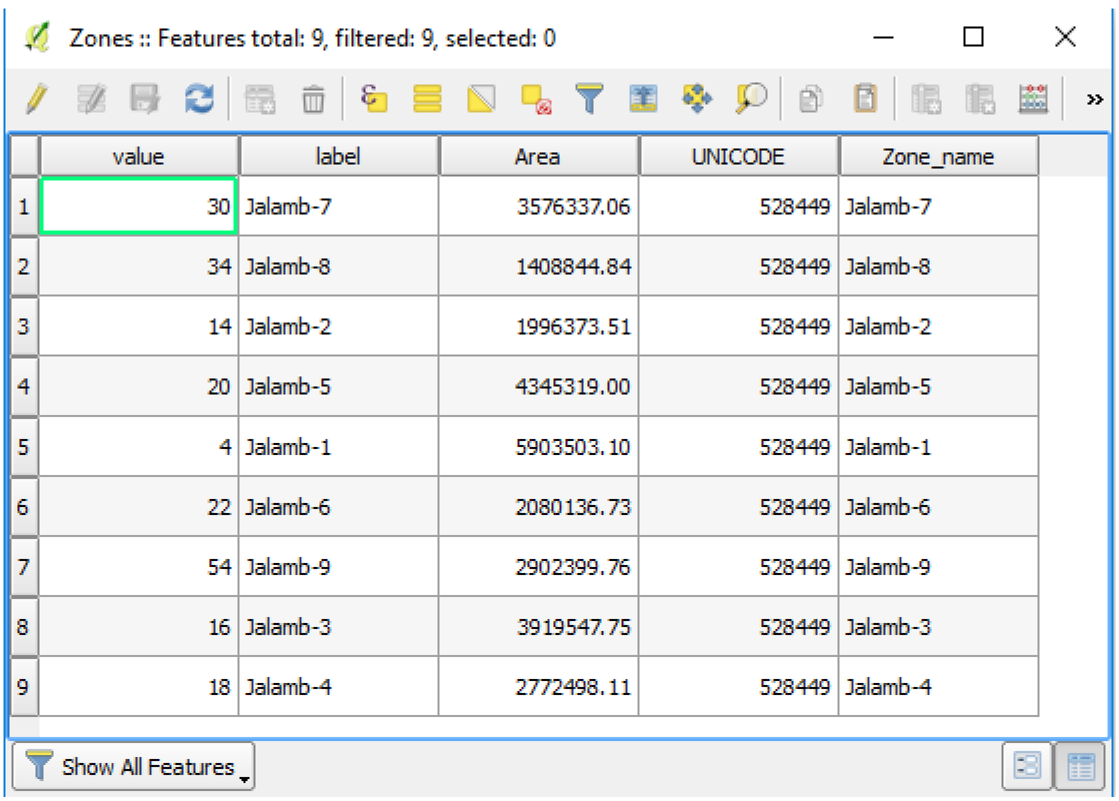


Figure 32 Zone Map



	value	label	Area	UNICODE	Zone_name
1	30	Jalamb-7	3576337.06	528449	Jalamb-7
2	34	Jalamb-8	1408844.84	528449	Jalamb-8
3	14	Jalamb-2	1996373.51	528449	Jalamb-2
4	20	Jalamb-5	4345319.00	528449	Jalamb-5
5	4	Jalamb-1	5903503.10	528449	Jalamb-1
6	22	Jalamb-6	2080136.73	528449	Jalamb-6
7	54	Jalamb-9	2902399.76	528449	Jalamb-9
8	16	Jalamb-3	3919547.75	528449	Jalamb-3
9	18	Jalamb-4	2772498.11	528449	Jalamb-4

Figure 33 Attribute Table of Zone Shapefile

Cadastral Map

The fourth file which user needs to input is cadastral shapefile. The file needs to be projected in the UTM projection before being fed into the plugin. User also needs to make sure that the spatial extent of this file should be at least equal to the cluster boundary file. An example of cadastral map has been given in figure 6. The cadastral shapefile should contain the “PIN” as an attribute. It contains the survey number for each polygon. This will be used in generating the gat level vulnerability map.

Slope Map

This is the fifth file which user needs to give as input. The slope map has been generated by using the "r.slope" command. This command can be found at processing toolbox. Slope map is generated by using the SRTM digital elevation model from USGS website. It has 30m*30m resolution. Any other DEM of same resolution or high resolution can also be used to generate the slope Map. Output of this command gives the slope map in raster format which needs to be fed into the plugin. The file needs to be projected in the UTM projection before being fed into the plugin. User also needs to make sure that the spatial extent of this file should be at least equal to the cluster boundary file. An example of slope Map has been given in figure 6.

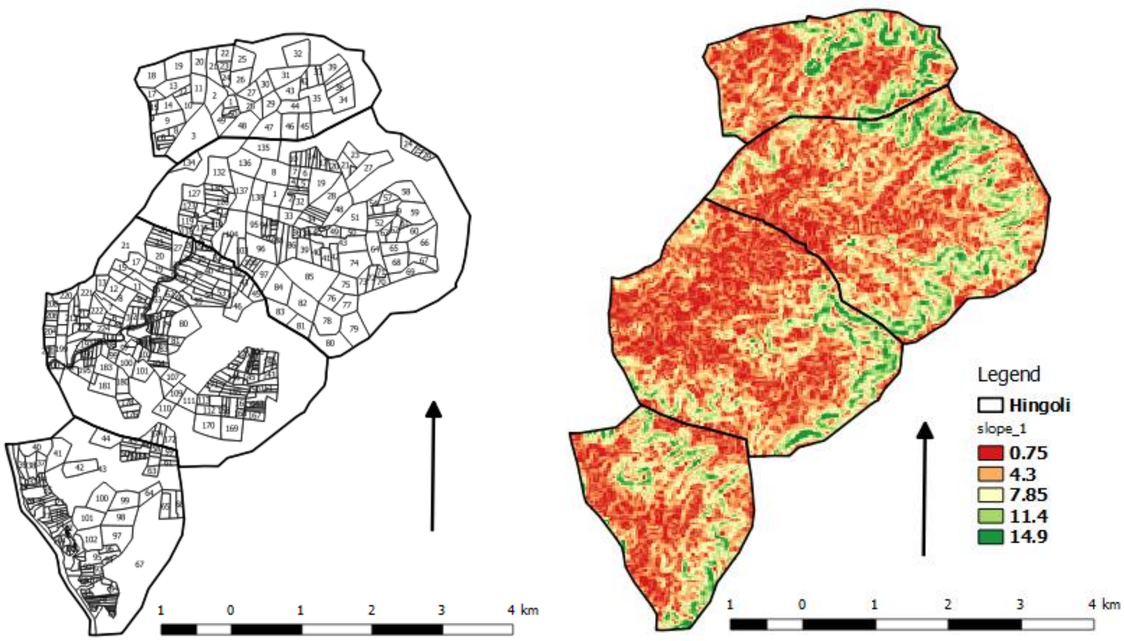
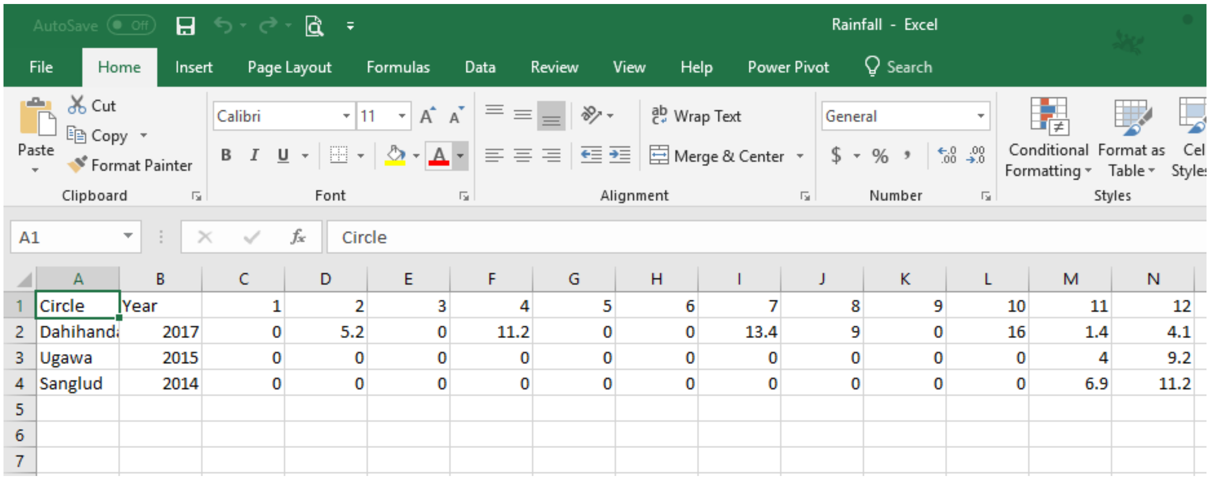


Figure 34 Cadastral and Slope Map

Rainfall Data

Daily rainfall data for the whole cluster having different circle rainfall needs to be fed into the plugin. Currently the rainfall data has been downloaded from "maharain.gov.in". It gives the daily circle wise data in the form of month wise excel. The user needs to find out the nearby circles to the village, available in the village shapefile. Rainfall data of different nearby circles present in village shapefile of a cluster should be fed into the plugin in CSV format. The rainfall data should be for the complete year. it should be kept in the same folder as other files. It should be in the following format shown in fig 7. Plugin will read the Rainfall column from the CSV. The user needs to make sure that it is named as "Rainfall.csv".



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Circle	Year	1	2	3	4	5	6	7	8	9	10	11	12
2	Dahihand	2017	0	5.2	0	11.2	0	0	13.4	9	0	16	1.4	4.1
3	Ugawa	2015	0	0	0	0	0	0	0	0	0	0	4	9.2
4	Sanglud	2014	0	0	0	0	0	0	0	0	0	0	6.9	11.2

Figure 35 Format for Rainfall file

Stream Buffer Map

"r.watershed" is used to extract drainage Map from the Dem and later using ***"r.to.vect"*** it is converted into the vector shapefile. We need to run ***"r.watershed"*** two different times with different size of exterior watershed basin. First during extraction of sub watershed, second time during extraction of drainage. In this case it was run with the size of exterior watershed basin as 200. Later using "***r.buffer"*** buffer area of around 200m is created around 3rd order and more than 3rd order streams. Similarly, Buffer area of around 100m is created around 1st and 2nd order streams. Drainage network provided by PMU can also be used to extract buffer zone around it. An example of the stream buffer is given in figure 8.

The module *r.stream.order* calculates Strahler's and other stream hierarchy methods. It is a basic module for topological analysis of drainage networks. The size of exterior watershed selected is equal to 200*30*30 = 180000 or 18 ha on 30*30 Dem with 200 as number of cells that needs to be drained from a cell. Currently this has been kept optional. Based upon the need to find gat numbers nearer to the streams or under the zone of influence such maps of stream buffer can also be generated.

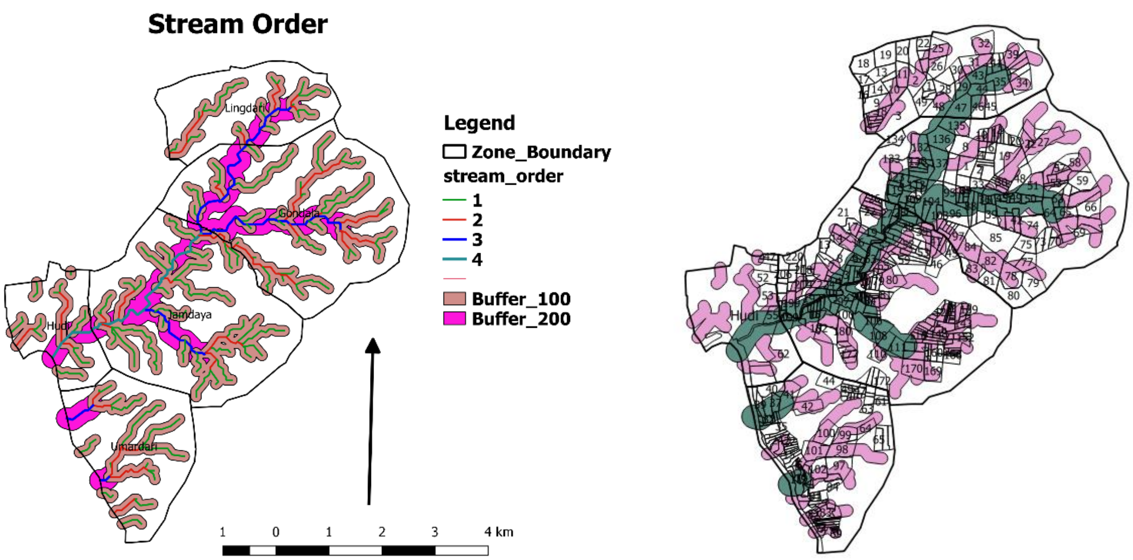


Figure 36 Stream Buffer

Running of Plugin

After the pre-processing the user needs to keep all the files in the same folder or directory which must be selected as Data set folder shown in fig 10. User can select the individual files or can give default names to the files. Default names for files are Zones for zone shapefile, Soil for soil shapefile, LULC for land use land cover shapefile, Cadastral for cadastral shapefile, Slope for Slope raster, Rainfall for rainfall csv. By giving the default names to files they will be automatically selected in dialogue box while selecting the data set folder. On the plugin the user needs to select the crop or multiple crops for which user wants to generate the computational water balance data. User can split the output into number of ET-Deficit intervals he wants. Sowing threshold will allow the user to define the amount of initial moisture required before sowing. Plugin display is shown in figure 9.

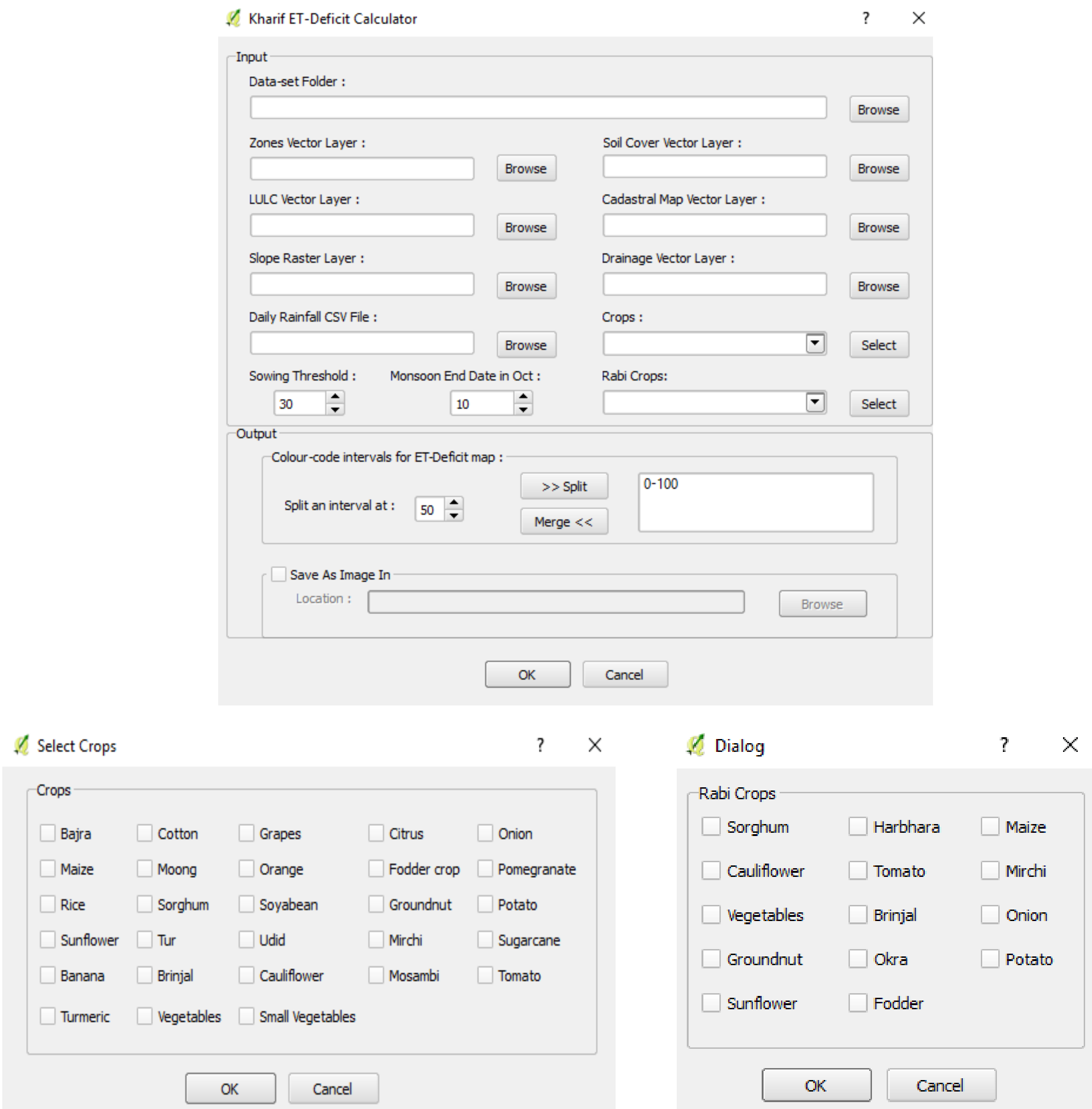


Figure 37 Plugin Display

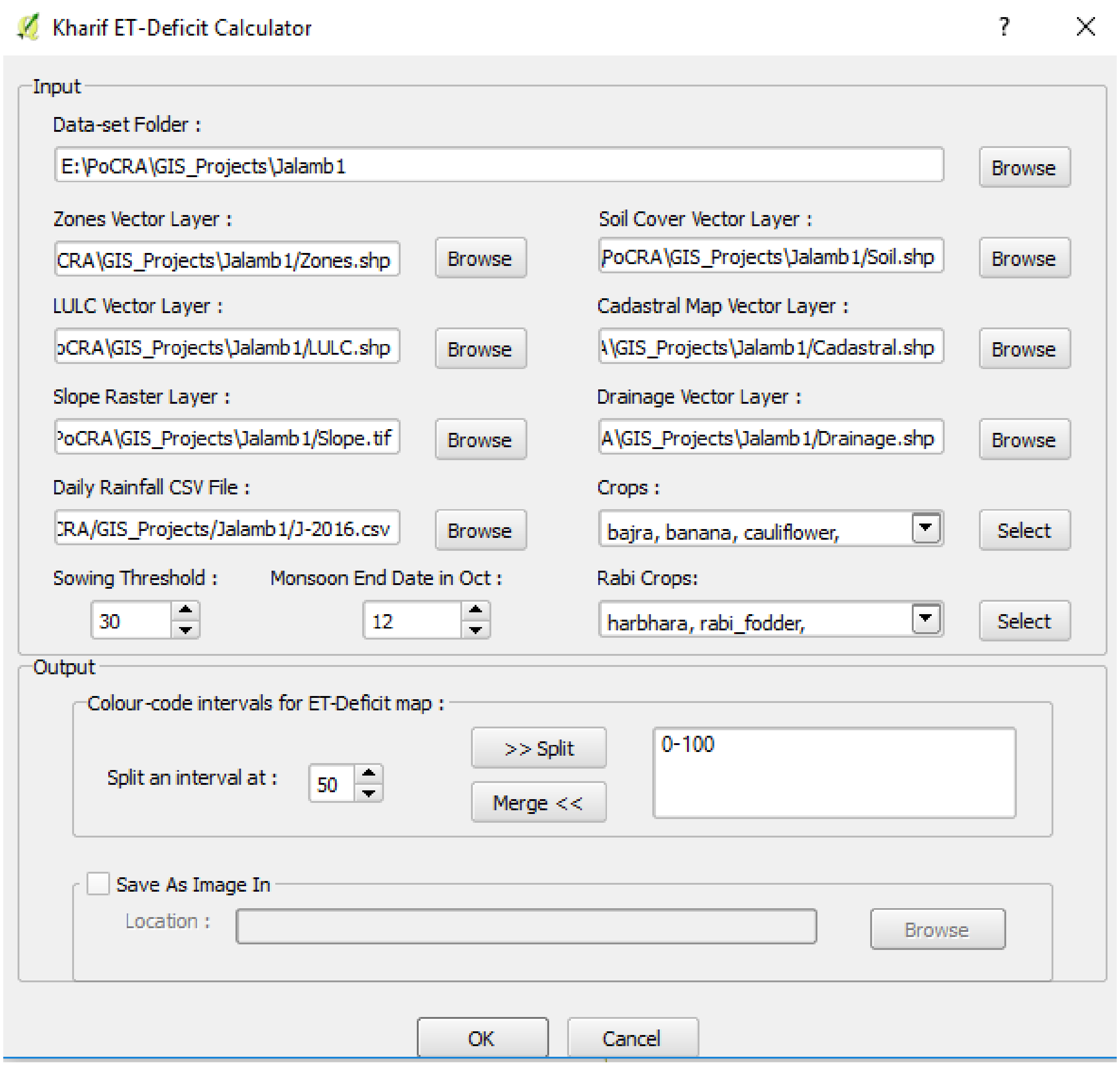


Figure 38 Filled Plugin Display

Preparation and transfer of database to PMU

A database based upon the cluster code provided in the village shapefile has been prepared for all the project area. 15 folders for 15 districts has been prepared.

1. Each folder contains cluster-based sub folders selected in that district for project implementation. Name of these folders is kept based upon their cluster codes. This has been shown for the Akola district in the figure 11. A cluster with code 501_pt-18_02 has been opened and data present in that folder is also shown in the figure 11.

2. These cluster folders contain the following pre-processed files required to run the plugin. List of pre-processed files is given below in table 5. Pre-processing steps required on the files before running the plugin have been described in this Document.

3. There are two rainfall files provided in the folder namely Rainfall and Rainfall_5_Years PMU. In the village shapefile, village and its circle are given. This information is used to prepare rainfall file and Rainfall_5_years file. In Rainfall_5_years file, for all the circles which belongs to a cluster, 5years rainfall data is given. This is shown in the fig 12.

4. The average rainfall data for number of different circles is given in the Rainfall file shown in fig 7. The average annual rainfall of last five years for circle present in cluster is compared with each year rainfall of same circle. For year whose rainfall value is close to average value is given in the Rainfall file. In case, user wants to run the plugin for different years, the data from the Rainfall_5_years file can be coped to Rainfall file.

Table 5 Database Prepared

Sr.No	Data	Default Name	Data Source
1	Cluster Boundary with Zones(Partial)	Zones	MRSAC
2	Land Use land Cover	LULC	MRSAC
3	Soil Layer	Soil	MRSAC
4	Cadastral Layer	Cadastral	MRSAC
5	Slope	Slope	Processing
6	Rainfall CSV	Rainfall	maharain.gov.in
7	Rainfall_5_Years CSV	Rainfall_5_Years CSV	maharain.gov.in
8	PET file	ETO_file	Walmi
9	Drainage	Drainage	Processing/MRSAC

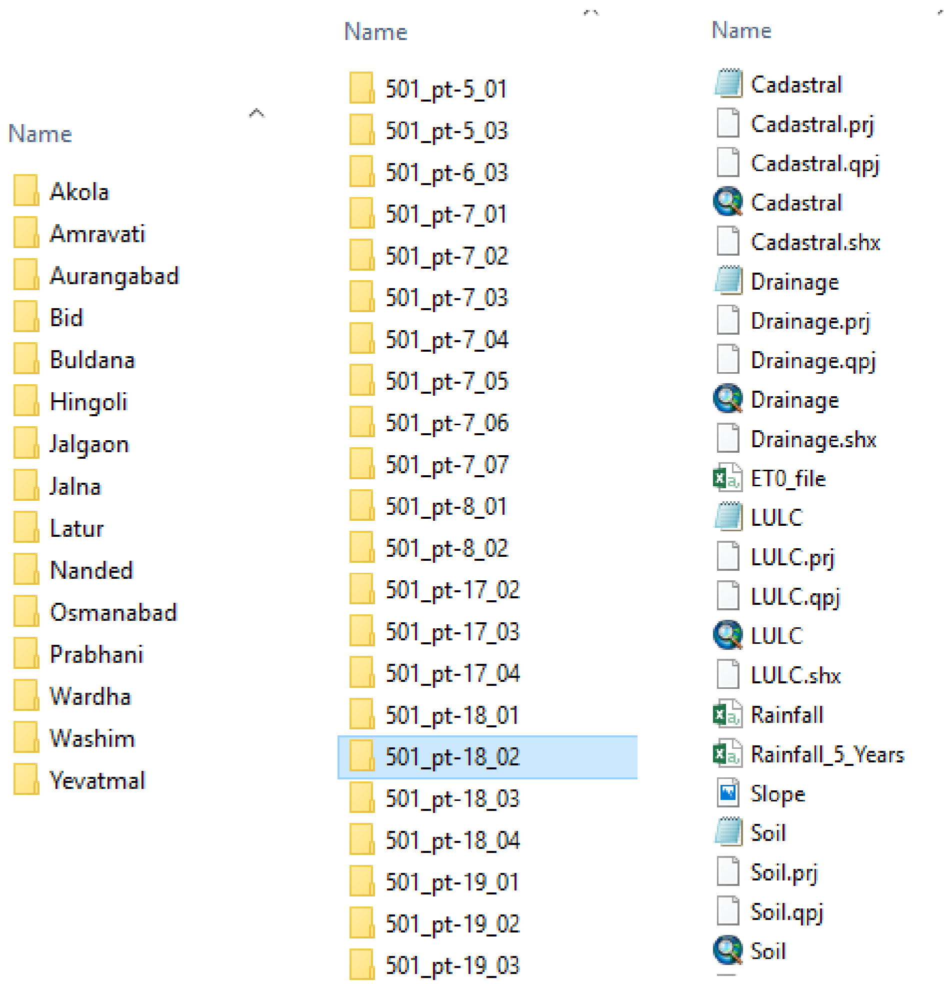
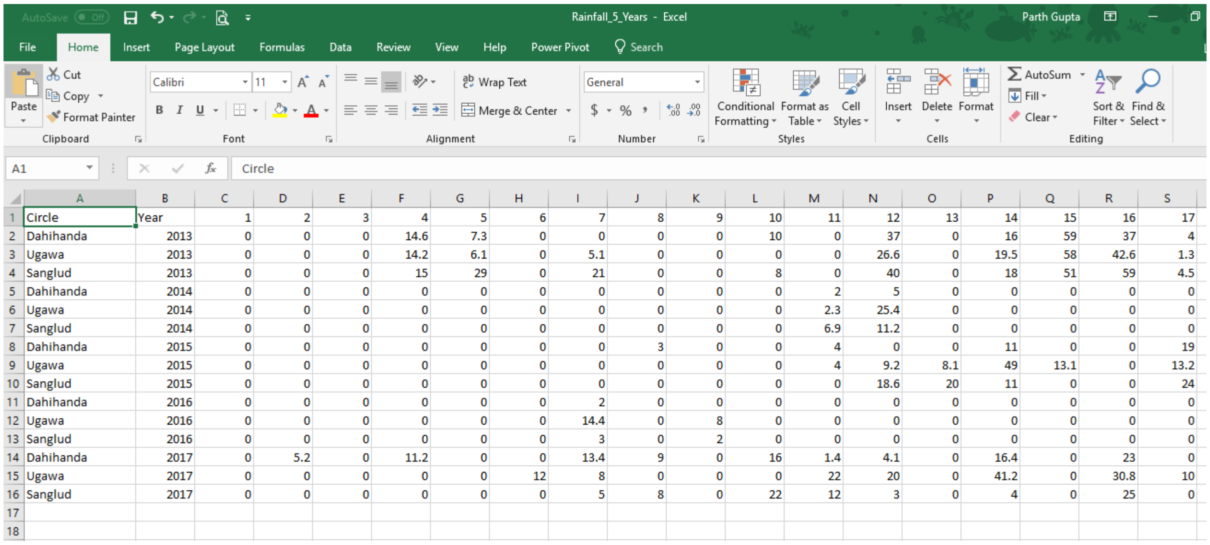


Figure 39 district wise Cluster Folders with pre-process files



Circle	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Dahihanda	2013	0	0	0	14.6	7.3	0	0	0	0	10	0	37	0	16	59	37	4
Ugawa	2013	0	0	0	14.2	6.1	0	5.1	0	0	0	0	26.6	0	19.5	58	42.6	1.3
Sanglud	2013	0	0	0	15	29	0	21	0	0	8	0	40	0	18	51	59	4.5
Dahihanda	2014	0	0	0	0	0	0	0	0	0	0	2	5	0	0	0	0	0
Ugawa	2014	0	0	0	0	0	0	0	0	0	0	2.3	25.4	0	0	0	0	0
Sanglud	2014	0	0	0	0	0	0	0	0	0	0	6.9	11.2	0	0	0	0	0
Dahihanda	2015	0	0	0	0	0	0	0	3	0	0	4	0	0	11	0	0	19
Ugawa	2015	0	0	0	0	0	0	0	0	0	0	4	9.2	8.1	49	13.1	0	13.2
Sanglud	2015	0	0	0	0	0	0	0	0	0	0	0	18.6	20	11	0	0	24
Dahihanda	2016	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Ugawa	2016	0	0	0	0	0	0	14.4	0	8	0	0	0	0	0	0	0	0
Sanglud	2016	0	0	0	0	0	0	3	0	2	0	0	0	0	0	0	0	0
Dahihanda	2017	0	5.2	0	11.2	0	0	13.4	9	0	16	1.4	4.1	0	16.4	0	23	0
Ugawa	2017	0	0	0	0	0	12	8	0	0	0	22	20	0	41.2	0	30.8	10
Sanglud	2017	0	0	0	0	0	0	5	8	0	22	12	3	0	4	0	25	0

Figure 40 5-year Rainfall File

Output

Cadastral Wise Vulnerability Map

After pre-processing the LULC layer shapefile, Soil shapefile, Rainfall data, Slope Map extracted from Dem using (“*r.slope.”*), zone boundary shapefile, cadastral shapefile all are fed into the plugin. UTM projections should be used while building this model. Cadastral wise vulnerability Map is generated when we fed all the shapefiles. This map will help us decide which survey numbers are more vulnerable and which are less vulnerable. Based upon this Map farmers from different gat numbers can be interviewed by cluster assistants. This will also help us decide which gat numbers required more watering’s compared to other gat numbers. This will also help us in prioritizing the vulnerable farmers who needs assistance first. This map will be generated for multiple crops which user has selected in the dialogue box. An example of the same has given in figure 13.

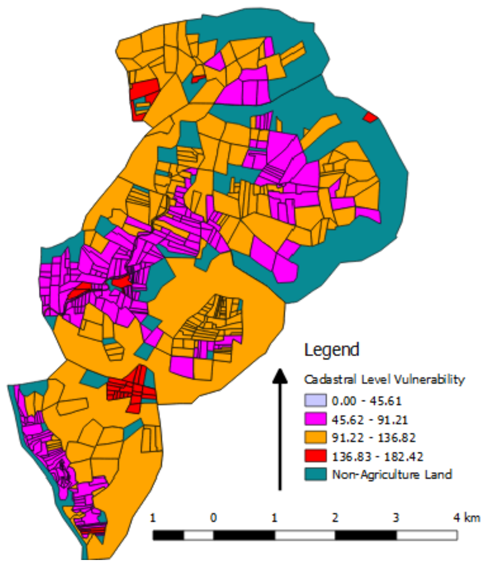


Figure 41 Cadastral Vulnerability Map

Vulnerability Map

Point wise vulnerability Maps are other outputs generated by plugin. The output will generate the Maps shown in the Following figure 14. It is an example of Gondala clusters. The map is made for single crop i.e. soybean crop for two years. In 2016 the area under vulnerability is less and in 2017 area under vulnerability has increased. The complete area is divide in 12 sub watersheds. The rainfall in both the years is almost the same. But in the year 2017 the rainfall is more erratic.

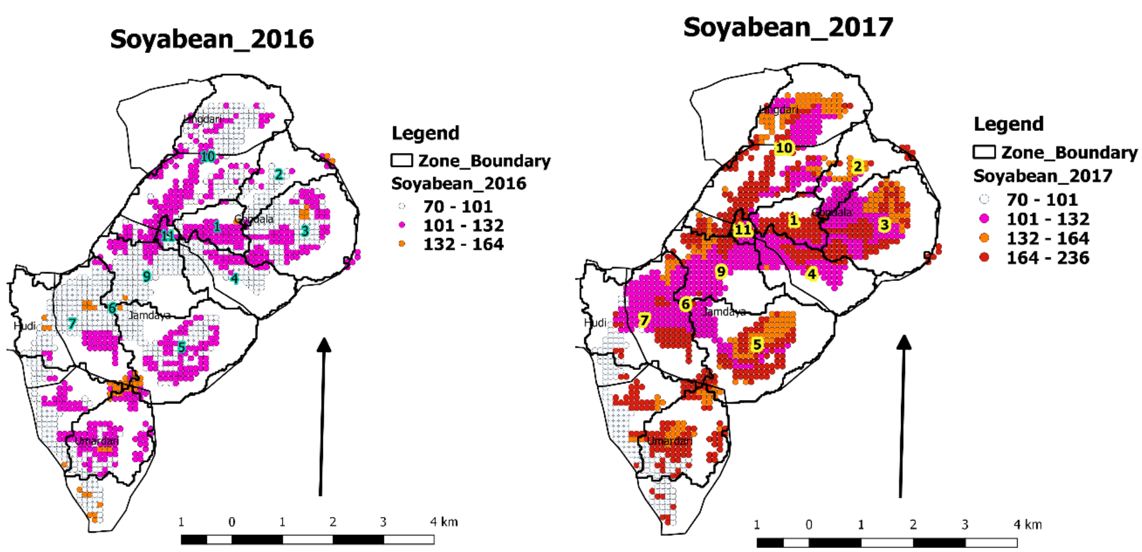
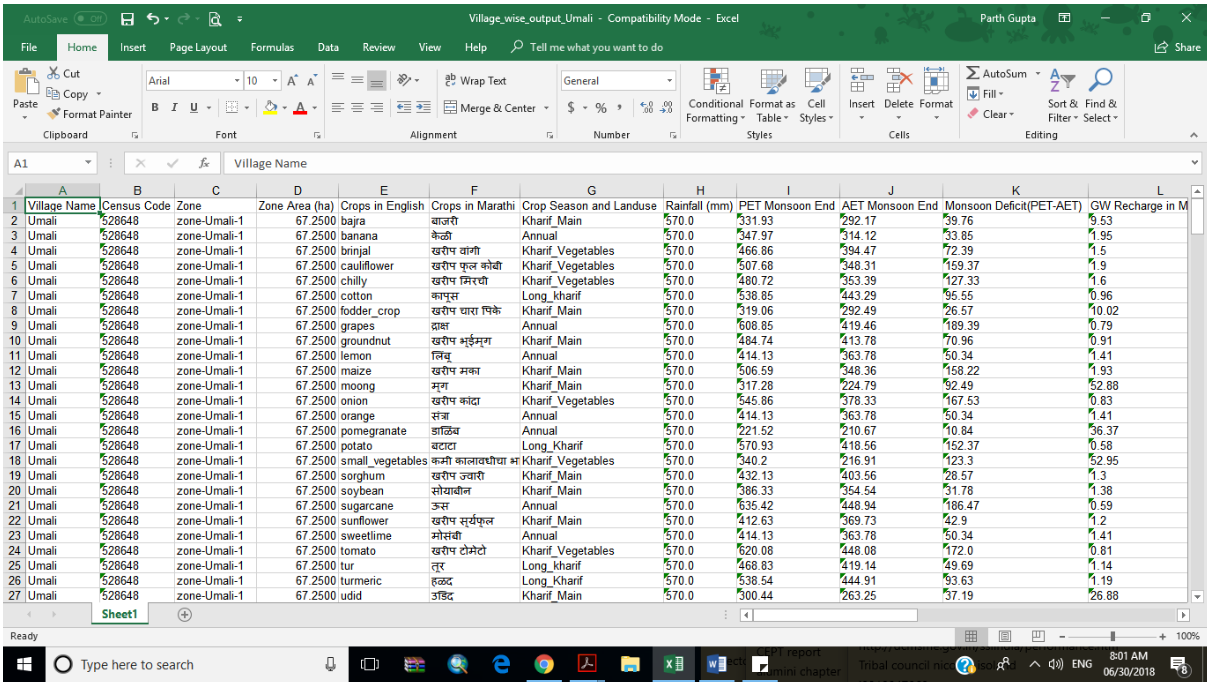


Figure 42 Point wise Vulnerability Map

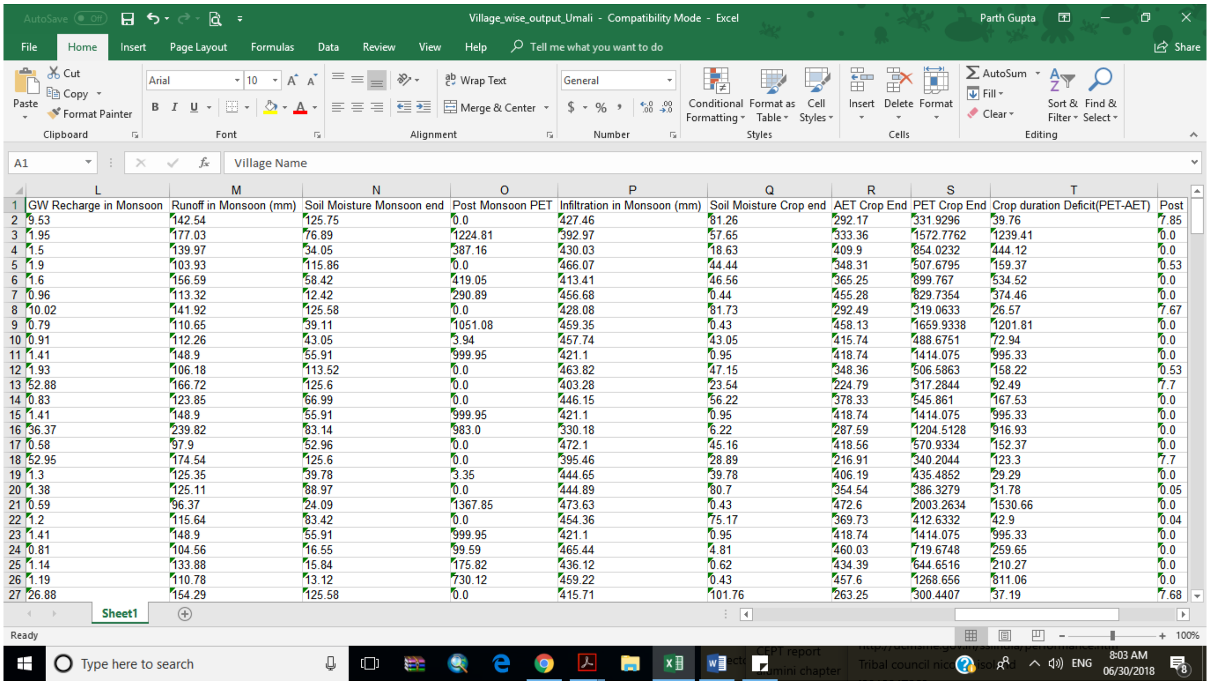
Zone wise table for each Sub watershed

In most of the cases our watershed is divided into more than one soil type and land use. In such cases it is not wise to have one common computational table for complete watershed or village. To ease that process the watershed is divided into sub watersheds or zones. But Within sub watershed there can be more than two types of soil and land use. Due to this weighted average of computational data is taken based upon the area under each soil type. For each crop for each zone there will be output in terms of runoff, infiltration, groundwater recharge etc. This has been shown in fig 15.

Value will be generated for each zone based upon the type of crops in the cluster. Once the layers are fed into the plugin, based upon the number of zones in the zone shapefile computational data will be generated in form of csv in the data folder directory shown in figure 15. Based upon the number of villages in the shapefile number of output csv will be generated in the same folder.



	Village Name	Census Code	Zone	Zone Area (ha)	Crops in English	Crops in Marathi	Crop Season and Landuse	Rainfall (mm)	PET Monsoon End	AET Monsoon End	Monsoon Deficit(PET-AET)	GW Recharge in M
2	Umali	528648	zone-Umali-1	67.2500	bajra	बाजरी	Kharif_Main	570.0	331.93	292.17	39.76	9.53
3	Umali	528648	zone-Umali-1	67.2500	banana	केळी	Annual	570.0	347.97	314.12	33.85	1.95
4	Umali	528648	zone-Umali-1	67.2500	brinjal	खरीप वांगी	Kharif_Vegetables	570.0	466.86	394.47	72.39	1.5
5	Umali	528648	zone-Umali-1	67.2500	cauliflower	खरीप फुल कोबी	Kharif_Vegetables	570.0	507.68	348.31	159.37	1.9
6	Umali	528648	zone-Umali-1	67.2500	chilly	खरीप मिरची	Kharif_Vegetables	570.0	480.72	353.39	127.33	1.6
7	Umali	528648	zone-Umali-1	67.2500	cotton	कापूस	Long_kharif	570.0	538.85	443.29	95.55	0.96
8	Umali	528648	zone-Umali-1	67.2500	fodder_crop	खरीप चारा पिके	Kharif_Main	570.0	319.06	292.49	26.57	10.02
9	Umali	528648	zone-Umali-1	67.2500	grapes	द्राक्ष	Annual	570.0	608.85	419.46	189.39	0.79
10	Umali	528648	zone-Umali-1	67.2500	groundnut	खरीप भुईमुग	Kharif_Main	570.0	484.74	413.78	70.96	0.91
11	Umali	528648	zone-Umali-1	67.2500	lemon	लिंबू	Annual	570.0	414.13	363.78	50.34	1.41
12	Umali	528648	zone-Umali-1	67.2500	maize	खरीप मका	Kharif_Main	570.0	506.59	348.36	158.22	1.93
13	Umali	528648	zone-Umali-1	67.2500	moong	मुग	Kharif_Main	570.0	317.28	224.79	92.49	52.88
14	Umali	528648	zone-Umali-1	67.2500	onion	खरीप कांदा	Kharif_Vegetables	570.0	545.86	378.33	167.53	0.83
15	Umali	528648	zone-Umali-1	67.2500	orange	संत्रा	Annual	570.0	414.13	363.78	50.34	1.41
16	Umali	528648	zone-Umali-1	67.2500	pomegranate	डाळिंब	Annual	570.0	221.52	210.67	10.84	36.37
17	Umali	528648	zone-Umali-1	67.2500	potato	बटाटा	Long_Kharif	570.0	570.93	418.56	152.37	0.58
18	Umali	528648	zone-Umali-1	67.2500	small_vegetables	कमी कालावधीचा भा	Kharif_Vegetables	570.0	340.2	216.91	123.3	52.95
19	Umali	528648	zone-Umali-1	67.2500	sorghum	खरीप ज्वारी	Kharif_Main	570.0	432.13	403.56	28.57	1.3
20	Umali	528648	zone-Umali-1	67.2500	soybean	सोयाबीन	Kharif_Main	570.0	386.33	354.54	31.78	1.38
21	Umali	528648	zone-Umali-1	67.2500	sugarcane	ऊस	Annual	570.0	635.42	448.94	186.47	0.59
22	Umali	528648	zone-Umali-1	67.2500	sunflower	खरीप सूर्यफूल	Kharif_Main	570.0	412.63	369.73	42.9	1.2
23	Umali	528648	zone-Umali-1	67.2500	sweetlime	मोसंबी	Annual	570.0	414.13	363.78	50.34	1.41
24	Umali	528648	zone-Umali-1	67.2500	tomato	खरीप टोमेटो	Kharif_Vegetables	570.0	620.08	448.08	172.0	0.81
25	Umali	528648	zone-Umali-1	67.2500	tur	तूर	Long_kharif	570.0	468.83	419.14	49.69	1.14
26	Umali	528648	zone-Umali-1	67.2500	turmeric	हळद	Long_Kharif	570.0	538.54	444.91	93.63	1.19
27	Umali	528648	zone-Umali-1	67.2500	udid	उडिद	Kharif_Main	570.0	300.44	263.25	37.19	26.88



	GW Recharge in Monsoon	Runoff in Monsoon (mm)	Soil Moisture Monsoon end	Post Monsoon PET	Infiltration in Monsoon (mm)	Soil Moisture Crop end	AET Crop End	PET Crop End	Crop duration Deficit(PET-AET)	Post
2	9.53	142.54	125.75	0.0	427.46	81.26	292.17	331.9296	39.76	7.85
3	1.95	177.03	76.89	1224.81	392.97	57.65	333.36	1572.7762	1239.41	0.0
4	1.5	139.97	34.05	387.16	430.03	18.63	409.9	854.0232	444.12	0.0
5	1.9	103.93	115.86	0.0	466.07	44.44	348.31	507.6795	159.37	0.53
6	1.6	156.59	58.42	419.05	413.41	46.56	365.25	899.767	534.52	0.0
7	0.96	113.32	12.42	290.89	456.68	0.44	455.28	829.7354	374.46	0.0
8	10.02	141.92	125.58	0.0	428.08	81.73	292.49	319.0633	26.57	7.67
9	0.79	110.65	39.11	1051.08	459.35	0.43	458.13	1659.9338	1201.81	0.0
10	0.91	112.26	43.05	3.94	457.74	43.05	415.74	488.6751	72.94	0.0
11	1.41	148.9	55.91	999.95	421.1	0.95	418.74	1414.075	995.33	0.0
12	1.93	106.18	113.52	0.0	463.82	47.15	348.36	506.5863	158.22	0.53
13	52.88	166.72	125.6	0.0	403.28	23.54	224.79	317.2844	92.49	7.7
14	0.83	123.85	66.99	0.0	446.15	56.22	378.33	545.861	167.53	0.0
15	1.41	148.9	55.91	999.95	421.1	0.95	418.74	1414.075	995.33	0.0
16	36.37	239.82	83.14	983.0	330.18	6.22	287.59	1204.5128	916.93	0.0
17	0.58	97.9	52.96	0.0	472.1	45.16	418.56	570.9334	152.37	0.0
18	52.95	174.54	125.6	0.0	395.46	28.89	216.91	340.2044	123.3	7.7
19	1.3	125.35	39.78	3.35	444.65	39.78	406.19	435.4852	29.29	0.0
20	1.38	125.11	88.97	0.0	444.89	80.7	354.54	386.3279	31.78	0.05
21	0.59	96.37	24.09	1367.85	473.63	0.43	472.6	2003.2634	1530.66	0.0
22	1.2	115.64	83.42	0.0	454.36	75.17	369.73	412.6332	42.9	0.04
23	1.41	148.9	55.91	999.95	421.1	0.95	418.74	1414.075	995.33	0.0
24	0.81	104.56	16.55	99.59	465.44	4.81	460.03	719.6748	259.65	0.0
25	1.14	133.88	15.84	175.82	436.12	0.62	434.39	644.6516	210.27	0.0
26	1.19	110.78	13.12	730.12	459.22	0.43	457.6	1268.656	811.06	0.0
27	26.88	154.29	125.58	0.0	415.71	101.76	263.25	300.4407	37.19	7.68

Figure 43 Computational Data

From the point wise computation following data following csv is generated which gives us the information for each Gat number. Based upon the crop selected deficit faced by each gat number is given the csv and number of watering required to maximize the yield is given in the Csv.

Table 6 Gat wise vulnerability

Zone	AREA m2	Gat Number	Deficit mm	Mean Soil M mm	Watering's Req
3	20186.6	55	300.6	51.7	6
3	43807.3	41	302.9	113	6
3	44932.4	42	305.2	113	6
3	35156.9	56	305.6	51.7	6
3	14577.5	61	306.6	51.7	6
3	109521	58	308.7	51.7	6
3	88572.8	75	310.6	109.8	6
3	294478	85	316.7	79	6
3	591.6	44	321.2	45	6
3	134575.8	59	325.5	48.5	6
3	40883.6	72	331.6	45	6
3	21333.8	71	332.3	45	6
3	18392.5	53	340.3	44.1	6
3	67894.1	67	265.7	195.8	5
3	53228.4	62	268.1	227.3	5
3	147266.7	74	268.7	224.2	5
3	64644.3	52	274.2	140.3	5
3	32742.7	63	277.5	213.3	5
3	91136.3	60	279.3	126.5	5
3	36062.2	54	279.4	128	5
3	38596.6	57	285.2	124.1	5
3	144678.5	43	287.6	134.8	5
3	128271.6	66	289.3	114.2	5
3	88826.1	68	289.5	132.2	5
3	97179.5	64	299.6	106.3	5
3	6889	46	229.1	280.5	4
3	25120.2	45	229.1	280.5	4
3	30278	49	229.6	279.5	4
3	137214.3	51	230.5	277.8	4
3	69217.1	65	231.4	276.1	4
3	98775.4	48	231.5	276	4
3	48181.9	40	243.1	310.5	4
3	45536.7	73	247.1	304.2	4
3	39155.5	50	247.5	233.4	4

Uploading the output to Server

Running the plugin from the database provided and Uploading the output to the server has been explained in the document available at https://www.cse.iitb.ac.in/~pocra/User_Manual.pdf

Appendix 1 Terminologies Explained

The runoff curve number (also called a curve number or simply CN) is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. The runoff curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition. To account for different soils' ability to infiltrate, they have been divided into four hydrologic soil groups (HSGs).

- **HSG Group A** (low runoff potential): Soils with high infiltration rates even when thoroughly wetted. These consist chiefly of deep, well-drained sands and gravels. These soils have a high rate of water transmission (final infiltration rate greater than 0.3 in./h).

- **HSG Group B** Soils with moderate infiltration rates when thoroughly wetted. These consist chiefly of soils that are moderately deep to deep, moderately well drained to well drained with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (final infiltration rate of 0.15 to 0.30 in./h).

- **HSG Group C:** Soils with slow infiltration rates when thoroughly wetted. These consist chiefly of soils with a layer that impedes downward movement of water or soils with moderately fine to fine textures. These soils have a slow rate of water transmission (final infiltration rate 0.05 to 0.15 in./h).

- **HSG Group D** (high runoff potential): Soils with very slow infiltration rates when thoroughly wetted. These consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious materials. These soils have a very slow rate of water transmission (final infiltration rate less than 0.05 in./h).

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 ET_o

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ET_o. The reference surface is a hypothetical grass reference crop with specific characteristics. FAO Penman-Monteith method is now 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 with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23. The reference surface closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground. The fixed surface resistance of 70 s m^{-1} implies a moderately dry soil surface resulting from about a weekly irrigation frequency.

Crop evapotranspiration (ET_c)

The crop evapotranspiration differs distinctly from the reference evapotranspiration (ET_o) 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 (K_c). In the crop coefficient approach, crop evapotranspiration is calculated by multiplying ET_o by K_c.

$ET_c = K_c \, ET_o$

Single crop coefficient approach (K_c)

The K_c predicts ET_c 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 ET_c predicted by $K_c$is adjusted if necessary to non-standard conditions, $ET_{c\ adj}$, where any environmental condition or characteristic is known to have an impact on or to limit ET_c.

ET_c under soil water stress conditions

Where the conditions encountered in the field differ from the standard conditions, a correction on ET_c is required. Low soil fertility, salt toxicity, soil waterlogging, pests, diseases and the presence of hard or impenetrable soil horizons in the root zone may result in scanty plant growth and lower evapotranspiration. Soil water shortage and soil salinity may reduce soil water uptake and limit crop evapotranspiration. The effects of soil water stress are described by multiplying the basal crop coefficient by the water stress coefficient, Ks.

Saturation

During a rain shower or irrigation application, the soil pores will fill with water. If all soil pores are filled with water the soil is said to be saturated. There is no air left in the soil. It is easy to determine in the field if a soil is saturated. After the rain or the irrigation has stopped, part of the water present in the larger pores will move downward. This process is called drainage or percolation.

Field capacity

Field Capacity is the amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement has decreased. This usually takes place 2–3 days after rain or irrigation in pervious soils of uniform structure and texture. After the drainage has stopped, the large soil pores are filled with both air and water while the smaller pores are still full of water. At this stage, the soil is said to be at field capacity. At field capacity, the water and air contents of the soil are ideal for crop growth.

Permanent wilting point

Little by little, the water stored in the soil is taken up by the plant roots or evaporated from the topsoil into the atmosphere. If no additional water is supplied to the soil, it gradually dries out. The dryer the soil becomes, the more tightly the remaining water is retained and the more difficult it is for the plant roots to extract it. At a certain stage, the uptake of water is not sufficient to meet the plant's needs. The plant loses freshness and wilts; the leaves change colour from green to yellow. Finally, the plant dies. The soil water content at the stage where the plant dies, is called permanent wilting point. The soil still contains some water, but it is too difficult for the roots to suck it from the soil.

Total Available water

As the water content above field capacity cannot be held against the forces of gravity and will drain and as the water content below wilting point cannot be extracted by plant roots, the total available water in the root zone is the difference between the water content at field capacity and wilting point.

$TAW = 1000(q_{FC} - q_{WP}) Z_r$

Readily Available Water

Although water is theoretically available until wilting point, crop water uptake is reduced well before wilting point is reached. Where the soil is sufficiently wet, the soil supplies water fast enough to meet the atmospheric demand of the crop, and water uptake equals ETc. As the soil water content decreases, water becomes more strongly bound to the soil matrix and is more difficult to extract. When the soil water content drops below a threshold value, soil water can no longer be transported quickly enough towards the roots to respond to the transpiration demand and the crop begins to experience stress. The fraction of TAW that a crop can extract from the root zone without suffering water stress is the readily available soil water.

RAW = p TAW

RAW the readily available soil water in the root zone [mm], p average fraction of Total Available Soil Water (TAW) that can be depleted from the root zone before moisture stress (reduction in ET) occurs [0-1]. The factor p differs from one crop to another. The factor p normally varies from 0.30 for shallow rooted plants at high rates of ET_c (> 8 mm d^{-1}) to 0.70 for deep rooted plants at low rates of ET_c (< 3 mm d^{-1}). A value of 0.50 for p is commonly used for many crops.

Appendix 2 Database used at the back end

Currently the values of Evapotranspiration for different regions are taken from the WALMI which are given in appendix 1. WALMI data also provides the total crop duration and total crop water requirement. But the current model requires the value of daily crop water requirement. As seasonal crop water requirement will not help us calculate the actual water taken by the crop and hence the impact of dry spells. FAO provides the different crop stages duration data and monthly crop coefficients Kc values. Monthly kc values can be used on daily basis. FAO values have been scaled up or scaled down to match the WALMI total crop water requirement and crop duration. The modified crop duration and Kc values have been given in appendix 2. Initial curve number to start the calculation process has been assigned based upon the soil hydrologic group, land use and soil type. The values of the curve number has been given in appendix 3.

Table 1 Montly ETo Values Region wise for POCRA Districts

Monthly ET0	Parbhani	Aurangabad	Amravati	Nanded	Yavatmal	Wardha
Jan	3.95	4.36	4.74	4.29	4.77	3.93
Feb	5.17	5.6	5.89	5.42	5.93	6.05
March	5.29	6.5	7.03	6.39	7.05	0.71
April	7.03	7.55	8.13	7.33	7.96	5.8
May	8.25	8.86	9.09	8.22	9.26	9
June	7.51	6.32	8.2	7.03	7.96	7.17
July	4.77	4.64	4.61	5.26	4.55	4.63
Aug	4.55	3.98	4.45	4.77	3.93	4.06
Sept	4.78	4.39	4.7	5.03	4.5	4.83
Oct	4.8	5.02	5.32	5.01	4.84	4.42
Nov	3.9	4.52	4.76	5.57	4.23	4.3
Dec	3.48	4.16	4.36	4.57	4.22	3.55
Agro climatic zone	7	7	7	7&8	8	8
Mapped Districts	parbhani, latur, osmanabad, beed	Aurangabad, jalna, jalgaon	buldhana, Amravati, Akola	Washim, Nanded, Hingoli	Yavatmal	Wardha

Duration and Kc values of different crops taken from FAO data have been adjusted based upon the total water requirement and total duration of crops available from WALMI data to match with local environment conditions. A document in detail describing this process is available at https://www.cse.iitb.ac.in/~pocra/Plugin/Kc%20note%20final.pdf

Table 2 Adjusted Kc and Crop duration values

Crop		Stage I	Stage II	Stage III	Stage IV
Bajra	Duration	13	21	34	22
	Kc	0.34	0.67	1.05	0.62
Banana	Duration	112	84	112	7
	Kc	0.53	1.17	1.06	1.06
Brinjal	Duration	44	58	58	30
	Kc	0.51	0.84	1.29	0.9
Cauliflower	Duration	14	18	43	10
	Kc	0.63	1.05	1.46	1.25
Lemon	Duration	60	90	120	95
	Kc	0.7	0.65	0.7	0.7
Cotton	Duration	30	50	55	45
	Kc	0.51	0.85	1.3	0.85
Fodder_Crop	Duration	14	25	29	22
	Kc	0.35	0.7	1.01	0.61
Grapes	Duration	30	61	183	91
	Kc	0.44	1.52	0.73	0.73
Groundnut	Duration	23	32	42	23
	Kc	0.47	0.79	1.1	0.74
Maize	Duration	14	25	29	22
	Kc	0.56	1.11	1.6	0.97
Chilly	Duration	40	55	63	32
	Kc	0.44	0.87	1.31	1.12
Moong	Duration	8	12	24	16
	Kc	0.57	0.95	1.4	0.63
Sweetlime	Duration	60	90	120	95
	Kc	0.7	0.65	0.7	0.7
Onion	Duration	12	19	54	30
	Kc	0.53	0.75	1.07	1.07
Orange	Duration	60	90	120	95
	Kc	[0.7	0.65	0.7	0.7
Pomegranate	Duration	21	77	56	211
	Kc	0.46	0.26	0.56	0.7
Potato	Duration	25	30	30	20
	Kc	0.62	1.03	1.58	1.16

Small_Vegetables	Duration	20	20	15	5
	Kc	0.73	0.97	1.61	1.45
Sorghum	Duration	20	30	40	30
	Kc	0.34	0.72	1.06	0.63
Soybean	Duration	16	23	47	19
	Kc	0.33	0.7	1.03	0.56
Sugarcane	Duration	28	48	151	138
	Kc	0.51	1.58	0.95	0.95
Sunflower	Duration	17	29	38	21
	Kc	0.36	0.78	1.19	0.57
Tomato	Duration	30	41	41	25
	Kc	0.58	0.97	1.49	1.04
Tur	Duration	28	46	50	41
	Kc	0.43	0.72	1.1	0.72
Turmeric	Duration	40	67	73	60
	Kc	0.59	0.98	1.51	0.98
Udid	Duration	11	17	33	22
	Kc	0.41	0.69	1.01	0.46
Vegetables	Duration	24	33	33	20
	Kc	0.53	0.89	1.36	0.94

Table 3 Hydrologic soil groups and Curve numbers

Lookup table (don't move)			Lookup used				
Soil type	HSG						
Clay Loam	D		LU	HSG A	HSG B	HSG C	HSG D
Clayey	D		Agriculture	67	78	85	89
Gravelly Clay	D		Deciduous - Dense	30	55	70	77
Gravelly Clay Loan	D		Deciduous open	36	60	73	79
Gravelly Loam	B		Fallow land	77	86	91	94
Gravelly Sandy Cla	B		habitation	77	85	90	92
Gravelly Sandy Loa	B		Scrub dense	49	69	79	84
Gravelly Silty Clay	C		Scrub Forest	57	73	82	86
Gravelly Silty Loan	C		Scrub open	68	79	86	89
Loamy	B						
Loamy sand	A						
Sandy	A						
Sandy Clay	D						
Sandy Clay loam	C						
Sandy loam	A						
Silty clay	D						
Silty clay loam	D						
Silty loam	B						

Table 4 Soil Depth

S.No	Soil Depth from Map	Soil Depth used m
1	deep (50 to 100 cm)	1
2	habitation mask	0.1
3	shallow (10 to 25 cm)	0.25
4	very deep (> 100 cm)	1.5
5	waterbody mask	0.1
6	moderately deep (25 to 50 cm)	0.5
7	shallow to very shallow (< 25 cm)	0.25
8	very shallow (< 10 cm)	0.1

Table 5 Crop Root Depth

Sr.No	Crops and LU	Root Depth
1	Soyabean	0.9
2	Bajra	1.5
3	Moong	0.75
4	Sorghum	1.5
5	Cotton	1.35
6	Udid	0.75
7	Banana	0.75
8	Sugarcane	0.75
9	Orange	1.1
10	Rice	0.75
11	Sunflower	1.15
12	Tur	0.75
13	Grapes	0.9
14	Maize	1.35
15	Deciduous - dense crop	3
16	Deciduous open crop	1.5
17	Scrub dense crop	1.5
18	Scrub forest crop	1.5
19	Scrub open crop	0.5

Table 6 Soil Parameters

SN No	Soil Type	HSG	Sand %	Clay %	Gravel %	WP	FC	Saturation	Ksat mm/hr	Bulk Density	AWC
1	Clay loam	D	32	34	0	0.206	0.341	0.442	2.7	1.48	0.14
2	Clayey	D	28	51	0	0.303	0.427	0.487	0.52	1.36	0.12
3	Gravelly clay	D	23	48	10	0.285	0.415	0.488	0.83	1.36	0.12
4	Gravelly clay loam	D	31	34	10	0.206	0.343	0.444	2.32	1.47	0.12
5	Gravelly loam	B	41	17	10	0.109	0.024	0.408	10.83	1.57	0.12
6	Gravelly sandy clay loam	B	49	26	10	0.16	0.273	0.412	5.83	1.56	0.1
7	Gravelly sandy loam	B	63	10	10	0.065	0.158	0.402	33.29	1.58	0.08
8	Gravelly silty clay	C	7	47	10	0.277	0.42	0.512	1.7	1.29	0.13
9	Gravelly silty loam	C	21	15	10	0.099	0.282	0.415	6.8	1.55	0.16
10	Loamy	B	42	20	0	0.126	0.256	0.411	10.2	1.56	0.13
11	Loamy sand	A	82	8	0	0.05	0.106	0.41	69.09	1.56	0.06
12	Sandy	A	91	5	0	0.03	0.071	0.424	108.06	1.53	0.04
13	Sandy clay	D	51	42	0	0.254	0.364	0.43	0.73	1.51	0.11
14	Sandy clay loam	C	57	28	0	0.172	0.271	0.406	6.09	1.57	0.1
15	Sandy loam	A	65	11	0	0.172	0.258	0.399	6.67	1.59	0.09
16	Silty clay	D	9	46	0	0.272	0.415	0.506	1.9	1.31	0.14
17	Silty clay loam	D	11	34	0	0.206	0.371	0.47	2.65	1.41	0.17
18	Silty loam	B	19	16	0	0.105	0.291	0.418	6.97	1.54	0.19
19	Waterbody mask	D	28	51	0	0.303	0.427	0.487	0.52	1.36	0.12
20	Habitation mask	D	32	34	0	0.206	0.341	0.442	2.7	1.48	0.14

Appendix 3 Excel Model

The current Excel model has been made as two soil layer model. First layer represents the crop root zone and second layer represents the remaining soil depth. Initially, we need to fix a land use, soil type, and slope and HSG group for our area to select a CN number which is known as **CN_2**. From this CN number **CN_3** and **CN_1** values are calculated. After the calculation of CN numbers Smax and S3 Soil retention parameters are calculated for **CN_1** and **CN_3**. Then S (retention parameter) is calculated for initial soil moisture content. After that value of S is varied daily with daily change in soil moisture content. With new soil retention parameter, value of CN number is revised to get new CN number every day. With daily change in CN number daily calculations for runoff is done. Initial Soil Moisture for day1 has been set equal to wilting point of soil. Initial soil moisture for Day2 is computed from the previous day soil moisture, infiltration, near surface storage values and the water taken by the crop. Initially, without any rainfall and If there is no infiltration the soil moisture is set equal to wilting point. If there is some infiltration happening then it is added to the first layer and the value is compared to the field capacity of the soil. If infiltration is more than field capacity the moisture is added to the second layer. Similarly the amount of water added to the second layer is compared against its field capacity and extra water is added to the ground.

Runoff Calculation

Initial CN_2 value is selected based upon the look up table given in the appendix 2 table 3. Based upon the soil texture, the soil has been classified into different hydrologic groups. Depending on the land use and HSG curve number value is selected.

Runoff is affected by the soil moisture before a precipitation event, or the *antecedent moisture condition* (AMC). A curve number, as selected above, may also be termed AMC II or **CN_2**, or average soil moisture. The other moisture conditions are dry or wilting point, AMC I or **CN_1**, and moist or field capacity, AMC III or **CN_3**. Based upon the amount of rainfall the moisture condition of the soil or AMC will change daily. The curve number can be adjusted based upon their AMC condition by using the following formulas. **Both CN_1 and CN_3** can be calculated using the following equations.

$$CN_1 = CN_2 - \frac{20 \cdot (100 - CN_2)}{(100 - CN_2 + \exp[2.533 - 0.0636 \cdot (100 - CN_2)])}$$

$$CN_3 = CN_2 \cdot \exp[0.00673 \cdot (100 - CN_2)]$$

Retention Parameter

Retention Parameter varies spatially due to change in Land use, management, and slope and temporally due to change in soil moisture content. Retention Parameter can be calculated using two methods. One method allows retention parameter to vary with plant ET. Traditional method allows it vary with soil water content. We are using traditional method for computation.

$$S = S_{max} \cdot \left(1 - \frac{SW}{[SW + \exp(w_1 - w_2 \cdot SW)]}\right)$$

S_{max} is the potential maximum soil moisture retention after runoff begins. SW is the soil moisture value excluding the wilting point. W_1 and W_2 are the shape coefficients. The value of S_{max} is calculated using the CN1 value and using the following equation.

$$S = 25.4\left(\frac{1000}{CN} - 10\right)$$

The value of W_1 and W_2 is calculated using the following equations. FC is the amount of water in soil profile at field capacity. S3 is the retention parameter for the moisture condition III or **CN_3** value. SAT is the amount of water in the soil profile when soil is completely saturated.

$$w_1 = \ln\left[\frac{FC}{1 - S_3 \cdot S_{max}^{-1}} - FC\right] + w_2 \cdot FC \quad 2$$

$$w_2 = \frac{\left(\ln\left[\frac{FC}{1 - S_3 \cdot S_{max}^{-1}} - FC\right] - \ln\left[\frac{SAT}{1 - 2.54 \cdot S_{max}^{-1}} - SAT\right]\right)}{(SAT - FC)}$$

The daily retention parameter is adjusted by using the new soil moisture values every day. Then the Daily curve number value is calculated from the new value of the retention parameter based upon the new soil moisture value for that day.

$$CN = \frac{25400}{(S + 254)}$$

The initial curve number **CN_2** used as starting point for all the calculations is appropriate for slope 5%. To take into account the slope factor the value of **CN_2** is modified based upon the following equation where CN_{2s} is the modified curve number based upon the slope. Slp is the slope value corresponding to the point where calculation is being done. **CN_3** is curve number value corresponding to the AMC III.

$$CN_{2s} = \frac{(CN_3 - CN_2)}{3} \cdot [1 - 2 \cdot \exp(-13.86 \cdot slp)] + CN_2$$

Runoff

The model was built to provide the runoff for varying land use and soil types. The Runoff is calculated by using the following equation. R_{day} is the rainfall on any given day.

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)}$$

Ia is the initial abstraction, or the amount of water before runoff, such as infiltration, or rainfall interception by vegetation; historically, it has generally been assumed Ia =0.2S

If rainfall value is more than initial abstraction than the above equation is used to calculate the runoff for the given day otherwise the value of runoff for that day is set equal to 0.

CN has a range from 30 to 100; lower numbers indicate low runoff potential while larger numbers are for increasing runoff potential. The lower the curve number, the more permeable the soil is. As can be seen in the curve number equation, runoff cannot begin until the initial abstraction has been met. It is important to note that the curve number methodology is an event-based calculation, and should not be used for a single annual rainfall value, as this will incorrectly miss the effects of antecedent moisture and the necessity of an initial abstraction threshold.

Infiltration

It is the process by which water on the ground surface enters the soil. Daily infiltration is calculated by subtracting the runoff value from the rainfall value.

Infiltration = Rainfall – Runoff

Reference evapotranspiration ETo Values are taken from the data provided by the Walmi given in Table 1 Appendix 2.

Crop evapotranspiration (ET_c)

The crop evapotranspiration differs distinctly from the reference evapotranspiration (ET_o) 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 (K_c). In the crop coefficient approach, crop evapotranspiration is calculated by multiplying ET_o by K_c.

$ET_c = K_c \, ET_o$

Single crop coefficient approach (K_c)

The K_c predicts ET_c 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 ET_c predicted by $K_c$is adjusted if necessary to non-standard conditions, $ET_{c\ adj}$, where any environmental condition or characteristic is known to have an impact on or to limit ET_c. Kc Values used in the model for crops is given in the **Table 2 Appendix 2.**

ET_c under soil water stress conditions

Where the conditions encountered in the field differ from the standard conditions, a correction on ET_c is required. Low soil fertility, salt toxicity, soil waterlogging, pests, diseases and the presence of hard or impenetrable soil horizons in the root zone may result in scanty plant growth and lower evapotranspiration. Soil water shortage and soil salinity may reduce soil water uptake and limit crop evapotranspiration.

Forces acting on the soil water decrease its potential energy and make it less available for plant root extraction. When the soil is wet, the water has a high potential energy, is relatively free to move and is easily taken up by the plant roots. In dry soils, the water has a low potential energy and is strongly bound by capillary and absorptive forces to the soil matrix, and is less easily extracted by the crop. When the potential energy of the soil water drops below a threshold value, the crop is said to be water stressed. The effects of soil water stress are described by multiplying the basal crop coefficient by the water stress coefficient, Ks:

If Soil Moisture is > F.C – RAW than Ks = 1

For D_r > RAW or Soil Moisture < F.C – RAW

$$K_s = \frac{TAW - D_r}{TAW - RAW} = \frac{TAW - D_r}{(1-p)TAW}$$

Where, K_s is a dimensionless transpiration reduction factor dependent on available soil water, D_r root zone depletion [mm], TAW total available soil water in the root zone [mm],p fraction of TAW that a crop can extract from the root zone without suffering water stress

Ks = IF(Day 1 Soil Moisture <Wilting Point,0,(IF(Day 1 Soil Moisture >(Field Capacity*(1-depletion factor p)+depletion factor *wilting point),1,(Day 1 Soil Moisture – Wilting Point)/(Field Capacity-Wilting Point)/(1-depletion factor))))

After the computation of K_s, the adjusted evapotranspiration $ET_{c\ adj}$ is computed

Soil Moisture Calculations

Initially the soil moisture is set equal to wilting point. There are two terms being calculated soil moisture after infiltration and soil moisture. Soil moisture after infiltration means when current day infiltration and AET is taken into account and added to the last day soil moisture or previous day readings or end of the day soil moisture.

SM after Recharge (Day 1) = Wilting Point

SM after Recharge (Day 2) = ((SM Layer 1 Day1*1*Soil Thickness Layer 1 + (Infilteration+NSS2-AET-NSS3)/1000)/ Soil Thickness Layer 1)

SM Day 1 = (SM after infiltration Day1 *Soil Thickness*1000-Recharge to Secondary Layer)/Soil Thickness Layer 1/1000

From this value recharge to secondary layer is subtracted to arrive at the actual soil moisture at the end of the day.

SM Day 2 =MIN(((SM after infiltration Day2 *Soil Thickness*1000-Recharge to Secondary Layer)/Soil Thickness Layer 1/1000),Saturation Point)

The value of Soil Moisture after infiltration is compared with field capacity of layer 1, if the value is less than field capacity, recharge to secondary layer is set to 0. Now if value of soil moisture after infiltration is more than field capacity of layer 1 and If previous day soil moisture of layer 2 is less than saturation capacity of layer 2 then water to second layer is added. The amount of water that percolates from layer 1 to 2 depends upon the unsaturated conductivity of the soil layer, the remaining capacity of layer 2 to absorb the water and availability of water above the field capacity of first layer.

Recharge to Secondary Layer=IF(Soil Moisture after infiltration layer 1<Field Capacity,0,IF(Layer 2 Soil Moisture Day1 <Saturation point, MIN((Saturation Point-Layer 2 Soil moisture day1)*Thickness of soil layer 2*1000,(SM after infiltration Layer 1 - Field Capacity)* Thickness of soil layer *1000* daily percolation factor),0))

After accounting the recharge for secondary layer if the water entering the top layer is higher than its saturation point then that water is removed as secondary runoff.

Secondary Runoff = IF(((SM Layer 1 Day 1*1*Soil Layer Thickness 1+(Infilteration+NSS2-AET-NSS-Recharge to secondary Layer)/1000)/Soil Thickness)>Saturation Point,(((SM Layer 1 Day 1*1*Soil Layer Thickness 1+(Infilteration+NSS2-AET-NSS-Recharge to secondary Layer)/1000)/Soil Thickness)-Saturation)*Soil Layer Thickness*1000,0)

Similarly Soil Moisture after infiltration for layer 2 is computed. Infiltration for layer 2 is equal to the recharge to secondary layer.

SM after infiltration layer 2= (Soil Moisture Layer 2 Day 1*Soil Thickness*1000+Recharge to secondary layer or infiltration)/Soil Thickness/1000

If soil moisture for layer 2 is less than field capacity there will no percolation to GW. If it is more than field capacity then the difference between the two will be added as groundwater recharge.

Percolation to Groundwater=IF(SM after infiltration layer 2<Field Capacity, 0, (SM after infiltration layer 2-Field Capacity)*Soil Layer 2*1000* daily percolation factor)

$$w_{perc,ly} = SW_{ly,excess} \cdot \left(1 - \exp\left[\frac{-\Delta t}{TT_{perc}}\right]\right)$$

$$TT_{perc} = \frac{SAT_{ly} - FC_{ly}}{K_{sat}}$$

After filling the layer 2 till field capacity some water is removed from the layer as GW percolation. Maximum water that layer 2 can hold is till saturation point.

Layer 2 Soil Moisture = MIN (((SM after infiltration layer 2*)/Soil Thickness *1000-Percolation to Gw)/Soil Thickness /1000), Saturation Point)

Layer 2 can have maximum water till it is saturated. When layer 2 is above field capacity water is removed from layer 2 added as groundwater recharge.

Soil moisture for both the layers are added in the end to get the complete soil moisture. These calculations are done pointwise. At end of the model we get runoff, infiltration, soil moisture, groundwater PET and AET value for at given point or location and crop. Final output will be in the form of table 6 described above.

Annexure III: Plugin User Manual

This document is the user guide for the plugin described in the Plugin Description Document (Phase III Deliverable), and available at https://www.cse.iitb.ac.in/~pocra/.

1. User needs to open the Qgis version 2.18.12 on his/her desktop PC where plugin is already added to his QGIS. Installation process is already described in the plugin description document. Once opened user needs to click on the plugin icon described in the Figure 44 below.

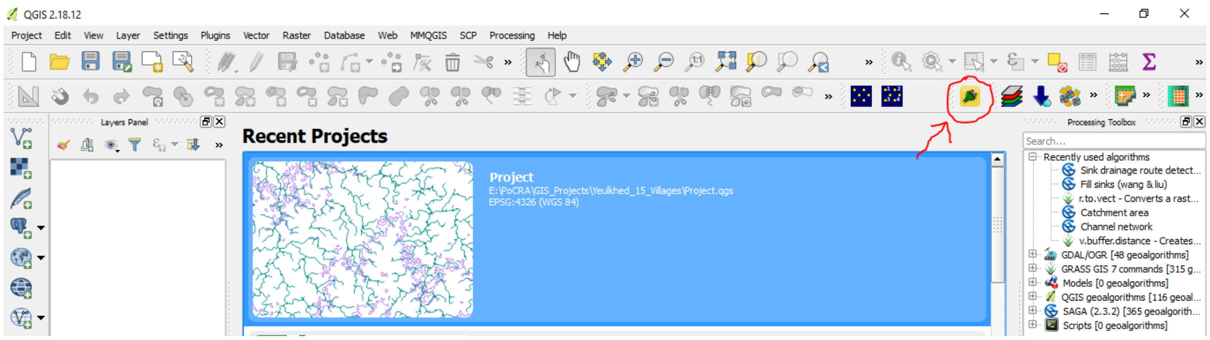


Figure 44 Qgis Interface with Plugin Icon

2. A database based upon the cluster code provided in the village shapefile has been prepared for all the project area. 15 folders for 15 districts has been prepared.

3. Each folder contains cluster-based sub folders selected in that district for project implementation. Name of these folders is kept based upon their cluster codes. This has been shown for the Akola district in the figure below. A cluster with code 501_pt-18_02 has been opened and data present in that folder is also described in the figure and table given below.

4. These cluster folders contain the following files required to run the plugin which have been already pre-processed. Pre-processing steps required on the files before running the plugin have been described in the Plugin Description Document.

Table 1 Data Provided

Sr.No	Data	Default Name	Data Source
1	Cluster Boundary with Zones(Partial)	Zones	MRSAC
2	Land Use land Cover	LULC	MRSAC
3	Soil Layer	Soil	MRSAC
4	Cadastral Layer	Cadastral	MRSAC
5	Slope	Slope	Processing
6	Rainfall CSV	Rainfall	maharain.gov.in
7	Rainfall_5_Years CSV	Rainfall_5_Years CSV	maharain.gov.in

8	PET file	ETO_file	Walmi
9	Drainage	Drainage	Processing/MRSAC

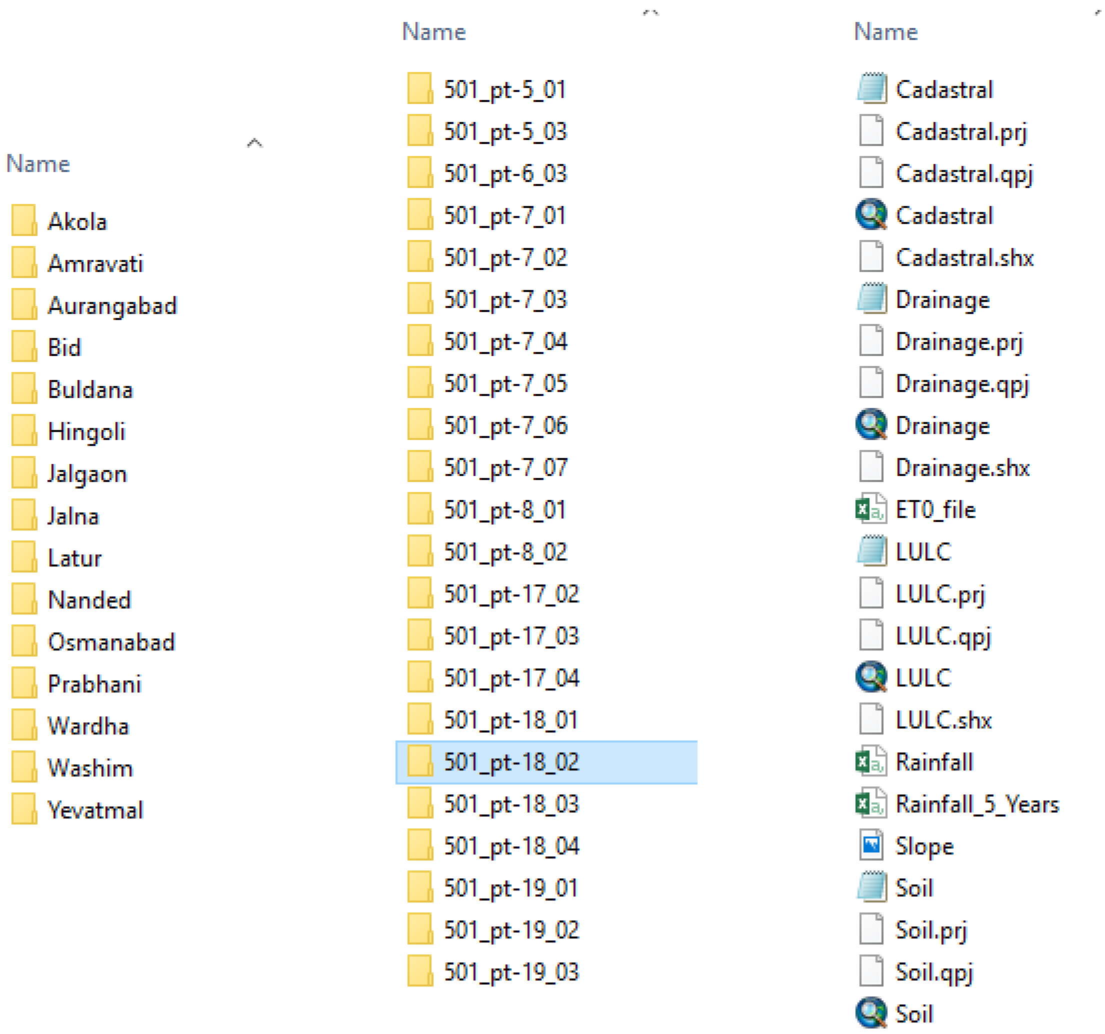
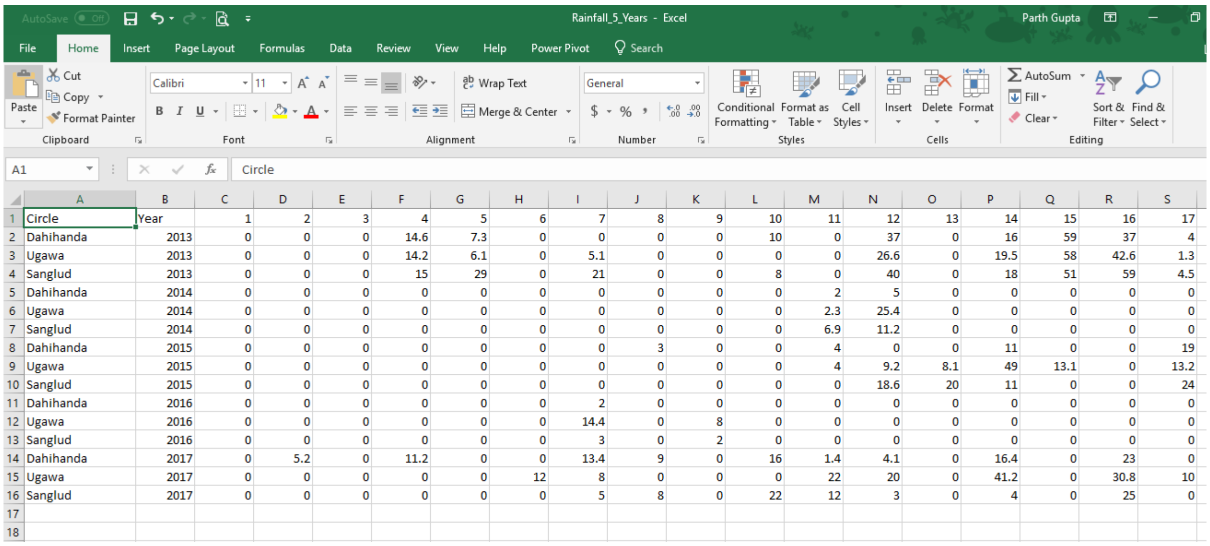


Figure 45 Data Base Folder

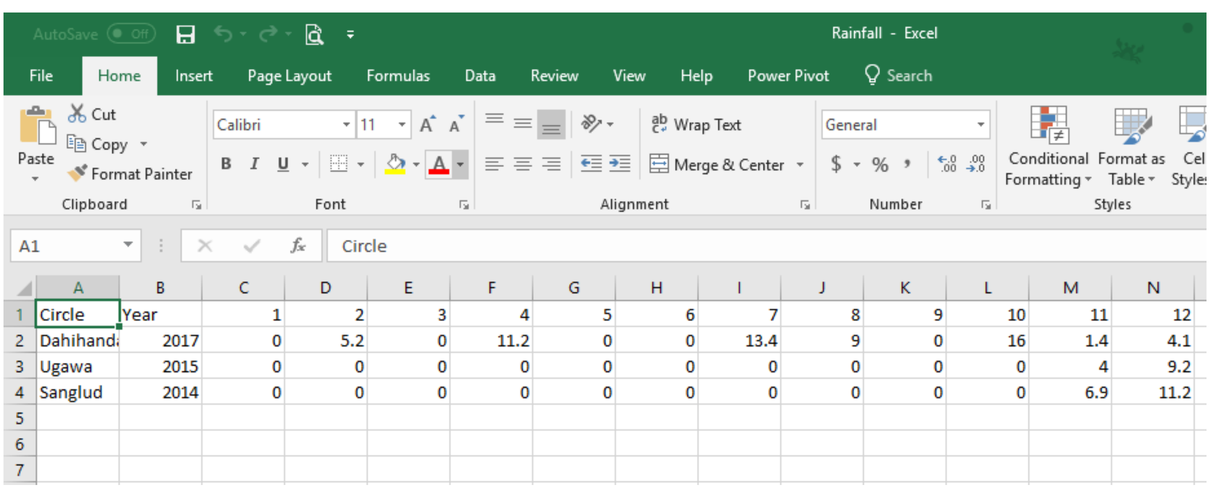
5. The cluster Boundary with Zones files shared in the folder requires further pre-processing. Small zones need to be merged with near ones to form the zone of optimum size. This step requires some manual inspection. The process of preparation of zones is described in the separate document available at (https://www.cse.iitb.ac.in/~pocra/Zoning%20Process.pdf).

6. There are two rainfall files provided in the folder namely Rainfall and Rainfall_5_Years. In the village shapefile, village and its circle are given. This information is used to prepare rainfall file and Rainfall_5_years file. In Rainfall_5_years file, for all the circles which belongs to a cluster, 5years rainfall data is given. This is shown in the image below.



Circle	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Dahihanda	2013	0	0	0	14.6	7.3	0	0	0	0	10	0	37	0	16	59	37	4
Ugawa	2013	0	0	0	14.2	6.1	0	5.1	0	0	0	0	26.6	0	19.5	58	42.6	1.3
Sanglud	2013	0	0	0	15	29	0	21	0	0	8	0	40	0	18	51	59	4.5
Dahihanda	2014	0	0	0	0	0	0	0	0	0	0	2	5	0	0	0	0	0
Ugawa	2014	0	0	0	0	0	0	0	0	0	0	2.3	25.4	0	0	0	0	0
Sanglud	2014	0	0	0	0	0	0	0	0	0	0	6.9	11.2	0	0	0	0	0
Dahihanda	2015	0	0	0	0	0	0	0	3	0	0	4	0	0	11	0	0	19
Ugawa	2015	0	0	0	0	0	0	0	0	0	0	4	9.2	8.1	49	13.1	0	13.2
Sanglud	2015	0	0	0	0	0	0	0	0	0	0	0	18.6	20	11	0	0	24
Dahihanda	2016	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Ugawa	2016	0	0	0	0	0	0	14.4	0	8	0	0	0	0	0	0	0	0
Sanglud	2016	0	0	0	0	0	0	3	0	2	0	0	0	0	0	0	0	0
Dahihanda	2017	0	5.2	0	11.2	0	0	13.4	9	0	16	1.4	4.1	0	16.4	0	23	0
Ugawa	2017	0	0	0	0	0	12	8	0	0	0	22	20	0	41.2	0	30.8	10
Sanglud	2017	0	0	0	0	0	0	5	8	0	22	12	3	0	4	0	25	0

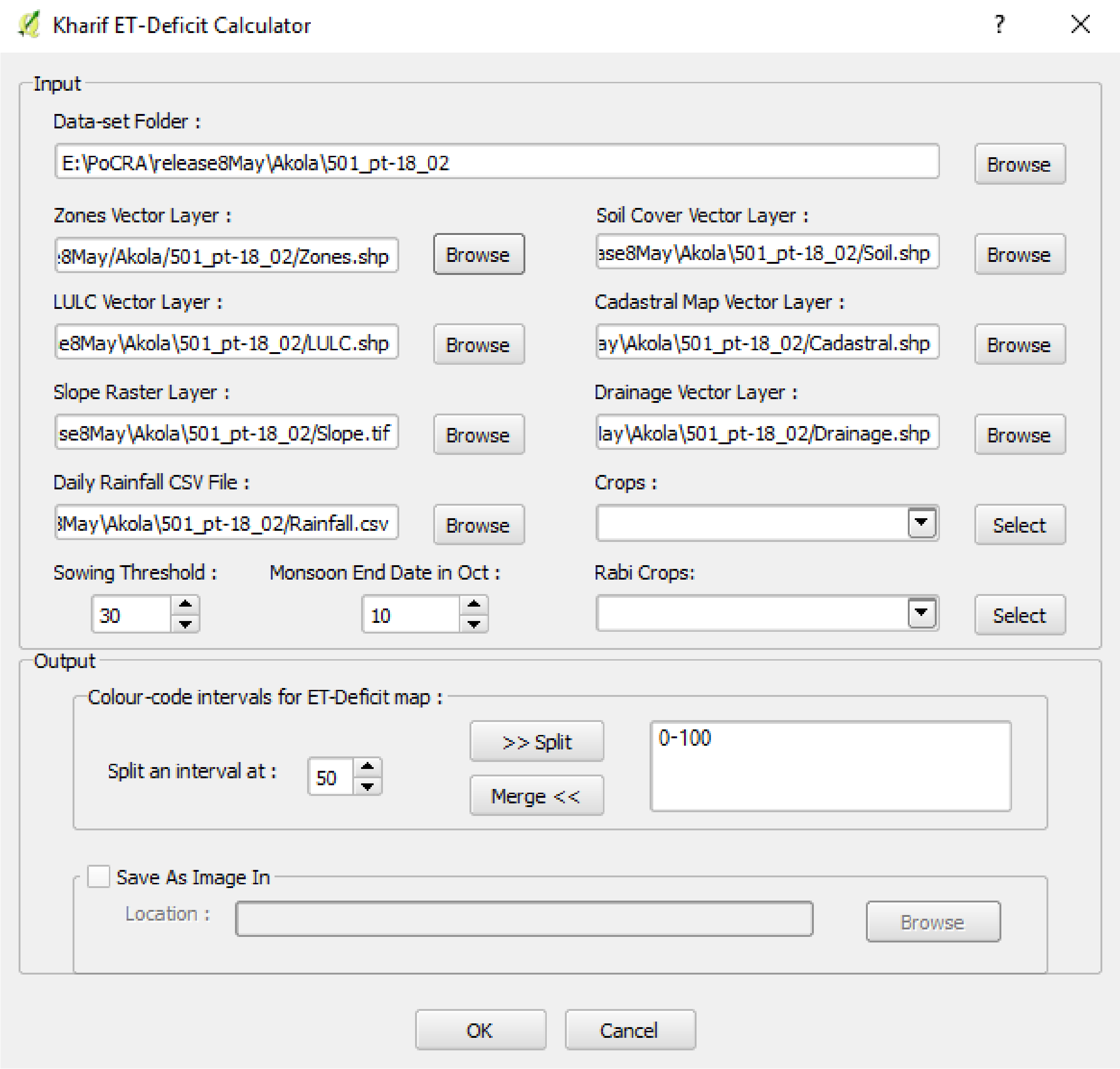
7. Based upon above information, the average rainfall data for number of different circles is given in the Rainfall file. The average annual rainfall of last five years for circle present in cluster is compared with each year rainfall of same circle. For year whose rainfall value is close to average value is given in the Rainfall file. This is shown in the image below.



Circle	Year	1	2	3	4	5	6	7	8	9	10	11	12
Dahihanda	2017	0	5.2	0	11.2	0	0	13.4	9	0	16	1.4	4.1
Ugawa	2015	0	0	0	0	0	0	0	0	0	0	4	9.2
Sanglud	2014	0	0	0	0	0	0	0	0	0	0	6.9	11.2

8. In case, user wants to run the plugin for different years, the data from the Rainfall_5_years file can be coped to Rainfall file.

9. After this the plugin is ready to be run. After clicking the plugin icon, dialogue box with heading Kharif ET-Deficit calculator will appear. User can select the dataset folder on which it wants to run the plugin by browsing to the folder directory. With the default names given to the files it will capture all the files automatically on selecting the folder. if the user wants to select the individual files he can do so. In following image with in Akola district folder cluster with code 501_pt-18_02 has been selected.

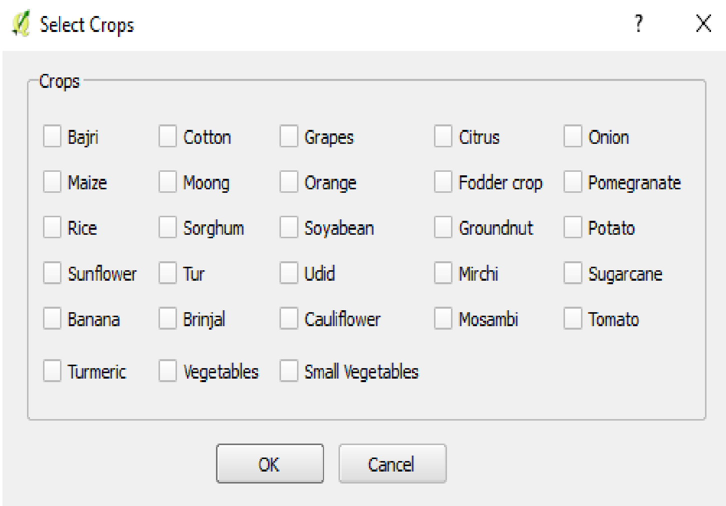


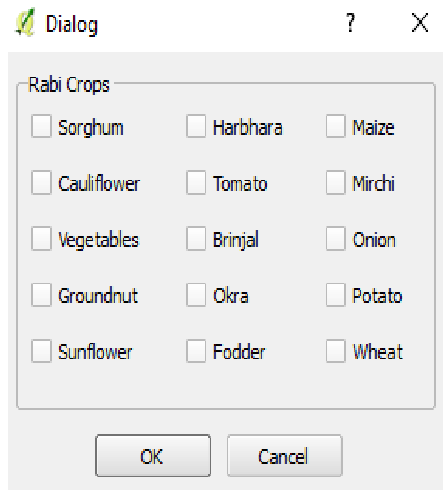
10. By default, the plugin has captured all the required files present in the folder. The user needs to select the crops for which it wants to run the plugin. The crops dialogue boxes have been shown in the image below.

11. By default, sowing threshold of 30mm is given, User can change it to any suitable value.

12. By default, Monsson End Date in Oct is selected as 10^{th} October. User can change it to any value in the month of October.

13. After completing all these steps plugin is ready to run.

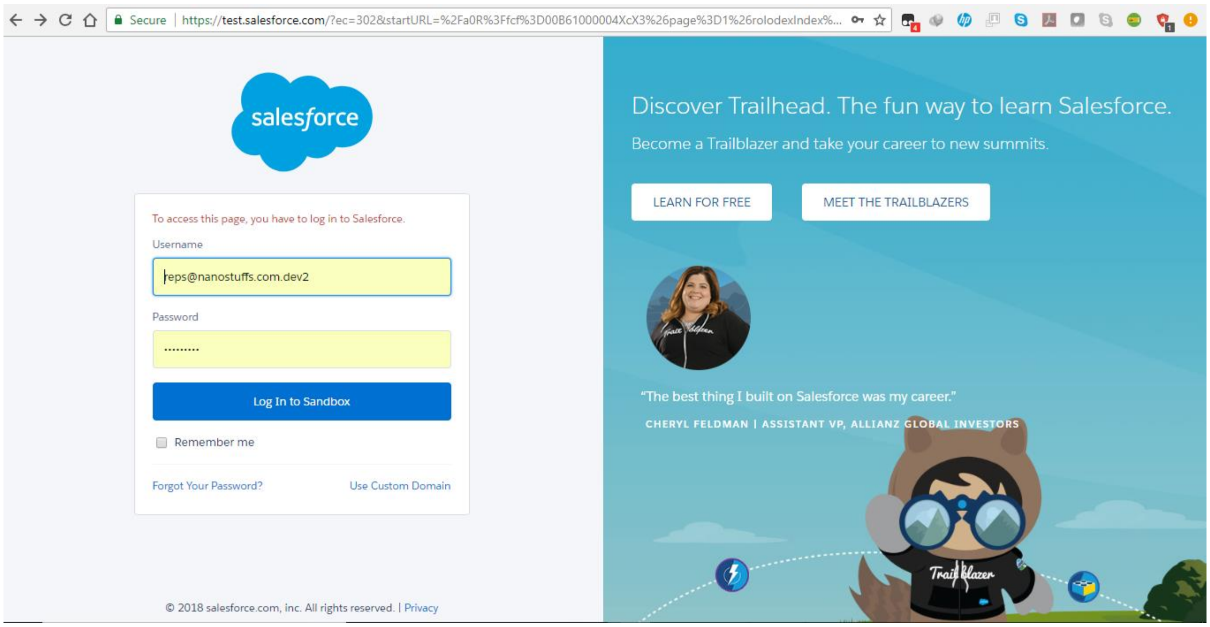




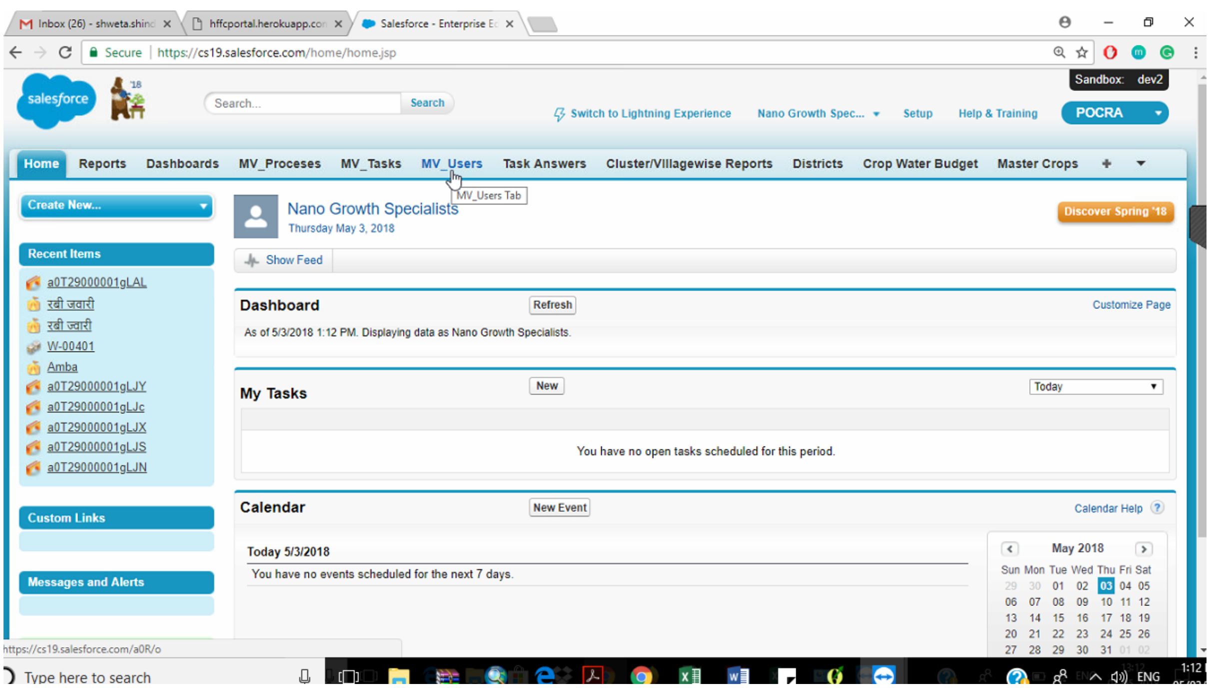
14. Once the plugin run its course, it will generate village wise output files in excel format for all the villages in the zone file.

15. This village wise data needs to be uploaded on the Salesforce server. By clicking on the flowing link, one can open the website where all the uploaded villages will be available. This will require id and password to be provided by the Nano stuff.

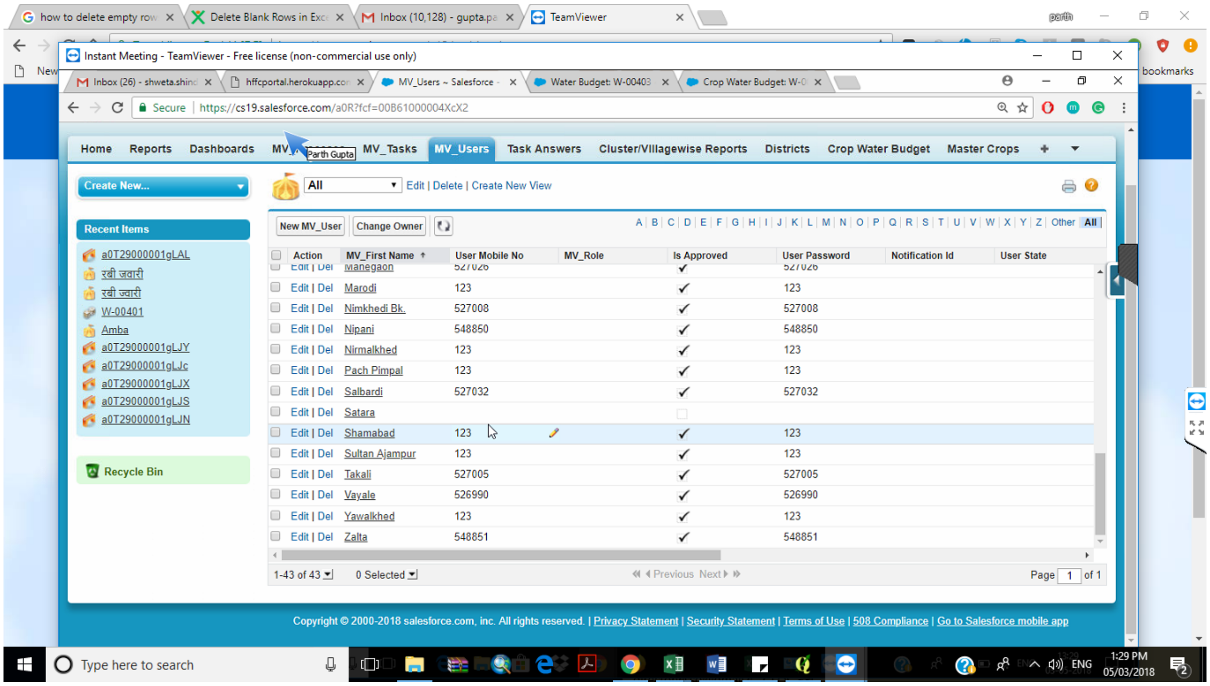
https://login.salesforce.com/?ec=302&startURL=%2Fa0R%3Ffcf%3D00B61000004XcX3



16. After successful login, user can check the villages for which data has already been uploaded. Go to Home->MV_Users.



17. This will open new window described in the image below. Here user can check for villages whose data has been uploaded. User can also delete the data by clicking on the delete button in front of the village name.



18. By opening the link given below one can open the window for uploading the data. The link will give one browse option where user can upload multiple village data at once.

http://hffcportal.herokuapp.com/pocra/multiple_uploads_live_pocra.php

References from IITB PoCRA repository.

[1] Delivery of Overall Solution Framework. link

[2] PoCRA report on description of water balance framework. link

[3] IITB - POCRA meeting and introduction of zone level water budgeting (based on Yeulkhed, Buldhana field visit). link

[4] Single crop Plugin report. (Technical details of model, datasets used and user instructions). link

[5] Report on Need for Zonal Planning Framework (Karanja, Malkapur visit). link

[6] Single crop plugin delivery presentation, meeting and demo. link

[7] Presentation - Karanja Malkapur Field Visit and Zonal Planning presentation. link

[8] Technical advisory progress presentation on scope for refinement. link

[9] Plugin Refinement - requirements presentation. link

[10] PoCRA Water Balance computation Manual in local language. (useful for Agri department and field staff). link

[11] Presentation on village plan analysis steps based on field visit. link

[12] PoCRA Vs JYS - Presentation to Agricultural committee on way forward to water budgeting. link

[13] Crop Water Requirement Calibration document. link

[14] Zoning Process Document. link

[15] Plugin User Manual. link

[16] PoCRA Water Budget and Planning - Scope for Improvements presentation. link

[17] Mahabhulekh data analysis presentation. link

[18] MLP App user manual in local language. link

[19] Plugin Functional Validation Document. link

[20] Multicrop refined plugin report (Technical details, datasets and user instructions). link

[21] Presentation - Divisional Officers Orientation Program, Yashada, Pune. link

[22] Presentation - Training of Trainers Water Budget – Yashada, Pune. link

[23] Presentation - Training VSTF, Pune. link

[24] Training - Beed, Aurangabad. link

[25] Presentation - SDAO level Water Budget, Planning and DPR Assessment – Nagpur. link

[26] Farmer survey format. link

[27] Farmer survey – cropping pattern detailed. link

Other References

[28] Da Silva (1985) Comparison of two computer models for predicting soil water in tropical monsoon climate, Netherlands: Elsevier

[29] Romano (2011) Parameterization of a bucket model for soil-vegetation-atmosphere modeling under seasonal climatic regimes, Italy, Hydrology and earth system sciences

[30] Rockstorm (2003) Dry spell analysis and maize yields for two semi-arid locations in east Africa, Netherlands: Elsevier

[31] Rockstorm (2010) Managing Water in Rainfed Agriculture a need for Paradigm shift, Netherlands: Elsevier

[32] Neitsh, (2009) Soil and Water Assessment Tool Theoretical Documentation, Texas: Texas Water Resources Institute

[33] Allen, FAO Irrigation and Drainage Paper no. 56, Rome: FAO