Planning tools for Water Budget of Watersheds

Submitted in partial fulfillment of the requirements of the degree of

Master of Technology (M.Tech)

by

Sudhanshu Deshmukh

***Roll no.* 163050050**

Supervisor:

Prof. Milind Sohoni

Department of Computer Science & Engineering

Indian Institute of Technology Bombay

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Dissertation Approval

This project report entitled **"Planning tools for Water Budget of Watersheds"**, submitted by **Sudhanshu Deshmukh** (Roll No. **163050050**), is approved for the award of degree of **Master of Technology (M.Tech)** in Computer Science & Engineering.

Prof. Milind Sohoni
Dept. of CSE, IIT Bombay
Supervisor

Prof. Bharat Adsul
CTARA, IIT Bombay
External and Internal Examiner

Prof. Om P. Damani
Dept. of CSE, IIT Bombay
Internal Examiner

Date: ...... July 2018

Place: ________________________

Declaration of Authorship

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Signature: ....

Sudhanshu Deshmukh

163050050

Date: ...... July 2018

Abstract

Water plays essential role in agricultural development, mostly regarding agricultural. Water is important input to enhance agricultural output.So it is essential to formulate supply demand of water(Water budgeting) in terms of computer based tools for easy and optimized methods. There are multiple tools available in water budgeting based on less secondary data, in this study we condsidered secondary data like spatial and temporal components. One of water budget model proposed by CTARA IITB which considers regional water budgeting based on farm level water budgeting and to design and develop IT tools to analyze, compute water budgeting. This water budgeting considers both temporal and spatial components rather than other water budgeting which are in practice in Maharashtra, India.

Current work in completed in two phases where we first studied proposed water budgeting model. After that we have analyzed type of data needed and later designed and developed tools to compute water budgeting. We have developed 2 tools for this. We have developed QGIS plguin for regional water budgeting and an Android app for farm based water budgeting which can support advisory for stress analysis, need for engineering structure to impound surface runoff, planning, etc.

Contents

List of Figures

Chapter 1

Introduction

Water is crucial for life and water scarcity is serious threat to human. According to United Nations Human Development Report 1.1 billion people in developing countries have inadequate access to water[13]. And lack of water can be related to lack of many other basic needs like education, as many human work hours are spent in collection of water.

Water balance is a study between supply and demand of water. Water balance study is also important to study water stress over a region. Water balance is a useful tool to understand the hydrological behavior of a study area. Water balance estimation is important to assess the current status and trends in water resource availability in an area over a specific period of time. Furthermore, water balance estimates strengthen water management decision-making, by assessing and improving the validity of visions, scenarios and strategies.

Currently in India existing official water budget models used in practice do not consider all aspects like soil moisture or ground water balance. Also do not consider spatial and temporal calculation and works on more global parameter assumption. IITB is working with PoCRA(Project on Climate Resilient Agriculture) for water budget by considering supply side and demand side analysis. This method compute regional budget based on considering local aspects variation like spatial and temporal differentiation into consideration. We will be working on this model to be designed into an tool which would compute regional water budget based on farm level water budget and will design tools for this water budgeting. We have developed QGIS plugin which will be used for computing agricultural water budget having zone(part of village) as a unit. We have also developed an Android app which computes farm level water budget.

1.1 Objective:

1. To understand water balance for agriculture and impact of other parameters like soil, usage and study of those parameters.
2. To Study given datasets and understanding and designing framework to utilize them for spatial and temporal water budgeting.
3. To build QGIS plug-in/tool for for water balance computation for regional water budgeting .
4. To build Android app for Farm level/ point level water budgeting for PoCRA project region.

1.2 Chapter Organization

This section shows the organization of remainder of the report. Water budget as a closed system of surface, soil and groundwater is explained in Chapter 2. Chapter 3 describes agricultural water requirements for and model for agricultural water budgeting. This also explain farm level and regional level water budgeting and relation among them. We designed and developed QGIS plugin for regional water budgeting, architecture and inputs of this plugin are explained in Chapter 4. Chapter 5 explains methodology used in QGIS plugin while chapter 6 explains output, its understanding and significance. Chapter 7 explains Android app for water budget which is framework for computing farm level water budgeting. Chapter 8 specifies GPU performance evaluation for GPU overdraw over android app.Chapter 9 concludes and explain future work which can be implemented later.

Chapter 2

Study of water budgeting

2.1 Water Budget

The hydrological cycle forms the basis of the water budget. Its key components include: precipitation, surface runoff, stored surface water, infiltration, ground water storage and discharge, evapotranspiration from atmosphere and vegetation, evaporation from stored surface water and so on. The total amount of water in the hydrological cycle is conserved due to mass balance, which forms the central principle of the water budget.

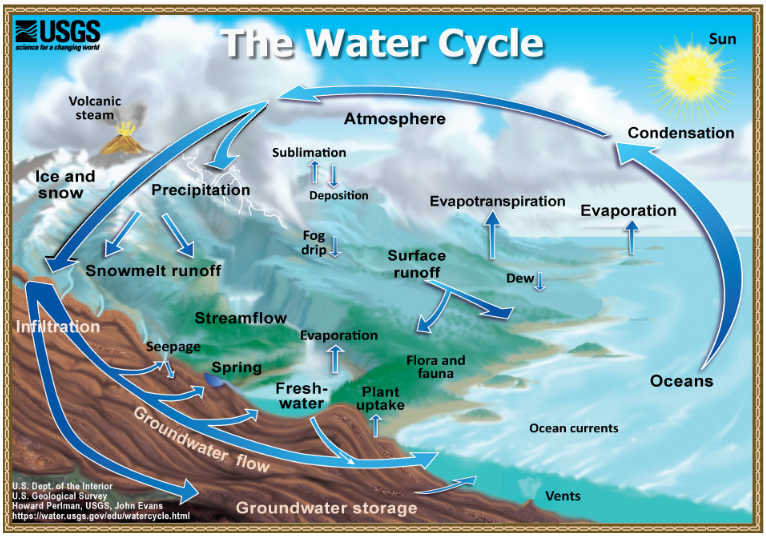


Figure 2.1: Water Cycle [11]

Water Budgeting: A water budget reflects the relationship between input and output of water through a region. A general water balance equation is:

$$P = E + Q + \frac{\mathrm{d}v}{\mathrm{d}t}[4] \tag{2.1}$$

where: P = precipitation, E = evapotranspiration, Q = Runoff, $\frac{\mathrm{d}v}{\mathrm{d}t}$ = is change in ground water level

Precipitation is all water/moisture from the atmosphere which can be from rain,snow,etc.

Evaporation is content of water which is evaporated in the atmosphere from plant or grass.This can be calculated based on land use (forest,agriculture,etc) as evaporation varies for land use due to vegetation type.

Runoff is part of water flows from surface, which is also dependent on soil type, Vegetation, Slope and catchment size and rainfall.

2.2 Water Balance Models in Practice

The hydrological cycle is made up different sub-cycles like the one seen above. Different sub-cycles have different stocks and flows. Various stocks and flows and the corresponding sub-cycles are of interest to different stakeholders and agencies. For example, the conversion of run-off to surface water storage is the primary domain of an irrigation engineer while the changes in soil water stock are of concern to the farmer[6].

Depending upon the objective of the exercise, these balances can be done on a daily, monthly, seasonal or annual basis. Moreover, they may be conducted across a farm boundary, a village boundary or a watershed. While in principle, such computations can be done at various scales and boundaries, the key issue which concerns the agency using a particular model is that of measuring or estimating the stocks and flows. Some quantities can be easily measured, like rainfall while, some require complicated procedures for measurement like evapotranspiration, while some can be only estimated, like groundwater stock. This poses constraints on the boundaries and scales to be used as well as on the accuracy of the models. Three different such scientific water balance models are discussed below:

1. **Regional surface runoff model**

   The system boundary for this model is the land surface of the chosen area. It can be a small land parcel like a farm, a village or a watershed or the whole river basin depending on the scale of interest. The key stock is the surface water stored or impounded within the system boundary.

   The most important incoming flow is the rainfall occurring within the boundary. The key phenomenon in this model is the generation of surface runoff as rain hits the land surface.

   The two main products of this phenomenon are surface runoff and infiltration of the remaining water into the ground. The outgoing flows are the water which infiltrates below the land surface into the soil, surface water which flows out of the boundary through streams, rivers, channels as runoff and the part of the stored/impounded water which leaves to atmosphere as evaporation. Surface water entering the boundary from outside through rivers, streams etc. is also an important incoming flow but the boundary can be so chosen (say, watershed) which makes this quantity redundant. For other boundaries (e.g. village), this quantity needs to be measured / estimated. The temporal scale can be a single rainfall event which lasts for few minutes or hours or can be a single day, the whole monsoon season or the whole year[6]. Following is schematic representation for water flows in Regional surface runoff model

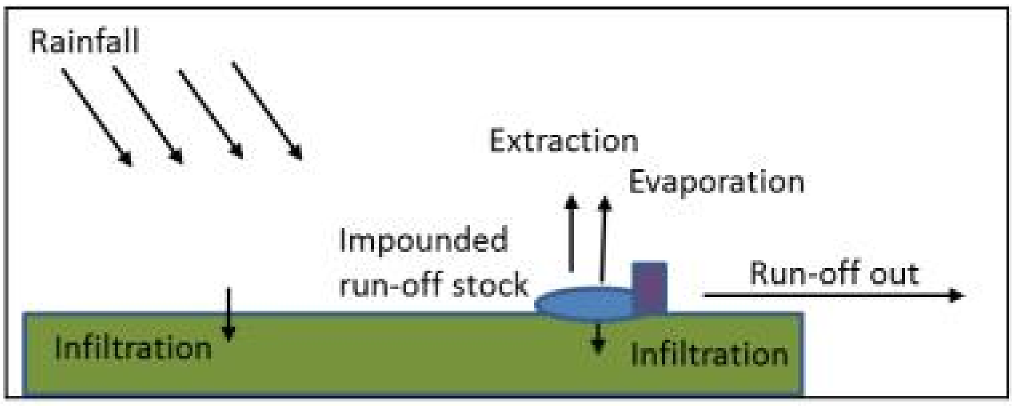


Figure 2.2: Regional surface runoff mode[6]

Following equation explains this model:

$$Rainfall = Surfacerunoff + infiltrationtoSoillayer \quad (2.2)$$

$$SurfaceRunoff = RunoffImpounded + Runoffflowingout \quad (2.3)$$

$$RunoffImpounded = WaterStock + Infiltration + EvaporationLoss \quad (2.4)$$

Explanation of in and out flows of system

Rainfall – this is measured using rain gauges at specific locations and frequency (hourly, daily, monthly or seasonal). In case of low density of rain gauges, the rainfall is generally extrapolated to nearby locations.

Surface run-off – this depends on factors such as the slope of the land, soil type, soil thickness, land use pattern, soil moisture and the daily or hourly distribution of rainfall.

Infiltration – this is computed from the difference between rainfall and runoff for a particular time step (i.e. hourly, daily, monthly or seasonal).

Runoff impounded – this is the key component for the planners. The objective is to impound the runoff and make it available for use. The amount of runoff impounded depends mainly on the type of water impounding structure and its storage capacity. There are different types of water harvesting structures, some are meant to only store the water while others are meant to store water and help it recharge the nearby wells. Various types of structures are cement bunds, earthen bunds, percolation tanks, farm level bunding, contour trenches, terracing etc.

Evaporation losses – The surface runoff which is impounded by engineering structures lead to evaporation loss based on climatic condition like temperature,humidity, surface area of impounding,etc. remaining of impounded runoff after evaporation losses is considered to be available for use.

2. **Soil water balance model**

The system boundary for this model is the soil layer just below the surface. This model is basically a 1-d model explaining vertical movement of water in soil. Consider flow of systems this water budget model has infiltration in surface model as input to the system. For this crop requirement or AET as shown in 2.3 act as demand side of system. key stock is the water held in the soil layer.

This depends on the soil thickness and soil texture. Thick black-cotton soils may hold as much as 200mm of water, while poor and thin soils may hold very little, and crops in such soils may need frequent watering [6].

Below Equation explain flow in Fig2.3:

$$Infiltration = \Delta SoilMoisturestock + ET + GWRecharge \tag{2.5}$$

ET in the above equation represents the demand side and is of prime importance

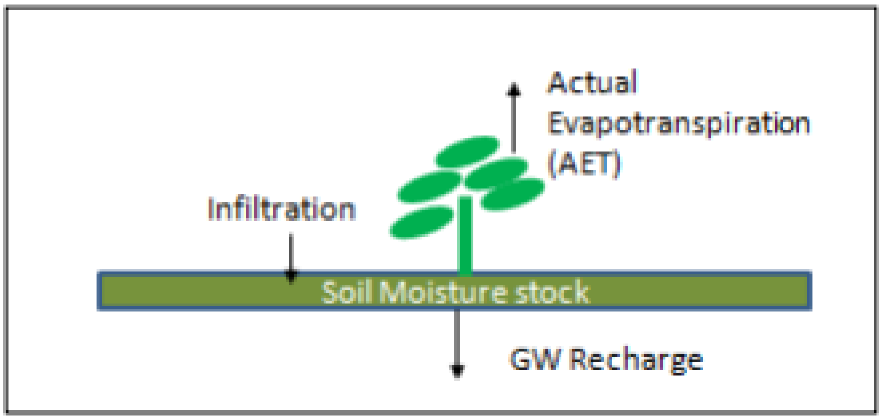


Figure 2.3: Soil Water Balance Model[6]

for plant or crop growth. If the full crop cycle is considered as the time scale, then the supply side can be infiltration from rainfall or irrigation provided by farmer or combination of both.

3. **Groundwater balance model**

   The system of this model is below soil layer or aquifer layer. Water stored in aquifer is key stock for this model. The water in this aquifer layer can be accessed through dug-wells, bore-wells etc for agricultural use. Though aquifer properties can be understood over a larger region to understand ground water flow of water so this is regional water model.

   Ground water balance model is shown in Fig. 2.4. The water percolation from soil layer during monsoon season during higher rainfall. When crop requirement is met from soil moisture and soil moisture level is above some level based on soil type,soil moisture level ,etc then water percolates to below soil layer. This acts as input to system. This is natural rainfall groundwater recharge from rainfall [7]. Also man made structures helps for ground water recharge. Surface impounded using structures like dam, water running from canals, rivers also infiltrates to ground layer and recharges ground water level.

For agricultural , drinking or other human needs water is pumped from aquifer by dug wells, bore-wells,etc. There is also natural discharge of ground water occurring when water exits out of system into lake, stream, etc. Recharge to deep aquifer is also an outgoing flow which depends on underneath rock characteristics. Ground water recharge occurs mostly in monsoon season. while extraction can be done anytime based on the water level (i.e. water available) after extractions.

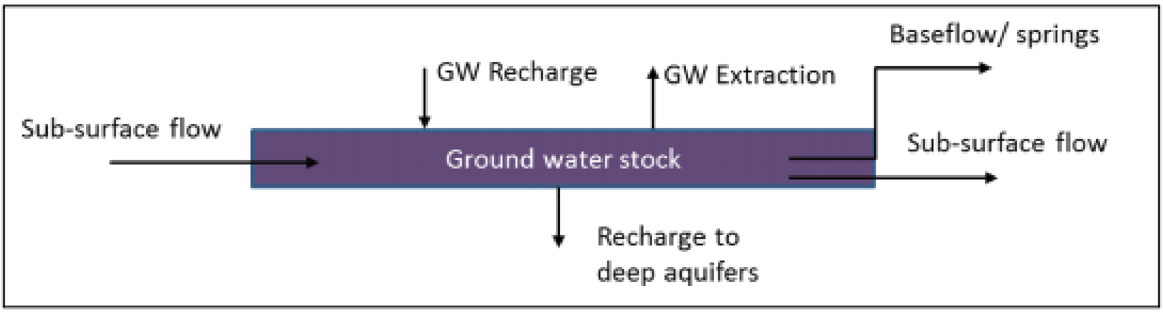


Figure 2.4: Ground Water Balance Model[6]

Chapter 3

Regional and Farm level Water Budgeting

3.1 Water and Agriculture

As above we have discussed 3 water budget models and these interconnected models deals with various stocks and flows. As per the behavior of these flows and temporal availability. This flows help to determine various agriculture demands

1. Surface runoff if impounded can be help for maximum utilization of rainwater for human needs.

2. Knowing or computing soil moisture levels helps to determine crop water stress.

3. Need to compute groundwater stock for its use during soil moisture stress.

To design water budget framework for agricultural use we need to first determine challenges faced by farmers related to water security for agriculture. Major problems are:

1. Erratic, low and intense rainfall scenarios.

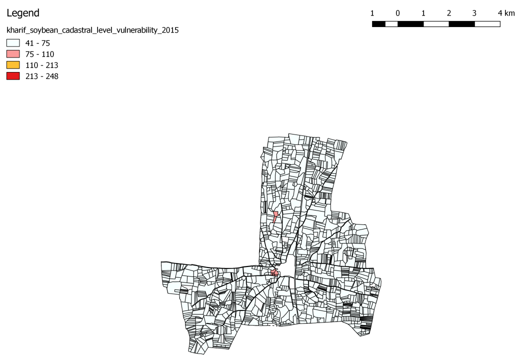
2. Impact of water scarcity due to such rainfall on crop productivity and inability to provide protective irrigation for crop sustainability.

3. Excessive ground water extraction or lower ground water level due to irrigation.

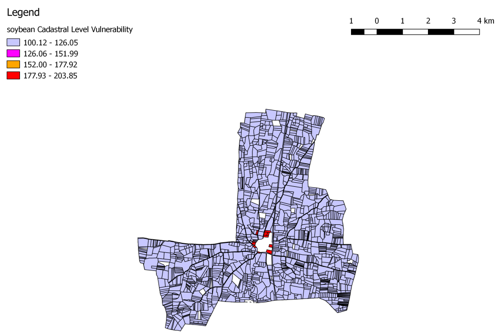
4. Incorrect cropping pattern as per market trends may also impact futuristic water levels and current productivity.

3.1.1 Impact of rainfall over water stress

Rainfall behavior is erratic over the years, also there is large variation between initial rainfall (monsoon start). We will find one example to check rainfall's impact on water stress levels. For Shirala village in Amravati district we ran version of water-budgeting which we discussed earlier and for that we have represented data in maps to analyze water stress .



Water Budgeting for 2015



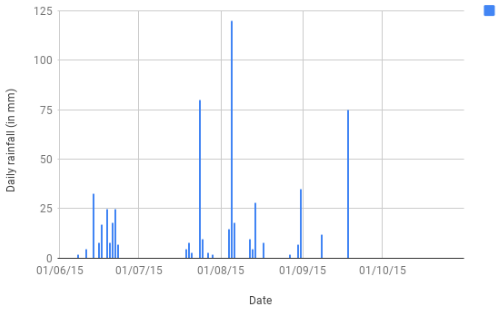
Water Budgeting for 2016

Figure 3.1: WaterBudgeting on Shirala Village for crop Soybean for year 2015 and 2016

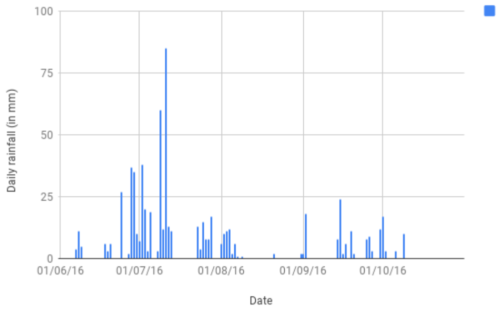
In fig 3.1 water budget is computed for year 2015 and 2016 for crop soybean where total rainfall over year was 594mm and 673 mm respectively. In This village major part of village is having stress in range of 41mm- 75mm in 2015 while similar region is having stress in range of 100mm - 126mm. Though rainfall in 2016 is higher still stress for Soybean crop over same location is higher in 2016. This shows that though rainfall is higher it does not guarantee lesser stress.

This can be better explained with comparing rainfall pattern for 2015 and 2016 in Shirala,Amravati.

Longer dry spell in 2016 after mid August in fig 3.2 is the reason for stress though higher total rain as there is longer haul in 2016 without rain after mid August. In 2016 from 10th August to 13th September there is only 3 rainy days with total rainfall of 25 mm, while for same duration in 2015 there are 7 rainy days with total rainfall of 107mm.



Rainfall in Shirala for 2015

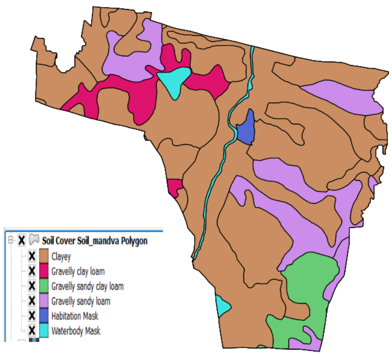


Rainfall in Shirala for 2016

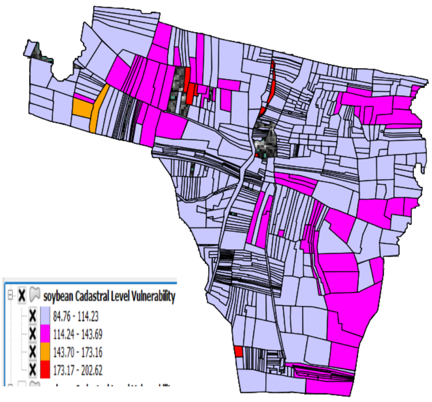
Figure 3.2: Rainfall of Shirala village for year 2015 and 2016

3.1.2 Impact of Spatial Difference

Spatial difference also impacts water stress over same rainfall. To show this we will take example of same village and compare that with soil data i.e comparing spatial soil difference with water stress for the village .



Soil Map with different soil type



Water Budgeting for 2017

Figure 3.3: Impact of Spatial difference on water stress

For Manava Village in Osmanabad district we ran version of water-budgeting which we discussed earlier and for that we have represented data in maps to analyze water stress. Fig 3.3 shows relation between water stress and soil type. As per fig it is evident that cadastral having clayey soil type has low water stress and gravelly clay loam having higher water stress. This shows clear relation between spatial difference and productivity. Thus it is important to consider natural and geographical components while computing water budget.

3.2 Regional and Farm level Water Budgeting

As we have seen in Chapter 2 that water balance in farm level is to optimize farm output, stabilizing and increasing crop productivity, increasing area under agriculture. Also there are factors like rainfall, soil type, geology controls supply of water.

Also surface runoff can be impounded using engineering structures which can provide supplement supply; but question regarding how much to impound, where to impound etc can be only answered when both supply and demand side are considered.

Thus, the ideal architecture would integrate both the supply side and the demand side, the engineering infrastructure as well as bio-physical cycles of water, the temporal scale of the seasons, as well as the spatial scales of the farm with the regional scales, which may be administrative or hydro-geological.

Figure 3.4 explains relation between farm level and regional level supply-demand relationship.

3.2.1 Farm Level Water Budget - correctness of water Demand

Farm level water budgeting as shown in figure 3.4 is based on Bio-Physical data, geographical properties, localized requirement(cropping pattern),etc. As we have seen in section 3.1 , water requirement, stress varies with local properties like soil, topography, rainfall (primary supply). So for a same rainfall water stress varies with change in soil type, slope, etc. So farm level analysis provides more correct values for water stress,GW recharge, runoff (from the farm) given local requirements and local bio-physical condition. Farm level water budgeting also supports micro level advisory at farm level to compare various cropping patterns for water stress analysis. Farm level irrigation requirements and micro planning by farmers to mitigate them.

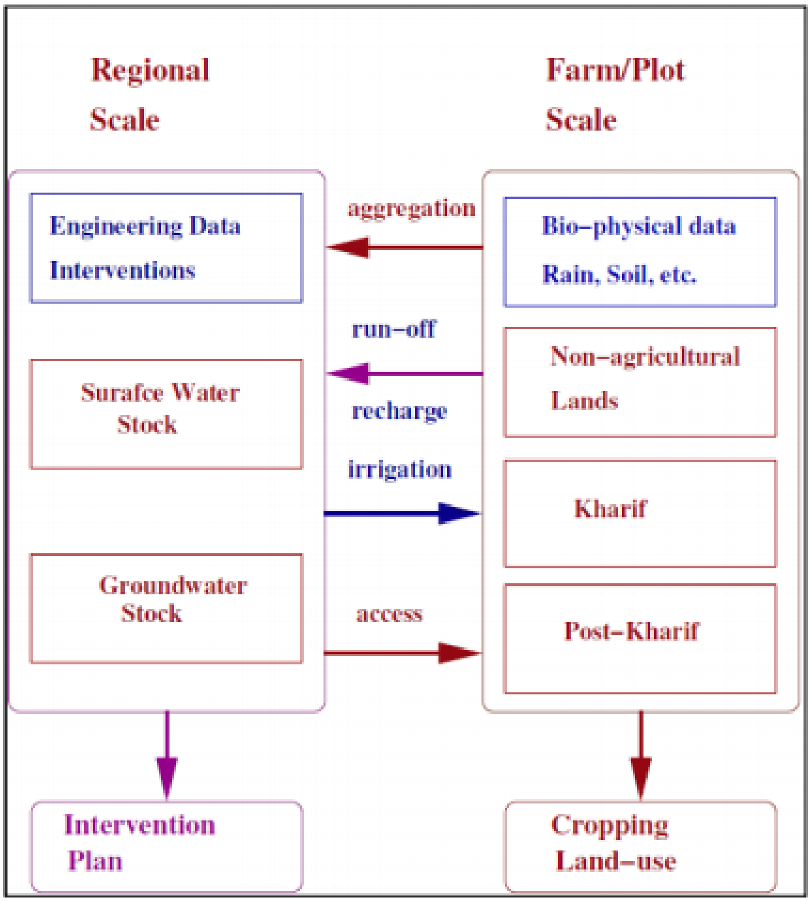


Figure 3.4: Farm Level and regional level water balance and planning [6]

3.2.2 Regional Level Water Budget - support for planning

As planning decisions like construction of impounding structures, their location are of regional aspect as it needs regional knowledge for such decisions. Regional aspect helps for deciding on irrigation demand based on surface runoff stock, ground water stock. Regional water stock is nothing but summation of water stock collected from all farms or samples which gives total value for region.

Thus, an ideal framework must run multiple copies of the farm-level water balance at the daily and local scale, and the surface-water and groundwater balances on the regional scale, and provide computational linkages between the same. We describe here an attempt in this direction.

3.3 Farm-Centric Regional Water balance Model

Based on the architecture in section 3.2.2, Figure 3.5 is the water budget model which can be used for the village / cluster /watershed level planning of interventions. In this

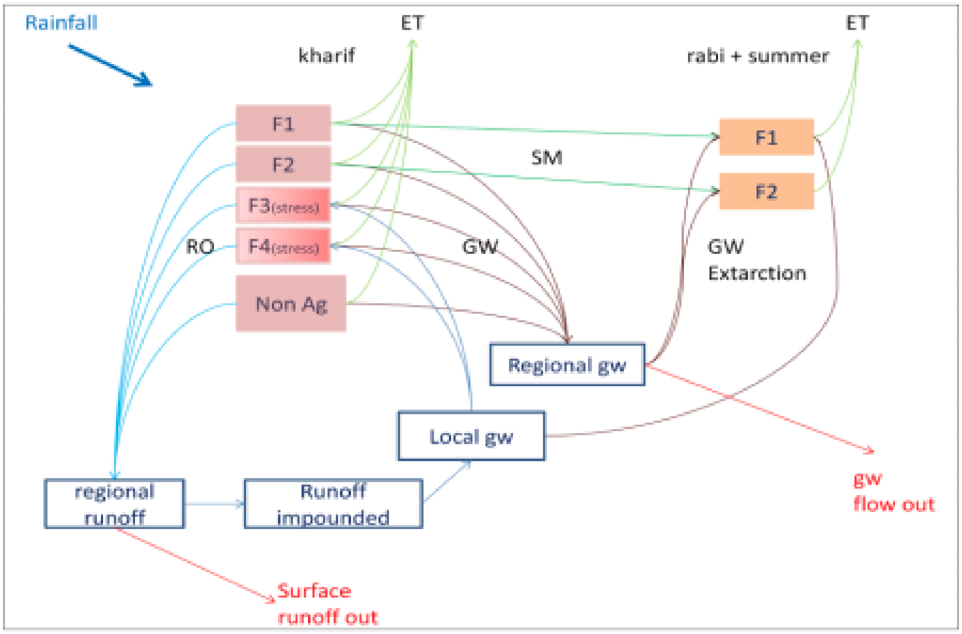


Figure 3.5: Farm centric Regional water balance model[6]

model we need to compute below components:

1. **Water balance computation**

   Water balance computation is performed on farm level to compute daily crop water requirement during crop duration. This daily computation includes computing daily requirement, runoff, soil moisture level, natural GW recharge and secondary runoff. Difference between potential crop water requirement (PET) and actual water given to crop(AET) is stress. The summation of this stress over a monsoon period gives total water required in field for crop. Also post monsoon stress requirement will give irrigation requirement in post monsoon season.

2. **Aggregation over a zone**

   As above components are computed over a single farm but for regional planning a more correct way is to compute water budget values like runoff, GW recharge over a region. A region can be administrative boundary or set of similar HRU(Hydrologic response unit) of administrative boundary. Computing aggregated stress over such zones would help to find critical area where need of mitigating stress is higher.

Chapter 4

Design and developement of QGIS Plugin for Regional Water Budgeting

This chapter presents our design of QGIS plugin for regional water budget and its architecture detailed analysis of input data and preprocessing, if required on those datasets. This chapter also explains few static data computed and used in plugin along with method to compute this data.

4.1 Objective

Objective of the designing and developing QGIS plugin for computation of regional water budgeting where region is divided into zones each having similar hydrological region. As we have seen in section 3.2.2, regional water budgeting acts as support system for advisory and planning, so objective was to build such tool for regional water budgeting. This plugin provide regional water budget where region over administrative cluster(Miniwatershed) which is divided into zones. This QGIS plugin computes water budgeting for multiple crops over agricultural land and similar water requirement for non agricultural land (forest, scrub,etc).

Table 4.1: Data requirement and Source

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/

4.2 Input Files

4.2.1 Data Requirement

Table 4.1 gives the summary of the user input data requirements used in the plugin with its sources. This include vector shapefiles for cluster boundary, LULC, soil, cadastral map and zone map. We also need raster shapefile for slope map which is derived from DEM slope map obtained from online source (SRTM).

4.2.2 LULC Shapefile

The Land Use Land Cover file obtained from MRSAC by PoCRA PMU unit containing 35 types of land use and land cover. This file has been obtained in the form of vector shapefile. This file has land use type for each polygon in attribute 'descriptio' which is queried while computing water budget of sampling point.

4.2.3 Soil Cover Vector Layer

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. This file has been obtained in the form of vector shapefile. We use this file to get soil type and soil layer depth of a sample point from attribute 'TEXTURE' and 'DEPTH' in MRSAC soil map file format. This file need to be in UTM projection.

4.2.4 Zone Map of cluster Boundary

Zoning makes an important step of the whole water budgeting 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. Zone is made from DEM and 'r.watershed' is used to generate basins of DEM clipped to cluster boundary. Sometimes while automatically generating sub watersheds smaller polygons do form. Such polygons need to be merged with other sub watersheds visually analyzing and is manual process.

4.2.5 Cadastral Map

Cadastral map is obtained from MRSAC by PoCRA PMU unit. This is used to compute cadastral based computation for water budget model and computation of number of watering for water deficit.

4.2.6 Slope Map

This is percentage slope raster file for entire region covered by area in Zone vector layer. This file is generated from DEM (Digital Elevation Model) in QGIS.

4.2.7 Rainfall.csv file

This file has annual rainfall for a circle. Each village belong to administrative circle and we have rainfall data for each administrative circle. Rainfall value at administrative circle is considered as rainfall values for each village.So we have to give rainfall file as a format where each row specifies circle name, rainfall year(for default rainfall case) and rainfall for entire year. Default rainfall has selected as average total rainfall condition (Annual rainfall from 2013 to 2018 which is near to average total rainfall).

4.2.8 Other User Inputs:

Also we need below user optional input:

1. **Crop Names := Value (required)**

   This is drop down option to select crops for kharif, long kharif , annual type where computation for water model for agriculture zone is computed based on crop. (Currently crop option includes ’soyabean’, ’bajra’, ’moong’, ’sorghum’, ’cotton’, ’udid’, ’banana’, ’sugarcane’, ’orange’, ’rice’, ’sunflower’, ’tur’, ’grapes’, ’maize).

2. **Rabi Crop Names := Value (required)**

   This is drop down option to select crop for rabi season for which we provide entries for this in zonewise output file . Computation for these crops are not carried out, only PET value is shown in zonewise output file. (Currently Rabi crop option includes ’sorghum’, ’harbhara’, ’maize’, ’onion’, ’mirchi’, ’tomato’, ’brinjal’, ’vegetables’, ’cauliflower’, ’potato’, ’okra’, ’groundnut’, ’sunflower’, ’fodder’, ’wheat’).

3. **Sowing Threshold:= Value (required)**

   Default value : 30 mm

   This value explains minimum rainfall requirement after which sowing is started i.e. selected crop’s evapotranspiration started once cumulative rainfall from June 1 reaches threshold value.

4. **Monsoon End Date in Oct: (required)**

   Default value : 10

   This is date in October till which we compute monsoon computation for our plugin. This parameter is generally decided based on rainfall analysis by user to decide monsoon end in region. By default this value is kept as 10 October.

5. **Save Image Path:**

   This is enabled after clicking checkbox near save Image path. This path is to store the output QGIS canvas to Image at given path.

4.3 Constant values used in Plugin:

In our plugin code we have used constants/lookups to map various soil or land related property to pre computed constants based on various methods which are explained in below subsections. This is explained in this section. constants_dicts_lookups.py in our code directory is used to keep constants used separated from water budget computation code.

4.3.1 Land use Mapping:

We are using (Maharashtra Remote Sensing Application Centre)MRSAC dataset for Land use and as per MRSAC dataset there are 64 LU types but we have broadly divided our LU types in 7 generic types. As multiple types in MRSAC datasets were having similar land usage. In our generalized types 'Agriculture' and 'Fallow land' are considered as agricultural types (where we compute water budget based on user selected crop). And our generic types 'Forest', 'Scrub' and 'Wasteland' are non agricultural types. This land usage mapping is shown in table A.4 in Appendix.

4.3.2 Soil type to Soil properties mapping :

As per (Maharashtra Remote Sensing Application Centre) MRSAC dataset there are 20 distinct Soil types and is retrieved from soil map shapefile attribute 'TEXTURE'. Soil related properties which are used for water budget computation are computed using SPAW's soil water characteristics program. SPAW is a water budgeting tool for farm fields, ponds and inundated wetlands. This tool is by developed by USDA(United States Department of Agriculture)- Agricultural Research Service. Soil Water Characteristics is a program include with the SPAW installation. It is used to simulate soil water tension, conductivity, wilting point, field capacity, Saturation fraction of soil based on the soil texture, with adjustments to account for gravel content, compaction, salinity, and organic matter [10].
For SPAW soil contents (Sand ,clay, gravel % in soil) based on soil type is taken as centroid point in for soil type's polygon in below Figure 4.1 and SPAW's output values are taken for hydrologic soil group (HSG), wilting point (WP), field capacity (FC), saturation point and conductivity(in mm/hr) for soil.

Table 4.2 shows the lookup used in plugin for various soil type. This lookup is used for getting hydrologic soil group (HSG), wilting point (WP), field capacity (FC), saturation

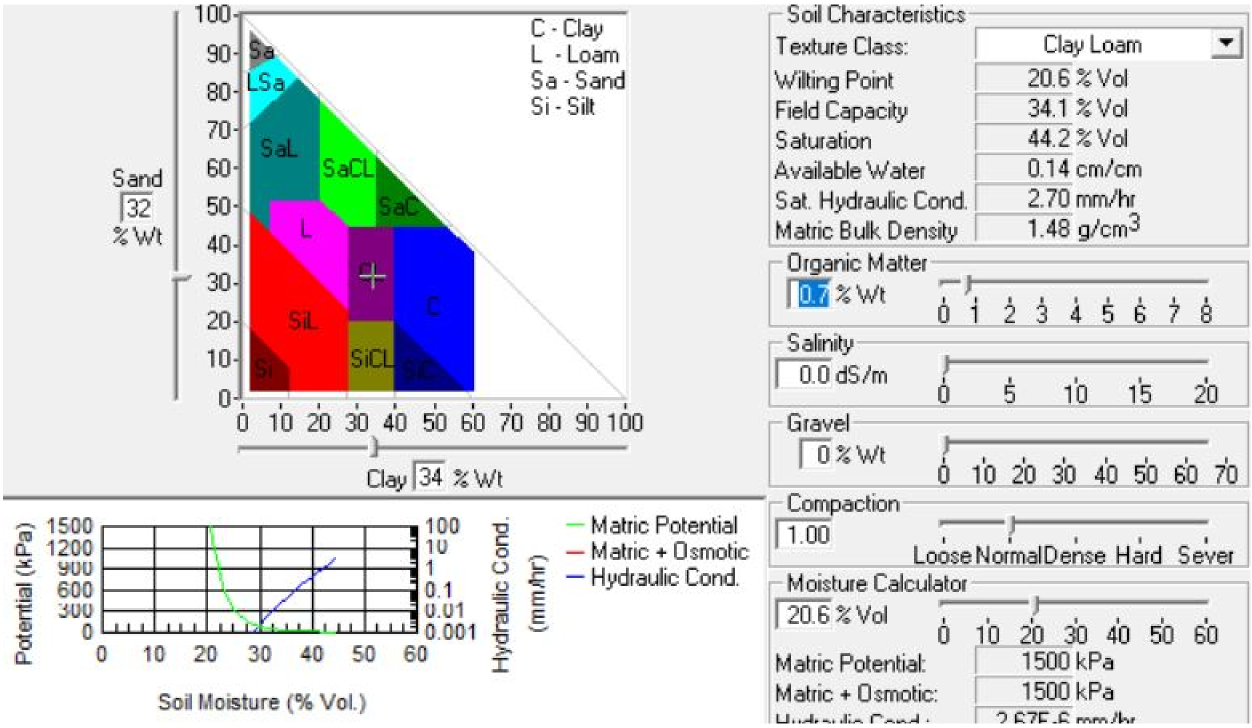


Figure 4.1: Using SPAW tool for Clay Loam soil type's properties

point for soil . Also Conductivity of soil in mm/hr is also given by this lookup. These terminologies and its importance in water budgeting and water infiltration is explained in Appendix B.1.

Also, Soil depth from Soil layer is categorized string value which need to converted to have numeric values for each soil depth type. This lookup for each soil type is as shown in table 4.3.

4.3.3 Crop Related constants:

For water budgeting crop is identified by two parameters - crop duration and total water requirement of crop. Also, water requirement of crop varies with stages of crop and crop growth stages are Initial stage, Crop Development stage, Mid-season stage and Late season stage as per FAO(Food and Agriculture Organization). The most basic crop coefficient, K_c, is simply the ratio of ET observed for the crop studied over that observed for the well calibrated reference crop under the same conditions. K_c for a given crop also changes from sowing till harvest due to variation in crop characteristics and crop requirement ,leaf anatomy,etc. Crop requirement is also based on Evaporation and Transpiration

Table 4.2: Soil types and soil parameters mapping lookup

Soil Type	**HSG**	**Sand %**	**Clay %**	**Gravel %**	**WP**	**FC**	**Saturation**	**Ksat mm/hr**
clay loam	D	32	34	0	0.206	0.341	0.442	2.7
clayey	D	28	51	0	0.303	0.427	0.487	0.52
gravelly clay	D	23	48	10	0.285	0.415	0.488	0.83
gravelly clay loam	D	31	34	10	0.206	0.343	0.444	2.32
gravelly loam	B	41	17	10	0.109	0.244	0.408	10.83
gravelly sandy clay loam	B	49	26	10	0.16	0.273	0.412	5.83
gravelly sandy loam	B	63	10	10	0.065	0.158	0.402	33.29
gravelly silty clay	C	7	47	10	0.277	0.42	0.512	1.7
gravelly silty loam	C	21	15	10	0.099	0.282	0.415	6.8
loamy	B	42	20	0	0.126	0.256	0.411	10.2
loamy sand	A	82	8	0	0.05	0.106	0.41	69.09
sandy	A	91	5	0	0.03	0.071	0.424	108.06
sandy clay	D	51	42	0	0.254	0.364	0.43	0.73
sandy clay loam	C	57	28	0	0.172	0.271	0.406	6.09
sandy loam	A	65	11	0	0.172	0.258	0.399	6.67
silty clay	D	9	46	0	0.272	0.415	0.506	1.9
silty clay loam	D	11	34	0	0.206	0.371	0.47	2.65
silty loam	B	19	16	0	0.105	0.291	0.418	6.97

Table 4.3: Soil depth mapping to numeric values of soil depth

Depth	**Depth Value in meters**
Deep (50 to 100 cm)	1
Habitation Mask	0.15
Shallow (10 to 25 cm)	0.25
Very deep (>100 cm)	1.5
Waterbody Mask	0.15
Moderately deep (25 to 50 cm)	0.5
Shallow to very shallow (<25 cm)	0.25
Very shallow (<10 cm)	0.1

which are dependent on climatic conditions such as temperature, wind speed, humidity, radiation and sunshine hours. The influence of these climatic conditions on crop water requirement is computed in terms of a factor called reference crop evapotranspiration (ET_0). In standard condition $ET_c = ET_0 * K_c$ This crop properties are expplained in Appendix B.2.

1. **Selection of ET_0 values:**

   PoCRA region's 15 district are mapped to 7 zones / weather stations as per WALMI datasets those ET_0 values as given in appendix A.2 for mapping of districts to station and values for each station. Sample ET_0 for one station is as follows:

Table 4.4: Sample ET_0 values for one station

ET_0 in mm/day	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Amravati	4.74	5.89	7.03	8.13	9.09	8.2	4.61	4.45	4.7	5.32	4.76	4.36

2. **Calibrating crop coefficient K_c:**

   - **Calibrate growth stage wise crop duration:**

     Duration of crop growth stages is calibrated first to match WALMI's total crop duration. This process is illustrated through an example.

     Bajra Crop

     Expected WALMI Duration: 90 days

     FAO Crop growth stages (days): 15, 25, 40, 25

     Total FAO crop duration: 105 days

     Multiplication factor: Expected value/Actual value = WALMI value/FAO value = 90/105

     Calibrated crop growth stages used in model: 13, 21, 34, 21

   - **Calibrate growth stage wise crop coefficients (Kc):**

     The process followed for this is similar to that followed for calibration of crop duration.In this example, the total crop water requirement (PET) based on

Table 4.5: Calibration of crop growth stages for Bajra as per WALMI datasets

Growth stages	**FAO duration (days)**	**Weighting based on WALMI**	**Calibrated values**
Initial	15	15 x (90/105)	13
Crop Development	25	25 x (90/105)	21
Mid season	40	40 x (90/105)	34
Late Season	25	25 x (90/105)	21
Total duration	105		90

FAO Kc values as per Amravati ET_0 station is computed. These Kc values are adjusted by multiplying with a factor based on computed CWR and expected WALMI CWR. These calibrated Kc values are then fed into the model. This process is illustrated with an example.

Bajra crop

Expected WALMI CWR: 312.5 mm

FAO Kc values for growth stages: 0.35, 0.7, 1.1, 0.65

Computed FAO CWR: 327 mm

Multiplication Factor: = WALMI Expected CWR/Computed FAO CWR = 312.5/327

Table 4.6: Calibrated Kc values for Bajra crop

Growth stages	**FAO Kc values**	**Weighting based on WALMI**	**Calibrated values**
Initial	0.35	0.35 x (312.5/327)	0.34
Crop Development	0.7	0.7 x (312.5/327)	0.67
Mid season	1.1	1.1 x (312.5/327)	1.05
Late Season	0.65	0.65 x (312.5/327)	0.62
Total CWR	327		312.5

- **Selection of K_c values from one ET_0 station:**

As per above steps K_c values are computed for each station and for each crop and K_c

values which when used with ET_0 of all stations gives minimum RMS error with WALMI PET is selected. K_c values used for all crops is given in Appendix A table A.1.

Chapter 5

Plugin Processing

5.1 Post Input Processing

This section gives detail explanation about processing of plugin for computation part which includes module :

1. Selection of sampling points

2. Running water budget computation on sampled points

3. Computation for current fallow and missing LUs in zone

4. Computation for cadastral polygons

5.1.1 Selection of sampling points

Water budgeting is done on the basis of computing water budget at various points and then computing mean of those sampling points. Sampling points are generated on basis of boundary extents of zone layer. Over the region of zone, points are sampled at distance specified in constants file as STEP. Default sampling distance is 100meters.

Filtering of Sampling Points:

Out of all the sampled points, points having insufficient data in any of required layer(i.e.Soil Layer, LULC layer, Slope layer) are removed from set of sampling points.

Table 5.1: Extraction of values for sampling points from shapefiles

Layer Name	Attribute Name	Siginficance
Soil Layer	TEXTURE	Soil type of a polygon to which sample point belongsin soil layer
Soil Layer	DEPTH	Soil depth of a polygon to which sample point belongs in Soil layer
LULC Layer	'descriptio'	Land use of a polygon to which sample point belongs in LULC layer
Slop Layer	Raster pixel value	Slope % value for a sample point

5.1.2 Running water budget computation on sampled points:

Extraction of values for sampling points from shapefiles:

For sampling points, its attributes are retrieved from containing polygon in layer shapefiles (Soil, LULC, slope ,etc).

Soil type is extracted from soil map layer. Sampling points belonging polygon from soil map layer has attribute 'TEXUTRE' which gives soil type.

Soil depth is extracted from soil map layer. 'DEPTH' attribute of soil map layer gives this value. This value is string literal categorized in 8 categories. This is converted to numeric value for each category as per table 4.3.

Land Use Type is extracted from soil map layer. Sampling points belonging polygon from soil map layer has attribute 'TEXUTRE' which gives soil type. This land use category is converted to generic land use type as per lookup table in Annexure A.4.

Slope value is extracted from raster input file slope map. This is percentage slope value for each sampling point.

Extraction of values for sampling points from Lookup tables:

After values at sampling point from shapefiles are retrieved, we need to compute and set dependent values which are required for water budget computation for each sampling point:

1. **Wilting Point (WP) :** Wilting point is the condition when soil moisture reaches wilting point the water content in soil can not be sucked by plant. This value are taken from table in 4.2.

2. **Saturation (Sat) :** When after rain or irrigation , all soil pores are filled with water, the soil is said to be saturated and soil will not absorb anymore water.This value are taken from table in 4.2.

3. **Field capacity (FC) :** 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 .This value are taken from table in 4.2.

4. **Hydraulic Saturated Conductivity (Ksat) :** Saturated hydraulic conductivity is a quantitative measure of a saturated soil's ability to transmit water. This value are taken from table in 4.2.

5. **Numeric soil depth value**: Soil depth from Soil layer is categorized string value which we convert to numeric value using table in 4.3.

6. **SCS Curve Number (CN) :** This is property of soil type and LULC type this values are taken from table in Annexure ref scsrunofftab. This values are as per SCS standards.

   Curve number for antecedent moisture condition I- dry (wilting point) is given by:

   $$CN_1 = CN_2 - \frac{20.(100 - CN_2)}{(100 - CN_2 + \exp[2.553 - 0.0636.(100 - CN_2)])} \tag{5.1}$$

   Curve number for antecedent moisture condition III- wet (field capacity) is given by:

   $$CN_3 = CN_2.\exp[0.00673\,(100 - CN_2)] \tag{5.2}$$

Computation of parameters before running daily model:

1. **Computation of water at various soil moisture condition:**

   As discussed above Wilting point, Field capacity and Saturation are various levels for soil moisture characteristics where and this varies from soil type to soil type. For water budegeting we need to compute moisture level in soil at these important soil condition.

$$SM_{WP} = WP * depth\_value * 1000 \tag{5.3}$$

$$SM_{FC} = FC * depth\_value * 1000 \tag{5.4}$$

$$SM_{SAT} = SAT * depth\_value * 1000 \tag{5.5}$$

   where SM_{WP}, SM_{FP} and SM_{SAT} are soil moisture content during Wilting point, Field capacity and Saturation respectively.

2. **Soil layer division in 2 layers:**

   Soil is divided into two layers. As generally crop has roots in upper part of soil so lower part acts as water storage rather than feeding water to crop. Crops root level are taken from table A.1 in Appendix A.

$$Soil\_Layer\_depth_1 = \begin{cases} crop\_root\_depth, \text{if } depth\_value \leq crop\_root\_depth \\ depth\_value - 0.05, & \text{otherwise} \end{cases} \tag{5.6}$$

$$Soil\_Layer\_depth_2 = \begin{cases} depth\_value - crop\_root\_depth, & \text{if } depth\_value \leq crop\_root\_depth \\ 0.05, & \text{otherwise} \end{cases} \tag{5.7}$$

   where $Soil\_Layer\_depth_1$ is root zone and $Soil\_Layer\_depth_2$ is below root zone.

3. **Slope adjustment for Curve Number (CN)**

   SCS curve number given by table A.3 is appropriate for slope above 5% we calculate

CN using below formula:

$$CN_{2s} = \frac{(CN_3 - CN_2)}{3}.[1 - 2.\exp(-13.86.slp)] + CN_2[8] \quad (5.8)$$

where CN_{2s}, is the moisture condition II curve number adjusted or slope, CN_3 is the moisture condition III curve number for default 5% slope,CN_2 is the moisture condition II curve number for default 5% slope, and slp is the slope percentage of the point[8].

For CN_1 and CN_3 we calculate respective retention parameters S_{max} and S_3 , where retention parameter S is potential soil moisture retention after runoff begins:

$$S_{max} = 25.4 * (1000/CN_1 - 10) \quad (5.9)$$

$$S_3 = 25.4 * (1000/CN_3 - 10) \quad (5.10)$$

4. **Computation parameter for daily percolation factor**

   To compute water percolation we need to compute total time required for travel time for percolation. This is dependent on maximum possible water in soil layer and Hydraulic Saturated Conductivity.

$$Total\_travel\_time(hrs) = (SM_{SAT} - SM_{FC})/Ksat\ [9] \quad (5.11)$$

$$depletion\_factor = 1 - \exp(-24/Total\_travel\_time)[9] \quad (5.12)$$

Daily run for water balance computation:

We compute daily water balance based on daily rainfall and daily crop water requirement this daily computation is mainly divided into 5 parts:

1. **Daily Primary Runoff**

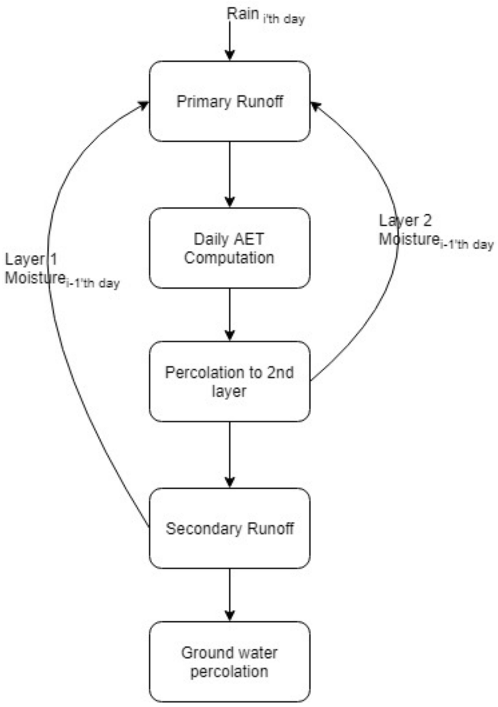


Figure 5.1: Daily Water balance computation

$$SM_{day} = (SM\_frac_{layer1_{day}} * Soil\_Layer\_depth_1) + (SM\_frac_{layer2_{day}} * Soil\_Layer\_depth_2) \tag{5.13}$$

where SM_day is total moisture in soil layer, $SM\_frac_{layer1_{day}}$ is soil moisture fraction for layer 1 and $SM\_frac_{layer2_{day}}$ is soil moisture fraction for layer 2.
Water available above Wilting point i.e. Maximum water that can be extracted by crop is calculated as:

$$SW = SM_{day} - SM_{WP} \tag{5.14}$$

Retention parameter is calculated for daily changing run off using below formula Daily retention parameter S is calculated using

$$S = S_{max}\left(1 - \frac{SW}{[SW + \exp(w1 - w2.SW)]}\right) [8] \tag{5.15}$$

Where S is retention parameter for given day in (mm), S_{max} is maximum value of retention parameter on any given day, SW is soil water content of entire profile excluding amount held in profile wilting point (mm). $w1$ and $w2$ are shape coefficient and S_{max} is calculated using CN1

$w1$ and $w2$ are calculated using below formulas:

$$w1 = \ln\left\lfloor \frac{SM_{FC}}{1 - S_3.S_{max}^{-1}} - SM_{FC} \right\rfloor + w2.SM_{FC}[8] \tag{5.16}$$

$$w2 = \frac{\left(\ln\left\lfloor \frac{SM_{FC}}{1-S_3.S_{max}^{-1}} - SM_{FC}\right\rfloor - \ln\left\lfloor \frac{SM_{SAT}}{1-2.54.S_{max}^{-1}} - SM_{SAT}\right\rfloor\right)}{(SM_{SAT} - SM_{FC})}[8] \tag{5.17}$$

where $w1$ is the first shape coefficient. $w2$ is the second shape coefficient.SM_{FC} is the amount of water in the soil profile at field capacity (mm H_2O). $S3$ is the retention parameter for the moisture condition III curve number,$S-max$ is retention parameter for the moisture condition I curve number. SM_{SAT} is the amount of water in in the soil profile when completely saturated(mm H_2O), and 2.54 is retention parameter value for curve number 99

Daily runoff is calculated using retention parameter S calculated daily by using below formula:

$$Runoff_{day} = \begin{cases} ((rain_{day} - 02 * S)^2)/(rain_{day} + 0.8 * S), & \text{if } (rain_{day} - 02 * S) > 0 \\ 0, & \text{otherwise} \end{cases} [8] \tag{5.18}$$

where $Runoff_{day}$ is runoff for the day, S is retention parameter is for the day, $rain_{day}$ is rainfall for day for which $Runoff_{day}$ is being calculated

2. **Daily Crop evapotranspiration (AET) calculation**

After calculating runoff and infiltration for day , Actual crop evapotranspiration (AET) is computed based on available soil moisture and potential crop evapotranspiration(PET) of crop for the day.We have discussed method to compute PET of crop in section B.2.

Although water is theoretically available until wilting point, crop water uptake decreases before wilting point is reached. When soil is sufficiently wet, crop uptake can be high but after some certain value water would not be readily available though soil moisture is above wilting point.

Readily available water can be calculated by depletion factor(p) which gives fraction of total available water which is readily available. and depletion factor (p) specifies water stress condition.This is explained with water stress coefficient in Appendix section B.2

Water stress coefficient describes effect of water stress on crop ET(ET_c). Ks is used to calculate ET_c Adj, and value of Ks is dependent on water stress condition. Ks is calculated as

$$K_s = \begin{cases} 0, & \text{if } SM\_frac_{layer1_{day}} \leq WP \\ 1, & \text{if} SM\_frac_{layer1_{day}} > (FC * p + WP \\ (SM\_frac_{layer1_{day}} - WP)/(FC - WP)/(1-p), & \text{otherwise} \end{cases} \tag{5.19}$$

So using this water stress coefficient we compute AET by,

$$AET_{day} = K_s * K_c * ET_0 = K_s * ET_c[2] \tag{5.20}$$

3. **Percolation to 2^{nd} (below root) layer**

   We calculate soil moisture of root layer once AET happens and then check if this soil moisture is above soil moisture at field capacity. Percolation to below root-zone starts only if soil moisture at root layer is more than field capacity and the soil below root-zone is not saturated,i.e. soil moisture at root layer is less than saturation. When percolation occurs it is derived as the minimum of the maximum possible percolation and the amount available in the root-zone for percolation [9].

4. **Daily Secondary Runoff calculation**

   Here we check if Soil moisture after percolation to below root zone is still greater than saturation or not. If it is greater than saturation level then we set soil moisture level as Saturation as soil can not hold any water above saturation level. Excess moisture is released as part of Secondary runoff. So secondary runoff occurs only in case of excess water in root level.

5. **Ground Water Percolation**
   Ground water percolation will occur only from below root zone as that layer is only connected with aquifer layer. Ground water recharge happens only in case if Soil moisture level of below root zone is above field capacity. In this case recharge happens based on daily percolation factor and soil moisture of below root zone above field capacity.

5.2 Computing water budgets for pseudo or additional Land use types:

As above computation is done on all points selected as per method in section 5.1.1 and LU types of these types are as per LU maps which we selected in section and computed water budget according to these types and respective crop requirement. But there may be possibility on field to find Land use type present which is not present in our LU map. Also there may be few agriculture land which is not in use for current year agriculture so we need to consider that type of land as different LU (i.e. current fallow) . Also as we expect our output to be used for village water budget computation using area per crop to compute entire water budget of village/cluster. Below are steps taken for above issues:

1. Consider all agriculture points for current fallow
   We consider current fallow as user specified land usage over entire agricultural points. This land use type is user defined type nad not present as per our generalized types. For this pseudo land use we use below curve number:

Table 5.2: Curve Number for current fallow

LU	HSG A	HSG B	HSG C	HSG D
current fallow	72	81	88	91

Also due to above this current fallow having lower crop water requirement we use land use crop (i.e. dummy crop) specifying water requirement

Table 5.3: Current fallow crop Kc values

Crop Name	Initial Duriation	Crop dev Duration	Mid Season Duration	Late Duration	Initial Kc	Crop dev Kc	Mid Season Kc	Late Kc	Root depth in meter	depletion factor
current fallow crop	30	30	31	31	0.2	0.2	0.3	0.3	0.9	0.5

There are also cases due when any landuse is present in LULC map but present in real scenario on field:

1. **When few Non agriculture types are absent in LULC**
   When few Non agriculture types are absent in LULC in any zone (i.e. Selected samples don't have all Non agriculture types but have at least one Non agriculture types from 3 Agriculture types). In this case we consider missing Land use type for copies of points having present Non ag type.
   Example. If zone-1 has Non agriculture types 'forest' and 'wasteland' present and 'scrub' is missing, then we will take copies of all Non agriculture sampling points (retaining properties of points related to soil,etc) and change Land Use type to missing Land use ('scrub' in this case) and run daily water budget on these sampling points. This will give us values for Missing LU Type.

2. **When Either Non Agriculture type or Agriculture type is absent in LULC map**
   In this case we will consider all points of other type and consider copies of these points for missing LU and run daily water budget on these copied sample points.
   Example 1 : If Non agriculture type is not present then we will make copies of all agriculture points and run water budgeting on these copied samples for 'scrub', 'forest' and 'wasteland' Land use.
   Example 2 : If agriculture type is not present then we will make copies of all Non agriculture points and run water budgeting on these copied samples for agriculture crops and again for current fallow with different Land Use properties than agriculture.

Chapter 6

QGIS Plugin Output

6.1 Output Files and Maps

Once Computation is done we provide 2 type of Outputs:

1. Cadastral wise Vulnerability Map
2. Zone wise wise Report for village

6.2 Cadastral wise Vulnerability Map

For cadestral wise vulnerability objective is to have crop end cadastral wise vulnerability and having maps for each crop selected by user when plugin starts. Cadastral wise vulnerability is computed by taking centroid for each gat/ cadastral and computing water budget on this points. If this gat also has any sampling points as selected in section 5.1.1 then cadastral wise vulnerability is computed for each Kharif crop by considering mean of all sampling points and centroid in each gat(survey no) and if there are no sampling points (in case of smaller surveys) then computing water budget on either centroid or boundary point of such polygon for water deficit. Once vulnerability is computed for each crop then vulnerability map is generated based on water deficit (PET -AET) for each crop for each survey polygon by categorizing vulnerability value for each crop.
Output file name: kharif_cropname_cadastral_level_vulnerability.shp

In figure 6.1,cadastral vulnerability map for crop Tur is shown. This is for cluster in

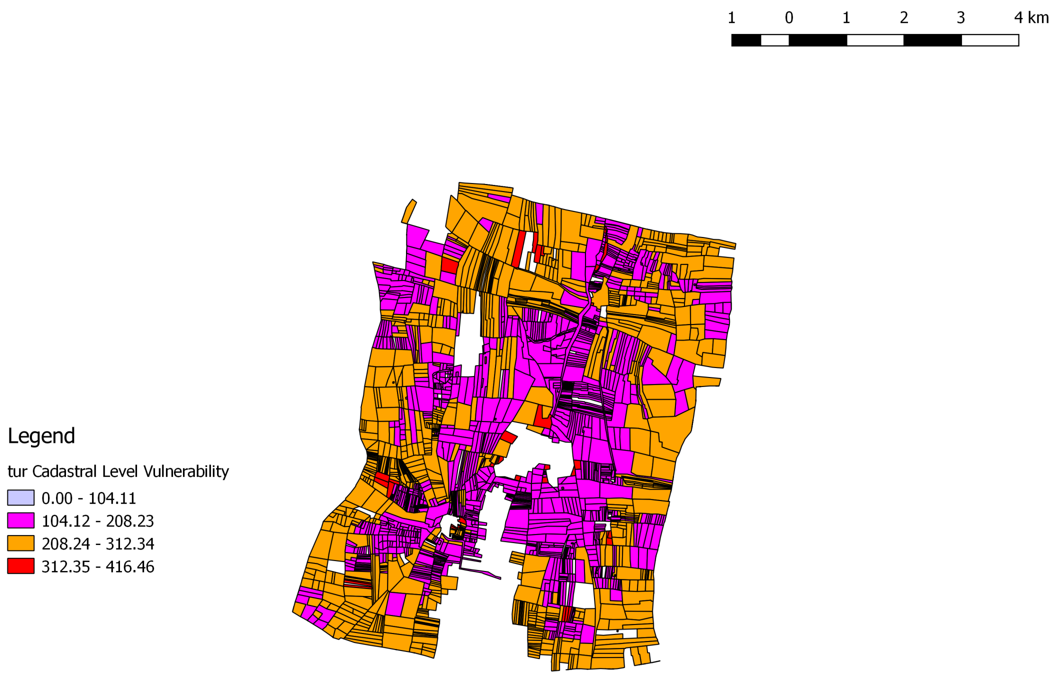


Figure 6.1: Cadastral wise Vulnerability Map

Osmanabad district for 3 villages Bavi, Sonarwadi and Mandva.

6.3 Zone wise Report for village

Consolidated zone-wise report is generated for each village in entire cluster. For each zone, Water budget is computed on agriculture and non agriculture points , also in case if any Land use type is not present then water budget of such type is computed by taking copy of existing points as mentioned in section 5.2. This file has crop entries for each zone as rows and computed values as columns. Each village has single file for reporting. Output File name: Village-wise_output_¡village Name¿.xls

In this file we compute aggregated output for all points selected inside a zone. As our village is divided into various zone . So zone is our smallest planning unit from this unit. Each row is for a single crop in a zone. This crop includes used selected kharif crop, rabi crop and all Non ag crop. If as per LULC map there is any Non ag not present and in real scenario it can present; for such scenario we compute this using methods specified in

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Village Name	Census Code	Zone	Zone Area (h	Crops in Eng	Crops in Mar	Crop Season	Rainfall (mm	PET Monsoo	AET Monsoo	Monsoon Def	GW Recharg	Runoff in Mo	Soil Moisture	Post Monsoo
2	Mandva	561274	zone-Mandva-1	417.6055792	cotton	कापूस	Long_kharif	677.7	595.12	435.1	160.01	20.15	205.98	16.47	207.2
3	Mandva	561274	zone-Mandva-1	417.6055792	soybean	सोयाबीन	Kharif_Main	677.7	406.54	336.64	69.9	29.69	224.48	86.89	0.0
4	Mandva	561274	zone-Mandva-1	417.6055792	tur	तूर	Long_kharif	677.7	511.09	393.99	117.1	26.0	231.66	26.05	119.66
5	Mandva	561274	zone-Mandva-1	417.6055792	gram	रब्बी हरभरा	Rabi	677.7	0	0	0	0	0	0	350
6	Mandva	561274	zone-Mandva-1	417.6055792	rabi_wheat	रब्बी गहू	Rabi	677.7	0	0	0	0	0	0	525
7	Mandva	561274	zone-Mandva-1	417.6055792	current fallow	चालु पड	Landuse	677.7	156.62	148.4	8.22	84.42	361.47	83.4	0.0
8	Mandva	561274	zone-Mandva-1	417.6055792	Non Agri	बिगर शेती	Landuse	677.7	156.62	148.4	8.22	84.42	361.47	83.4	0.0
9	Mandva	561274	zone-Mandva-1	417.6055792	permanant fa	कायम पड (गाव	Landuse	677.7	156.62	148.4	8.22	84.42	361.47	83.4	0.0
10	Mandva	561274	zone-Mandva-1	417.6055792	wasteland	पोटखराबा	Landuse	677.7	258.11	242.78	15.33	59.22	293.12	82.58	135.53
11	Mandva	561274	zone-Mandva-1	417.6055792	scrub	गायरान	Landuse	677.7	161.2	156.74	4.46	104.61	320.76	95.6	120.29
12	Mandva	561274	zone-Mandva-1	417.6055792	forest	वनक्षेत्र	Landuse	677.7	497.4	408.91	88.49	56.25	165.75	46.79	272.18
13	Mandva	561274	zone-Mandva-2	228.4076296	cotton	कापूस	Long_kharif	677.7	595.12	456.15	138.97	16.73	185.99	18.83	207.2
14	Mandva	561274	zone-Mandva-2	228.4076296	soybean	सोयाबीन	Kharif_Main	677.7	406.54	347.44	59.11	22.67	204.8	102.79	0.0
15	Mandva	561274	zone-Mandva-2	228.4076296	tur	तूर	Long_kharif	677.7	511.09	415.41	95.68	20.26	211.59	30.45	119.66
16	Mandva	561274	zone-Mandva-2	228.4076296	gram	रब्बी हरभरा	Rabi	677.7	0	0	0	0	0	0	350
17	Mandva	561274	zone-Mandva-2	228.4076296	rabi_wheat	रब्बी गहू	Rabi	677.7	0	0	0	0	0	0	525
18	Mandva	561274	zone-Mandva-2	228.4076296	current fallow	चालु पड	Landuse	677.7	156.62	148.46	8.16	71.19	344.88	113.17	0.0
19	Mandva	561274	zone-Mandva-2	228.4076296	Non Agri	बिगर शेती	Landuse	677.7	156.62	148.46	8.16	71.19	344.88	113.17	0.0
20	Mandva	561274	zone-Mandva-2	228.4076296	permanant fa	कायम पड (गाव	Landuse	677.7	156.62	148.46	8.16	71.19	344.88	113.17	0.0
21	Mandva	561274	zone-Mandva-2	228.4076296	wasteland	पोटखराबा	Landuse	677.7	258.11	244.08	14.03	46.95	273.94	112.73	135.53
22	Mandva	561274	zone-Mandva-2	228.4076296	scrub	गायरान	Landuse	677.7	161.2	156.31	4.89	91.95	302.43	127.01	120.29
23	Mandva	561274	zone-Mandva-2	228.4076296	forest	वनक्षेत्र	Landuse	677.7	497.4	437.57	59.83	38.56	137.8	63.78	272.18

Figure 6.2: Zone wise wise Report for village

section 5.2

For each crop in each zone this report file has columns specifying various entities like , PET Monsoon End,AET Monsoon End,Monsoon Deficit(PET-AET),GW Recharge in Monsoon,Runoff in Monsoon (mm),Soil Moisture Monsoon end,Post Monsoon PET,Infiltration in Monsoon (mm),Soil Moisture Crop end, etc.

Chapter 7

Water Budgeting Android App

7.1 Idea

In this chapter, we will look into design and architecture of android app created for farm level water budgeting. App is created for considering *"Krishi- Mitra"* and farmers as end user. This app provides user easy to access UI and also provide them info about their location-based soil properties as per MRSAC datasets without any technical background of water budgeting and GIS datasets.

As we have seen in section 3.2.1 the importance of farm level water budgeting which support result towards correctness and can help for micro level planning so building an tool was an objective which can feed into micro planning and advisory.

7.2 Design and Architecture

Design and architecture of android app is given below in fig 7.1. This shows stepwise actions performed before showing outputs. In our flow first user selects location in map and that location is sent to Apache server having Postgres+ PostGIS as database backend. The request is sent via Volley Liabrary in android which is used for REST API. Once request is sent to server server will send response to android in form of JSON object. This JSON object will have details like land use, slope, soil type, soil depth, district, rainfall, etc of selected location. This data is then used to set few location based input values at user from which user can change if required. User will also need to provide few user specific inputs and will run water budgeting for farm level. This request will create graphical as well as textual output. This is explained in later section 7.6.

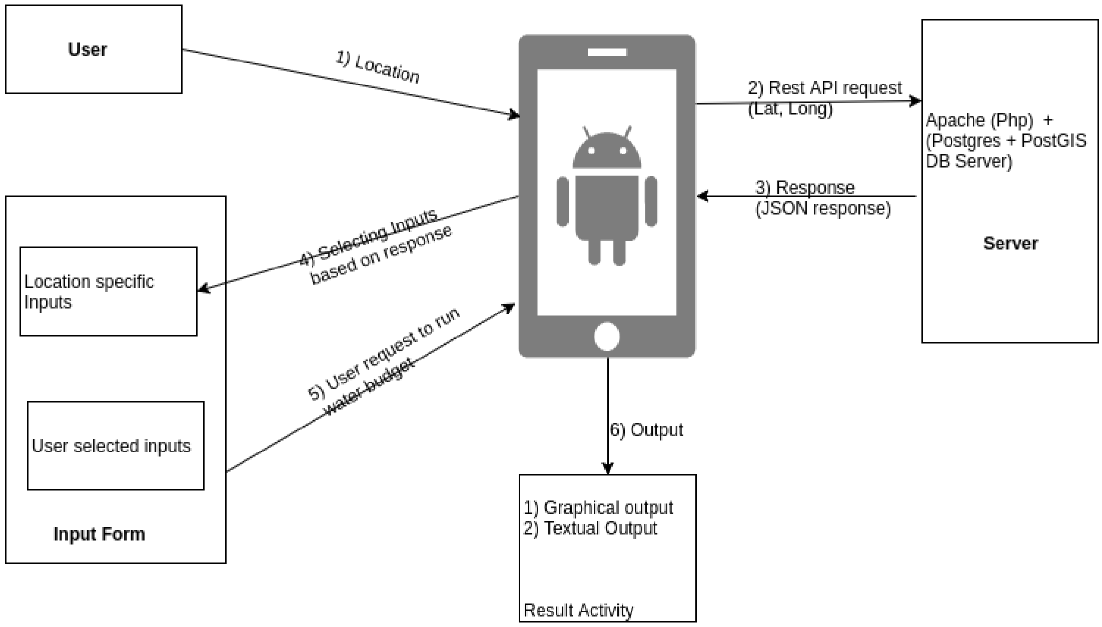


Figure 7.1: Design and flow for Android App

7.3 Database Schema

We have following table in database:

1. **lulc_4326** - This table has Land use land cover mapping for entire PoCRA region(15 district) where geometrical attributes having landuse type. We select geometry which contains lat,long of location point in this indexed table. This table is created from vector shapefile for LULC map.

2. **soil_4326** - This table has Soil type and soil depth mapping for entire PoCRA region(15 district) where geometrical attributes having depth and soiltype. we select geometry which contains lat,long of location point in this indexed table. This table is created from vector shapefile for soil map for PoCRA region.

3. **slope_4326** - This table has percentage slope values mapping for entire PoCRA region(15 district) where geometrical attributes having rast stores slope value. we

select band value at lat,long of location point in this indexed table using ST_Value() function of PostGIS . This table is created from raster percentage slope map.

4. **rainfall_circle** - This table has rainfall circles in maharashtra geocoded. This point vector map then stored as PostGIS table where we use this table to select rainfall station for given point based on nearest point. We then select this to get rainfall station to get rainfall data which we have scrapped from maharain for year 2013 - 2018.

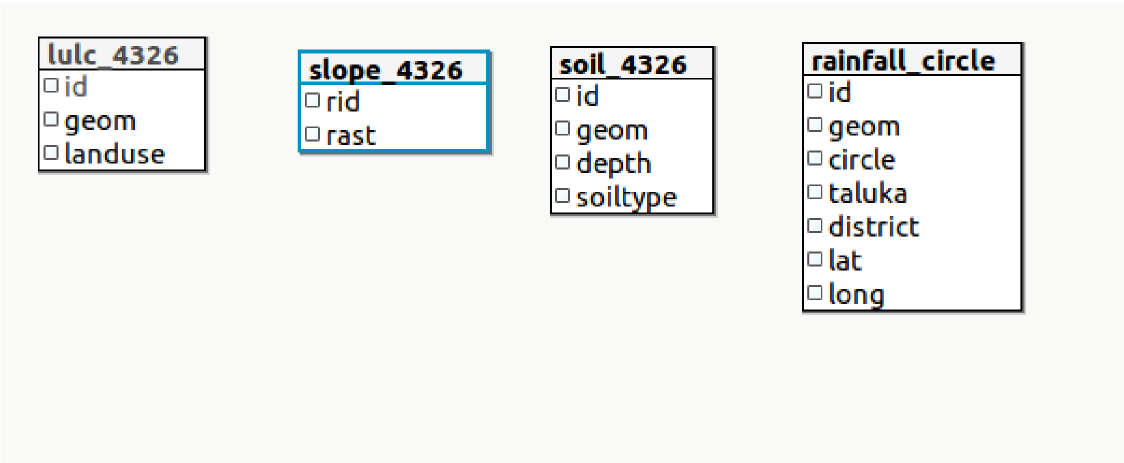


Figure 7.2: Database Table Schema

7.4 Rainfall Data

We have scrapped rainfall data for all rainfall station in Maharashtra. This data is collected using web-scrapping from maharain.gov.in . This data is for year 2013 to 2018. We have stored this data as annual rainfall csv files stored at server . Whenever user make query with lat long server returns rainfall data for 5 years to user via JSON response.

7.5 Context flow diagram

We discuss context flow for android app in this section. Figure 7.3 shows flows between activities and their communication with server. In this section we will also discuss about all the activity classes and flow.

Figure 7.3: Context flow Diagram

1. **MapActivity.java** In this activity class we display google map whose default location is set to current location. Also there is search bar to geolocate any address. We have used google maps API for this. To geolocate we have used 'android.location.Geocoder' class. Also on move location in google maps changes to centre of map. Figure 7.4 shows display of MapActivity and google map while testing android app at Kathora village in Amravati district, Maharahstra. On clicking button NEXT we starts instance of another activity StartActivity.java. Binding between two separate components like activities are given by intents in android. We also put lat and long of location with intent while creating instance of StartActivity.java.

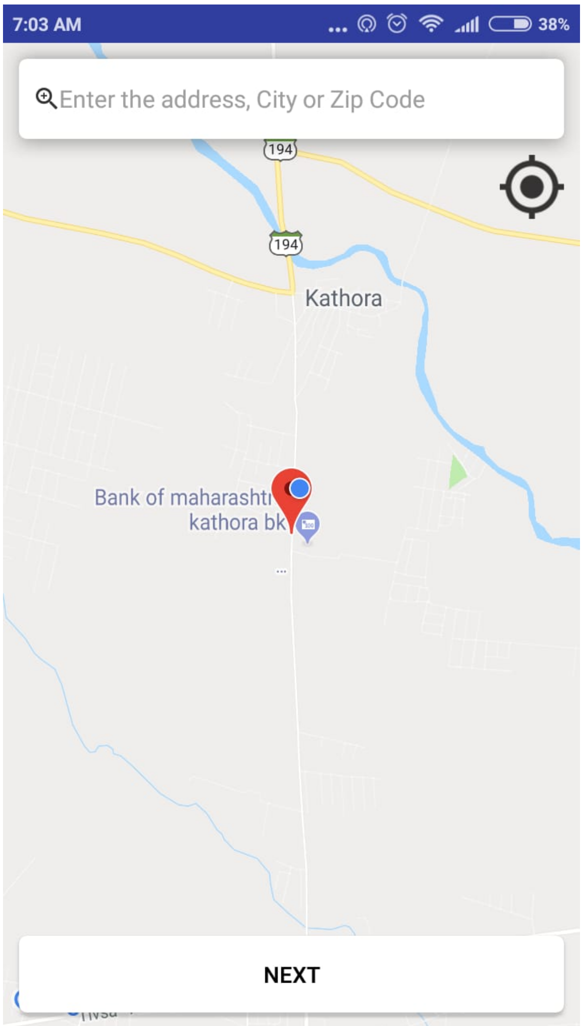


Figure 7.4: MapActivity

2. **StartActivity.java** In this activity class, once instace is created we retrieve lat,long of location from intent and using this value of lat long we make server communication to get values at this lat-long from our server. A request is made to php server passing lat and long and this request serves an JSON object from server to android app. Below figure 7.5 and 7.6 shows UI for StartActivity.java

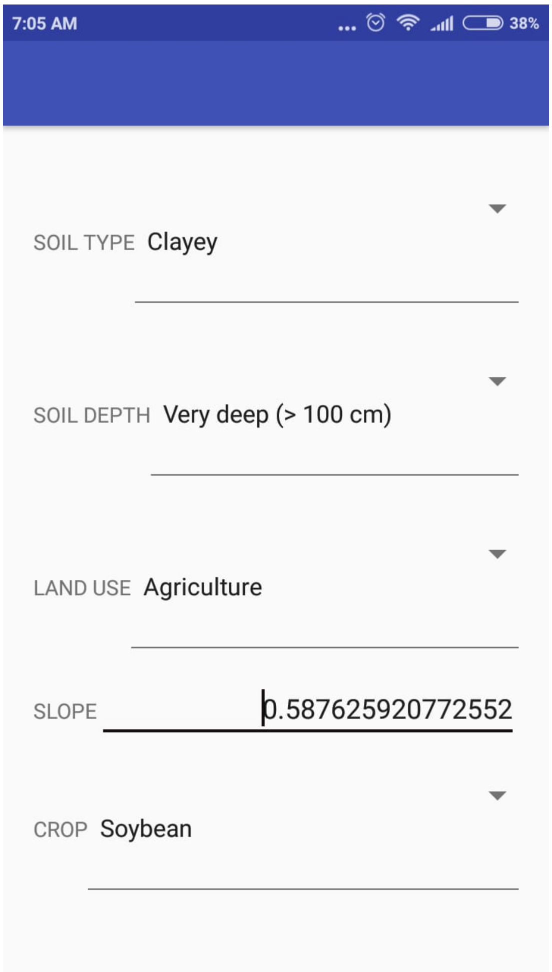


Figure 7.5: StartActivity

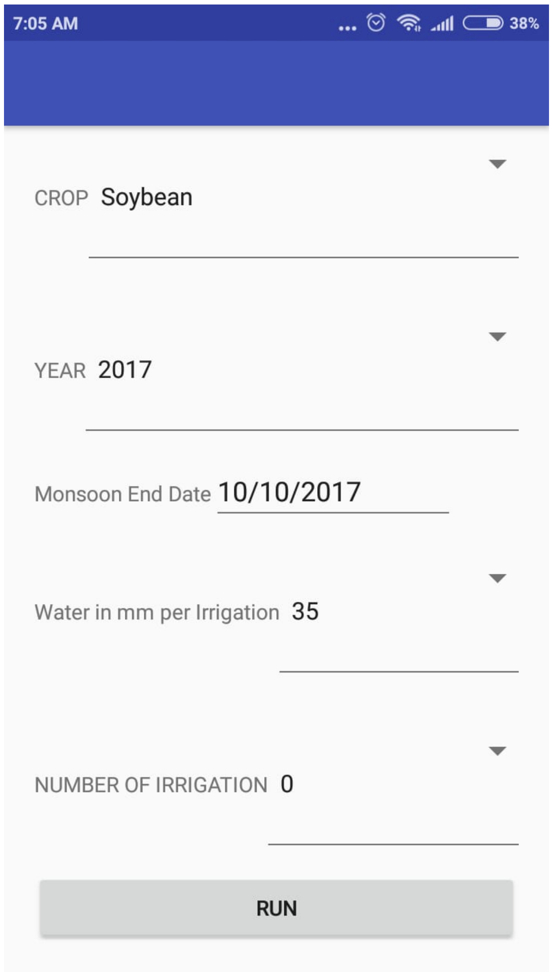


Figure 7.6: StartActivity

Below is partial JSON response which server sends to StartActivity.java. As in Json Response rainfall for 2013 is shown similarly in complete JSON response rainfall for all 6 years (2013, 2014, 201, 2016, 2017 and 2018) are present along with initial info like Soil type, soil depth, etc.

Listing 7.1: Partial JSON response

```
{"soil_type":"Clayey","soil_depth":"Very deep (> 100 cm)"
  ,"slope":"0.587625920772552","District":"Amravati","
```

```
Taluka":"Amravati","Circle":"Nawasari","lulc_type":"
Kharif","Rainfall2013":["0.0","0.0","0.0","0.0","0.0",
"0.0","39.8","0.0","18.8","9.4","0.0","11.8","0.0","32
.8","27.9","21.1","11.4","25.9","0.0","0.0","1.8","0.0
","6.9","11.5","9.6","25.4","10.9","0.0","0.0","0.0","
15.0","0.0","18.2","18.4","0.0","0.0","10.4","0.0","0.
0","13.4","2.2","9.0","28.0","28.6","10.4","15.0","0.0
","5.0","0.0","15.0","0.0","0.0","20.0","4.0","0.0","2
.4","2.4","2.0","1.0","0.0","32.0","89.4","1.6","1.2",
"1.2","6.4","0.0","1.2","0.0","0.0","3.6","4.0","0.0",
"0.0","6.4","0.0","4.2","0.0","0.0","0.0","0.0","13.2"
,"1.2","30.4","10.4","0.0","3.2","0.0","0.0","0.0","0.
0","0.0","0.0","0.0","0.0","0.0","0.0","0.0","0.0","0.
0","0.0","1.0","0.0","10.2","8.4","0.0","0.0","0.0","0
.0","0.0","0.0","0.0","25.2","85.0","0.0","0.0","0.0",
"5.2","0.0","0.0","0.0","0.0","0.0","0.0","6.2","90.4"
,"1.2","0.0","0.0","2.2","0.0","5.2","8.2","4.2","0.0"
,"0.0","0.0","0.0","0.0","0.0","0.0","0.0","0.0","0.0"
,"0.0","0.0","0.0","0.0","0.0","0.0","0.0","0.0","0.0"
,"0","0","0","0","0","0","0","0","0","0","0","0","0","
0","0","0","0","0","0","0","0","0","0","0","0","0","0"
,"0","0","0","0","0","0","0","0","0","0","0","0","0","
0","0","0","0","0","0","0","0","0","0","0","0","0","0"
,"0","0","0","0","0","0","0","0","0","0","0","0","0","
0","0","0","0","0","0","0","0","0","0","0","0","0","0"
,"0","0","0","0","0","0","0","0","0","0","0","0","0","
0","0","0","0","0","0","0","0","0","0","0","0","0","0"
,"0","0","0","0","0","0","0","0","0","0","0","0","0","
0","0","0","0","0","0","0","0","0","0","0","0","0","0"
,"0","0","0","0","0","0","0","0","0","0","0","0","0","
0","0","0","0","0","0","0","0","0","0","0","0","0","0"
```

```
,"0","0","0","0","0","0","0","0","0","0","0","0","0","
0","0","0","0","0","0","0","0","0","0","0","0","0","0"
,"0","0","0","0","0","0","0","0","0","0","0","0","0","
0","0","0","0","0","0","0","0","0","0"]}
```


Once the JSON response is received we select default values for SOIL TYPE, SOIL DEPTH, LANDUSE and slope from response value received in JSON. User has to select user defined values like Crop, year(for which he is running water budget). Also in case of irrigation scenario user need to select number of irrigation and in that case user need to provide irrigation dates in same year. When all inputs (user and location based) are fulfilled user need to click on RUN button which is in lower part of StartActivity UI to run the water budget. On clicking this button rainfall of selected year and other inputs are passed to Kharifmodel class functions (to calculate water budget and water requirement). The formulation at Kharif model is same as we discussed during QGIS plugin in chapter 5.

3. **ResultActivity.java** In this activity we describe output in form of textual or graphical format. The output is after we compute water budget over farm / point. The output for our test location in Kathora, Village in Amravati District is as shown in fig 7.7

7.6 Understanding Output

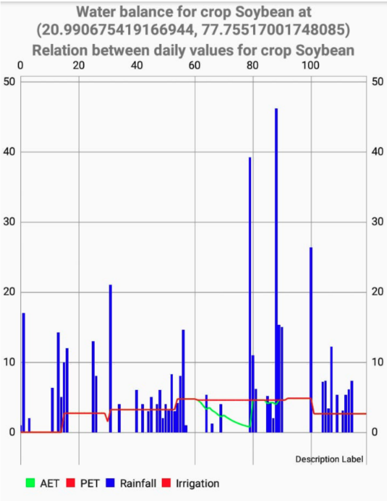
In our app at result page we provide 3 types of output as given in fig 7.7:

1. Graphical Output for daily values
2. Graphical output for cumulative values
3. Textual output representing seasonal values

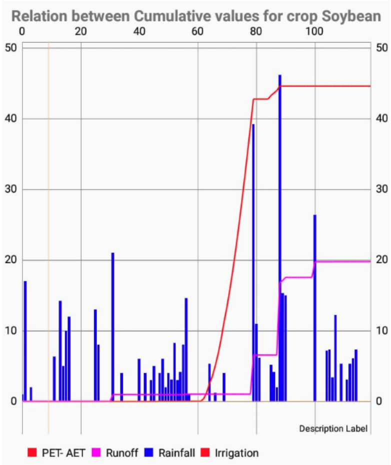
We will discuss these output in this section.

1. **Graphical output for daily values**

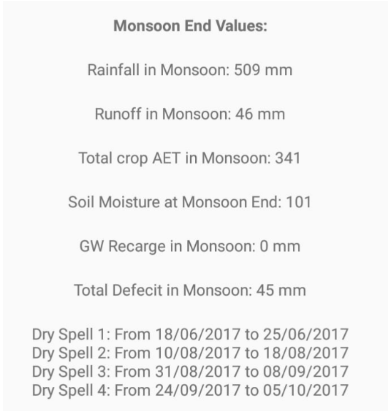
   In this output after running water budget we show graph between daily values of



Graph between Daily output values



Graph between Cumulative values



textual output for Seasonal values

Figure 7.7: ResultActivity

Potential ET, actual ET with bar graph of daily values of rainfall and irrigation. This graph helps to understand impact of dry spell and understanding crop stress during that period. This graph help to proper planning and irrigation if app had realtime and future predicted rainfall data. In this scenario it will help farmer to take preventive measures.

2. **Graphical output for cumulative values**

   In this output after running water budget we show graph between cumulative values of water stress (PET - AET) , cumulative runoff with bar graph of daily values of rainfall and irrigation. This graph helps to understand seasonal impact on various crop when run with different cropping pattern over a same farm. This graph help to proper planning of crop by analysing outputs for various crop given legacy rainfall data.

3. **Textual output representing seasonal values**

   This section represents seasonal values like rainfall in monsoon season, total runoff in monsoon, Actual crop ET in monsoon season, Soil moisture at Monsoon end, GW recharge in monsoon and total deficit in monsoon. Values like Soil moisture at Monsoon end, GW recharge in monsoon helps for cropping selection and planning for Rabi season. Also this section lists dry spells in monsoon (a duration ¿=7days without a rainfall) so that user can analyze graphical outputs and behavior during the same.

Chapter 8

GPU Performance Evaluation of Android App

An app is considered to have poor performance if it responds slowly, shows choppy animations, freezes, crashes, or consumes a lot of power. To avoid these performance problems, we have analyzed our app for inefficient use of resources by checking it for GPU overdraw.

8.1 GPU Overdarw

GPU overdraw issue is when an app asks system to draw something on top of another. Like an example when an application asks system to draws a button on top of white background it is overdraw. Overdraw problem is inevitable but excessive overdraw is an issue. Overdraw uses excessive GPU resources and can lead to lower performance on low end devices. Sometime we need to overdraw things over another for better user interface but many cases it can be avoided by proper placing of layout elements differently. We have analyzed GPU overdraw using android device's inbuilt ability to analyze GPU overdraw in developer options.

In figure 8.1 shows color coding used by android inbuilt GPU overdraw debugging tool where dark red is maximum overdraw and Blue in case of lesser overdraw. In case of no overdraw true colors are shown. Also in figure 8.2, Overdraw example is shown which contain lots of overdraw and right is after removing this overdraw.

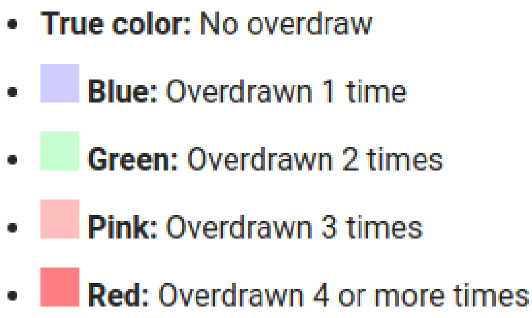


Figure 8.1: Color mapping for amount of overdraw [5]

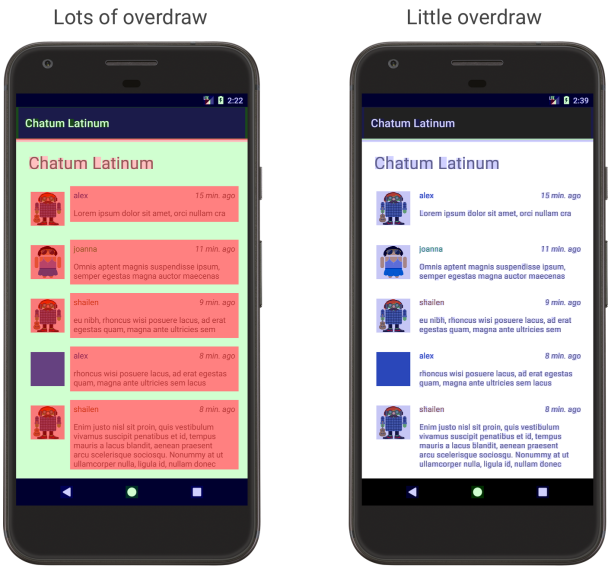
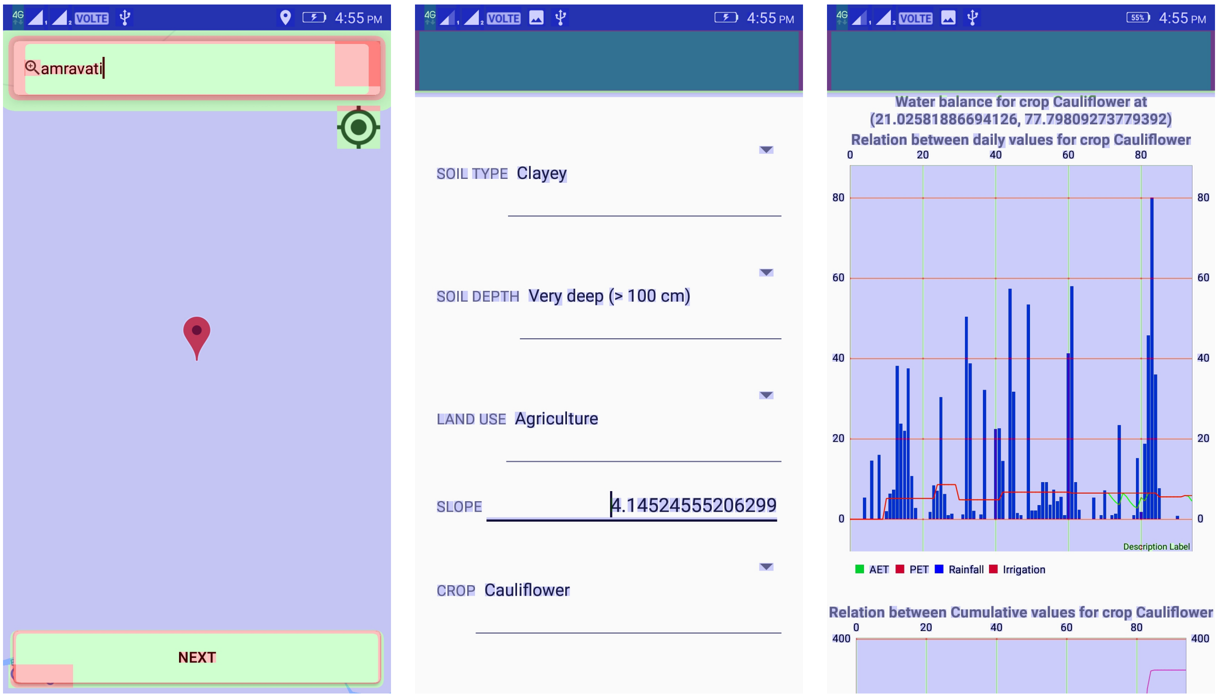


Figure 8.2: Example of Overdraw [5]

8.2 Evaluation of overdraw for water Budgeting App

In figure 8.3 our apps overdraw evaluation is shown. In our app all the activity have lesser overdraw except for MapActivity's UI. This having 3 overdraw in case of searchtextbox and button as this is overdrawn over map. This is kept as it is to have better UI otherwise it would have broken UI feel to user. And for other activities UI is having true colors or light blue color which is no overdraw or 1 time overdraw.



Mapactivity StartActivity ResultActivity

Figure 8.3: Overdraw Evaluation for Water Budget App

Chapter 9

Conclusion and Future Work

9.1 Conclusion

In this report, we have discussed about importance of water budget for agriculture. We have also discussed about various system for water budgets and we have also discussed about CTARA,IITB's water budget used in practice for PoCRA. We have discussed about role of water budgeting in advisory support for better agricultural use.

we have discussed about our implementation of QGIS plugin for regional water budgeting. This plugin is currently in use in PoCRA for water budgeting in phases and will be used over 5000 villages. This provides regional water budgeting support for planning and advisory. We have studied datasets received from PoCRA for these and designed and architecture to get data from this datasets. And then used this data to design a regional water budget for a village.

We have also developed an android app which can be used to compute farm level water budgeting over a mobile device. This support selection of data from a server based on geo-location and computes water budget based on user inputs.

9.2 Future Work

9.2.1 Integration of cropping data in QGIS plugin

QGIS plugin is currently being used in practice by running cropping pattern over entire region and then aggregating over entire agricultural region of zone. If we had access to cropping data which can be consistent with cadastral maps then this can be used to compute water budget of region by knowing exact cropping pattern rather than aggregating cropping pattern of zone.

9.2.2 Automation of Zoning for QGIS Plugin

As we have seen in section 4.2.4 that zoning is manual process based on considering spatial component and local conditions. This can be automated using processes like considering relation between watersheds and proximity to streams. This well help to automate regional water budgeting plugin more.

9.2.3 Use of Real time and prediction data

Currently our farm based model implementation i.e. android app for water budget uses legacy rainfall data. If rainfall data is fed with current real time data by any means of API, etc as well as with prediction data in rainfall then it can be used for current season advisory as well as futuristic advisory to farmers for decision like irrigation, sowing, etc. to gain optimal productivity.

9.2.4 Web dashboard for planning Advisory for entire Region

As stated above with access to real time and predictive rainfall we can also create web dashboard like tool to provide an support tool for planning and predictive. This can be used by high level advising agency , government agencies for taking necessary preventive measures.

Appendix A

Lookups

A.1 Kc values of crops

Table A.1 shows lookup for kc values used for various crops. This kc values are computed using relation between WALMI and FAO values. FAO values[2] are adjusted according to total duration and requirement as per WALMI [12]. This table also has root depth and depletion factor for each crop.

Table A.1: Kc values of crops

Crop Name	**FAO Crop Name**	**Initial Duriation**	**Crop dev Duration**	**Mid Season Duration**	**Late Duration**	**Initial Kc**	**Crop dev Kc**	**Mid Season Kc**	**Late Kc**	**Root depth in meter**	**depletion factor**
Sorghum	Sorgum	20	30	40	30	0.34	0.72	1.06	0.63	1	0.55
Bajri	Millet	13	21	34	22	0.34	0.67	1.05	0.62	1	0.55
Moong	Lentils	8	12	24	16	0.57	0.95	1.4	0.63	0.6	0.4
Udid	Lentils	11	17	33	22	0.41	0.69	1.01	0.46	0.6	0.4
Soyabean	Soyabean	16	23	47	19	0.33	0.7	1.03	0.56	0.6	0.5
Maize	Maize	14	25	29	22	0.56	1.11	1.6	0.97	0.9	0.55
Groundnut	Groundnut	23	32	42	23	0.47	0.79	1.1	0.74	0.5	0.5
Sunflower	Sunflower	17	29	38	21	0.36	0.78	1.19	0.57	0.8	0.45
Fodder Crop	Maize	14	25	29	22	0.35	0.7	1.01	0.61	0.8	0.55
Onion	Onion	12	19	54	30	0.53	0.75	1.07	1.07	0.3	0.35
Mirchi	Pepper	40	55	63	32	0.44	0.87	1.31	1.12	0.5	0.3
Brinjal	Egg plant	44	58	58	30	0.51	0.84	1.29	0.9	0.7	0.45
Tomato	Tomato	30	41	41	25	0.58	0.97	1.49	1.04	0.7	0.4
Cauliflower	Cabbage	14	18	43	10	0.63	1.05	1.46	1.25	0.4	0.45
Vegetables	Tomato	24	33	33	20	0.53	0.89	1.36	0.94	0.4	0.35
Small Vegetables	Spinach	20	20	15	5	0.73	0.97	1.61	1.45	0.3	0.3
Tur	Cotton	28	46	50	41	0.43	0.72	1.1	0.72	1	0.65
Turmeric	Cotton	40	67	73	60	0.59	0.98	1.51	0.98	1	0.65
Potato	Potato	25	30	30	20	0.62	1.03	1.58	1.16	0.4	0.35
Cotton	Cotton	30	50	55	45	0.51	0.85	1.3	0.85	1	0.65
Grapes	Grapes	30	61	183	91	0.44	1.52	0.73	0.73	1	0.35
Banana	Banana	112	84	112	57	0.53	1.17	1.06	1.06	0.5	0.35
Pomegranate	Pomegranate	21	77	56	211	0.46	0.26	0.56	0.7	1.1	0.5
Citrus	Citrus	60	90	120	95	0.7	0.65	0.7	0.7	1.1	0.5
Orange	Citrus	60	90	120	95	0.7	0.65	0.7	0.7	1.1	0.5
Mosambi	Citrus	60	90	120	95	0.7	0.65	0.7	0.7	1.1	0.5
Sugarcane	Sugarcane	28	48	151	138	0.51	1.58	0.95	0.95	1.2	0.5
current fallow crop	–	30	30	31	31	0.2	0.2	0.3	0.3	0.9	0.5

A.2 ET_0 values of various WALMI stations

This values are used as input in plugin as ET0 values for various agroclimatic zone. This values are taken from WALMI datasets [12].

Table A.2: ET0 values

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

A.3 Runoff table based on land usage and Soil type

Table A.3 provide mapping between land use and hydrologic soil group (HSG) for SCS curve number. This values are taken as per SWAT datasets [8]. This values are used in plugin and android app to select curve number based on landuse and soiltype.

Table A.3: Runoff table based on land usage

LU	HSG A	HSG B	HSG C	HSG D
Agriculture	67	78	85	89
Deciduous - Dense	30	55	70	77
Deciduous open	36	60	73	79
Fallow land	77	86	91	94
habitation	77	85	90	92
Scrub dense	49	69	79	84
Scrub Forest	57	73	82	86
Scrub open	68	79	86	89
current fallow	72	81	88	91
Water	100	100	100	100

A.4 LU mapping between attribute values and generic types

We had converted LU types as given by MRSAC dataset into generic landuse types. This generic types are then used to define landuse for this region and water budgeting is calculated based on this values.

Table A.4: LU Mappings

LU Type	**Generic LU Type**
forest-forest blank	scrub
forest-deciduous (dry/moist/thorn)-open	scrub
agricultural land-crop land-rabi crop	agriculture
forest-scrub forest	scrub
agricultural land-crop land-kharif crop	agriculture
agricultural land-fallow-current fallow	fallow land
wastelands-scrub land-open scrub	wasteland
wastelands-gullied/ravinous land-gullied	wasteland
forest-deciduous (dry/moist/thorn)-dense/closed	forest
wastelands-scrub land-dense scrub	scrub

Continued on next page

Table A.4 – continued from previous page

LU Type	Generic LU Type
built up-built up (rural)-built up area (rural)	habitation
waterbodies-reservoir/tanks-dry-zaid extent	water
waterbodies-reservoir/tanks-dry-rabi extent	water
waterbodies-canal/drain-lined	water
agricultural land-crop land-zaid crop	agriculture
waterbodies-reservoir/tanks-dry-kharif extent	water
agricultural land-crop land-two crop area	agriculture
built up-built up (urban)-vegetated area	habitation
wastelands-barren rocky/stony waste	scrub
agricultural land-plantation-agriculture plantation	agriculture
agricultural land-crop land-more than two crop	agriculture
waterbodies-river/stream-perennial	water
built up-built up (urban)-transportation	habitation
built up-built up (urban)-recreational	habitation
built up-built up (urban)-residential	habitation
cropped in more than two seasons	agriculture
cropped in two seasons	agriculture
rabi	agriculture
zaid	agriculture
kharif	agriculture
agricultural plantation	agriculture
deciduousdry/ moist/ thorn - dense/ closed	forest
evergreen/ semi evergreen - dense/ closed	forest
forest plantation	forest
tree clad area - dense/ closed	forest
fallow land	fallow land
built up - compactcontinuous	habitation

Continued on next page

Table A.4 – continued from previous page

LU Type	Generic LU Type
built up - compact (continuous)	habitation
built up - sparsediscontinuous	habitation
industrial area	habitation
rural	habitation
tree clad area - open	scrub
deciduousdry/ moist/ thorn - open	scrub
evergreen/ semi evergreen - open	scrub
scrub	scrub
ash/ cooling pond/ effluent and other waste	wasteland
mining - abandoned	wasteland
mining - active	wasteland
quarry	wasteland
barren rocky	wasteland
gullied/ ravinous land - gullied	wasteland
scrub land - dense/ closed	wasteland
scrub land - open	wasteland
vegetated/ open area	wasteland
reservoir/ tanks - permanent	water
reservoir/ tanks - seasonal	water
river - non perennial	water
river - perennial	water
canal/ drain	water
lakes/ ponds - permanent	water
lakes/ ponds - seasonal	water
deciduous (dry/ moist/ thorn) - open	scrub
deciduous (dry/ moist/ thorn) - dense/ closed	forest
built up - sparse (discontinuous)	habitation

Appendix B

Soil Characteristics and Crop evapotransipiration calculation

B.1 Soil Characteristics

Saturation

When after rain or irrigation , all soil pores are filled with water, the soil is said to be saturated and soil will not absorb anymore water, such condition of soil saturation and saturation % is given by volume of water soil . Plants need air and water in the soil. At saturation, no air is present and the plant will suffer. 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.

Permanent wilting point (WP)

Permanent wilting point is the condition when soil moisture reaches stage when water content in soil can not be sucked by plant. As soil moisture decreases, 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 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. [3]

Field capacity (FC)

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 considered to be ideal for crop growth

Hydraulic Saturated Conductivity (Ksat)

Saturated hydraulic conductivity is a quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient. It can be thought of as the ease with which pores of a saturated soil permit water movement[1].

B.2 Crop evapotransipiration calculation

Evapotransipration Process

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

Evaporation is process of conversion of water into vapors. Water evaporates from a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation. As evaporation proceeds, the surrounding air becomes gradually saturated and the process will slow down and might stop if the wet air is not transferred to the atmosphere. The replacement of the saturated air with drier air depends greatly on wind speed. Hence, solar radiation, air temperature, air humidity and wind speed are climatological parameters to consider when assessing the evaporation process. Where the evaporating surface is the soil surface, the degree of shading of the crop canopy and the amount of water available at the evaporating surface are other factors that affect the evaporation process.

Transpiration

Transpiration consists of the vaporization of liquid water contained in plant tissues and the vapour removal to the atmosphere. Crops predominately lose their water through stomata.These are small openings on the plant leaf through which gases and water vapour pass.Transiration rates vary for type of plants. With type of crop, crop developement stage,enviornment also affects transpiration. [2]

Evapotranspiration (ET)

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area.

Reference crop evapotranspiration (ET_0)

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_0. The reference surface is a hypothetical grass reference crop with specific characteristics. The use of other denominations such as potential ET is strongly discouraged due to ambiguities in their definitions.

Crop evapotranspiration under standard conditions (ET_c)

The crop evapotranspiration under standard condition (ET_c), is evapotranspiration when crop is well wetted, disease-free, optimal soil and and acheiving full production. Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach. As

Table B.1: K_c table for soyabean

Stage	Initial	Crop Developement	Mid Season	End Season
Soyabean	20	30	60	25
K_c for Soyabean	0.35	0.75	1.1	0.6

there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapotranspiration rate, i.e., ET_0. Experimentally determined ratios of ET_c/ET_0, called crop coefficients (K_c), are used to relate ET_c to ET_0 or $ET_c = K_c$* ET_0.[2]

Crop coefficient K_c for crop

Crop coefficients are properties of plants used in predicting evapotranspiration (ET). The most basic crop coefficient, Kc, is simply the ratio of ET observed for the crop studied over that observed for the well calibrated reference crop under the same conditions. K_c for a given crop also changes from sowing till harvest due to variation in crop characteristics and crop requirement ,leaf anatomy,etc

Ex. K_c table for soyabean is given in below table Crop evapotranspiration under non-standard conditions (ET_c adj or AET) The crop evapotranspiration under non-standard conditions (ET_c adj) is the evapotranspiration from crops grown under management and environmental conditions that differ from the standard conditions. In field condition real crop evapotranspiration varies from ET_c due to non optimal condition in filed and by ET_c adj or AET is calculated using a water stress coefficient K_s and adjusting ET_c.

$$ET_c adj = K_s * K_c * ET_0 = K_s * ET_c \tag{B.1}$$

Water Stress coefficient:

Although water is theoretically available until wilting point, crop water uptake decreases before wilting point is reached. When soil is sufficiently wet crop uptake can be high but after some certain value water would not be readily available thought soil moisture is above wilting point. Readily available water can be calculated by depletion factor(p) which gives fraction of total available water which is readily available. and depletion factor (p) specifies water stress condition.

Water stress coefficient describes effect of water stress on crop ET(ET_c). Ks is used to calculate ET_c Adj, and value of Ks is dependent on water stress condition. Ks is calculated as

$$K_s = \begin{cases} 0, & \text{if } SM_{root} \leq WP \\ 1, & \text{if } SM_{root} > (FC * p + WP * (1-p))1 \\ (SM_{root} - WP)/(FC - WP)/(1-p), & \text{otherwise} \end{cases} \tag{B.2}$$

Appendix C

QGIS Plugin System Requirements

This chapter explains plugin setup and system requirements.

- **Operating System:**
  Windows 8, windows 10 , or Linux based versions like Ubuntu, Debian, Fedora, etc.

- **GIS application:**
  QGIS 2.18 or later

- **Python Library dependency:**
  We need python library to output unicode output in excel file. For this purpose we have used python library xlwt. In windows version of QGIS comes with its own python installation along with its packages. This is independent of regular python installation and this already includes xlwt library.
  But in Linux version QGIS uses system version of python so we need to install xlwt using below steps:
  sudo apt-get install python-pip python-dev build-essential (If pip package management system is not installed in ubuntu)
  python -m pip install -xlwt

- **Path to keep plugin folder in system:**
  QGIS plugin need to be copied to path:
  In Windodws:

user directory/.qgis2/python/plugins

In Ubuntu:

~/.qgis2/python/plugins

- **Code Repository for QGIS Plugin:**
  `https://github.com/sudhanshudeshmukh/kharif_model_multicrop`

Appendix D

Acronyms and Abbreviations

Table D.1: Acronyms and Abbreviations

PoCRA	Project on Climate Resilient Agriculture
MRSAC	Maharashtra Remote Sensing Application Centre
PMU	Project Management Unit
ET	Evapotranspiration
PET	Potential Evapotranspiration of Crop
AET	Actual Evapotranspiration of Crop
SWAT	Soil & Water Assessment Tool
FAO	Food and Agriculture Organisation of United Nations
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WALMI	Water and Land Management Institute

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Signature: ....

Sudhanshu Deshmukh

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