IIT Bombay – PoCRA MoU III

Phase III delivery report

Part A - Model improvements, on-field measurements and validation

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1. Report on Hourly Water balance calculation and Results

Prepared

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1.1 Introduction

This document looks into the performance of the hourly FAO Penman-Monteith approach vis a vis the daily FAO Penman-Monteith method. The FAO Penman-Monteith method is recommended as the sole standard method for the computation of ETo when all the weather parameters are available. It is a method with a strong likelihood of correctly predicting ETo in a wide range of locations and climates and has provision for application in data-short situations. The relatively accurate and consistent performance of the Penman-Monteith approach in both arid and humid climates has been indicated in both the ASCE and European studies. The 1985 Hargreaves' method is also another temperature-based method which has shown reasonable ETo results with a global validity as well. Earlier a document was shared with PMU which looks into different methods for computation of ETo. It gives an idea of the various weather parameters being received from the skymet for the computation of ETo. Solar radiation data and sunshine hour data are missing from the skymet data set. The sensitivity of different ETo methods to available weather parameters was analyzed. Based on the results and recommendations from the SAU's it was decided to use the Hargreaves method for the computation of the daily ETo. The document and results can be accessed on the following Link.

The data from the skymet is available at the hourly interval. Given this, there is a need to move to hourly time-steps for most methods, such as the pointwise soil water balance, the stream-flow model, as well the ETo model. The equations and calculation procedure for ETo are also given in FAO Irrigation and drainage paper 56 for computation of hourly ETo using the Penman-Monteith approach. Another approach is tested to compute the ETo using the Hargreaves method at an hourly interval. The ETo calculated at hourly intervals will also be added to streamflow and water budget simulation routine which will be migrated to hourly intervals from daily interval. This report consists of three sections described below.

1 Section one gives detail about the selected locations
2 Section two gives details about the method used for computation
3 Section 3 talks about the results

1.2 Selected locations

Six different circles are selected for analysis which are spread across a wide swath of area including the project area and represent a wide variety of geography and climatic conditions. Details of these circles are given in the table 1 below and locations are represented on the image below in fig 1.

Table 1- Selected Locations

Sr. No	District	Taluka	Rain_Circle	latitude	longitude
1	Amravati	Chikhaldara	Chikhaldara	21.4015	77.3299

2	Ahmednagar	Shrigonda	Dev Daethan	18.8258	74.4481
3	Beed	Aashti	Kada	18.8457	75.1141
4	Chandrapur	Nagbhid	Midhala	20.5404	79.7277
5	Hingoli	Sengaon	Sengaon	19.7961	76.8839
6	Dhule	Shindkheda	Wikharan	21.2852	74.6204

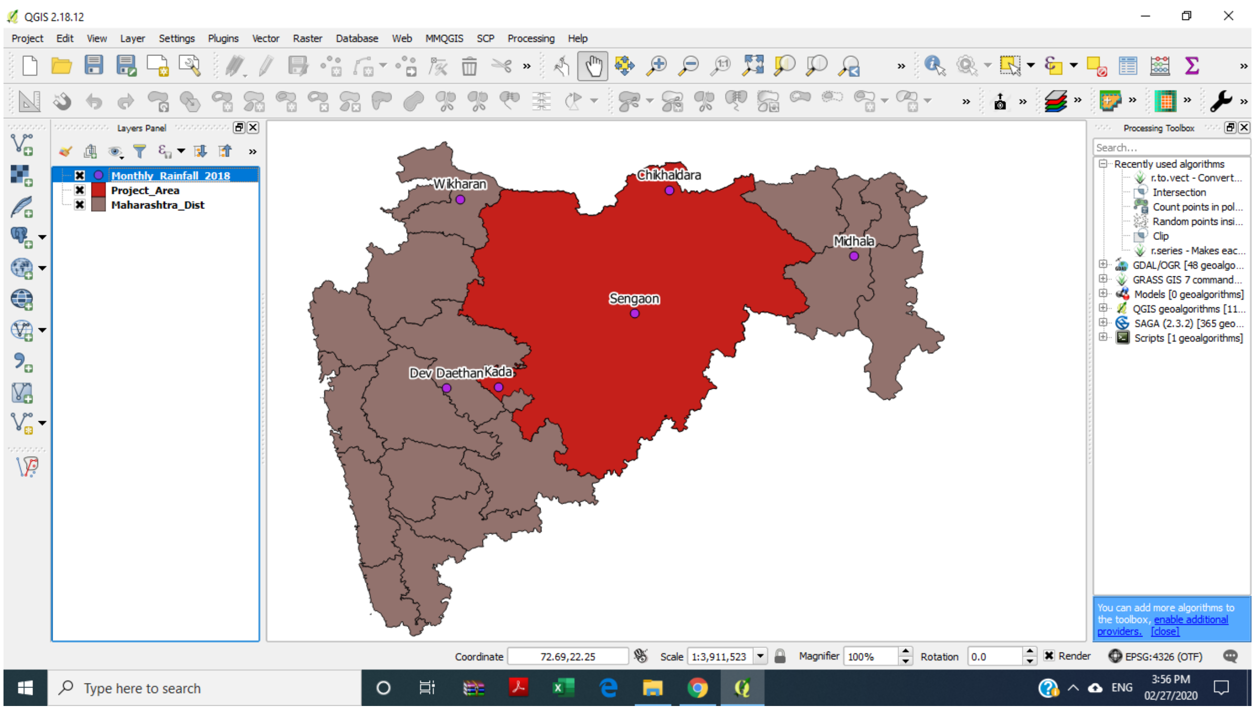

Figure 1- Selected Locations

1.3 Method for Computation

Hargreaves's method for the computation of the daily ETo is currently in use. Details regarding the equations used for ETo computation and its comparison with the other method are given in the the document and results can be accessed on the following Link.

With the availability of data at the hourly interval, the Penman-Monteith approach is used to compute the ETo at hourly intervals. Equations are given in detail in FAO Irrigation and drainage paper 56. Flow chart describing the equations used in computing the hourly ETo is given in the chart below fig 2. Missing parameters like a net short wave and net longwave radiation are estimated using the procedure described in the FAO paper.

From the results discussed in the section below it can be seen that there is quite a difference in daily ET0 values computed using Hargreaves and ET0 computed from the Penman-Monteith approach. It seems Penman-Monteith is underestimating the ET0. To analyze results in a better way and avoid two changes at a time which are, the change of method and interval, an attempt is made to spread Hargreaves's daily output to hourly output. In this approach, the daily spread vectors derived from the hourly Penman-Monteith approach are used to distribute the daily ET0 computed at the daily level using Hargreaves's to the hourly interval. This is reducing the time step to the hourly interval and helping in analyzing the impacts of the intense and normally distributed rainfall over a day on components like runoff, infiltration, Etc(Crop PET), ETcadj(AET) and groundwater recharge. The results are shared in the next section.

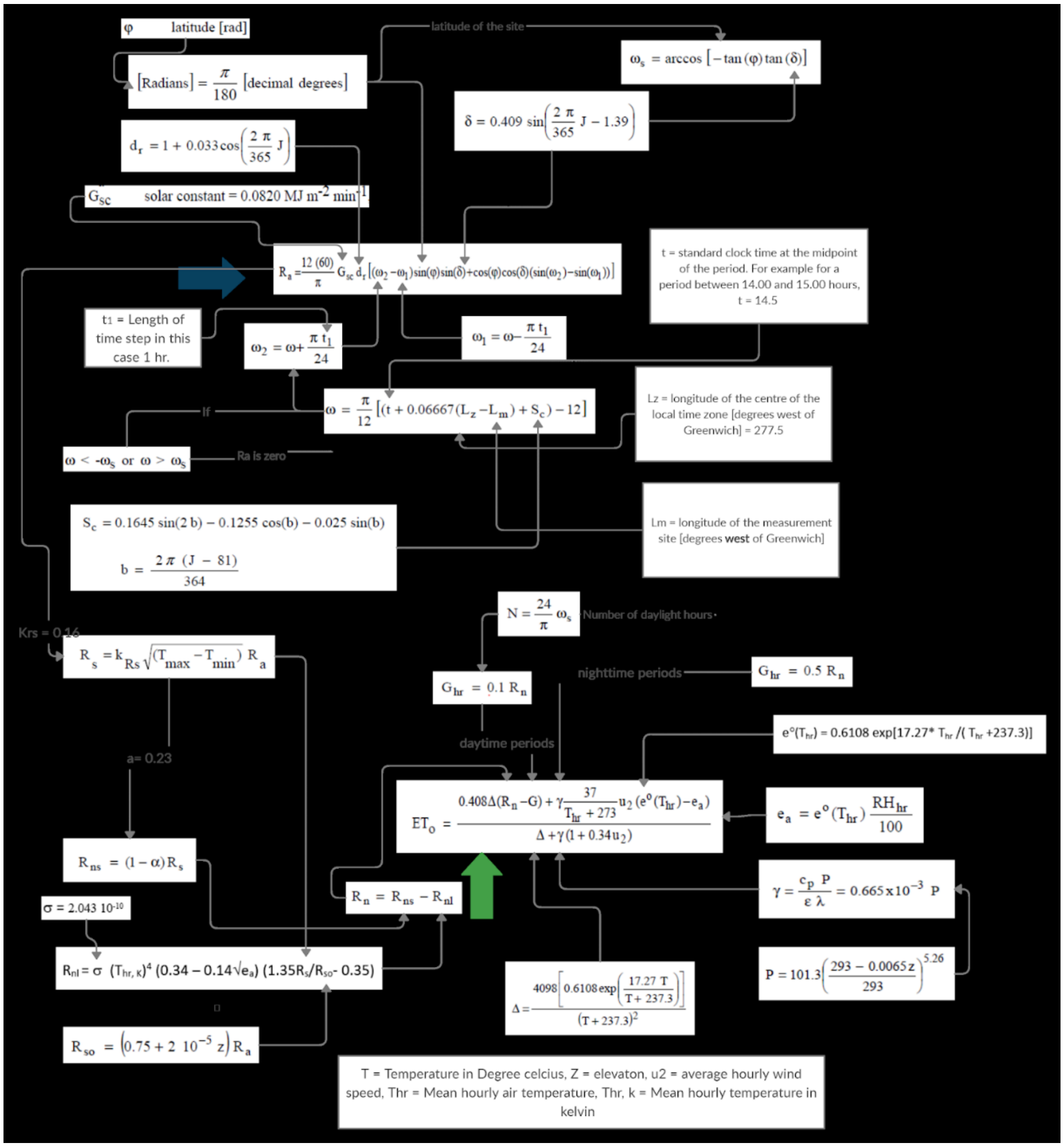

Figure 2 - Equations used for ETO computation

Another place where change in the model is made is during the calculation of percolation factor. Water is allowed to percolate if the water in the layer is mor the the field capacity. Volume of water available in the soil for percolation is calculated by subtracting field capacity from the saturation point of the layer. This is also known as drainable excess. Percolation factor is computed using the following equation. Δt is the time step for hourly interval it is 1 hour and for daily interval it is 24 hours. travel time for percolation in hours.

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

Percolation factor = $\left(1-\exp\left[\frac{-\Delta t}{TT_{perc}}\right]\right)$

TT_{perc} is calculated using the equation given below. SAT_{ly} (mm)is the amount of water in the soil layer at saturation and FC_{ly} (mm) is the amount of water in the soil layer at the field capacity. K_{sat} is the saturated hydraulic conductivity given in mm/hr.

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

W_{perc} is the amount of water percolated down the given layer. These equations are given in the SWAT theory documentation Chapter 2:3-page 151.

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

Table 2 and figures 3,4,5 provide us with the estimates of percolation factors at hourly and daily interval for different soil types like clay loam, silty loam and clay. Fixed soil depth and its properties like saturation, field capacity and wilting point, saturated hydraulic conductivity etc are used to calculate the daily and hourly percolation factors. Results from the table shows that the aggregated hourly percolated factor over the period of 24 hours is far greater than the daily percolation factor in all the soil types. This is the reason we are observing high ground water recharge in case of hourly models.

Table 2 - Percolation parameters for different soil type

Sr	Soil type	Clay loam	Silty loam	Clay
1	Total soil thickness (m)	0.25	0.25m	0.25m
2	Saturation % (mm)	0.4420 (110.5)	0.418 (104.5)	0.487 (121.75)
3	wilting point % (mm)	0.2060 (51.5)	0.105 (26.25)	0.303 (75.75)
4	FC % (mm)	0.3410 (85.25)	0.291 (72.75)	0.427 (106.75)
5	K_{sat} mm/hr	2.7	6.97	0.52
6	TT_{perc} hr	9.37	4.6	28.8
7	Daily Percolation factor	0.94	0.99	0.56
8	Hourly percolation factor	0.1	0.2	0.03

9	Hourly percolation factor*24	2.4	4.8	0.72

Percolation function is used to compute the graph for percolation factor vs time step for different soil types and given below in figure below 3,4,5. Blue dot represents the hourly percolation factor and red dot represents the daily percolation factor.

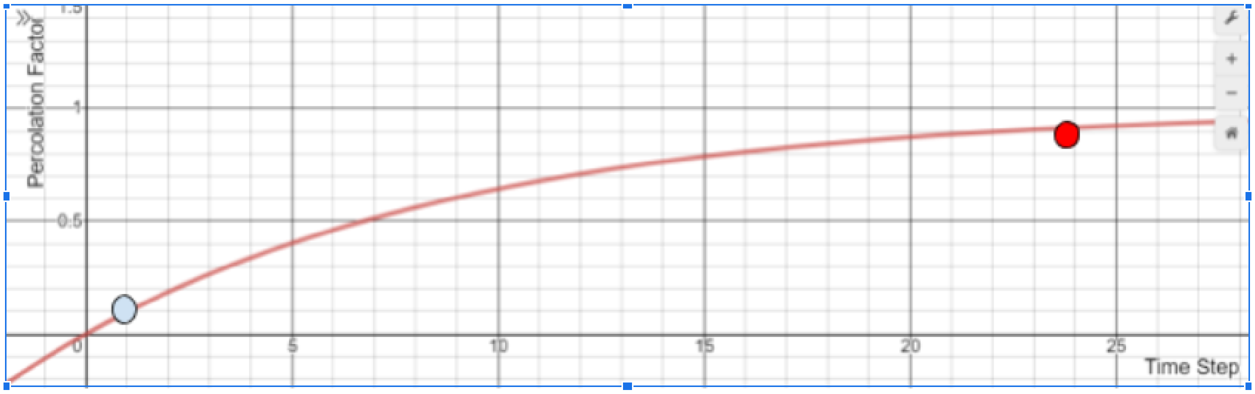

Figure 3 - Percolation factor vs time step Clay loam

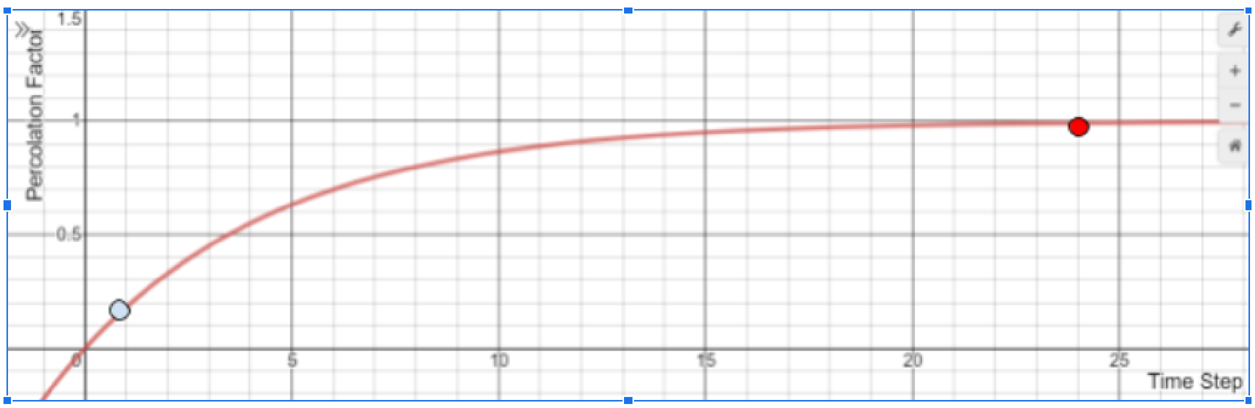

Figure 4 - Percolation factor vs time step Silty loam

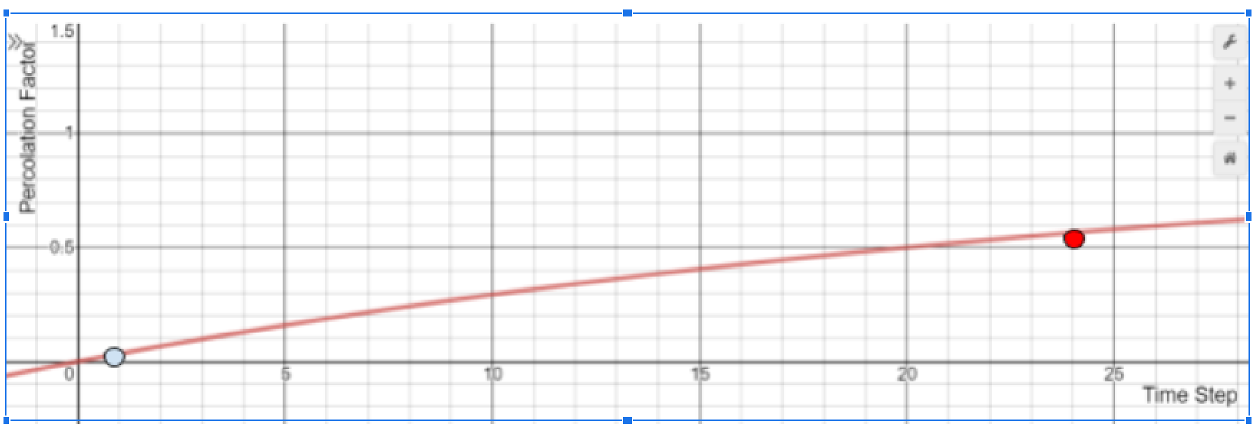

Figure 5 - Percolation factor vs time step Clay

1.4 Results

1.4.1 Comparison of Daily and hourly ETO using Penman-Monteith

The results of ETo obtained from the hourly Penman-Monteith aggregated at the daily level are plotted against the daily Penman-Monteith ETo and are shown in the figure below. For comparison, six circles are selected and locations are given in the table. The results from the six circles show that the ETo computed from these circles follow the same trend and almost overlap with each other from fig 6 to 11.

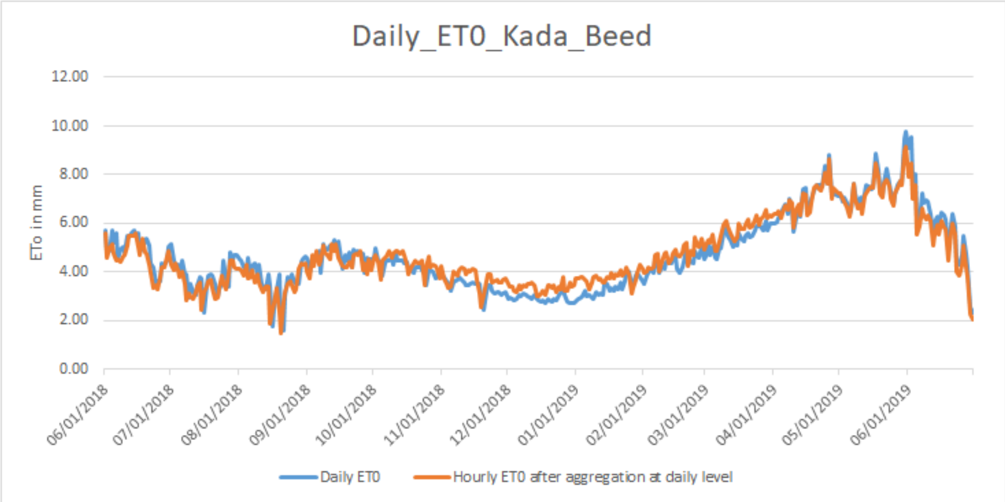

Figure 6 - Comparison of Daily and hourly ETO for Kada

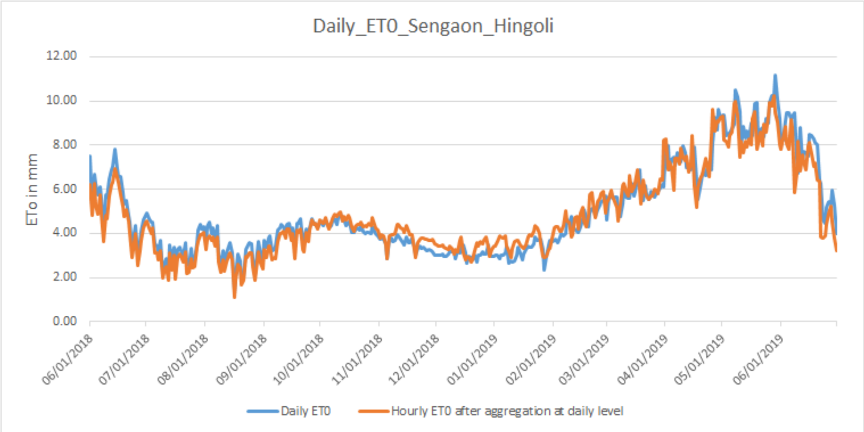

Figure 7 - Comparison of Daily and hourly ETO for Sengaon

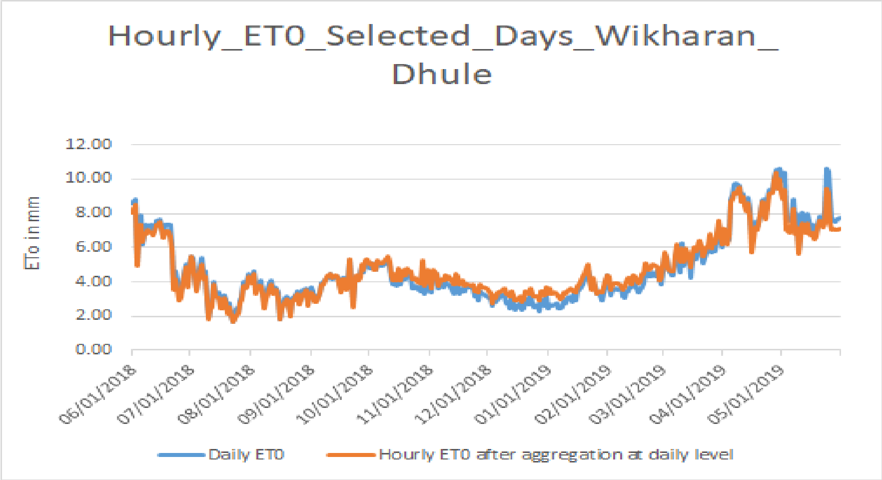

Figure 8 - Comparison of Daily and hourly ETO for Wikharan

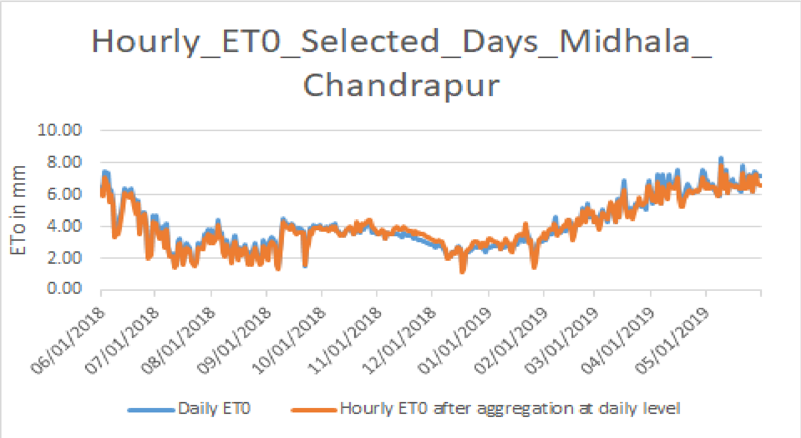

Figure 9 - Comparison of Daily and hourly ETO for Chandrapur

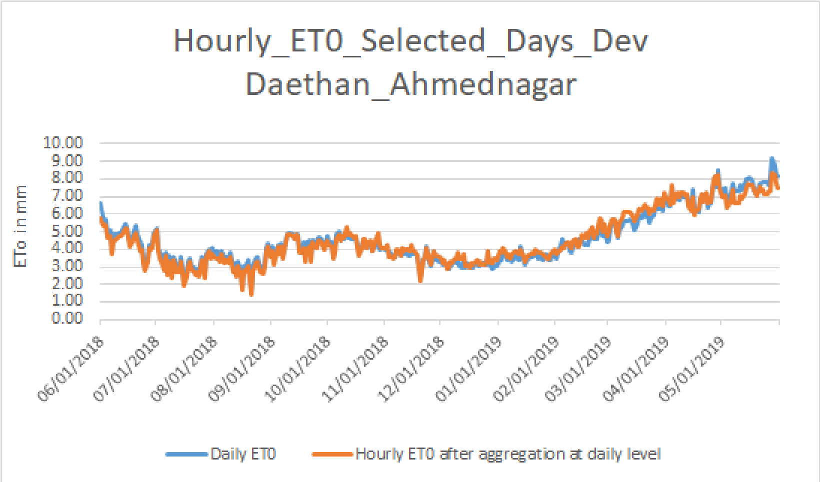

Figure 10 - Comparison of Daily and hourly ETO for Dev Daethan

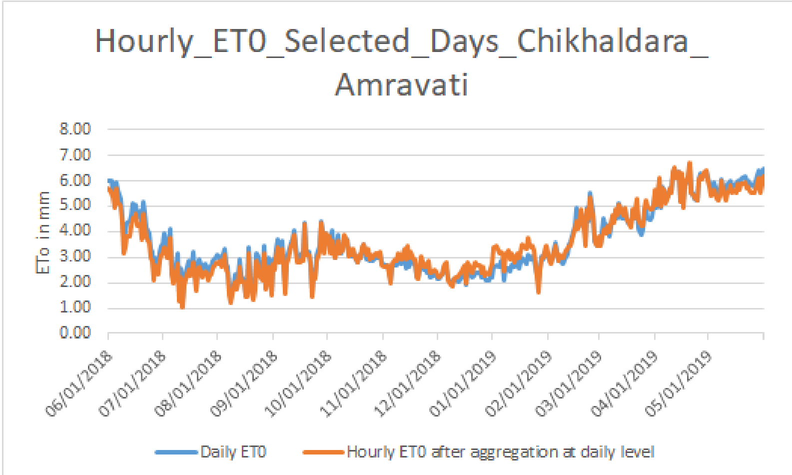

Figure 11 - Comparison of Daily and hourly ETO for Chikhaldara

1.4.2 Comparison of Hourly ETO on different days of year

The following two graphs figure 12 and 13 show the spread of hourly ETo computed using Penman-Monteith at different times of the year on selected days. This shows the fluctuation in the same circle and at time of the year.

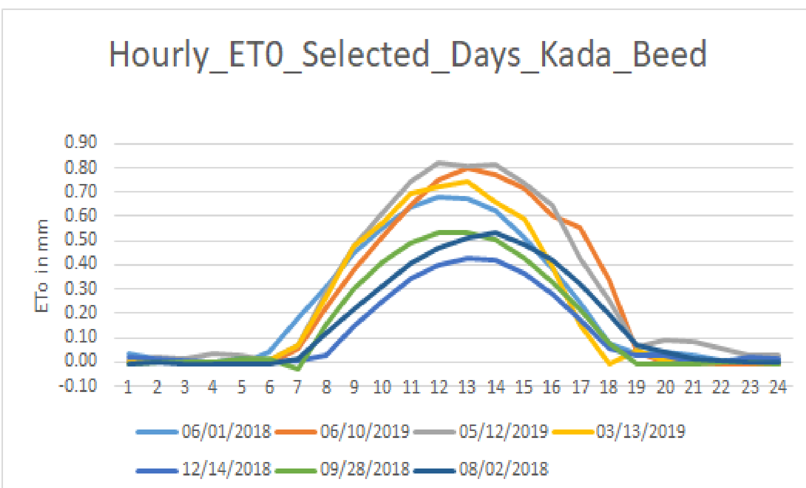

Figure 12 - Hourly ETO for Different days Kada

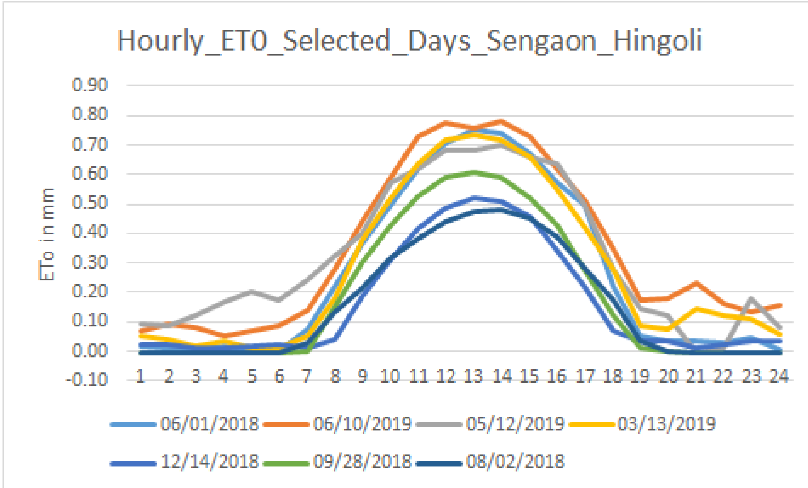

Figure 13 - Hourly ETO for Different days Sengaon

1.4.3 Comparison between water balance components using different methods

The tables below describe the comparison between water balance components for different crops in different soil type having different depth for various circles. This is done to consider different rainfall patterns. The comparison is made between water balance computed using three different ET0 approaches which are Penman hourly, Hargreaves daily and Hargreaves hourly. Sowing date, Monsoon end date and crop harvest date for both the circles are different based upon the rainfall received by the respective areas.

It can be seen from the table 3,4 and 5 below that ET0 computed using the PM approach is less as compared to Hargreaves for all the circles. This means lower crop water requirements. Runoff computed using Hargreaves hourly has reduced in all the circles compared to Hargreaves daily. In case of Chikhaldara and Midhala circles for soybean runoff remains same for PM hourly as compared to Hargreaves daily. However, for other circles runoff shows slightly reduction. Infiltration computed using Hargreaves hourly has increased in all the circles compared to Hargreaves daily. In case of Chikhaldara and Midhala circles for soybean infiltration remains same for PM hourly as compared to Hargreaves daily. However, for other circles infiltration increases. In the case of Hargreaves hourly, AET has increased for both all the circles whereas for PM hourly it has reduced as compared to the Hargreaves daily for soybean and cotton. Both the methods have shown an increase in groundwater recharge as compared to Hargreaves daily where PM hourly showing slightly more recharge compared to Hargreaves hourly in all the circles. Both the methods have shown a considerable difference in monsoon end soil moisture values as compared to Hargreaves daily and shown more availability of soil moisture.

Table 3 – Water balance comparison Chikhaldara, Sengaon cotton, clayey

Crop: Cotton, Soil : Clayey, Depth: 0.5 m						
Circle	Chikhaldara			Sengaon		
Sowing Date	06/10/2018			06/05/2018		
Monsoon_End_ Parameters	09/24/2018			09/27/2018		
	Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
Rain	1163	1163	1163	663	663	663
ET0	289.9	387.33	384.83	403.18	516.15	515.12
Pet	248.12	328.1	327.64	349.94	454.24	453.95
Runoff	731.52	743.78	684.22	287.91	303.59	250.77
Infil	431.48	419.22	478.78	375.59	359.91	412.73
Aet	233.58	282.16	287.21	287.9	315.2	331.71
Gw_Rech	103.59	69.59	97.67	75.3	35.34	69.55
Avail_Sm	94	67	95	12	9	11
Crop_End_ Parameters	12/06/2018			12/01/2018		
Rain	1167	1167	1167	664	664	664
ET0	505.84	648.53	656.03	672.52	837.15	834.57
Pet	476.6	601.21	606.04	620.75	776.58	775.12
Runoff	731.52	743.78	684.22	287.91	303.59	250.77
Infil	435.98	423.72	483.28	376.84	361.16	413.98
Aet	314.57	346	368.83	293.27	319.59	336.28
Gw_Rech	111.59	71.34	104.6	75.3	35.34	69.55
Avail_Sm	9	6	9	7	6	8

Table 4 - Water balance comparison Chikhaldara, Sengaon - soybean, clayey

	Crop: soyaben, Soil : Clayey, Depth: .5 m						
	Circle	Chikhaldara			Sengaon		
	Sowing Date	06/10/2018			06/05/2018		
Sr	Crop_End_ Parameters	09/22/2018			09/17/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	1134	1134	1134	655	655	655
2	ET0	285.45	380.98	378.43	363.66	467.03	466.11

3	Pet	206.37	274.48	273.35	258.84	339.94	339.84
4	Runoff	731.4	729.69	673.1	285.16	307.02	252.67
5	Infil	402.6	403.56	460.9	369.84	347	402.33
6	Aet	206.37	269.48	270.9	248.19	288.97	301.26
7	Gw_Rech	102.21	63.88	95.19	80.1	34.63	71.2
8	Avail_Sm	94	70	94.81	40	23	29.87

Table 5 - Water balance comparison, Kada, Midhala- soybean, clayey

	Crop: soyaben, Soil : Clayey, Depth: .5 m						
	Circle	Kada			Midhala		
	Sowing Date	06/23/2018			06/09/2018		
Sr	Crop_End _ Parameters	10/05/2018			09/21/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	191.5	191.5	191.5	973.7	973.7	973.7
2	ET0	404.08	514.61	513.46	327.55	439.32	437.64
3	Pet	309.27	391.75	391.1	233.08	316.33	315.03
4	Runoff	1.69	4.35	0.86	576.84	576.18	513.45
5	Infil	189.81	187.15	190.64	396.86	397.52	460.25
6	Aet	162.98	163.58	166.54	233.08	298.18	307.04
7	Gw_Rech	0	0	0	83.19	46.28	77.03
8	Avail_Sm	26.83	23.57	24.1	80.59	53.06	76.18

Soil – clay 1m

The soil type is clay and depth is increased to 1m. It can be seen from the table below that ET0 computed using the PM approach is less as compared to Hargreaves for both the circles. This means lower crop water requirements. Runoff computed using Hargreaves hourly has reduced in all the circles compared to Hargreaves daily. In case of Chikhaldara circles for cotton runoff remains same for PM hourly as compared to Hargreaves daily. However, for other circles runoff decreases. Infiltration computed using Hargreaves hourly has increased in all the circles compared to Hargreaves daily. In case of Chikhaldara for cotton infiltration remains same for PM hourly as compared to Hargreaves daily. However, for other circles infiltration increases. In the case of Hargreaves hourly, AET has increased for both all the circles whereas for PM hourly it has reduced as compared to the Hargreaves daily for soybean and cotton. Both the methods have shown an increase in groundwater recharge as compared to Hargreaves daily where PM hourly showing slightly more recharge compared to Hargreaves hourly in all the circles. Both the methods have shown a considerable difference in monsoon end soil moisture values as compared to Hargreaves daily and shown more availability of soil moisture.

Table 6 - Water balance – Chikhaldara, Sengaon - cotton, clayey, 1m

Crop: Cotton, Soil : Clayey, Depth: 1 m						
Circle	Chikhaldara			Sengaon		
Sowing Date	06/10/2018			06/05/2018		
Monsoon_End_Parameters	09/24/2018			09/27/2018		
Monsoon_End_Parameters	Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
Rain	1163	1163	1163	663	663	663
ET0	289.9	387.33	384.83	403.18	516.15	515.12
Pet	248.12	328.1	327.64	349.94	454.24	453.95
Runoff	687.17	685.63	621.08	231.57	253.29	184.23
Infil	475.08	476.62	541.17	431.43	409.71	479.16
Aet	248.09	326.29	327.65	348.6	384.09	425.02
Gw_Rech	62.96	40.1	60.22	49.25	11.01	38.17
Avail_Sm	164	110.3	153	33.58	14.61	16
Crop_End_Parameters	12/06/2018			12/01/2018		
Rain	1167	1167	1167	663	663	663
ET0	508.74	648.86	651.64	672.52	837.15	834.57
Pet	476.6	601.21	606.04	620.75	776.58	775.12
Runoff	687.17	685.63	621.08	231.57	253.29	184.23
Infil	480.58	478.12	546.67	431.43	409.71	479.16
Aet	408.12	434.64	480.04	382.77	393.31	439.25
Gw_Rech	71.62	40.11	66.57	49.25	11.01	38.17
Avail_Sm	2	3	0	0	5.39	2

Table 7 - Water balance Chikhaldara , Sengaon - soybean, clayey, 1m

	Crop: soyaben, Soil : Clayey, Depth: 1 m						
	Circle	Chikhaldara			Sengaon		
	Sowing Date	06/10/2018			06/05/2018		
Sr	Crop_End_Parameters	09/22/2018			09/17/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly

1	Rain	1134	1134	1134	655	655	655
2	ET0	285.45	380.98	378.44	363.66	467.03	466.11
3	Pet	206.37	274.48	273.35	258.84	339.94	339.84
4	Runoff	507.48	660.25	465.01	161.85	258.56	140.73
5	Infil	626.52	473.75	668.99	493.15	396.44	514.27
6	Aet	206.36	272.37	272.93	254.05	302.98	315.94
7	Gw_Rech	257.44	80.65	232.55	138.82	18.13	112.23
8	Avail_Sm	162.72	120.73	163.51	100.28	75.33	86.1

Table 8 - Water balance Kada, Midhala - soybean, clayey, 1m

	Crop: soyaben, Soil : Clayey, Depth: 1 m						
	Circle	Kada			Midhala		
	Sowing Date	06/23/2018			06/09/2018		
Sr	Crop_End_Parameters	10/05/2018			09/21/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	191.5	191.5	191.5	973.7	973.7	973.7
2	ET0	404.08	514.61	513.46	327.55	439.32	529.97
3	Pet	309.27	391.75	391.1	233.08	316.33	315.03
4	Runoff	0	0.47	0	412.58	524.55	378.05
5	Infil	191.5	191.03	191.5	561.12	449.15	595.65
6	Aet	165.12	165.54	166.59	232.99	307.22	309.87
7	Gw_Rech	0	0	0	189.19	33.42	160.53
8	Avail_Sm	26.38	25.49	24.91	138.94	108.51	125.25

In clayey soil for cotton and soybean with increase in depth reduction in runoff is observed for all the circles for both PM hourly and Hargreaves hourly method as compared to Hargreaves daily. Both the methods have shown an increase in infiltration as compared to Hargreaves daily. Both the methods have shown an increase in AET as compared to Hargreaves daily. For cotton crop in case of Chikhaldara and Sengaon circles with increase in soil depth there is decrease in groundwater recharge is observed for all the three methods. For soyabean crop with increase in soil depth PM hourly and Hargreaves hourly have shown increase in the groundwater recharge whereas daily Hargraves method has shown decrease in groundwater recharge. All the methods have shown increase in the available soil moisture.
For Silty clay soil and depth .5m

It can be seen from the table below that ET0 computed using the PM approach is less as compared to Hargreaves for all the circles. This means lower crop water requirements. Runoff computed using Hargreaves hourly and PM hourly has reduced in all the circles compared to Hargreaves daily. Infiltration computed using Hargreaves hourly and PM hourly has increased in all the circles compared to Hargreaves daily. In the case of Hargreaves hourly, AET has increased for all the circles whereas for PM hourly it has reduced as compared to the Hargreaves daily. Both the methods have shown an increase in groundwater recharge as compared to Hargreaves daily where PM hourly showing slightly more recharge compared to Hargreaves hourly in all the circles. Both the methods have shown a considerable difference in monsoon end soil moisture values as compared to Hargreaves daily and shown more availability of soil moisture.

Table 9 - Water balance Chikhaldara, Sengaon - soybean, silty clay, 0.5m

	Crop: soyaben, Soil : Silty Clay, Depth: .5 m						
	Circle	Chikhaldara			Sengaon		
	Sowing Date	06/10/2018			06/05/2018		
Sr	Crop_End_Parameters	09/22/2018			09/17/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	1134	1134	1134	655	655	655
2	ET0	285.45	380.98	378.44	363.66	467.03	466.11
3	Pet	206.37	274.48	273.35	258.84	339.94	339.84
4	Runoff	508.58	669.83	476.05	171.65	284.21	147.02
5	Infil	625.42	464.17	657.95	483.35	370.79	507.98
6	Aet	206.37	269.3	270.95	247.91	291.72	305.07
7	Gw_Rech	311.64	120.98	281.22	193.89	50.13	172.33
8	Avail_Sm	107.41	73.89	105.78	41.55	28.94	30.58

Table 10 - Water balance Kada, Midhala - soybean, silty clay, 0.5m

	Crop: soyaben, Soil : silty Clay, Depth: .5 m						
	Circle	Kada			Midhala		
	Sowing Date	06/23/2018			06/09/2018		
Sr	Crop_End_Parameters	10/05/2018			09/21/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	191.5	191.5	191.5	973.7	973.7	973.7

2	ET0	404.08	514.61	513.46	327.55	439.32	437.64
3	Pet	309.27	391.75	391.1	233.08	316.33	315.03
4	Runoff	1.17	4.18	0.86	418.62	543.34	381.17
5	Infil	190.33	187.32	190.64	555.08	430.36	592.53
6	Aet	164.83	162.17	166.54	232.93	299.26	302.81
7	Gw_Rech	0	0	0	245.76	74.02	219
8	Avail_Sm	25.5	25.15	24.96	76.39	57.08	70.72

For Silty clay soil and depth 1m

It can be seen from the table below that ET0 computed using the PM approach is less as compared to Hargreaves for all the circles. This means lower crop water requirements. Runoff computed using Hargreaves hourly and PM hourly has reduced in all the circles compared to Hargreaves daily. Infiltration computed using Hargreaves hourly and PM hourly has increased in all the circles compared to Hargreaves daily. In the case of Hargreaves hourly, AET has increased for all the circles whereas for PM hourly it has reduced as compared to the Hargreaves daily. Both the methods have shown an increase in groundwater recharge as compared to Hargreaves daily where PM hourly showing slightly more recharge compared to Hargreaves hourly in all the circles. Both the methods have shown a considerable difference in monsoon end soil moisture values as compared to Hargreaves daily and shown more availability of soil moisture.

Table 11 - Water balance Chikhaldara, Sengaon - soybean, silty clay, 1m

	Crop: soyaben, Soil : Silty Clay, Depth: 1 m						
	Circle	Chikhaldara			Sengaon		
	Sowing Date	06/10/2018			06/05/2018		
Sr	Crop_End_Parameters	09/22/2018			09/17/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	1134	1134	1134	655	655	655
2	ET0	285.45	380.98	378.44	363.66	467.03	466.11
3	Pet	206.37	274.48	273.35	258.84	339.94	339.84
4	Runoff	349.82	630.32	335.05	96.1	246.34	84.97
5	Infil	784.18	503.68	798.95	558.9	408.66	570.03
6	Aet	206.35	272.89	272.97	255.28	304.67	318.3
7	Gw_Rech	387.44	99.51	341.4	188.7	18.56	151.51
8	Avail_Sm	190.39	131.28	184.58	114.92	85.43	100.22

Table 12 - Water balance Kada, Midhala - soybean, silty clay, 1m

	Crop: soyaben, Soil : silty Clay, Depth: 1 m						
	Circle	Kada			Midhala		
	Sowing Date	06/23/2018			06/09/2018		
Sr	Crop_End_Parameters	10/05/2018			09/21/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	191.5	191.5	191.5	973.7	973.7	973.7
2	ET0	404.08	514.61	513.46	327.55	439.32	437.64
3	Pet	309.27	391.75	391.1	233.08	316.33	315.03
4	Runoff	0	0.77	0	315.53	509.67	296.2
5	Infil	191.5	190.73	191.5	658.17	464.03	677.5
6	Aet	163.59	163.8	165.42	232.87	309.73	310.07
7	Gw_Rech	0	0	0	274.89	31.12	223.07
8	Avail_Sm	27.91	26.93	26.08	150.41	123.18	144.36

In Silty clay soil for soybean with increase in depth reduction in runoff is observed for all the circles for both PM hourly and Hargreaves hourly method as compared to Hargreaves daily. Both the methods have shown an increase in infiltration as compared to Hargreaves daily. Both the methods have shown an increase in AET as compared to Hargreaves daily. With increase in soil depth there is decrease in groundwater recharge is observed for daily Hargreaves method. PM hourly has shown slight increase or similar recharge with increase in depth. Hargreaves hourly has shown both increase and decrease in the groundwater recharge. All the methods have shown increase in the available soil moisture.

For Sandy Clay Loam soil and depth 0.5m

It can be seen from the table below that ET0 computed using the PM approach is less as compared to Hargreaves for all the circles. This means lower crop water requirements. Runoff computed using Hargreaves hourly and PM hourly has reduced in all the circles compared to Hargreaves daily. Infiltration computed using Hargreaves hourly and PM hourly has increased in all the circles compared to Hargreaves daily. In the case of Hargreaves hourly, AET is similar for all the circles whereas for PM hourly it has reduced as compared to the Hargreaves daily. Both the methods have shown an increase in groundwater recharge as compared to Hargreaves daily where PM hourly showing slightly more recharge compared to Hargreaves hourly in all the circles. Both the methods have shown a considerable difference in monsoon end soil moisture values as compared to Hargreaves daily and shown more availability of soil moisture.

Table 13 - Water balance Chikhaldara, Sengaon - soybean, sandy clay loam, 0.5m

	Crop: soyaben, Soil : Sandy Clay Loam, Depth: .5 m						
	Circle	Chikhaldara			Sengaon		
	Sowing Date	06/10/2018			06/05/2018		
Sr	Crop_End_Parameters	09/22/2018			09/17/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	1134	1134	1134	655	655	655
2	ET0	285.45	380.98	378.44	363.66	467.03	466.11
3	Pet	206.37	274.48	273.35	258.84	339.94	339.84
4	Runoff	330.19	586.03	318.79	78.35	240.14	73.12
5	Infil	803.81	547.97	815.21	576.65	414.86	581.88
6	Aet	203.14	258.81	258.6	229.22	265.24	270.79
7	Gw_Rech	507.11	229.56	464.29	323.58	131.56	292.38
8	Avail_Sm	93.56	59.6	92.32	23.85	18.06	18.71

Table 14 - Water balance Kada, Midhala - soybean, sandy clay loam, 0.5m

	Crop: soyaben, Soil : Sandy Clay loam, Depth: .5 m						
	Circle	Kada			Midhala		
	Sowing Date	06/23/2018			06/09/2018		
Sr	Crop_End_Parameters	10/05/2018			09/21/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	191.5	191.5	191.5	973.7	973.7	973.7
2	ET0	514.61	514.61	513.46	324	439.32	437.64
3	Pet	391.75	391.75	391.1	231.89	316.33	315.03
4	Runoff	7.17	7.17	1.98	287.81	485	276.11
5	Infil	184.33	184.33	189.52	685.89	488.7	697.59
6	Aet	156.26	156.26	158.45	221.25	283.68	282.6
7	Gw_Rech	0.65	0.65	4.49	408.83	162.74	365.11
8	Avail_Sm	27.42	27.42	28.56	55.81	42.28	325.99

For Sandy Clay Loam soil and depth 1m

It can be seen from the table below that ET0 computed using the PM approach is less as compared to Hargreaves for all the circles. This means lower crop water requirements. Runoff computed using Hargreaves hourly and PM hourly has reduced in all the circles compared to Hargreaves daily. Infiltration computed using Hargreaves hourly and PM hourly has increased in all the circles compared to Hargreaves daily. In the case of Hargreaves hourly, AET is similar for all the circles whereas for PM hourly it has reduced as compared to the Hargreaves daily. Both the methods have shown an increase in groundwater recharge as compared to Hargreaves daily where PM hourly showing slightly more recharge compared to Hargreaves hourly in all the circles. Both the methods have shown a considerable difference in monsoon end soil moisture values as compared to Hargreaves daily and shown more availability of soil moisture.

Table 15 - Water balance Chikhaldara, Sengaon - soybean, sandy clay loam, 1 m

	Crop: soyaben, Soil : Sandy Clay Loam, Depth: 1 m						
	Circle	Chikhaldara			Sengaon		
	Sowing Date	06/10/2018			06/05/2018		
Sr	Crop_End_Parameters	09/22/2018			09/17/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	1134	1134	1134	655	655	655
2	ET0	285.45	380.98	378.44	382.48	490.02	466.11
3	Pet	206.37	274.48	273.35	258.84	339.94	339.84
4	Runoff	275.48	565.45	267.12	60.15	238.3	56.42
5	Infil	858.52	568.55	866.88	594.85	416.7	598.58
6	Aet	205.99	267.34	267.5	242.91	284.69	291.08
7	Gw_Rech	506.69	200.45	456.53	282.95	74.38	248.11
8	Avail_Sm	145.84	100.76	142.85	68.99	57.63	59.39

Table 16 - Water balance Kada, Midhala - soybean, sandy clay loam, 1 m

	Crop: soyaben, Soil : Sandy Clay loam, Depth: 1 m						
	Circle	Kada			Midhala		
	Sowing Date	06/23/2018			06/09/2018		
Sr	Crop_End_Parameters	10/05/2018			09/21/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly

1	Rain	191.5	191.5	191.5	973.7	973.7	973.7
2	ET0	404.08	514.61	513.46	327.55	439.32	437.64
3	Pet	309.27	391.75	391.1	233.08	316.33	315.03
4	Runoff	0.06	1.19	0.05	248.23	479.43	239.35
5	Infil	191.44	190.31	191.45	725.47	494.27	734.35
6	Aet	164.62	167.02	168.77	229.92	296.54	295.87
7	Gw_Rech	0	0	0	391.15	114.2	340.77
8	Avail_Sm	26.82	23.29	22.68	104.4	83.53	97.71

In sandy clay loam soil for soybean with increase in depth reduction in runoff is observed for all the circles for both PM hourly and Hargreaves hourly method as compared to Hargreaves daily. Both the methods have shown an increase in infiltration as compared to Hargreaves daily. AET is similar for Hargreaves hourly as compared to Hargreaves daily where as it reduces for PM hourly. With increase in soil depth there is decrease in groundwater recharge is observed for daily Hargraves method. Hargreaves hourly has shown decrease in recharge with increase in depth. PM hourly has shown both increase and decrease in the groundwater recharge. All the methods have shown increase in the available soil moisture.

Table 17 - Water balance Itkur - soybean, cotton - clayey, 1 m

	Crop: soyaben, Soil : Clayey, Depth: 1 m				Crop: Cotton, Soil : Clayey, Depth: 1 m		
	Circle	Itkur					
	Sowing Date	06/28/2018			06/28/2018		
Sr	Crop_End_Parameters	10/10/2018			12/24/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	378	378	378	558	558	558
2	ET0	357.99	464.18	462.97	566.18	736.39	727.95
3	Pet	272.04	352.55	351.75	517.77	674.81	667.4
4	Runoff	19.84	21.99	13.54	39.64	60.09	19.45
5	Infil	358.16	356.01	364.46	518.36	497.91	538.55
6	Aet	241.67	261.43	263.68	486.32	496.77	524.92
7	Gw_Rech	0	0	0	14.57	0	6.94
8	Avail_Sm	116.49	94.58	100.78	17.47	1.14	6.69

Table 18 - Water balance Itkur – soybean, cotton - clayey, 0.5 m

	Crop: soyaben, Soil : Clayey, Depth: 0.5 m				Crop: Cotton, Soil : Clayey, Depth: 0.5 m		
	Circle	Itkur					

	Sowing Date	06/28/2018			06/28/2018		
Sr	Crop_End_Parameters	10/10/2018			12/24/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	378	378	378	558	558	558
2	ET0	353.67	459.02	457.74	566.18	736.39	727.95
3	Pet	272.04	352.55	351.75	517.77	674.81	667.4
4	Runoff	51.2	59.83	42.2	97.86	106.55	74.32
5	Infil	326.8	318.17	335.8	460.14	451.45	483.68
6	Aet	227.95	245.77	249.11	421.24	438.47	460.36
7	Gw_Rech	30.56	12.07	24.13	32.52	6.29	18.04
8	Avail_Sm	68.29	60.33	62.56	6.38	6.69	5.28

Table 19 - Water balance Itkur - soybean, cotton - silty clay, 0.5 m

	Crop: Soybean, Soil: Silty Clay, Depth: 0.5 m				Crop: Cotton, Soil: silty Clay, Depth: 0.5 m		
	Circle	Itkur					
	Sowing Date	06/28/2018			06/28/2018		
Sr	Crop_End_Parameters	10/10/2018			12/24/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	378	378	378	558	558	558
2	ET0	353.67	459.02	457.74	566.18	736.39	727.95
3	Pet	272.04	352.55	351.75	517.77	674.81	667.4
4	Runoff	42.1	55.99	37.85	72.99	94.76	47.57
5	Infil	335.9	322.01	340.15	485.01	463.24	510.43
6	Aet	231.79	249.91	253.97	427.03	452.75	466.09
7	Gw_Rech	34.28	3.84	18.02	52.45	2.64	39.71
8	Avail_Sm	69.83	68.26	68.16	5.53	7.85	4.63

Table 20 - Water balance Itkur - soybean , cotton - silty clay, 1 m

	Crop: Soybean, Soil: Silty Clay, Depth: 1 m				Crop: Cotton, Soil: Silty Clay, Depth: 1 m		
	Circle	Itkur					

	Sowing Date	06/28/2018			06/28/2018		
Sr	Crop_End_Parameters	10/10/2018			12/24/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	378	378	378	558	558	558
2	ET0	353.67	459.02	457.74	566.18	736.39	727.95
3	Pet	272.04	352.55	351.75	517.77	674.81	667.4
4	Runoff	18.04	23.94	14.62	35.85	66.04	22.01
5	Infil	359.96	354.06	363.38	522.15	491.96	535.99
6	Aet	242.54	259.07	262.38	478.13	489.76	525.37
7	Gw_Rech	0	0	0	22.06	0	0.32
8	Avail_Sm	117.42	94.99	101	21.96	2.2	10.3

Table 21 - Water balance Itkur - soybean, cotton - sandy clay loam, 0.5 m

	Crop: Soybean, Soil: Sandy Clay loam, Depth: 0.5 m				Crop: Cotton, Soil: sandy clay loam Clay, Depth: 0.5 m		
	Circle	Itkur					
	Sowing Date	06/28/2018			06/28/2018		
Sr	Crop_End_Parameters	10/10/2018			12/24/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	378	378	378	558	558	558
2	ET0	353.67	459.02	457.74	566.18	736.39	727.95
3	Pet	272.04	352.55	351.75	517.77	674.81	667.4
4	Runoff	33.9	53.03	31.12	51.94	105.79	43.86
5	Infil	344.1	324.97	346.88	506.06	452.21	514.14
6	Aet	218.11	234.96	238.38	380.41	408.74	418.26
7	Gw_Rech	77.8	42.61	61.98	120.73	36.85	92.06
8	Avail_Sm	48.19	47.4	46.52	4.92	6.62	3.82

Table 22 - Water balance Itkur- soybean, cotton - sandy clay loam, 1 m

	Crop: Soybean, Soil : Sandy Clay loam, Depth: 1 m		Crop: Cotton, Soil: Sandy Clay Loam, Depth: 1 m
	Circle	Itkur	

Sr	Sowing Date	06/28/2018			06/28/2018		
	Crop_End_Parameters	10/10/2018			12/24/2018		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	378	378	378	558	558	558
2	ET0	353.67	459.02	457.74	566.18	736.39	727.95
3	Pet	272.04	352.55	351.75	517.77	674.81	667.4
4	Runoff	28.18	38.2	24.59	38.87	68.08	23.33
5	Infil	349.82	339.8	353.41	519.13	489.92	534.67
6	Aet	228.73	246.96	250.49	452.79	487.28	496.08
7	Gw_Rech	23.96	0	7.24	60.97	0	35.64
8	Avail_Sm	97.13	92.84	95.68	5.37	2.64	2.95

1.5 Conclusions

1. ET0 computed using the PM approach is less as compared to Hargreaves.
2. Runoff computed using Hargreaves hourly reduced as compared to Hargreaves daily and in case of PM it has shown reduction except few cases.
3. Both the methods have shown an increase in infiltration as compared to Hargreaves daily.
4. In the case of Hargreaves hourly, AET has increased whereas for PM hourly it has reduced as compared to the Hargreaves daily due to less ET0.
5. Both the methods have shown an increase in groundwater recharge as compared to Hargreaves daily.
6. Both the methods have shown a considerable difference in monsoon end soil moisture values as compared to Hargreaves daily and shown more availability of soil moisture.
7. With increase in depth reduction in runoff is observed.
8. With increase in depth increase in infiltration is observed.
9. With increase in depth some circles have shown both increase and decrease in groundwater recharge.
10. There is an increase in availability of soil moisture with increase in the depth.

1.6 Appendix

Hourly Model and stream model result for Mandwa Cluster

In this case study result for Mandwa cluster is given. This builds upon the work done on stream model and hourly model. In the stream model we tried to improve on the accounting of groundwater by incorporation of stream simulation process. This is explained in the next chapter in the report. Water from different farms was routed into the stream. Within the streams, water was routed using the variable storage method. Rate and velocity component in a stream were computed using the Manning's equation. Transmission loses computed were added to the groundwater. The link for the document is given here Link. In hourly model, we tried to improve the accounting of farm level runoff by migrating daily water balance model to hourly time-steps. For this hourly weather parameters were used to compute hourly ETo and time step in equations was reduced to hourly interval wherever it was required. Comparison for water balance components for hourly and daily interval for different physical conditions was done and given in the report.

In this report two micro watersheds were selected in the Mandwa cluster. In these two watersheds the output of the farm level model was fed into the stream model to get improved water balance components. Out of these two watersheds One lies in the Bavi village and other in the Sonarwadi village. The location of these two with in the cluster is given in the figure 14.

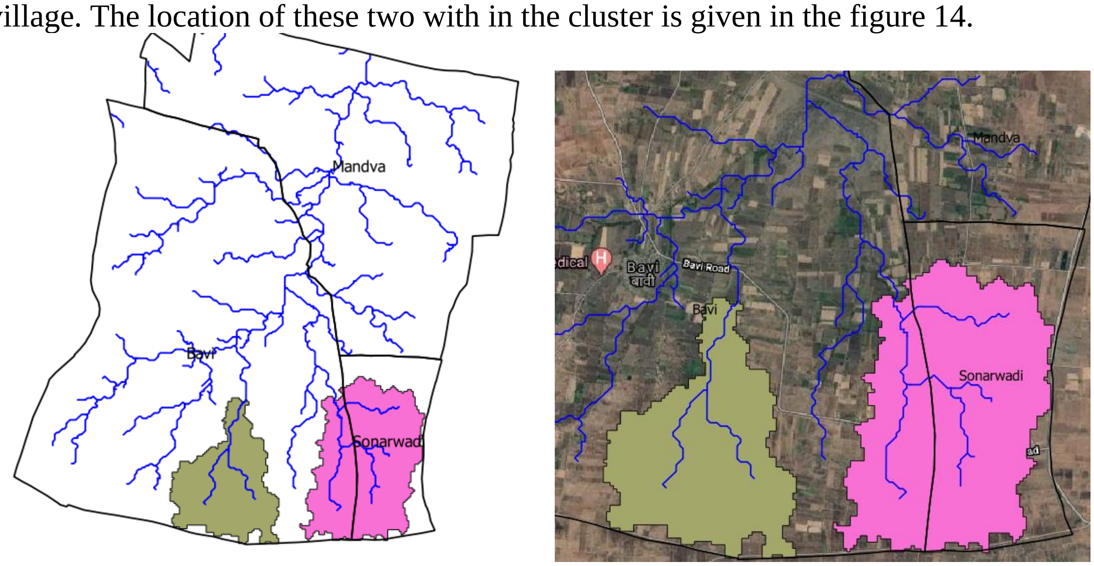

Figure 14 - Bavi and Sonarwadi Watershed

Both the watersheds have first and second order streams only. Figure 15 and 16 gives the location of different streams and their respective contributing areas.

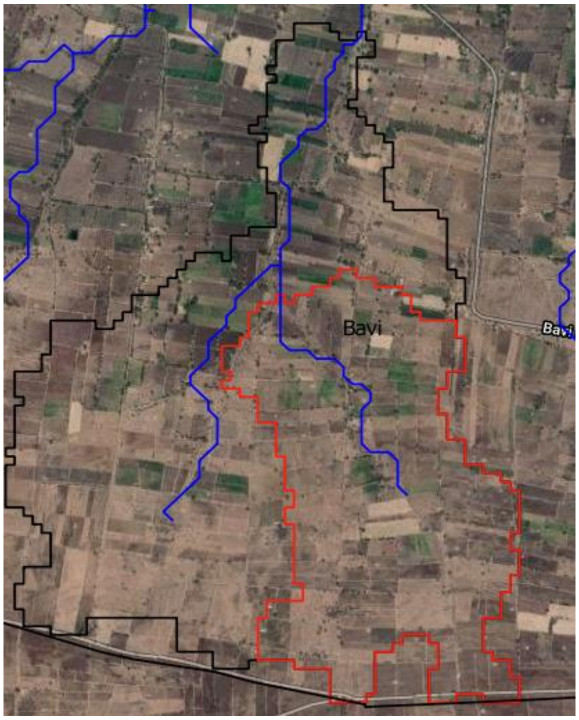

Figure 15 - Bavi Watershed

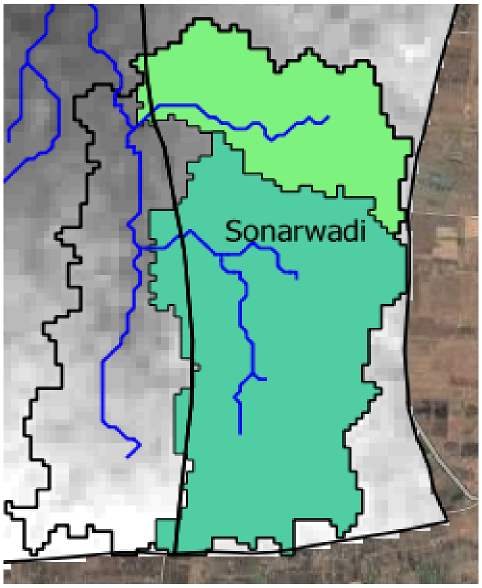

Figure 16 - Sonarwadi Watershed

The cluster is dominated by clayey soil type and its depth varies from the 0.5m to 1m. In the selected watersheds we have gravelly sandy clayey loam and gravelly sandy loam. Both of them have depth of 0.25m. Figure 17 and 18 represents the description of soil type and soil depth in the region.

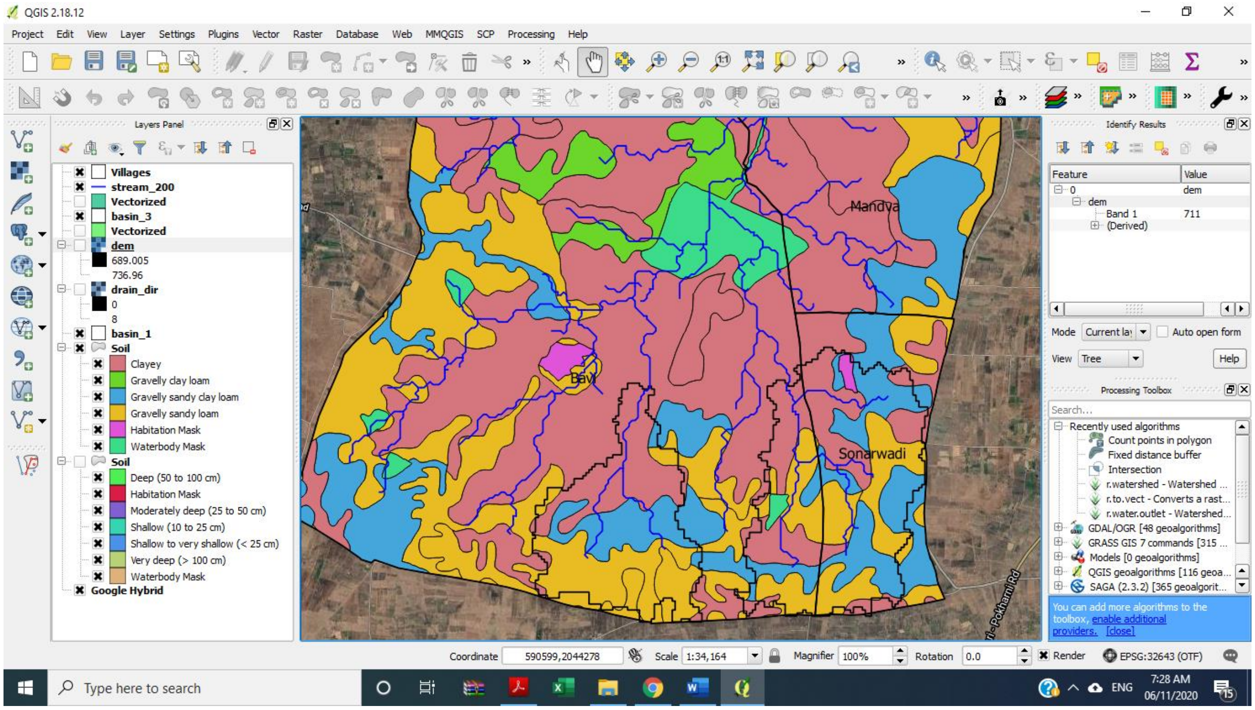

Figure 17 - Soil types

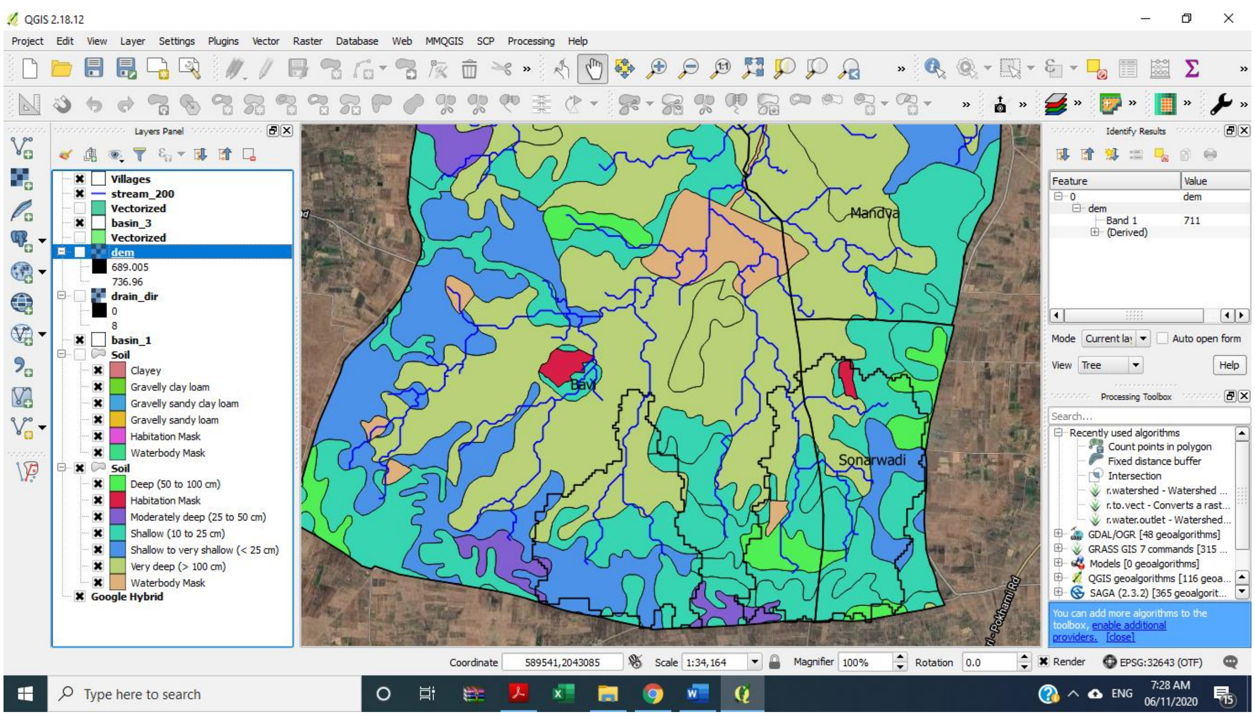

Figure 18 - Soil Depths

For streams lying in the respective watersheds their length, width slope and contributing area was computed using the qgis and google earth. These characteristics are given in the table 17 and table 18 below.

Table 23 - Stream Characteristics Bavi Watershed

Sr.No	Stream order	Stream length (m)	Stream Width (m)	Watershed area (ha)	Channel_slope
1	1	1000	8	94	0.01
2	2	1900	13	137	0.008

Table 24 - Stream Characteristics Sonarwadi watershed

Sr.No	Stream order	Stream length (m)	Stream Width (m)	Watershed area (ha)	Channel_slope
1	1	900	6	71	0.012
2	1	1500	6	170	0.009
3	2	1900	13	121	0.009

Soybean was observed to be the major crop in the region in 2019. The combination of soil type and depth such clayey-1m, clayey-0.5m, gravelly sandy clayey loam-0.25m and gravelly sandy loam-0.25m as observed from the soil layer were used to understand their impact on the individual combination on the water balance components for this cluster for year 2019. Results were obtained using three different methods and for two crops: soybean and cotton. These results are presented below in Table 19,20,21 and 22.   Details of these methods were given in the document link. For the year 2019 there was late monsoon rainfall observed in this cluster.

Hargreaves hourly produced least amount of runoff as compared to other methods. In comparison to Hargreaves daily, the reduction in runoff varies from 15% for clayey soil to 60% for gravelly sandy loam for soybean crop for full rainfall season including late monsoon. As cotton is a long duration crop, runoff amount reduced by minimum 30% in all the cases and it reduces up to 70%. ETo was less in case of Penman Monteith. Due to this Aet was less compared to other methods. Groundwater percolation is more in case of penman Monteith as compared to other methods. This difference is significantly higher in comparison to Hargreaves daily but very less compared to Hargraves hourly. In case of groundwater recharge Hargreaves hourly has shown 30% increase in ground water recharge value in case of soybean for complete rainfall season when compared with Hargreaves daily. In case of cotton for deep clay soil groundwater recharge did not increase much but in other cases it had shown significant increase in value.

Table 25 - Water balance components for Clay 1m

	Crop: soyaben, Soil : Clayey, Depth: 1 m		Crop: Cotton, Soil : Clayey, Depth: 1 m
	Circle	Itkur	

Sr	Sowing Date	06/28/2019			06/28/2019		
	Monsoon _ Parameters	10/10/2019			10/10/2019		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	378	378	378	378	378	378
2	ET0	353.67	459.02	457.74	353.67	459.02	457.74
3	Pet	272.04	352.55	351.75	300.19	390	389.28
4	Runoff	19.84	21.99	14.37	32.39	33.39	6.69
5	Infil	358.16	356.01	363.63	345.61	344.61	371.31
6	Aet	241.67	261.43	263.57	284.77	317.73	321.9
7	Gw_Rech	0	0	0	12.68	0	0
8	Avail_Sm	116.49	94.58	100.06	48.16	26.88	49.41
	Condition till	12/24/2019					
1	Rain	558	558	558	558	558	558
2	ET0	566.18	736.39	727.95	566.18	736.39	727.95
3	Pet	272.04	352.55	351.75	517.77	674.81	667.4
4	Runoff	113.76	127.86	106.78	97.86	106.55	20.75
5	Infil	444.24	430.14	451.22	460.14	451.45	537.25
6	Aet	241.67	261.43	263.57	421.24	438.47	523.83
7	Gw_Rech	79.93	44.87	64.16	32.52	6.29	6.7
8	Avail_Sm	122.64	123.84	123.49	6.38	6.69	6.72

Table 26 - Water balance components for Clay 0.5m

	Crop: soyaben, Soil : Clayey, Depth: 0.5 m				Crop: Cotton, Soil : Clayey, Depth: 0.5 m		
	Circle	Itkur					
	Sowing Date	06/28/2019			06/28/2019		
Sr	Monsoon _ Parameters	10/10/2019			10/10/2019		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	378	378	378	378	378	378
2	ET0	353.67	459.02	457.74	353.67	459.02	457.74
3	Pet	272.04	352.55	351.75	300.19	390	389.28

4	Runoff	51.2	59.83	42.2	32.39	33.39	21.27
5	Infil	326.8	318.17	335.8	345.61	344.61	356.73
6	Aet	227.95	245.77	249.11	284.77	317.73	321.23
7	Gw_Rech	30.56	12.07	24.13	12.68	0	2.01
8	Avail_Sm	68.29	60.33	62.56	48.16	26.88	33.49
	Condition till	12/24/2019			12/24/2019		
1	Rain	558	558	558	558	558	558
2	ET0	566.18	736.39	727.95	566.18	736.39	727.95
3	Pet	272.04	352.55	351.75	517.77	674.81	667.4
4	Runoff	181.63	191.69	171.72	97.86	106.55	74.32
5	Infil	376.37	366.31	386.28	460.14	451.45	483.68
6	Aet	227.95	245.77	249.11	421.24	438.47	460.36
7	Gw_Rech	86	58.04	74.14	32.52	6.29	18.04
8	Avail_Sm	62.42	62.5	63.03	6.38	6.69	5.28

Table 27 - Water balance components for Gravely Sandy Clay Loam 0.25m

	Crop: soyaben, Soil : Gravelly sandy Clayey loam , Depth: 0.25 m			Crop: Cotton, Soil : Gravelly sandy Clayey loam, Depth: 0.25 m			
	Circle	Itkur					
	Sowing Date	06/28/2019			06/28/2019		
Sr	Monsoon _ Parameters	10/10/2019			10/10/2019		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	378	378	378	378	378	378
2	ET0	353.67	459.02	457.74	353.67	459.02	457.74
3	Pet	272.04	352.55	351.75	300.19	390	389.28
4	Runoff	13.79	29.61	12.14	6.05	16.84	3.59
5	Infil	364.21	348.39	365.86	371.95	361.16	374.41
6	Aet	187.3	208.4	208.29	239.59	268.42	267.25
7	Gw_Rech	131.89	96.75	114.36	98.57	61.04	75.55
8	Avail_Sm	45.02	43.24	43.21	33.79	31.7	31.61
	Condition till	12/24/2019					
1	Rain	558	558	558	558	558	558
2	ET0	566.18	736.39	727.95	566.18	736.39	727.95
3	Pet	272.04	352.55	351.75	517.77	674.81	667.4

4	Runoff	59.52	125.8	58.02	33.99	86.48	30.66
5	Infil	498.48	432.2	499.98	524.01	471.52	527.34
6	Aet	187.3	208.4	208.29	308.75	343.74	343.21
7	Gw_Rech	265.2	177.15	244.97	191.62	103.64	161.04
8	Avail_Sm	45.98	46.65	46.72	23.64	24.14	23.09

Table 28 - Water balance components for Gravely Sandy Loam 0.25m

	Crop: soyaben, Soil : Gravelly sandy loam , Depth: 0.25 m				Crop: Cotton, Soil : Gravelly sandy loam, Depth: 0.25 m		
	Circle	Itkur					
	Sowing Date	06/28/2019			06/28/2019		
Sr	Monsoon_End_Parameters	10/10/2019			10/10/2019		
		Pen_Hourly	Har_Daily	Har_Hourly	Pen_Hourly	Har_Daily	Har_Hourly
1	Rain	378	378	378	378	378	378
2	ET0	353.67	459.02	457.74	353.67	459.02	457.74
3	Pet	272.04	352.55	351.75	300.19	390	389.28
4	Runoff	14.15	32.41	12.78	6.94	23.61	5.12
5	Infil	363.85	345.59	365.22	371.06	354.39	372.88
6	Aet	174.96	196.26	195.36	223.36	249.73	245.26
7	Gw_Rech	143.99	106.08	126.74	111.65	69.26	92.78
8	Avail_Sm	44.9	43.25	43.12	36.05	35.4	34.84
	Condition till	12/24/2019					
1	Rain	558	558	558	558	558	558
2	ET0	566.18	736.39	727.95	566.18	736.39	727.95
3	Pet	272.04	352.55	351.75	517.77	674.81	667.4
4	Runoff	40.29	112.09	39.55	25.48	85.31	23.67
5	Infil	517.71	445.91	518.45	532.52	472.69	534.33
6	Aet	174.96	196.26	195.36	286.11	320.94	315.95
7	Gw_Rech	296.92	202.94	276.55	218.81	123.62	191.48
8	Avail_Sm	45.83	46.71	46.54	27.6	28.13	26.9

Differential watersheds were delineated for individual streams and using their contributing area and stream characteristics output of farm model was fed into stream model. Results for different soil type and stream order are given below. Table 7 gives the result for Bavi watershed. Total transmission losses in the Bavi water for different combinations of soil types varies from 15% to 25% of the farm runoff. Clay with 0.5m shows maximum transmission loss which amounts to 30mm of 171mm runoff. This can be seen from table 23

Table 29 - Stream Model Output for Bavi

Sr	Soil Type	Streams	Runoff (m3)	Voume in (m3)	Volume out (m3)	Transmission loss (m3)
1	Soya_clay_1m	Order_1	100373	0	96314	4386
		Order_2	146288	96314	212324	32731
2	Soya_Clay_0.5m	Order_1	161501	0	150284	12115
		Order_2	235379	150284	331496	58574
3	Gravely_Sandy_ Loam_0.25m	Order_1	38079	0	35038	3288
		Order_2	55498	35038	70346	21854
4	Gravely_Sandy_ Loam_0.25m	Order_1	55384	0	51121	4611
		Order_2	80720	51121	104665	29404

Differential watersheds were delineated for individual streams and using their contributing area and stream characteristics output of farm model was fed into stream model. Results for different soil type and stream order are given below. Table 8 gives the result for Sonarwadi watershed. Total transmission losses in the Sonarwadi watershed for different combination of soil types varies from 9% to 17% of the farm runoff. Clay with 0.5m shows maximum transmission loss which amounts to 23mm of 171mm runoff. This can be seen from table 23, 24

Table 30 - Stream Model Output for Sonarwadi

Sr	Soil Type	Streams	Runoff (m3)	Voume in (m3)	Volume out (m3)	Transmission loss (m3)
1	Soya_clay_1m	Order_1	75873		73566	2427
		Order_1	181526		174719	7365
		Order_2	129203	248277	351467	28111
2	Soya_Clay_0.5m	Order_1	121985		115291	7231
		Order_1	292077		273952	19596
		Order_2	207890	389244	543699	57801
3	Gravely_Sandy_ Loam_0.25m	Order_1	28762	0	27132	1762
		Order_1	68867	0	63242	6086
		Order_2	49017	90374	118003	23153
4	Gravely_Sandy_ Loam_0.25m	Order_1	41833	0	39305	2731
		Order_1	100161	0	92736	8036
		Order_2	71293	132041	128023	27383

Table 31 - Transmission Loss and Runoff

		Bavi		Sonarwadi	
Sr	Soil Type	Total loss in mm	Runoff in mm	Total loss in mm	Runoff in mm
1	Soya_clay_1m	16.07	106.78	10.47	106.80
2	Soya_Clay_0.5m	30.60	171.81	23.38	171.81

3	Gravely_Sandy_Loam_0.25m	10.88	40.51	8.56	40.51
4	Gravely_Sandy_Loam_0.25m	14.73	58.92	10.54	58.92

2. Report on Results of two clusters using Stream-flow simulation plugin

Prepared
by
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Contents

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2.1 Introduction

This document provides the detail of the work done under MOU III component A1-Development of GIS framework for regional flows and component A2-Development of stream simulation framework and incorporation of near stream budget.

This document is in continuation of the earlier work done on the design of a conceptual framework for surface water accounting using stream network. The current water balance accounting framework computes the water budget components at the farm level. Then those components are aggregated over micro watershed (200-500 ha), which is part of the village (1000 ha). Things like losses across the stream network, amount of water flowing into the village watersheds, water leaving the village watersheds were missing. Improving upon the existing framework will help in the correct assessment of various stocks and flows, especially the considerable amount of runoff made available to the downstream villages from the upstream villages. This can be used to tackle the crop water deficit more effectively and to plan infrastructure around the streams. Detailed description of the surface accounting framework is given in this document Link.

Using the conceptual framework, we designed a QGIS plugin. The plugin has mainly two functionalities. The first is to identify the stream characteristics of various streams. The second is to incorporate the stream simulation process. Water from different farms is routed into the stream using the physical network derived in the first step of the plugin. Within the streams, water is routed using the variable storage method. The rate and velocity component in a stream is computed using Manning's equation. The theoretical framework and equations used for the process are given in the document Link. Technical description about the plugin is provided in this document link.

2.2 Objective

1. Given a DEM (Digital Elevation Model), extract the stream network. Using stream and watershed outlet as reference point, delineate the watershed for the area of interest.
2. For the given area of interest, extract the physical properties and stream interconnectedness.
3. Using the above network, simulate the water through these stream segments using routing methods and account for losses.
4. Summarize the results for the cluster.

2.3 Description of the plugin

2.3.1 Inputs

Plugin mainly requires only DEM file. This file can be downloaded from the given link https://asf.alaska.edu/. Dem has a resolution of 12.5 meters which is the highest freely available resolution. The second input is the input point for watershed delineation in the region of interest. Reference Stream network for selecting the point is generated using DEM. Runoff file generated using an hourly water balance plugin is the input file to the plugin. The plugin extracts the peak runoff value from the file and uses it for further computations.

2.3.2 Output 1

Within the selected region of interest, the plugin generates contributing areas for each stream, also known as differential watersheds. Using DEM file and different modules, it computes the segment id's, stream order, node points, stream linkages, length, depth, etc. The plugin uses peak runoff data and Manning's equation for calculation of width for different streams. At this point, the extraction of all the physical characteristics of the stream is complete and saved in the attribute table of the stream network. The next step is to use this network in streamflow simulation process.

2.3.2 Output 2

Water storage routing method given in the swat theory is used for calculation of stream flows and losses across the stream network. A CSV file is generated, which contains the details of flows, stocks at each time step for each stream segment.

2.4 Modules used in the plugin

All the following modules are interlinked with each other. This means the user needs to provide input only once. The output of one algorithm will be fed as input to the next algorithm in fixed flow.

1. grass: r.watershed - module is used to generate the stream segment. It uses a dem file as input. A threshold value is selected based upon the density of the stream network required is selected. The default value is 500.
2. r.water.outlet - is used to compute the watershed for the area of interest (Figure 1). Drainage direction and input coordinates are the input for this module. Drainage direction is generated using r.watershed. It is required by the algorithm to understand the flow direction.
3. The raster file of the generated watershed is converted into the vector file using r.to.vect command. Clip command is used to clip the dem file, stream file to the region of interest.
4. saga: channelnetworkanddrainagebasins - this module is used to compute the stream network with the required segment id, node points, order, stream connections. All the parameters are added to the stream shapefile.
5. An algorithm is written, which computes the depth of the individual stream segment using the elevation pixels on both sides of the stream bed pixel. Based upon the difference of elevation on both sides of the stream bed pixel, minimum value is selected as the depth value for the stream.
6. r.water.outlet - is used to compute the watersheds for each segment on the network. This will provide us the water contributing area for each segment (Figure 2).
7. Width calculation - Manning's flow equation is used to calculate the width of stream segments. It uses the peak runoff, depth and width computed using the above algorithms.
8. All these parameters are added to the stream network file in order of their generation (Figure 3). The list of parameters are as Segment Id - unique segment id, Noda_A - the starting point of a stream, Node_B - endpoint of a stream, Order - strahler order of stream, Length - lenght of stream segment (m), Slope of stream segment, Basin area - contributing area to stream segment (m2), Slope - slope of stream segment, B_Width - Bottom Width (m), T_Width - Top Width (m), Sources - Contributing streams to given stream, Q- Peak Discharge rate (m3/h).

a) Input DEM Raster layer

b) Watershed basin is generated for the given point

c) Stream network is generated from clipped Raster layer

Figure 19- Watershed delineation for area of interest

a) Watershed basin for order 2 stream segment

b) Watershed basin for (1st source) order1 stream segment

c) Watershed basin for (2nd source) order1 stream segment

d) Subtracting basin area of source streams from order 2 stream network

Figure 20 - Watershed extraction for individual stream segment

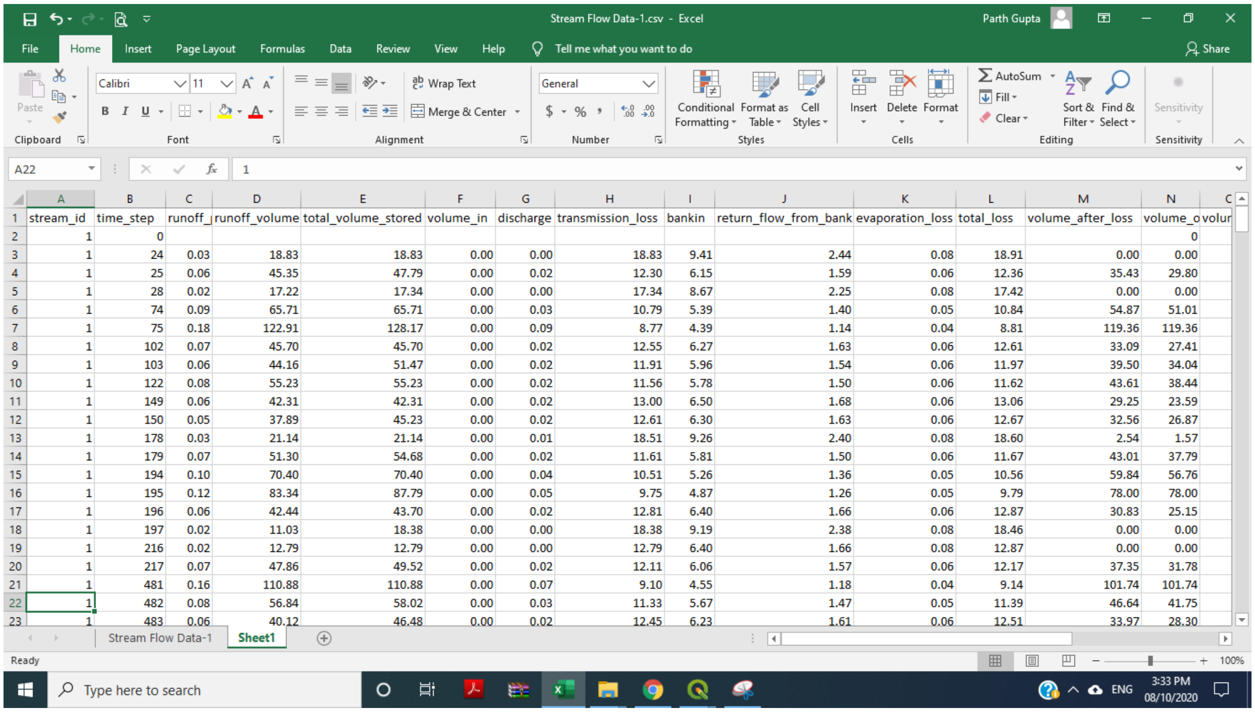
	SEGMENT_ID	NODE_A	NODE_B	BASIN	ORDER	ORDER_CELL	LENGTH	DEPTH	BASIN AREA	SLOPE	B_WIDTH	T_WIDTH	SOURCES	Q
1	1	3	2	2	1	6	405.6980515300	1.00000	387187.50000	0.01232	1.14420	1.14420	NULL	1.29493
2	2	4	1	1	3	8	631.5863991800	1.11111	209062.50000	0.00317	16.08731	16.08731	4, 5	19.79754
3	3	5	7	1	1	6	530.6980515300	1.31579	245000.00000	0.01696	0.60764	0.60764	NULL	0.81939
4	4	6	4	1	2	7	316.4213562400	1.25000	89062.50000	0.00948	5.80522	5.80522	6, 7	12.91530
5	5	7	4	1	2	7	887.6524163600	1.13333	460468.75000	0.01239	3.21680	3.21680	3, 8	6.18304
6	6	8	6	1	1	6	468.1980515300	1.29412	267187.50000	0.02349	0.58536	0.58536	NULL	0.89359
7	7	9	6	1	2	7	571.2310601200	1.42105	299218.75000	0.0105	4.43099	4.43099	9, 13	11.72385
8	8	10	7	1	1	6	1269.6067812000	1.27451	1143281.25000	0.00945	2.19435	2.19435	NULL	3.82364
9	9	11	9	1	2	7	279.8097038900	1.20000	134218.75000	0.00357	4.53081	4.53081	10, 11	5.52931
10	10	12	11	1	1	6	319.4543648300	1.83333	549218.75000	0.01878	0.77919	0.77919	NULL	1.83683
11	11	13	11	1	2	7	929.4417382400	1.80952	326093.75000	0.01076	1.37492	1.37492	12, 14	3.24359
12	12	14	13	1	1	6	191.4213562400	1.00000	350625.00000	0.00522	1.44695	1.44695	NULL	1.17265
13	13	15	9	1	1	6	1677.4494937000	1.18919	1552968.75000	0.00835	3.10997	3.10997	NULL	5.19382
14	14	16	13	1	1	6	277.6650429400	1.00000	293125.00000	0.0036	1.45412	1.45412	NULL	0.98034

Figure 21 - Attribute table with the generated parameters

2.5 Streamflow process

Brief summary of the stream flow process is described below. For a detailed description of the process and equations used, please refer to the document submitted earlier Link. The screen shot of the output of the stream flow process is given in figure 4. This output csv is saved in the input directory.

1. Initially, it is assumed that the side slope (run to rise ratio) is 1:1 or Zch =1 for stream segment.
2. For given watershed, at the beginning of first-time step amount of water stored in the channel is set equal to the amount of runoff generated for that differential watershed + existing storage, if any, which is generally zero.
3. If there is no inflow from the upstream, the volume in the component will be set equal to zero.
4. The amount of runoff generated is routed into the channel, and depth of water in the channel is calculated for a given volume of water.
5. Once the depth of water level is known cross-section area at water level, wetted perimeter, and hydraulic radius is calculated.
6. Using manning's equation flow/discharge in the channel is computed.
7. Volume out, at the end of the time step, will be computed using the storage coefficient.
8. Various losses are computed and subtracted from the existing storage to get the net storage in the channel at the end of the time step.
9. Net storage will act as initial storage for the next time step, and runoff generated from the watershed for the next time step will be added into this to compute the Total storage for the next time step.
10. This total storage will be used as volume to compute the new area of depth, hydraulic radius, wetted perimeter velocity, etc.
11. Volume out for the first-time step of one segment will act as volume in, for the next stream segment in line for the second time step.



	stream_id	time_step	runoff_	runoff_volume	total_volume_stored	volume_in	discharge	transmission_loss	bankin	return_flow_from_bank	evaporation_loss	total_loss	volume_after_loss	volume_o	volur
2	1	0												0	
3	1	24	0.03	18.83	18.83	0.00	0.00	18.83	9.41	2.44	0.08	18.91	0.00	0.00	
4	1	25	0.06	45.35	47.79	0.00	0.02	12.30	6.15	1.59	0.06	12.36	35.43	29.80	
5	1	28	0.02	17.22	17.34	0.00	0.00	17.34	8.67	2.25	0.08	17.42	0.00	0.00	
6	1	74	0.09	65.71	65.71	0.00	0.03	10.79	5.39	1.40	0.05	10.84	54.87	51.01	
7	1	75	0.18	122.91	128.17	0.00	0.09	8.77	4.39	1.14	0.04	8.81	119.36	119.36	
8	1	102	0.07	45.70	45.70	0.00	0.02	12.55	6.27	1.63	0.06	12.61	33.09	27.41	
9	1	103	0.06	44.16	51.47	0.00	0.02	11.91	5.96	1.54	0.06	11.97	39.50	34.04	
10	1	122	0.08	55.23	55.23	0.00	0.02	11.56	5.78	1.50	0.06	11.62	43.61	38.44	
11	1	149	0.06	42.31	42.31	0.00	0.02	13.00	6.50	1.68	0.06	13.06	29.25	23.59	
12	1	150	0.05	37.89	45.23	0.00	0.02	12.61	6.30	1.63	0.06	12.67	32.56	26.87	
13	1	178	0.03	21.14	21.14	0.00	0.01	18.51	9.26	2.40	0.08	18.60	2.54	1.57	
14	1	179	0.07	51.30	54.68	0.00	0.02	11.61	5.81	1.50	0.06	11.67	43.01	37.79	
15	1	194	0.10	70.40	70.40	0.00	0.04	10.51	5.26	1.36	0.05	10.56	59.84	56.76	
16	1	195	0.12	83.34	87.79	0.00	0.05	9.75	4.87	1.26	0.05	9.79	78.00	78.00	
17	1	196	0.06	42.44	43.70	0.00	0.02	12.81	6.40	1.66	0.06	12.87	30.83	25.15	
18	1	197	0.02	11.03	18.38	0.00	0.00	18.38	9.19	2.38	0.08	18.46	0.00	0.00	
19	1	216	0.02	12.79	12.79	0.00	0.00	12.79	6.40	1.66	0.08	12.87	0.00	0.00	
20	1	217	0.07	47.86	49.52	0.00	0.02	12.11	6.06	1.57	0.06	12.17	37.35	31.78	
21	1	481	0.16	110.88	110.88	0.00	0.07	9.10	4.55	1.18	0.04	9.14	101.74	101.74	
22	1	482	0.08	56.84	58.02	0.00	0.03	11.33	5.67	1.47	0.05	11.39	46.64	41.75	
23	1	483	0.06	40.12	46.48	0.00	0.02	12.45	6.23	1.61	0.06	12.51	33.97	28.30	

Figure 22 - Output of streamflow process

2.6 Results for Gondala Cluster

Palsar DEM of 12.5-meter resolution was used for calculating the depth of streams. Two cases were made for depth calculation. One with 1 pixel (12.5m) both sides across the stream bed and second with 2 pixels both sides across the stream bed. Figure 5 and 6 gives an idea about the output generated from the plugin for the given cluster. In Figure 5, the stream id and stream order generated using the plugin is given. In figure 6, the slope and peak discharge rate calculated for each stream segment is given.

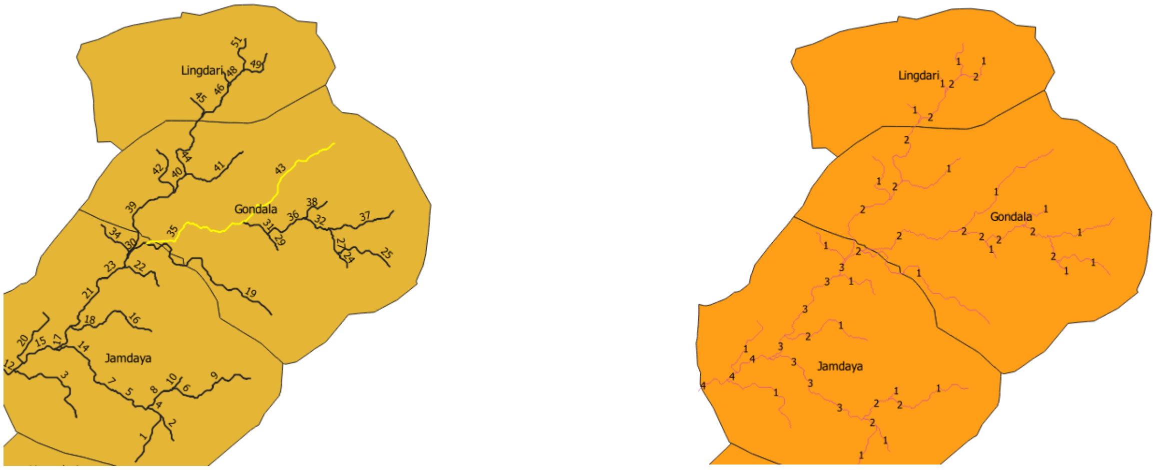


Figure 23 - Segment Id(left) and stream order (right)

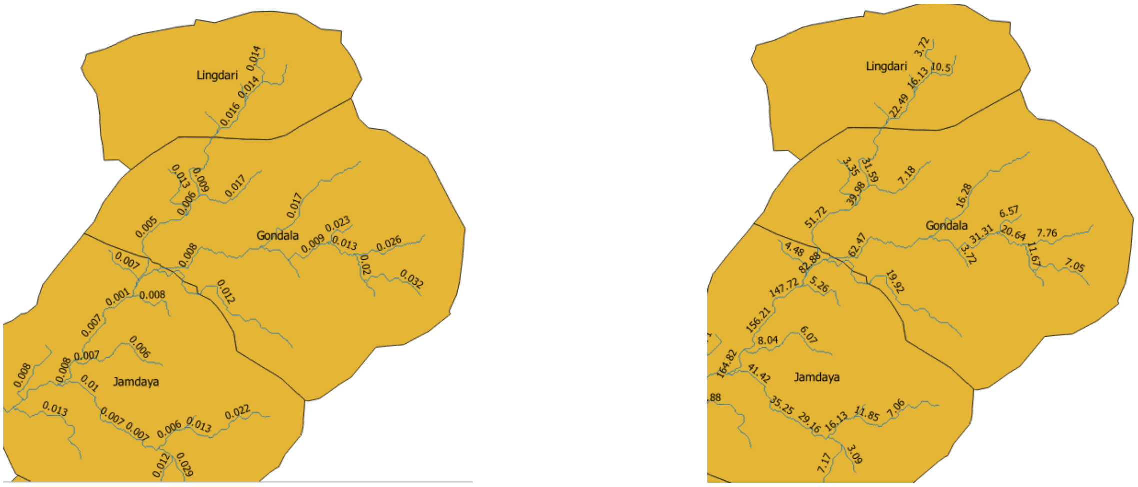


Figure 24 - Slope (left) and peak discharge (right) rate m3/hr (2019)

For the computation of depth, two cases were considered. One with 1 pixel both sides across the stream bed and second with 2 pixels both sides across the stream bed. When we used 2 pixels across the stream bed pixel, depth increased. As the depth of the stream increased, the width of the stream reduced. This can be seen in table 7 and figure 8,9. Two segments id is selected 35 and 43. Segment id 43 has width 1.27 m when depth is 2m. The same segment has a width of 1m when depth is 5m. This pattern can be observed for the segment id 35 as well.

Table 32- Variation of depth and width with pixels

Segment Id	Width Single pixel	Width double pixel	Depth single pixel	Width double pixel
43	1.27	1	2	5
35	5.1	3	3	4

Figure 25- Width (left) and depth (right) when single pixel is used for depth Calculation (2019)

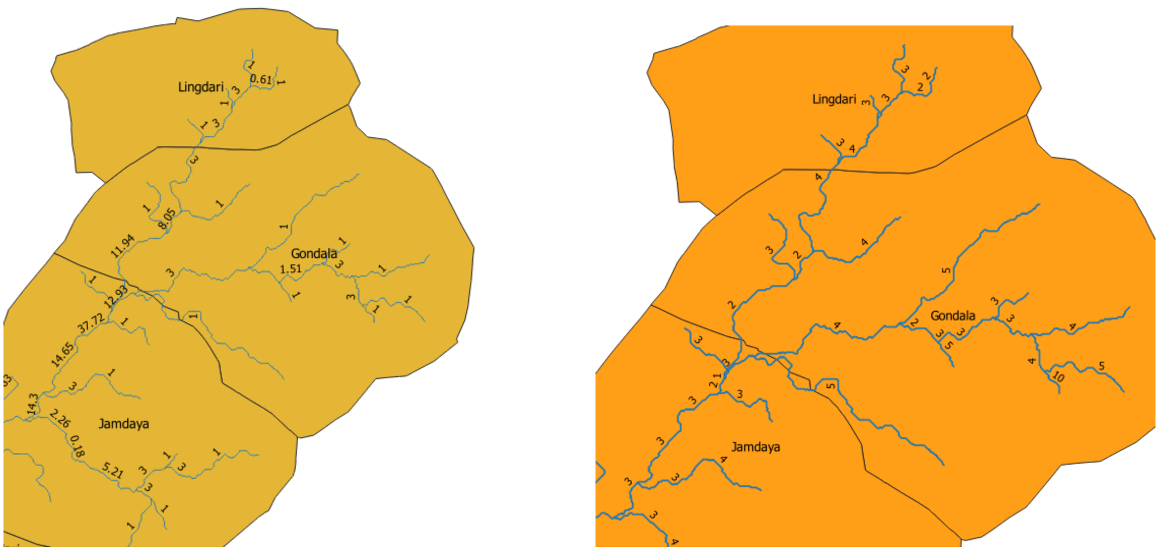


Figure 26 - Width(left) and depth (right) when double pixel is used for depth calculation (2019)

Consider Tables 2 and 3, where results for the streamflow process are summarized. When double pixel was used for depth calculation, it reduced the width for the streams. This led to a reduction in the wetted perimeter. Hence reduced transmission losses. When a single pixel was used for the depth calculation, it increased the width for the streams. More wetted perimeter means more transmission losses in the streams. For the computation year 2019 was used. It had a rainfall of 1000mm. Consider table 2 where transmission losses for village Lingdari, Gondala, and Jamdaya are 6.2mm, 30mm and 41mm. now consider table 3 where transmission losses for village Lingdari, Gondala and Jamdaya are 6.6mm, 37mm, and 75mm. It can be clearly seen that with the increase in the width transmission losses have increased. Runoff out when became runoff in for next village it was normalized based upon that village area.
As we move from high slope areas (Lingadari) to low slope areas or relatively flatter areas, transmission losses increased. There is more water available in stream proximity region in jamdaya village as compared to the lingdari and gondala.

Table 33 - Runoff balance when depth computed using double pixel (2019)

Sr.No	Year_2019	Lingdari (mm)	Gondala (mm)	Jamdaya (normlized). mm)
1	Area	250 (ha)	1060 (ha)	825 (ha)
2	Runoff_Generated	269	269	269
3	Runoff_In	0	62	392
4	Transmission_loss	6.2	30	41
5	Bank in	3	15	20
6	Return Flow	1	4	5
7	Runoff_Out	264	305	625

Table 34 - Runoff balance when depth computed using single pixel (2019)

Sr.No	Year_2019	Lingdari (mm)	Gondala (mm)	Jamdaya (mm)
1	Area	250 (ha)	1060 (ha)	825 (ha)
2	Runoff_Generated	269	269	269
3	Runoff_In	0	62	383.7
4	Transmission_loss	6.6	37	75
5	Bank in	3.3	18.4	37.4
6	Return Flow	1	4.7	9.7
7	Runoff_Out	264	298.7	587.4

Width is calculated using the peak runoff value; in the case of 2019, peak runoff value is more, so width calculated for streams is more. In the case of 2018, peak runoff is less width calculated is less. Rainfall for 2019 was 1000mm as compared to 2018, which was 663mm. Runoff generated in the year 2019 was 269mm as compared to 139mm in the year 2018. This can be seen in table 4.

Transmission losses are more in the year 2019 due to more width and more rainfall-runoff conditions.

Table 35 - Runoff balance when depth computed using a single pixel (2018)

Sr.No	Year_2018	Lingdari (mm)	Gondala (mm)	Jamdaya (mm)
1	Area	250 (ha)	1060 (ha)	825 (ha)
2	Runoff_Generated	139	139	139
3	Runoff_In	0	32	208
4	Transmission_loss	2.7	10.2	13.8
5	Bank in	1.3	5.1	6.9
6	Return Flow	0.3	1.3	1.7
7	Runoff_Out	136.5	162	317.7

In table 5 summary of hourly runoff events, volume out events and volume stored events is given for the year 2018 and 2019 for two segments 21 and 35 of the gondala cluster. In 2018 the number of runoff events was less as compared to the year 2019 for given stream segments. There were more storage events in 2019 as compared to 2018. When there were low runoff events, then there were only a volume of storage events and no volume out events. In case of a high amount of runoff events it there was storage or continuous volume out events from the streams.

Table 36 - Runoff and flow events in 2018, 2019

Segment id	Runoff events	Volume out events	Volume stored events	Year	Village
35	147	276	512	2018	Gondala
21	147	300	521	2018	Jamdaya
35	279	326	975	2019	Gondala
21	279	232	895	2019	Jamdaya
42	102	107	494	2019	Paradgaon

2.7 Results for Paradgaon village 2019

Paradgaon is a lot more flatter as compared to the Gondala cluster. Due to this streams are wider compare to paradgaon. This led to higher transmission loss in the stream network. 50% of runoff water is lost as transmission loss and 50% is going out as runoff. This can be seen in table 6. Due to higher transmission losses in the stream vicinity, wells are located in the stream proximity. This can be seen from figure 9.

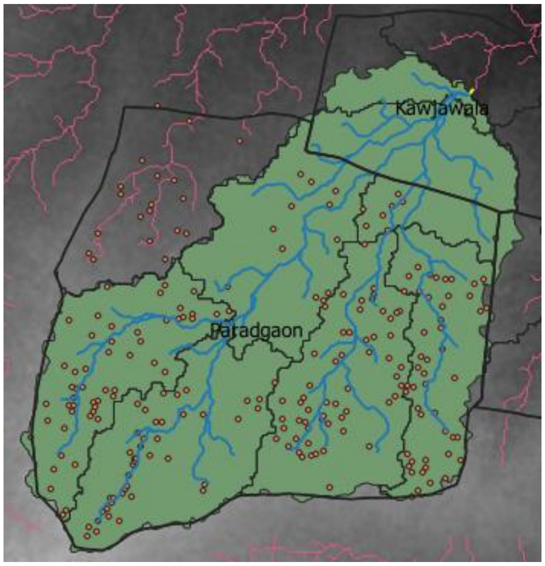


Figure 27- Paradgaon Village with stream network

Table 37 - Runoff balance when depth computed using single pixel (2019)

Sr.No	Year_2019	Paradgaon (mm)
1	Rainfall	868mm
2	Area	2864 (ha)
3	Runoff_Generated	101 mm
4	Runoff_In	0
5	Transmission_loss	56
6	Bank in	28
7	Return Flow	7.2

8	Runoff_Out	52.2

2.8 Future work

1. Two different modules from different sources were used in QGIS for the calculation of stream characteristics. There is a need to shift the entire routine to modules from a single source.
2. Considerable recharge in-stream proximity is observed in flatter areas, some field validation is required.
3. The plugin should be run for the last 6 years and based upon the highest runoff width parameter should be computed and fixed permanently for future use.
4. More testing is required on different clusters in different geographies.
5. In 80% of the cases, the width/depth seems to be in the range as per field observations. Further plugin optimization is required after looking into results from more clusters. Remaining 20% cases that are showing poor results are probably due to different modules used in the plugin.

3. Report on Hourly Model QGIS Plugin

Prepared By
Ashish Wankhade

With guidance from
Parth Gupta

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3.1 Introduction

1. Earlier point level script was developed to test the output for the water balance model at different time steps(daily/hourly) for a single point.
2. This script used the hourly weather parameters available from Skymet.
3. Functionality for running the water balance model at the aggregate level (cluster or village level) was missing.

3.2 Objective

1. To incorporate the functionality of running the QGIS plugin at different time steps.
2. Make suitable changes in the output format as per needs.
3. Update code to latest Qgis version
4. Validate the results produced for the hourly model

This report describes the existing architecture and input data format for the QGIS plugin along with the changes incorporated to run the model at both daily and hourly intervals.
The report also describes a comparison between the daily and hourly model result for a village.

3.3 Existing QGIS Plugin

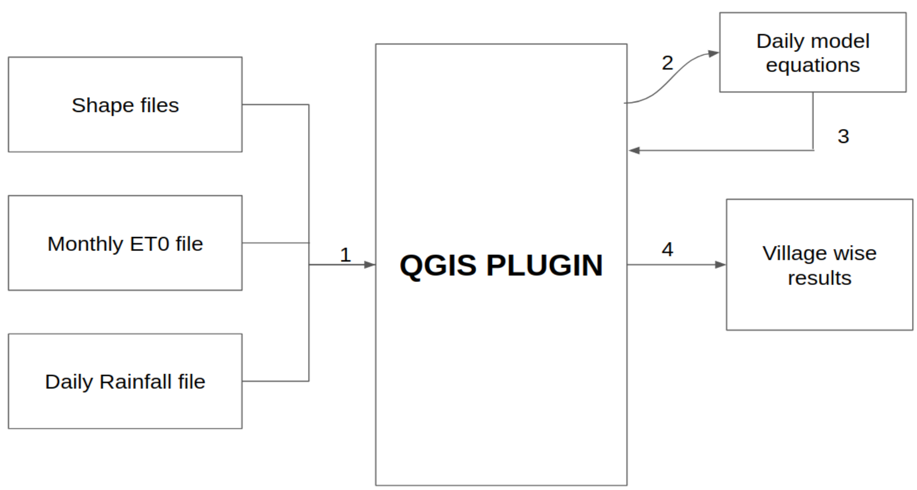


Figure 28- The architecture of existing QGIS plugin (daily-model based)

Fig 1. depicts the high-level architectural design of the existing QGIS2 based plugin. This plugin was used to run the water balance model at a daily interval. The plugin takes shape-files, et0 file, and a rainfall file as input and produces the village-wise aggregated results by running the model at daily intervals.

The representation of the input data is as follows:

Sample Daily Rainfall file:

Circle	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Sengaon	2017	0	0	0	19	0	52	45	0	11	0	0	30	4	2	0	20	0	0	0	0	0	0	0	0	0	0	60	0	0	0	0	0

Figure 29 - Sample Input Rainfall file (.csv) for QGIS plugin (daily-model based)

The daily rainfall file which is given as an input to the plugin is a csv file with the first column as circle name followed by the rainfall year. Remaining 365 columns specify the rainfall amount for the day.

Sample ET0 File:

The et0 file provided to the plugin is a static monthly et0 file as shown in fig 3. This et0 is then spread on daily intervals for a given month and used further for PET calculation.

Month	ET0
Jun	7.03
Jul	5.26
Aug	4.77
Sep	5.03
Oct	5.01
Nov	5.57
Dec	4.57
Jan	4.29
Feb	5.42
Mar	6.39
Apr	7.33
May	8.22

Figure 30 - Sample ET0 file (.csv) for QGIS plugin (daily-model based)

3.4 Hourly QGIS Plugin

3.4.1 Hourly QGIS Plugin Architecture

Fig 4 depicts the high-level changes that were incorporated so that model could be run on both daily and hourly intervals using the standalone script. This script is a black-box to the plugin which expects the weather data, crop-name & field parameters (latitude, longitude, slope, depth, elevation, etc.) as input and produces the simulation results based on the time-step specified as output. The plugin then performs post-processing on this output so that it's representation matches the existing data format and finally aggregates them at the zone level.

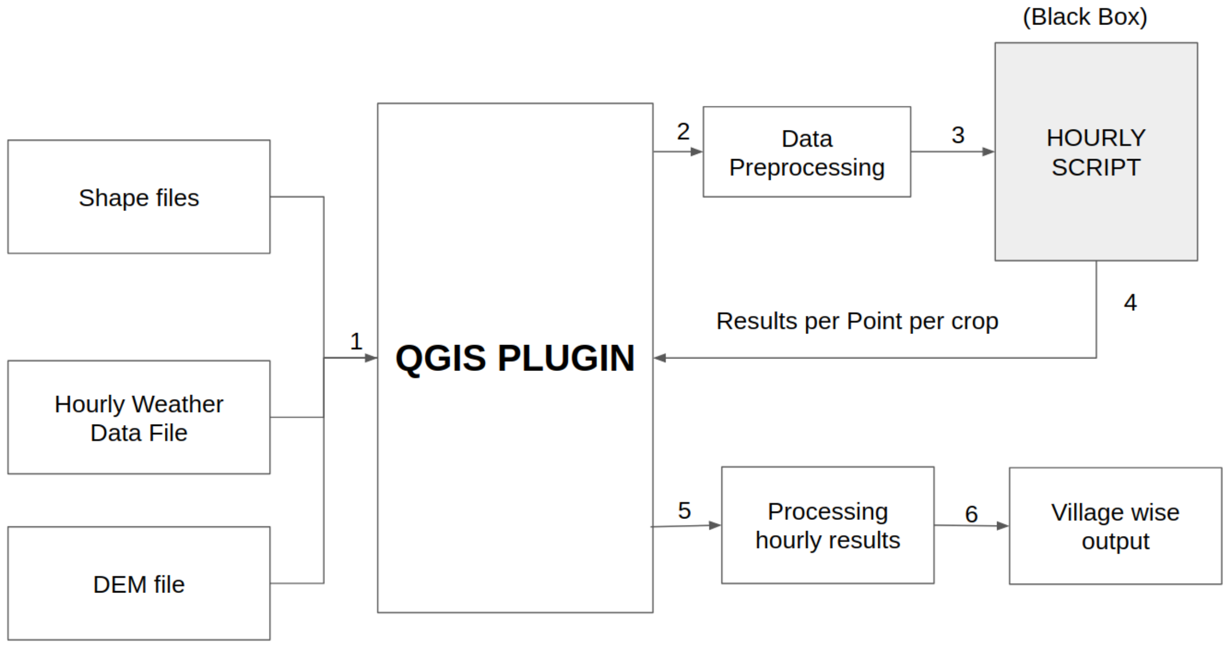


Figure 31 - The architecture of the updated QGIS plugin (both daily & hourly model)

3.4.2 Changes incorporated within existing QGIS2 Plugin:

Comparing Fig 1 and Fig 4, the changes between the existing and updated plugin are as follows:

1. Changes to the input data.

The older plugin expected daily rainfall CSV and a monthly et0 CSV as input along with other raster files. This has been changed to an hourly weather data file. The format of this file is similar to the input to the standalone script for the hourly/daily model.

Fig 5. shows the representation of a sample hourly weather data file.

lat	lon	district	taluka	rain_circle	rain_year	data_fetched_up	rain	temp_min	temp_max	temp_avg	rh_min	rh_max	rh_avg	wind_min	wind_max	wind_av
18.8258	74.4481	Ahmednagar	Shrigonda	Dev Daethan	2018	365	[['0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '2', '1.75', '0', '0', '0', '0', '0', '0', '0'], ['0.25', '0.25', '0', '0', '0', '0', '0', '0', '0',							[['0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0'		
21.4015	77.3299	Amravati	Chikhaldara	Chikhaldara	2018	365	[['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'		
18.8457	75.1141	Beed	Aashti	Kada	2018	365	[['0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0.75', '4.5', '0', '0', '0', '0.75', '0', '0', '0.75', '0'], ['0', '0', '0', '0', '0', '0', '0', '0', '							[['0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0'		
20.5404	79.7277	Chandrapur	Nagbhid	Midhala	2018	365	[['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', '4.25', '0', '0', '0', '0', '0', '0							[['0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0'		
19.7847	79.3666	Chandrapur	Rajura	Rajura	2018	365	[['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', '0.25', '0.5', '0', '0', '0', '0', '0.2							[['0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0'		
21.2852	74.6204	Dhule	Shindkheda	Wikharan	2018	365	[['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'		
19.7961	76.8839	Hingoli	Sengaon	Sengaon	2018	365	[['0.5', '0', '1.75', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '2.5', '2.75', '0', '0', '0', '0', '3.25'], ['2.25', '0', '0', '1.5', '0', '0', '							[['0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0', '0'		

Figure 32 - Hourly weather data (.csv) file

Another change to the input data is the requirement of the DEM file along with other rasters. This DEM is required to take elevation for a point that is required by the simulation script for intermediate equations in hourly et0 computation.

2. Major internal changes to the previous versions

The main difference between the previous version and the new version is calculating the ET0 through hourly weather data instead of using an external Static monthly ET0 file. This calculated ET0 is further used to compute PET.

The model was previously running for 365 days (where 1 time step=1 day) only, and now the model will be running for both 365 and 365*24 times (1-time step = 1 hour) based on the timestep specified by the user.

3. Use of script to run the model

The script is used to simulate a point and run model based on the user inputs and other properties. The script expects weather data for the circle and field parameters like soil texture, slope, depth, etc. and a crop-name. The script returns the result based on the time step either daily or hourly. This result is manipulated so that the representation matches the older plugin's format. The indexes for daily and hourly are also made variable (which were fixed earlier as daily). With the script being used as a black box for the plugin, it helps us in having a single point of change for running the model at the point level. This is important because the plugin in the daily model had an error where one of the field parameters (KSat) was returning an incorrect value. Although the error induced because of that was minute, but it got uncovered after a thorough check of the result. Also, the lookups of the script and existing plugin varied for a few pseudo crops. Having a single point of change will help in maintaining and validating the code easily in the future.

3.4.3 How Results were validated?

1. Increased the spacing in configuration.py file (step=2000) so that at most 2 or 3 points lie within a zone.
2. Logged the results produced by the hourly script for every point and crop.
3. Logged the attributes of the points lying within a zone. [eg. slope, depth, etc.]
4. Using the above two logs the village-wise results were verified by taking an average of the attribute values in point-wise result logs.
5. The point-wise logs for plugin were also matched with the output of the standalone script when run independently with exact parameters.

3.4.4 QGIS3 Update

The existing plugin was written in python2 and was compatible with QGIS 2. The plugin was not compatible with QGIS 3 since there are considerable migrations between QGIS3 and QGIS2 and a lot of API calls have changed or migrated. The plugin code was updated so that it could be used with QGIS 3 as well. This required migrating from python2 to python3 and using QGIS 3 based APIs that were changed in place of QGIS 2 based APIs at various places in the code.

3.4.5 UI Changes

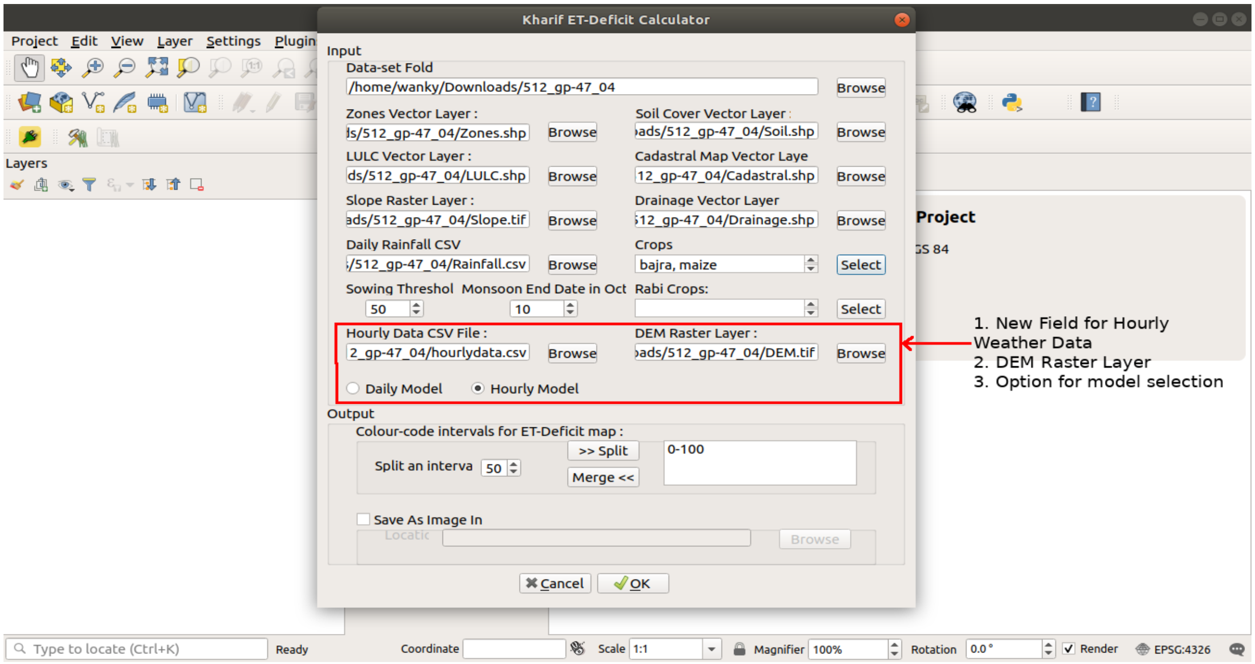


Figure 33 - Addition of new inputs

Three new inputs were added to the existing input dialog of the plugin. These inputs are hourly weather data file, DEM raster layer, and radio button for model interval selection. The weather file will be preprocessed and go to the script as input. The DEM file serves for providing the elevation at each point. This elevation is later used in calculating hourly et0 intermediate equations.

3.4.6 Debugging

To debug the results for a particular point we have added a Flag in the configuration.py file in the plugin code. These flags are
GENERATE_LOGS
GENERATE_LOGS_ZONEWISE
If GENERATE_LOGS is set as True then it will generate the point-wise simulation
results of the script per crop. If GENERATE_LOGS_ZONEWISE is set as True then it will generate the zonewise hourly output for a village. These logs will also contain the information of a point such as slope/depth/crop type etc.
One can verify the results using the pointwise logged results for a crop and the points lying in the zone information. Just average out the pointwise results which are lying in a zone it should match the zone-level value. If one has to debug to the core level then he can match the point-wise result generated by the plugin & the script independently. If both are matching then average out the point-wise results for a particular zone and crop. This should match the value in the final village_wise_output for a zone & crop.

3.4.7 Logs and Intermediate Results

Figure 34 - Sample Log file for a zone depicting the properties of points lying inside it and the total number of points

Fig 7 shows a sample zone-file log that contains the total number of points lying inside the zone and the properties of the point. This log can be used to verify the result for a particular zone and crop in a village by adjusting the input of the standalone script as per the logged parameters and averaging out the value based on monsoon end and crop end.

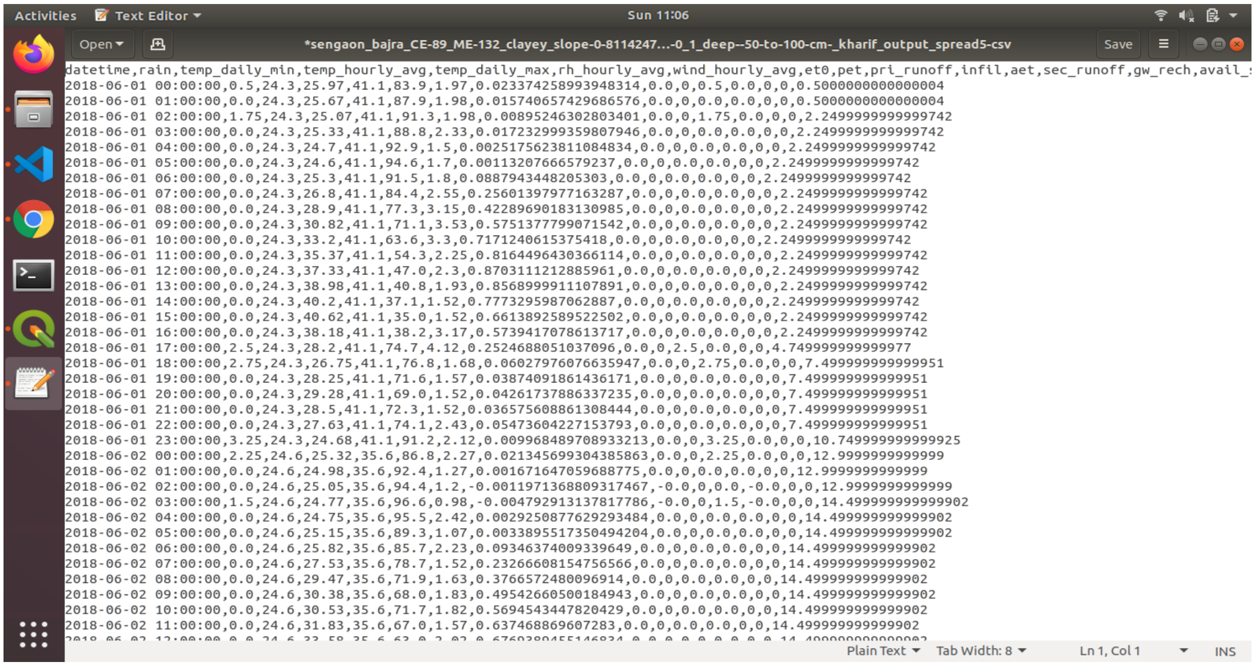


Figure 35 - Sample Log File per point per crop

Fig 8 shows a logged result for a point and a crop that was returned to the plugin by the (black-box) script. Using the log in Fig 7 and Fig 8 one can verify the results easily.

3.5 Testing and Results

The model was run on a cluster in Jalna district for both daily and hourly models with the weather data of 2019. Rainfall circles for the weather were Ranjani and Partur.

The sample results at the village level are as follows:

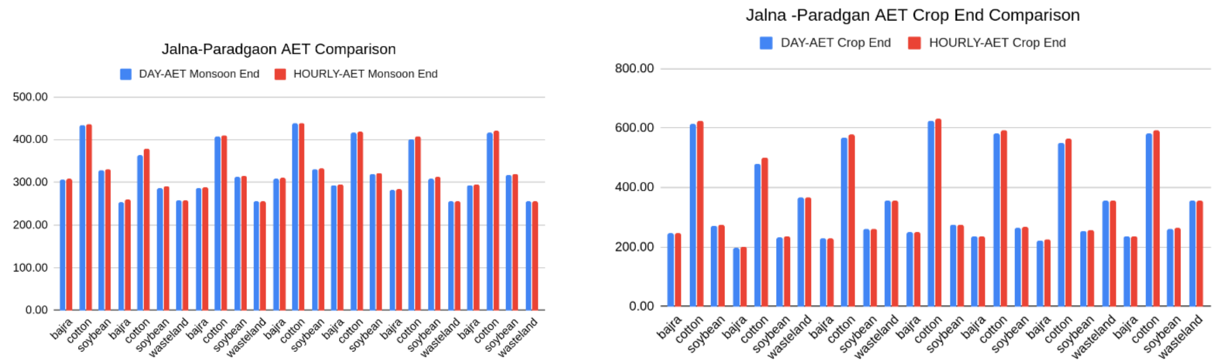


Figure 36 - AET comparison

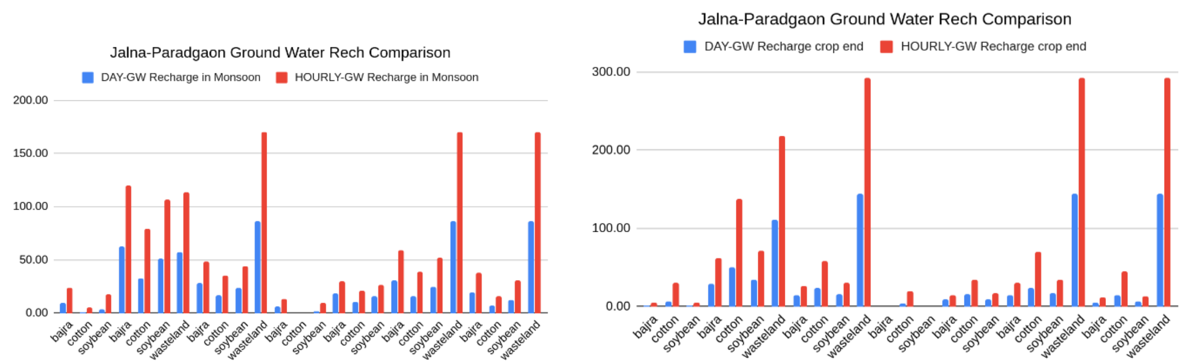


Figure 37 - GW Recharge Comparison

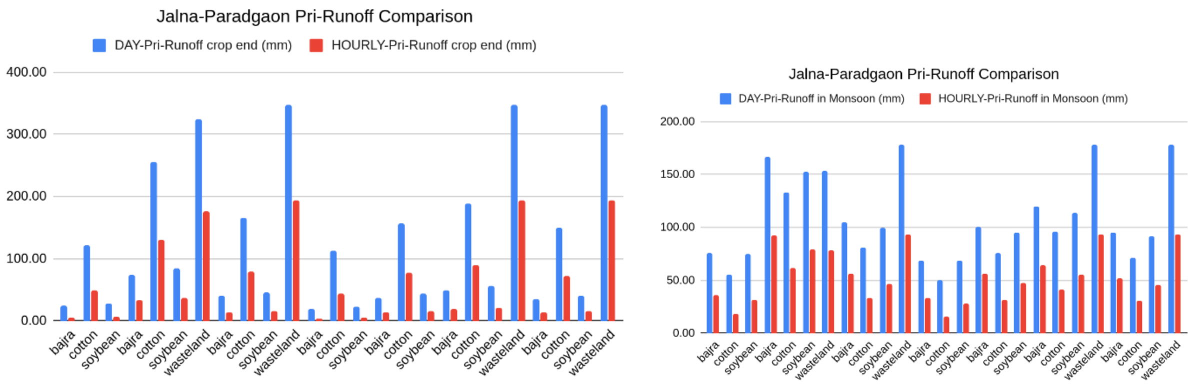


Figure 38 - Primary Runoff Comparison

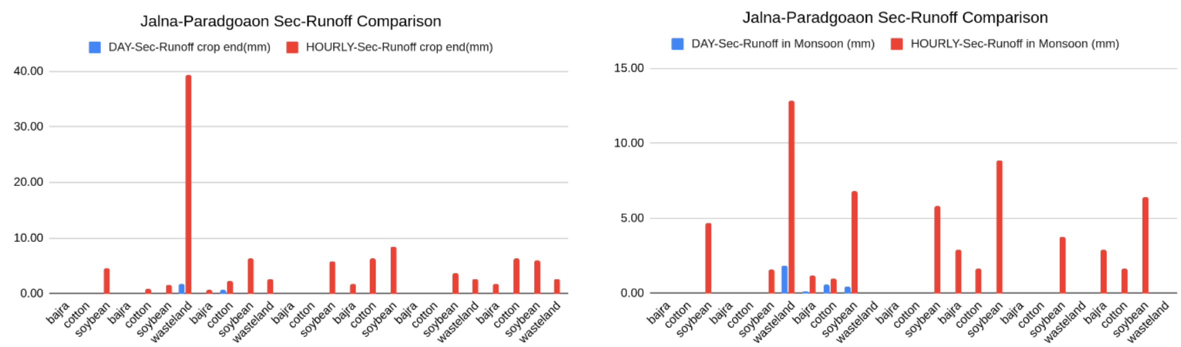


Figure 39 - Secondary Runoff Comparison

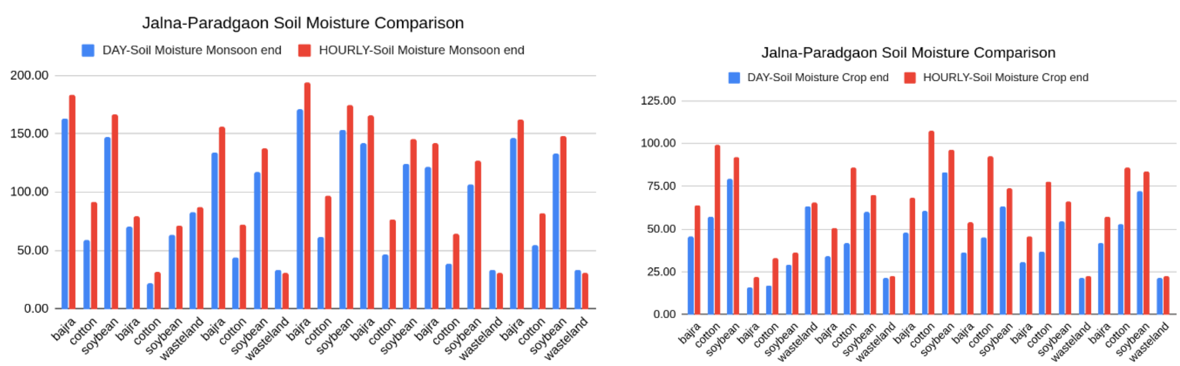


Figure 40 - Soil Moisture comparison

Studying the bar chart comparisons between daily and hourly values, we see that AET doesn't change that much.

Primary runoff computed using the hourly model is less than that of the daily model for all the crops (i,e cotton, bajra, and soybean).

Secondary runoff is more evident in the hourly model simulation.

Groundwater recharge in hourly model simulation exceeds the one in the daily model by a fair margin.

A detailed comparison can be found at:
https://docs.google.com/spreadsheets/d/1LyyvMh0jKmawMB557fG-RuYGcjkHec_QZ_hb90U2nNU/edit#gid=1787277649

Running Time:
The model was run for two different clusters with three crops viz Bajra, Cotton & Soybean. The running time for the simulation is as follows:

Table 38- Running time for two clusters

Cluster - I	Cluster - II
Number of crops selected: **3**	Number of crops selected: **3**
Number of grid points to process: **219**	Number of grid points to process: **119**
Number of cadastral points to process: **1709**	Number of cadastral points to process: **588**
Daily Model Time:**115.398** seconds	Daily Model Time: **39.3** seconds
Hourly Model Time:**2974.8** secs (~50 mins)	Hourly Model Time: **818.53** seconds (~14 mins)

Grid points are the points within the grid with the specified spacing. Cadastral points are the points for every survey number.

As we can see from the above table, the hourly model takes roughly 24x more time than the daily simulation.

4. Report on Soil survey application

Prepared By
Ashish Wankhade

With guidance of
Parth Gupta

Contents

List of Figures

4.1 Objective:

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

4.2 Goals:

1. To Integrate SSO login from the *mahapocra* API.
2. Migration of database to the *mahapocra* servers.
3. Image Upload
4. Addition of new fields

4.3 Introduction:

'माती सर्वेक्षण' is an android app which was developed to collect the soil & crop-related data. However, the app had few flaws and some missing functionalities. This report points to those features and addresses them with the functionality added in the updated application.

Who to be surveyed?
Farmers in the project villages.

Who will carry out the survey?
Cluster Assistant.

4.4 Update w.r.t previous version

4.4.1 Integration of SSO Login

The login credentials for the app were hard-coded. This was a major flaw that restricted us to find the user who uploaded the data. Further, the credibility of the data is also lost due to this as anyone with the credentials can upload the data to the server.
To tackle this, we integrated the SSO login API with the android app.
The details for the same are as follows:

API URL	http://api-ffs.mahapocra.gov.in/3rd-party/authService/sso
METHOD	POST

Request Parameters	JSON Object
	{
	"mob":"1234567890",
	"pass":"**********",
	"secret":"API Key"
	}

Response	“Login success” or “Unauthorized access” along with user and village data

4.4.2. DB Migration

The database for the application was previously hosted on iitb servers. This was also migrated to the *mahapocra* server. The schema for DB is as follows:

```
CREATE TABLE public.soil_info
(
  sample_id serial primary key,
  district_name character varying(100) not null,
  taluka_name character varying(100) not null,
  village_name character varying(100) not null,
  farmer_name character varying(100) not null,
  contact_no character varying(100) not null,
  gat_no character varying(100) not null,
  landuse character varying(100) not null,
  soil_type character varying(100) not null,
  soil_depth numeric not null,
  latitude numeric not null,
  longitude numeric not null,
  time_info character varying(100) not null,
  year character varying(100),
  crop_name_kharif character varying(100),
  watering_kharif numeric,
  watering_type_kharif character varying(100),
  yield_kharif numeric,
  crop_name_rabi character varying(100),
  watering_rabi numeric,
  watering_type_rabi character varying(100),
  yield_rabi numeric,
  crop_name_other character varying(100),
  watering_other numeric,
  watering_type_other character varying(100),
  yield_other numeric,
  image1 character varying(200) not null,
  image2 character varying(200) not null,
  uploaded_by_uname character varying(30) not null,
  uploaded_by_fullname character varying(100) not null,
  constraint atleast_one_crop__and__non_sheti_or_year_and_watering_type check (
    (
      landuse != 'शेती'
      or (
        year is not null
        and num_nonnulls(crop_name_kharif, crop_name_rabi, crop_name_other) > 0
      )
    )
    and
    (
      (num_nulls(crop_name_kharif, watering_kharif,  watering_type_kharif, yield_kharif) in (0, 4))
      and (num_nulls(crop_name_rabi, watering_rabi,  watering_type_rabi, yield_rabi) in (0, 4))
      and (num_nulls(crop_name_other, watering_other,  watering_type_other, yield_other) in (0,
4))
    )
  )
)
WITH (
  OIDS=FALSE
```

```
);
ALTER TABLE public.soil_info
  OWNER TO soil_survey_app;
```

4.4.3. Image Upload

Two new fields were added for the survey. These were for images that the user can upload. The uploaded images will be stored on the *mahapocra* server as well. The uploaded image will be watermarked with the Lat-Long information along with farmer namer and phone number.

Figure 41 - UI changes for Image upload integration

4.4.4. Addition of new fields:

New fields were added to the database and application UI to take "पीक पाणी" input per crop. Proper validation is also added so that there is no inconsistency in the input data.
The new fields added are as follows:

```
image1 character varying(200) not null --- image-1 name
image2 character varying(200) not null --- image-2 name
uploaded_by_uname character varying(30) not null --- uploaded by username
uploaded_by_fullname character varying(100) not null -- uploaded by full name
crop_name_kharif character varying(100),
watering_kharif numeric,
watering_type_kharif character varying(100),
 yield_kharif numeric,
 crop_name_rabi character varying(100),
 watering_rabi numeric,
 watering_type_rabi character varying(100),
 yield_rabi numeric,
```

crop_name_other character varying(100),
watering_other numeric,
watering_type_other character varying(100),
yield_other numeric,

When “शती” is selected as the land-use type, then three options will be given to the user.

i. Kharif
ii. Rabi
iii. Other

If Kharif crop is selected then its yield, watering and watering_type is mandatory. Similar validation is added to Rabi and others. These new entries are also added as columns in the soil_info table.

4.4.5 Default data from SSO

When the cluster assistant logs in with his credential, the API responds with data containing the **census code** assigned to the user as well as the district, taluka and village names assigned to him. We fix these district, taluka and village names as dropdown options. The census code in the response can further be used for having a predefined dropdown for input of farmer names field. We have tested this functionality of having farmer names in dropdown for Gondala village only (for other villages it will show input text box as usual). This can be extended to other villages provided that there is an API which responds with farmer names given a census code.

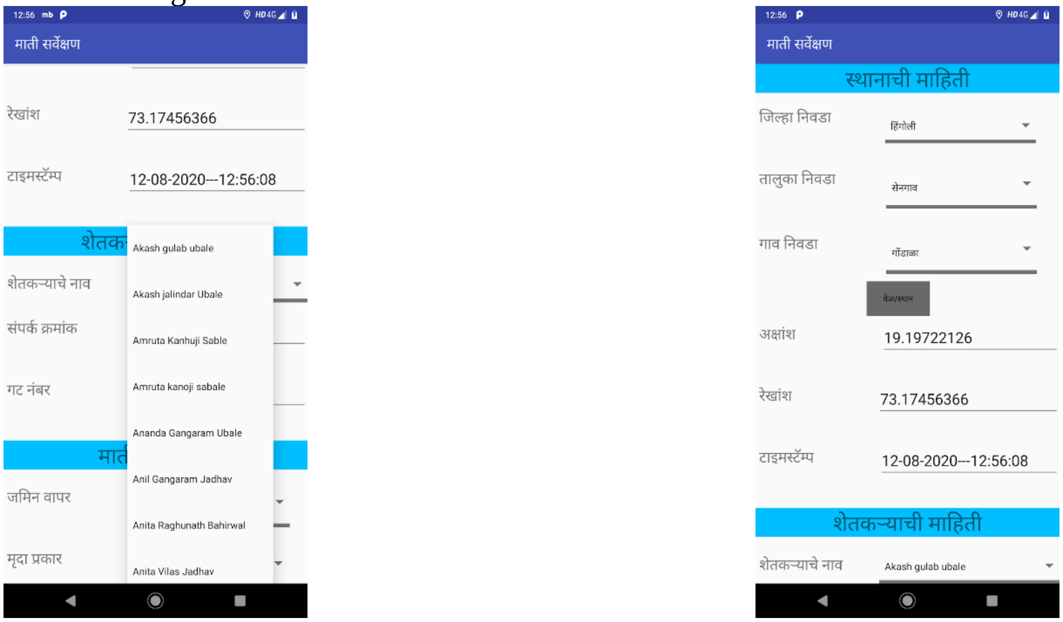


Figure 42 - Default data from SSO

4.5 User Manual / Implementation

4.5.1 Login Screen -

- While filling the data GPS of mobile needs to be turned on. Users must fill the login credentials provided to him/her for filling the data in the selected clusters.

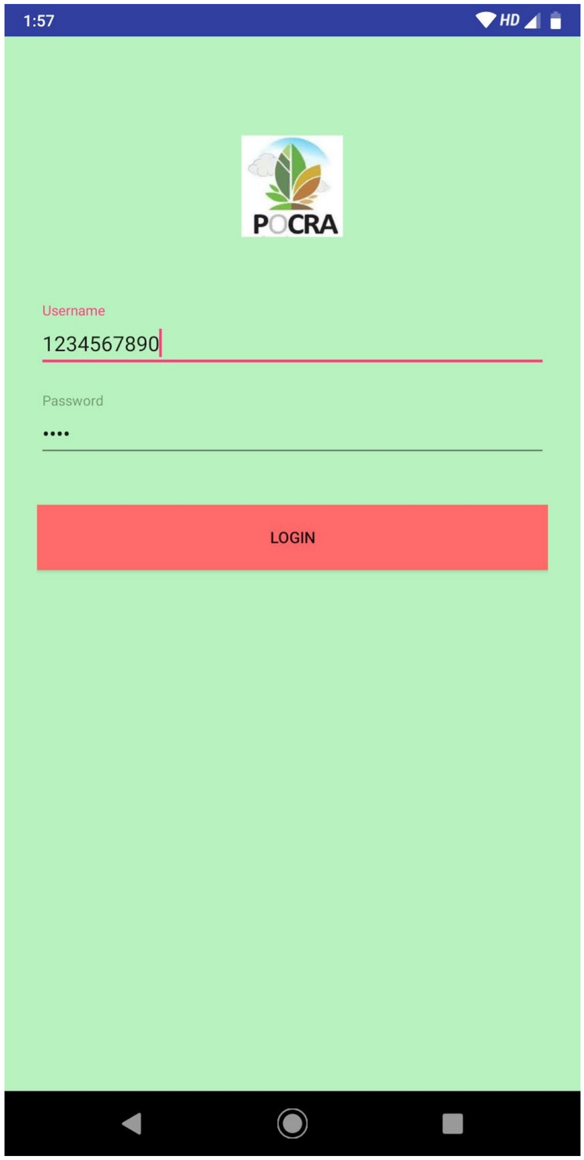


Figure 43 - Login Screen

4.5.2 Form Options

- The app will set the district and taluka automatically for the Cluster Assistant once he logs in (based on the API response). If he/she is assigned multiple villages then it has to be selected in the village drop-down.
- In order to capture the location and time stamp, users must be in the field while capturing the information. Once the user clicks the "**वेळ / स्थान**" option, the app will automatically capture the latitude, longitude, and time of the reading.

- The next step is to fill the farmer information which includes its name, mobile number, and survey number. Farmer names can be a dropdown or input box depending on the village (refer to point 5 in the previous chapter for more info).
- The next step is to fill the soil information of the plot. This includes land use type on the plot, soil type, and soil depth.

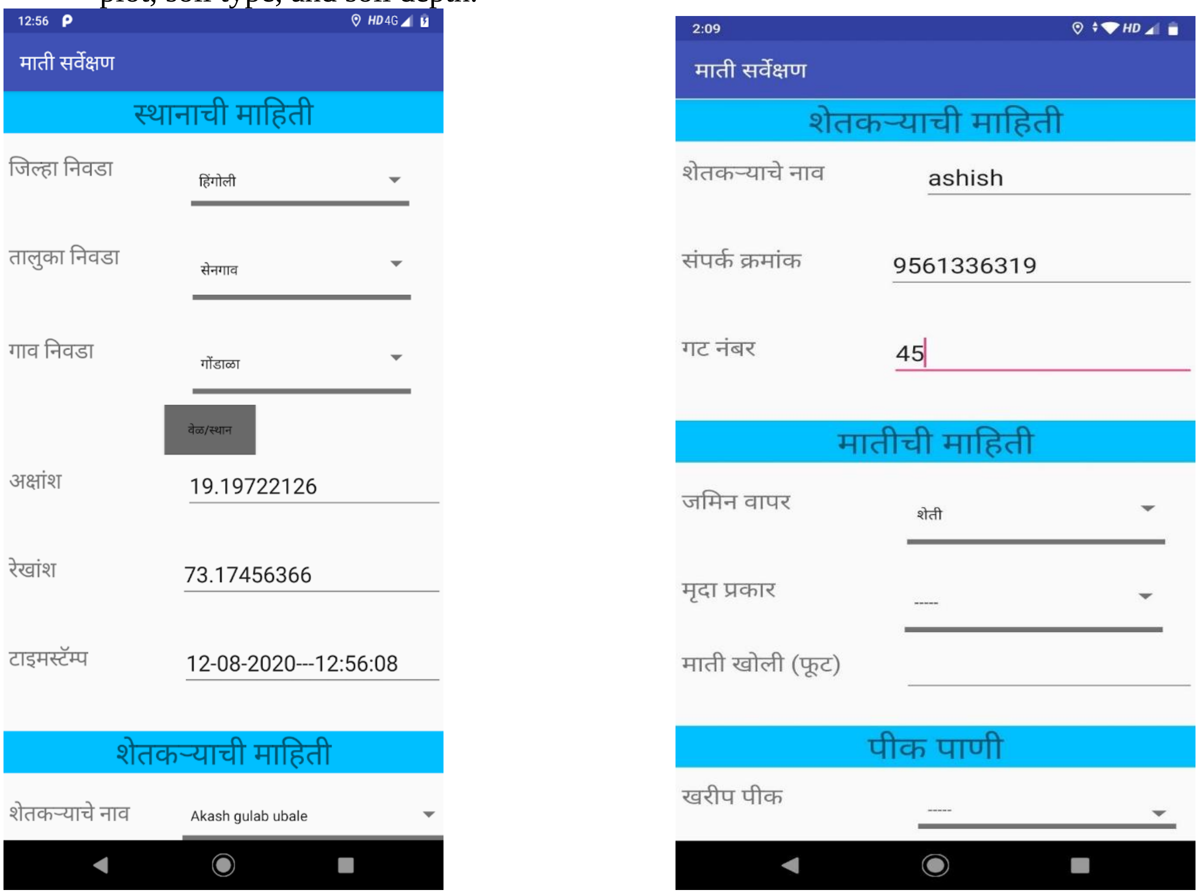


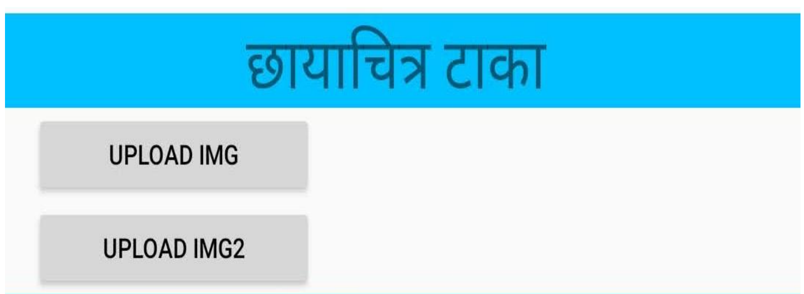
Figure 44 - Entering Soil information for a plot

- Once the user selects the land use type information as agriculture further drop down will appear related to crop sowing information.
- Dropdown for Kharif crops is provided if the user needs to select the Kharif crop. Yield per acre, type of watering can be added using a text editor and dropdown.
- Dropdown for Rabi crops is provided if the user needs to select the Rabi crop. Yield per acre, type of watering can be added using a text editor.
- Dropdown for other crops is provided if the user needs to select the Kharif crop. Yield per acre, type of watering can be added using a text editor.

Figure 45 - Crop related details in the form

4.5.3 Image Selection

- The user needs to click two images from his mobile camera. Please make sure the image is less than 2mb in size.
- The image should be of cross-section where soil depth is visible such as dug well, farm pond, pit, etc.
- After clicking the image user needs to upload both the images using upload img and upload img2 button.



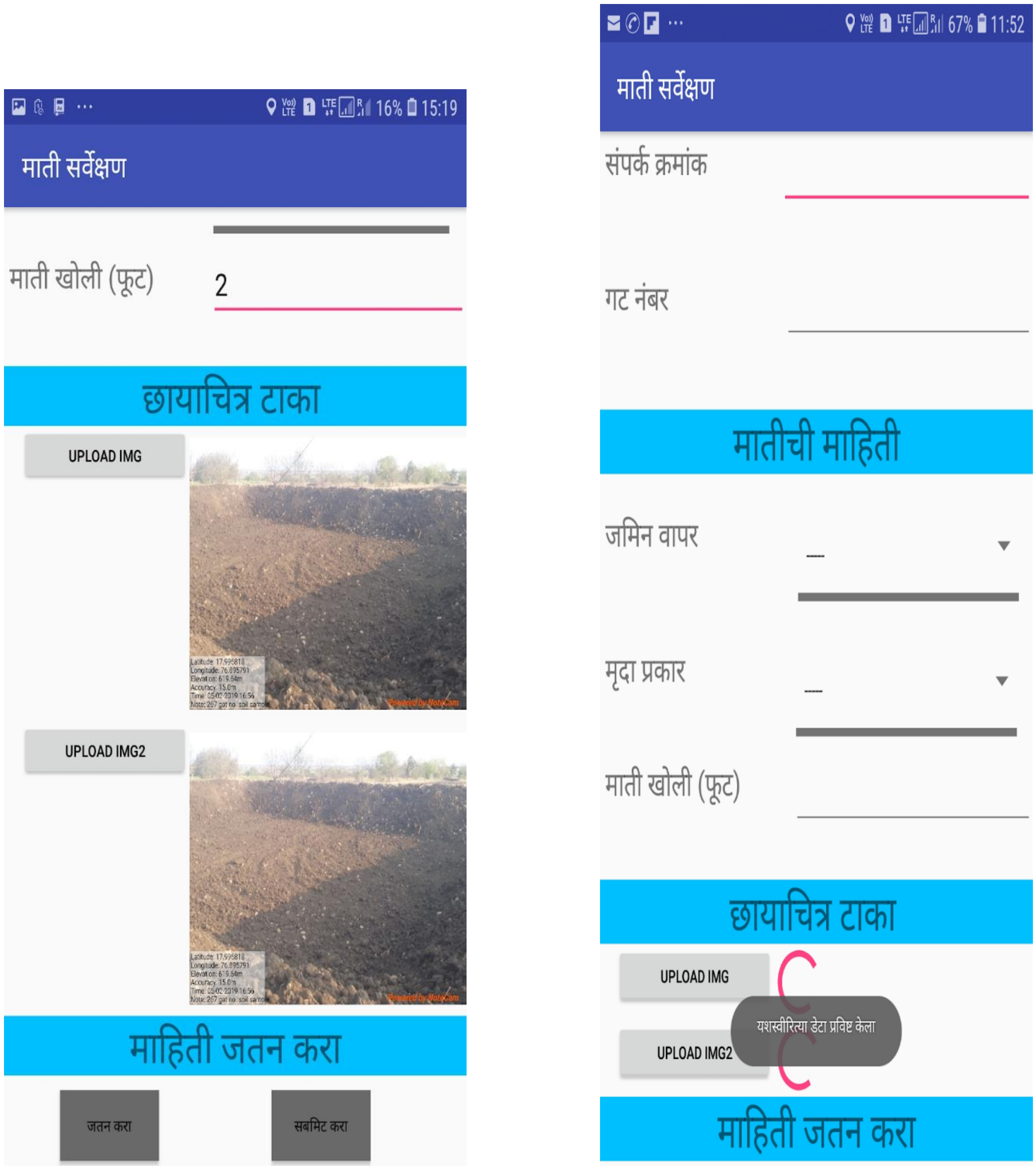


Figure 46 - Images selected by the user

- Once the user clicks the save option it will save the data locally.
- After this user needs to click the submit option to successfully submit the information to the PoCRA server.

4.5.4 Usage Flow Diagram:

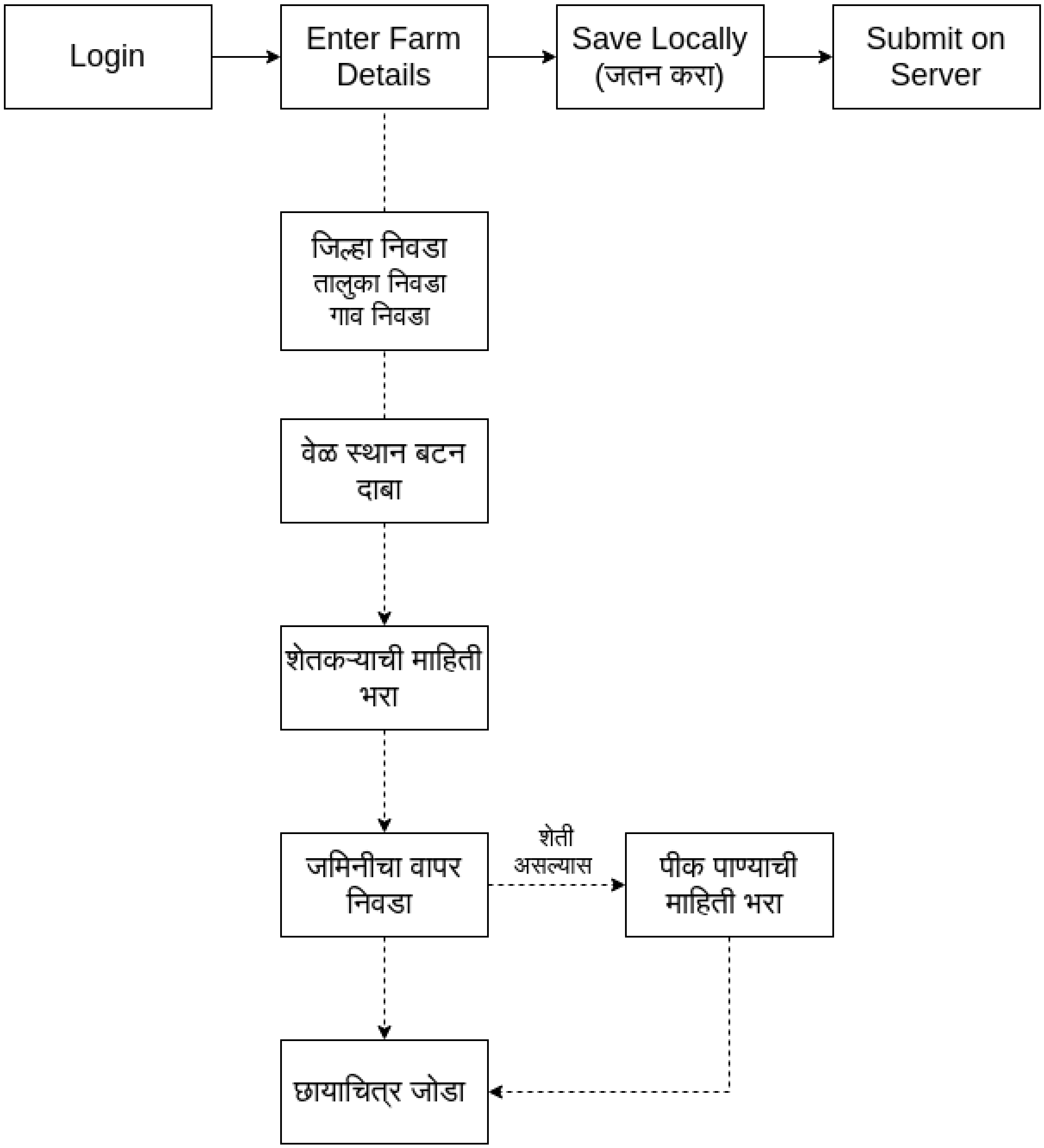


Figure 47 - Flow diagram of Soil Survey App

5. Report on GSDA Recharge Plan Analysis

Prepared By: Chirag MM, Hemant Belsare

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Preamble

The A3 component of the MoU III between IITB and PoCRA needs IITB to coordinate with external agencies like GSDA on run-off measurements and improvements in the overall water balance model. Similarly, GSDA has an MoU with PoCRA wherein GSDA is supposed to prepare Groundwater Recharge Plans for 70 PoCRA clusters. These recharge plans are primarily based on field work and the estimates made by GSDA for run-off, groundwater recharge, groundwater extraction etc. IITB already has a model in place which is being used for calculating the water budget of the villages in PoCRA clusters. As pointed out by the World Bank experts in one of the review meetings, estimates by IITB model and GSDA groundwater budget should broadly match with each other and should be as close as possible to the ground reality. It was therefore decided to come up with a strategy for collaboration so as to improve the estimates by both IITB as well as GSDA for their accuracy with ground reality. This report is the first in the series of reports dealing with IITB-GSDA cross-calibration and compatibility.

5.1. Introduction

One of the very first steps for IITB to evolve a strategy for collaboration with GSDA is to study and understand Groundwater Recharge Plans prepared by GSDA for some of the clusters. This report thus briefly documents the highlights of the recharge plans including different components of the plan, methodology, computation methods and data used for these components and summarizes some of the comments on the same by IITB. Lastly, this report also discusses the framework which can be adopted for integrating the GSDA findings with the IITB water balance model.

This report has also documented some of the issues found during study and analysis of the recharge plans. These findings are based on the study of the Groundwater Recharge Plans received by the IITB team from PoCRA PMU for the 28 PoCRA clusters. The IITB team has also used raw data shared by PoCRA PMU for the 16 clusters used by GSDA for preparation of the groundwater recharge plans for those respective clusters. The list of these clusters with necessary details is attached in Annexure separately.

5.2 Objective

- To study and understand the Groundwater Recharge Plans prepared by GSDA and methodology used for estimation of the groundwater recharge and groundwater extraction from the viewpoint of calibration
- To document some of the key issues found in the recharge plans and the raw data used for computation of groundwater recharge and groundwater extraction
- To study, analyze and compare the results of the 28 clusters for which PMU has shared the groundwater recharge plans prepared by GSDA

- To devise a framework for improvements in the IITB water balance model using GSDA results, data and methodology

5.3 GSDA Groundwater Recharge Plan

5.3.1GSDA Recharge Plan Structure

GSDA Recharge Plans are reports prepared by the GSDA on studying the selected clusters for their demographics, agriculture practices including cropping pattern and irrigation details, and hydrology. This is done by a field survey of the villages using standardized formats. These recharge plans of GSDA primarily consists of i) estimation of the quantities for the parameters like runoff (for planning NRM activities), and groundwater recharge, groundwater extraction (for computing groundwater budget) and ii) observations, inferences and recommendations by GSDA followed proposed interventions along with the spatial maps (for preparation of Groundwater Management Action Plan).

This report focuses only on the first component mentioned above which is important as far as calibration and compatibility requirements are concerned. It deals with estimation of the quantities for different parameters like runoff, and groundwater recharge and groundwater draft used in groundwater budget. The following sections discuss the methodology used for the computation of the above parameters.

5.3.2 Methodology Used

i.Data Used

The recharge plan uses information collected from the baseline survey and hydrological survey for computation of quantities for different parameters.

Baseline Survey: The baseline survey covers information on demographics, domestic water supply, crops and micro-irrigation, and water conservation structures in clusters from the secondary sources. The data from the baseline survey is used in computation of all the three parameters viz. surface runoff, groundwater recharge and groundwater extraction.

Hydrological Survey: The hydrological survey discusses overall hydrology of the clusters with detailed maps on surface hydrology, subsurface hydrology, mapping of surveyed wells and corresponding post-monsoon, pre-monsoon groundwater level and annual groundwater fluctuations. As far as data collected through hydrological survey conducted by GSDA is concerned, pre-monsoon and post-monsoon groundwater levels, and pumping data for surveyed farmers are used for computation of the specific yield, groundwater recharge and groundwater extraction. Whereas other data collected on aquifers and maps prepared using this data especially those of surface hydrology and subsurface hydrology are not used for computation of any of the parameters. These maps and data are used by GSDA only while proposing different interventions like NRM activities in the Groundwater Management Action Plan.

ii. Methods used for Execution

This section discusses methods used for estimation of surface runoff.

Surface Runoff: GSDA has used the Strange Table method to compute the runoff generated in the concerned clusters. The run-off coefficient values from Strange's table and 75% of dependable rainfall of the average rainfall of the area are used for the computation of the runoff generated in the cluster.

> Runoff Generated in Cluster (TCM) = [Cluster Area (Ha) * 75 % dependable rainfall of average annual rainfall (mm) * Runoff coefficient for the area (from Strange Table)] / 100

A summary sheet is attached in Annexure showing estimates for runoff generated in all the 28 clusters as calculated by GSDA. A snippet of GSDA recharge plan showing runoff estimation is attached below for a cluster in Jalna district for reference.

Table 39 - Runoff Computed for 514_GP-41A_01 (Taluka: Jalna, Mantha (Jalna))

RUN OFF ESTIMATION		
1	Total catchment area (Cluster area) in Ha	3132.00
2	Average annual rainfall in mm	715.74
3	75% dependable rainfall in mm	514.00
4	Average slope of area in %	2 to 4
5	Run off coefficient for the area in fraction	0.12
6	Run off yield from the area in TCM	1851.33
7	Utilizable Run off for harvesting in TCM = 65% of Row 6 (35% left as riparian rights of the downstream)	1203.36
8	Run off booked for existing WCS structures in **TCM**	145.00
9	Run off ultimately available for harvesting (7-8) in **TCM**	1058.36
10	No. of fillings assumed	2.00
11	Approximate water storage capacity that can additionaly be created (50% of 9) in **TCM**	529.18

In the overall GSDA groundwater budget, run-off is concerned only for NRM planning activities and is assumed to have almost no effect on the quantities of other parameters like groundwater recharge and groundwater extraction used in the budget. The use of 75% dependable rainfall for run-off estimation while planning NRM activities is based on the limiting conditions pertaining to NRM activities like i) ensuring sufficient run-off water available for impounding in normal year ii) one time / non-reversible nature of the activity (eg. construction of CNB) iii) costing involved, to name the few. Having said this, the issue with this computation is that the run-off generated for the clusters for a given year is almost independent of the overall rainfall and the rainfall distribution of the concerned year, and rainfall intensity of the rainfall events during that year which plays a crucial role in generation of run-off. Also, one of the key shortcomings of using this method is that estimated run-off for a given cluster/village/area remains unchanged over many years and does not depend on conservation measures undertaken. Moreover, in the project area, it is customary to store peak run-offs of one year in percolation tanks. This water is utilized in subsequent years.

As groundwater budget is one of the most important components of GSDA's recharge plan from IITB's perspective, it is discussed separately in the next section.

5.4 Groundwater Budget

GSDA's method for computation of the groundwater budget is based on the Groundwater Estimation Committee (GEC) methodology which uses groundwater water balance equation. The GEC methodology referred by GSDA is supposedly well accepted among hydrologists, groundwater experts and various government departments for its robust framework.

The equation for the groundwater budget is given by,

Groundwater Budget = Groundwater Available - Groundwater Draft
[surplus (+), deficit (-)]
where,
Groundwater Available = Gross Groundwater Recharge - Base Flows, and
Groundwater Draft = Groundwater draft for (Domestic + Agriculture) use

When the groundwater budget is in surplus it indicates that the annual groundwater draft is less than that of the annual groundwater draft. Whereas when it is in deficit, it indicates higher groundwater use than that of the available for the concerned year.

5.4.1 Groundwater Available

Annual groundwater availability is calculated by GSDA on deducting base flows from gross groundwater recharge where gross groundwater recharge is the sum of the monsoon and non-monsoon recharge.

i.Monsoon Recharge

To calculate total monsoon recharge GSDA has used rainfall recharge, recharge from WCS structure, recharge from surface water irrigation (if any) and net groundwater draft during monsoon. Rainfall recharge is computed using pre and post-monsoon WTF, area of the cluster and the specific yield as calculated by GSDA using the dry season method.

Rainfall Recharge (Ham) = Area (Ha) * WTF (m) * Specific Yield (%)
where 1 Ham = 10 TCM

Rainfall recharge is the main contributing component to the monsoon recharge. To get the monsoon recharge, GSDA adds recharge from WCS structures, net groundwater extraction and recharge from surface water irrigation (during monsoon) to the rainfall recharge as shown in the image below.

Table 40 - Monsoon Recharge for 514_GP-41A_01 (Taluka: Jalna, Mantha (Jalna))

Groundwater Estimation (2018-19)		
Monsoon Recharge		**TCM**
1	Rainfall recharge during monsoon (by WTF) in TCM =(area × wtf × sy) (3132*5*0.009)	1409.40
2	Recharge from WCS during monsoon in TCM	15.40
3	Recharge from groundwater irrigation during monsoon in TCM (considered 10 % of water applied)	45.54
4	Groundwater Draft during monsoon in TCM	455.40
5	Recharge from Surface water irrigation during monsoon in TCM	4.4
6	**Total groundwater recharge during monsoon in TCM =(1+2+(4-3)+5)**	**1839.06**
Non-Monsoon Recharge		
7	Recharge from WCS during non-monsoon in TCM	15.40
8	Recharge from canal in TCM	0
9	Recharge from Surface water irrigation during non-monsoon in TCM (10% of SW applied)	0.00
10	Recharge from Groundwater irrigation during non-monsoon in TCM (considered 10 % of water applied)	96.91
11	Recharge from Tanks and ponds in TCM (as per GEC norms)	0
12	**Total groundwater recharge during non-monsoon in TCM (7+8+9+10+11)**	**112.31**
13	**Gross groundwater recharge (6+12) in TCM**	**1951.37**
14	**Net groundwater availability in TCM (11-(10 % 0f 13)) by deducting base flow- Nil**	**1951.37**

ii. Non-Monsoon Recharge

Non-monsoon recharge is summation of recharge from all the possible sources during non-monsoon season; this includes recharge from WCS, Canal, surface water irrigation, groundwater irrigation, and from tanks and ponds.

Table 41- Non-Monsoon Recharge 524_MR-34_03 (Taluka: Nilanga, Latur)

Non-Monsoon Recharge		
7	Recharge from WCS during non-monsoon in TCM	15.40
8	Recharge from canal in TCM	0
9	Recharge from Surface water irrigation during non-monsoon in TCM (10% of SW applied)	0.00
10	Recharge from Groundwater irrigation during non-monsoon in TCM (considered 10 % of water applied)	96.91
11	Recharge from Tanks and ponds in TCM (as per GEC norms)	0
12	**Total groundwater recharge during non-monsoon in TCM (7+8+9+10+11)**	**112.31**

iii. Base Flows

After calculating gross groundwater recharge for the concerned year, groundwater base flows are deducted from it to get overall groundwater availability for the said year. The method for estimation of base flows for the respective clusters is not explained in the GSDA's recharge plan. These base flows are considered to be either 0%, 5% or 10% of the gross groundwater recharge for respective clusters, possibly based on the field observation of the GSDA team. Sample snippets from GSDA recharge plans where different percentages of base flow are considered are shown below.

Table 42 - 0 % Base flows: 501_PT-19_01 (Taluka: Akola (Akola))

13	**Gross groundwater recharge (6+12) in TCM**	**594.86**
14	**Net groundwater availability in TCM (13-(5%0f 13)) by deducting base flow-Nil**	**594.86**

Table 43- 5 % Base flows: 524_MR-34_03 (Taluka: Nilanga (Latur))

13	**Gross groundwater recharge (6+12) in TCM**	**7085.49**
14	**Net groundwater availability in TCM (13-(5%0f 13)) by deducting base flow**	**6731.22**

Table 44- 10 % Base flows : 512_GP-52_03 (Taluka: Aundha, Hingoli (Hingoli))

13	**Gross groundwater recharge (6+12) in TCM**	**5721.38**
14	**Net groundwater availability in TCM (13-(10 %0f 13)) by deducting base flow**	**5149.24**

A summary sheet is attached in the annexure showing quantities of base flows considered for all the 28 clusters. For 6 out of 28 clusters base flows are considered to be nil whereas for 9 and 13 clusters base flows are considered to be of 5% and 10% respectively.

5.4.2 Groundwater Draft

Groundwater draft for the concerned year is calculated by GSDA by adding groundwater draft for the domestic usage and for agricultural usage i.e. irrigation. Groundwater draft for domestic use is calculated using the requirement (demand) method whereas groundwater draft for agriculture use also known as irrigation draft is calculated using the well census method.

i.Groundwater Draft for Domestic Use

In the requirement (demand) method for domestic use, the total domestic water requirement of the cluster for a year is first calculated considering water demand for the human and cattle population of the cluster as per GEC norms and presence of small scale industry if any. Based on the availability of the water for domestic usage from other sources like water supply schemes or tankers, the dependability on the groundwater is estimated in percentage. The multiplication of the total annual domestic water requirement and percentage dependability on groundwater for domestic usage gives groundwater draft for the domestic use.

ii. Groundwater Draft for Agriculture Use

Groundwater draft for irrigation is estimated using well inventory data at the village level and pumping data collected by GSDA for the surveyed wells in the clusters. The well inventory data for both dug well as well bore well is taken from the revenue record. To select survey wells, cluster is divided in grids (of 600*400 m each) to cover the complete cluster area and one well (either dug well or bore well) is selected from each grid for observation and data collection. Average annual draft for the surveyed wells is calculated from the pumping data collected which is then multiplied with the total number of wells in use to get groundwater extraction for the village for the concerned village. Groundwater extraction for the agricultural use for the cluster is calculated by aggregating extraction for all the villages in the cluster.

Average annual draft of a well is calculated using average pump discharge per hour for the well and average pumping hours in a year. The methodology or description for arriving at the numbers of average discharge per hour is not clear from the report. Whereas annual pumping hours are calculated by using average pumping hours in a day and average pumping days in a year. In an attempt to capture seasonal variation for extraction in a year, it is divided in four quarters viz., June-September, October-December, January-March and April-May. Total annual draft of groundwater for agriculture is thus an addition to all of the above seasonal draft.

Table 45 - Groundwater Draft for Agriculture Use 514_GP-41A_01 (Taluka: Jalna, Mantha (Jalna))

Groundwater Draft Estimation (2018-19)								
	Village		Kirla		Jaipur		Borgaon	
Sr.	Well Type		Dug wells	Bore wells	Dug wells	Bore wells	Dug wells	Bore wells
1	Total no. of irrigation wells in the area		30	4	160	10	150	10
2	Total no. of wells in use		30	4	150	2	150	8
3	Total no. of wells surveyed		10	1	37	2	25	4
4	No of perrennial wells (perrenial pumping)		4	1	22	1	22	4
5	% of perrennial wells (perrenial pumping)		13.33	25.00	14.67	50.00	14.67	50.00
6	Average depth of wells in the area in m		15	120	16.5	150	15	120
7	Average pump discharge/well /per hour (cum/hr)		20	18	20	18	20	18
8	Average pumping hours a day	June-Sept	2.5	2.5	3	3	3	3
		Oct-Dec	5	5	4	4	4	4
		Jan-March	4	4	2	2	2	2
		April -May	0	0	0	0	0	0
9	Average pump operation days	June-Sept	22	22	20	24	25	25
		Oct-Dec	29	29	20	20	18	18
		Jan-March	37	37	24	24	25	25
		April -May	0	0	0	0	0	0
		Total	88	88	64	68	68	68
10	Average annual draft of a well (unit draft) in Ham	June-Sept	0.11	0.10	0.12	0.13	0.15	0.14
		Oct-Dec	0.29	0.26	0.16	0.14	0.14	0.13
		Jan-March	0.30	0.27	0.10	0.09	0.10	0.09
		April -May	0.00	0.00	0.00	0.00	0.00	0.00
		Total	0.70	0.63	0.38	0.36	0.39	0.35
11	Total groundwater draft in the area in Ham	June-Sept	3.30	0.40	18.00	0.26	22.50	1.08
		Oct-Dec	8.70	1.04	24.00	0.29	21.60	1.04
		Jan-March	8.88	1.07	14.40	0.17	15.00	0.72
		April -May	0.00	0.00	0.00	0.00	0.00	0.00
		Total	20.88	2.51	56.40	0.72	59.10	2.84
		Total	**23.39**		**57.12**		**61.94**	
12	Total groundwater draft in the area in **TCM**	**Total**	**142.44**	**Ham =**	**1424.424**	**TCM**		

Groundwater Draft for Agriculture Use in a cluster
= Σ Groundwater Draft for Agriculture for villages in a cluster
where,
Groundwater Draft for Agriculture in Village
= Number of operational wells in a village * Average Annual Draft of well;
Average Annual Draft = Σ Average draft for seasons;
Average Draft for a season
= Average pump discharge per hour * Number of pumping hours a day * Average pump operation days

Though the well census method for estimation of groundwater draft is recommended by GEC and is used widely, one of the issues with this method when GSDA has executed it, is that the accuracy of the overall groundwater draft calculated is very much dependent on reliability of the numbers used for wells, i.e., both dug wells as well as bore wells. As explained earlier in this report, these numbers for wells are taken from the revenue records. In some of the clusters, these numbers appear to be understated when normalized for the cluster area (say number of wells per 10 Ha). The field observations and discussions with farmers as well as field staff like Krushi Sahayaks, Cluster Assistants and Krushi Mitra from different clusters also suggests that the number reported in the revenue records may be very much underreported.

5.5 Comparison of GSDA and IITB Estimates

After studying the recharge plans prepared by GSDA, the results of the estimates for the quantities of the parameters like surface runoff and groundwater recharge were compiled and studied by the IITB team. This was an important exercise to understand any patterns emerging from the GSDA results.

5.5.1 GSDA Estimates and Water Balance Equation

As discussed earlier in the report, GSDA groundwater budget is based on the groundwater balance equation i.e. it considers only groundwater coming in the aquifer and groundwater moving out of the aquifer due to extraction and base flows. Essentially, it considers aquifer as a unit at which budgeting of groundwater is done. On the other hand, the IITB model considers a monsoon season as a unit for budgeting of water i.e. water coming in through monsoon rainfall in soil and water moving out through crop (evapotranspiration), runoff generated, groundwater recharge and moisture held by soil at the end of monsoon. Another point to be noted here is that, GSDA's budget is computed for a unit that has spatial nature whereas in case of IITB, the nature of the unit considered is temporal. It is therefore clear that both GSDA and IITB have different methods and units for budgeting which deals primarily with groundwater and monsoon respectively. Hence, both of these methods cannot be compared directly.

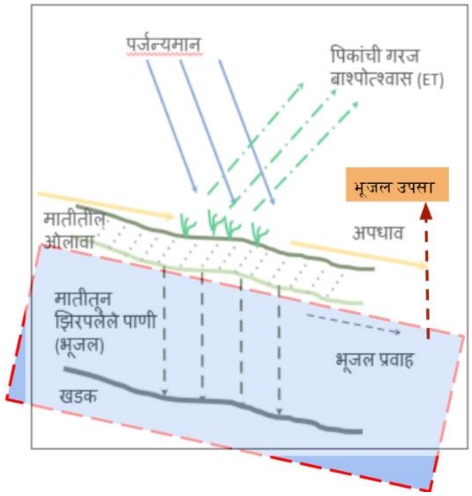


Figure 48 - Water budget schematic

Table 46 - IITB and GSDA water budget conceptual frameworks

	IITB Water Budget	GSDA Groundwater Budget
Rainfall	Used in computation of groundwater recharge	Not used in any computation
AET	Computed	Not considered
Runoff	Computed	Not considered (Only in Recharge Plan and not in Groundwater Budget)
Soil Moisture	Computed	Not considered
Groundwater Recharge	Computed	Computed
Groundwater Draft / Extraction	-	Computed

Base flows	-	Computed

Though methods used for estimation of groundwater recharge are different, it is also true that, whatever the method used, the quantities estimated for the parameters should roughly match if they have been calculated correctly. In an attempt to bring estimates by both of these methods on some common page, GSDA estimates were put together in a form of water balance equation for a monsoon season as is used by GSDA.

$$\text{Rainfall} = \text{Runoff} + \text{GW Recharge} + \text{AET} + \Delta\ \text{Soil Moisture (at Kharif end)}$$

As discussed earlier, GSDA has computed runoff generated and groundwater recharge and has also documented the rainfall for a concerned year. If these known parameters are put together, only AET and soil moisture at the end of Kharif are remaining two unknown. It can be safely assumed that these two are the main contributing parameters to the water that has been utilized from the rainfall received. Other contributing parameters where water may be considered to be utilized are base flows and water stored in water conservation structures. But contribution of both of these factors is very less when compared with AET and moisture held by soil at the end of kharif. This can be seen from the numbers reported by GSDA in their recharge plan for both of these quantities and is also evident from the field observations as reported by the IITB team. These quantities can be assumed to have contribution not more than 50 mm in any case (considering water storage of about 15-20 mm and base flows not exceeding 25-30 mm). With these assumptions, quantities of groundwater recharge and surface runoff as estimated by GSDA are put together in a water balance equation for the monsoon season. The groundwater recharge considered here is gross groundwater recharge computed by GSDA. A summary table for the same is attached in the Annexure.

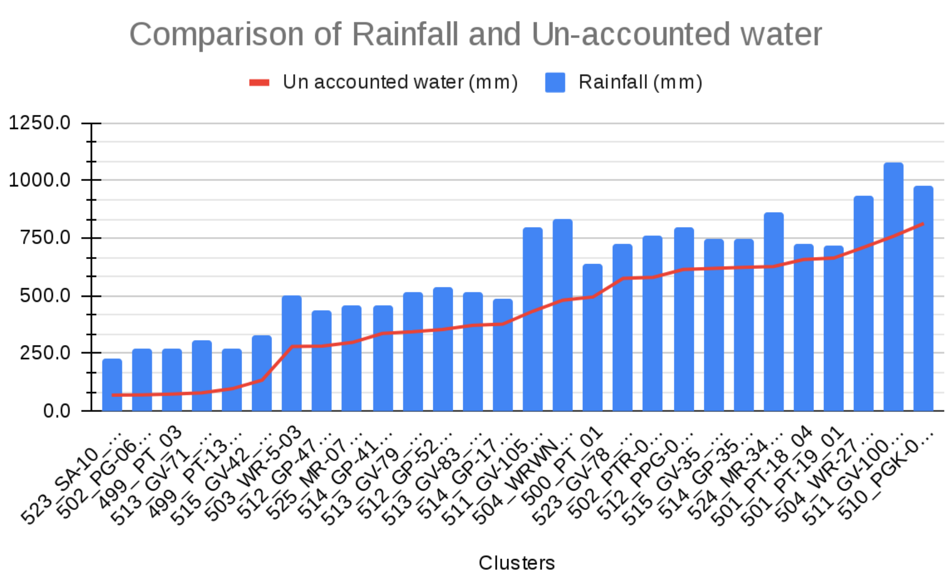


Figure 49- Comparison of rainfall and unaccounted water

As can be seen from the above graph, out of 28 clusters, results for at least 9 clusters on the right side and for 5 clusters on the left side seems unreasonable. The 9 clusters have unaccounted water of more than 600 mm out of the total rainfall which does not seem reasonable. Even if maximum AET of about 400 mm during monsoon and soil moisture of about 150 mm at the end of kharif is accounted for along with the other minor factors of base flow and water storage, the sum of all these parameters shall not exceed 600 mm. This indicates that there is possibility of error in computation of either one or both of the parameters as estimated by GSDA viz. runoff and groundwater recharge. Similarly, for 5 clusters on the left hand side, unaccounted water comes out to less than 100 mm which again seems unreasonable. Also, for 2 clusters from Akola district (placed at fourth and fifth position from the right in the above graph), in spite of having rainfall of more than 700 mm, summation of groundwater recharge and surface runoff estimates seems to be on lower side especially when compared with unaccounted water from the rainfall.

The basic idea to do this exercise was to do simple checks on the results of GSDA to test utility for the purpose of calibration of any of the parameters estimated by IITB water balance model.

5.5.2 Comparison of GSDA and IITB Estimates

Next important task for bringing GSDA and IITB results on common ground was to compare the estimates by GSDA and IITB for the respective clusters for the concerned year. A summary sheet is attached in Annexure that compiles the results of GSDA and IITB estimates for groundwater recharge and surface runoff computed using both the daily model as well as the hourly model. The hourly model is an adaptation of the daily model with a reduced time step so as to reduce discretization errors. It was suspected that the daily model overestimated run-off and under-estimated groundwater recharge.

Before we compare these compiled results, it is important to note that the results for GW recharge cannot be compared as it is. This is because the rainfall used by IITB for computation of groundwater recharge does not necessarily match with the rainfall considered by GSDA for all the 28 clusters. As IITB uses rainfall for computation of the groundwater recharge, different rainfall yields different results for groundwater recharge. Therefore, groundwater recharge of only those clusters shall be compared where rainfall considered by GSDA and used by IITB are in reasonable range (say clusters where variation in rainfall is not more than about 30 mm).

Apart from rainfall another important factor that may affect the computation of the groundwater recharge in some or the other way is cropping pattern. The IITB model as such uses cropping data as provided by field officials of PoCRA in MLP app. But to make the comparison fair and eliminate any error that may arise due to difference in the cropping pattern, the same cropping pattern as considered by GSDA while preparing recharge plans was used in the IITB model for all the respective clusters.

Further, GSDA’s groundwater recharge considered for comparison with IITB groundwater recharge estimates is the monsoon groundwater recharge and not the gross groundwater recharge. Gross groundwater recharge computed by GSDA is for the whole year whereas monsoon groundwater recharge is only for the monsoon. On the other hand, the IITB groundwater recharge estimate is essentially the groundwater recharge from the monsoon. Therefore it makes more sense to compare these two groundwater recharge estimates that are computed for the same time period.

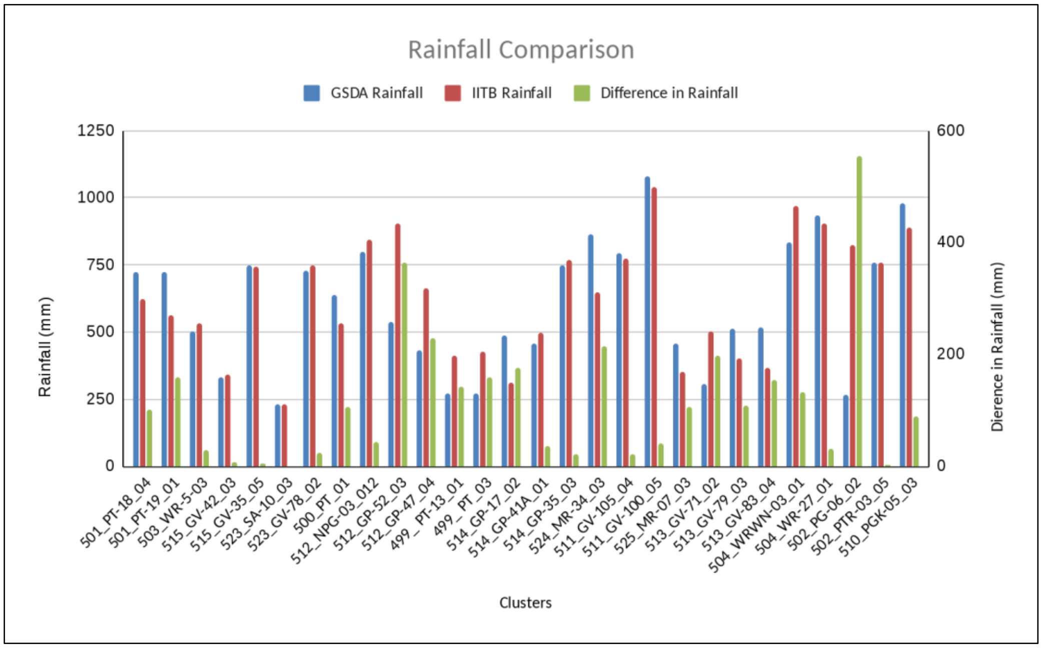


Figure 50- Rainfall comparison

As can be seen from the above graph, there is considerable variation in the rainfall considered by GSDA and IITB for a concerned year. Out of 28 clusters, rainfall roughly matches for about 9 clusters only and hence this limits the exercise of comparison for these 9 clusters. When groundwater recharge estimates by GSDA and IITB (hourly model) for these 9 clusters are compared, for 2 clusters these estimates roughly match with each other. Whereas for the rest of the clusters these estimates did not match and showed considerable deviation. The possible explanations for this deviation and strategy for minimizing the difference in these estimates for groundwater recharge are discussed later in this report.

Table 47- Rainfall comparison

Rainfall In Reasonable Range (+ / - 25 mm)	7
Rainfall Deviation of (>25 and <50) mm	5
Rainfall Deviation of (>50 and <100) mm	1
Rainfall Deviation more than 100 mm	15

Though the comparison of groundwater recharge ignoring rainfall considered by GSDA and IITB is not fair, when compared, the groundwater recharge estimates roughly matches for about 7 clusters in total (+ / - 25 mm). Similarly, for one more cluster apart from the above seven, deviation in the groundwater recharge estimates is about 30 mm. This is illustrated in the following chart.

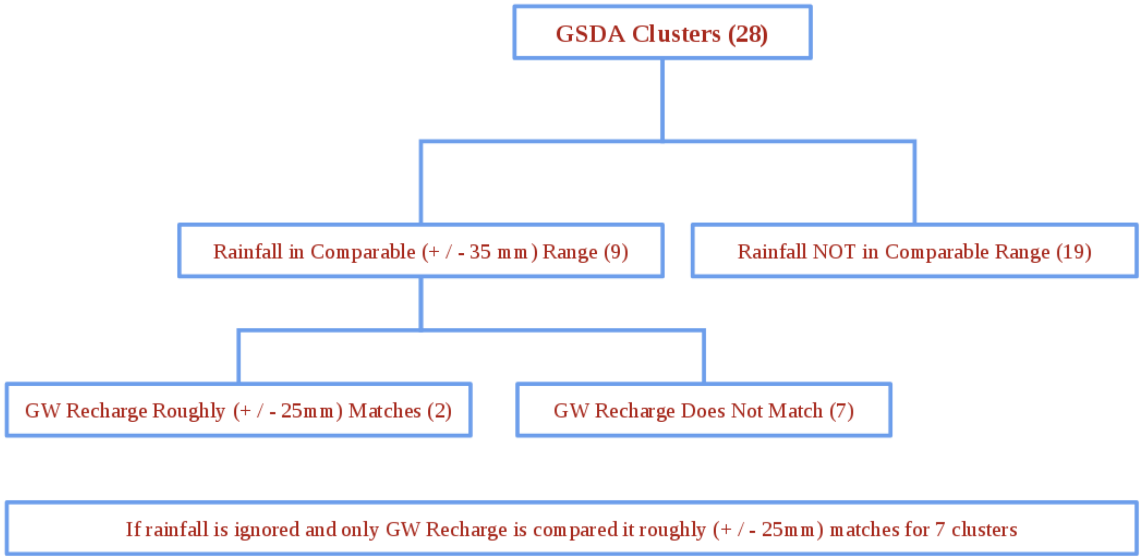


Figure 51 - GSDA - IITB GW recharge comparison

All of the above comparisons are for groundwater estimates as computed by GSDA and that of IITB hourly model as it is an improvised version of daily model. Since the detailed comparison of IITB daily and hourly model is covered separately in other reports, this is not emphasized here but some observations on the same are listed below with regards to GSDA groundwater estimates.

- IITB groundwater recharge estimates as calculated using the daily model are on the very much lower side whereas that of surface runoff are on the higher side when compared with GSDA estimates.
- When the hourly model was used instead of the daily model, the groundwater recharge estimates were found to be increased significantly as against the daily model. Also, estimates for surface runoff were reduced considerably whereas both, AET and soil moisture estimates were increased marginally.
- IITB estimates and GSDA estimates for groundwater recharge are summarized in the following graph and table to understand patterns if any.

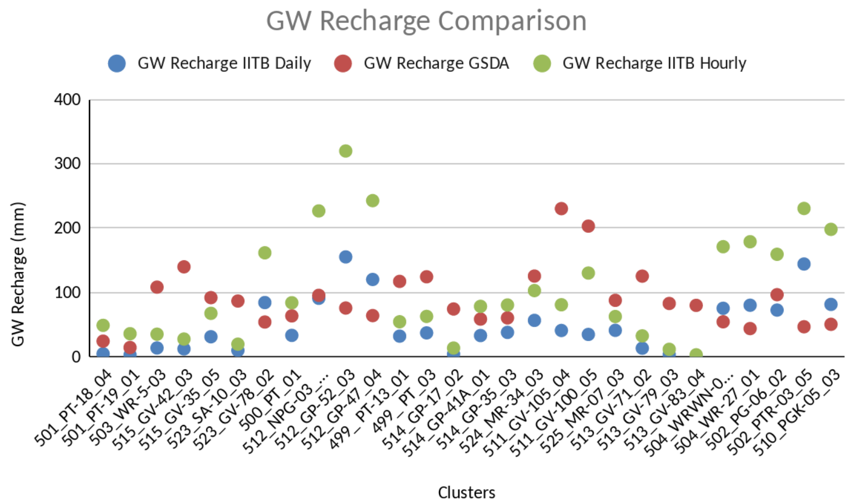


Figure 52 - IITB daily, IITB hourly and GSDA GW recharge comparison

Table 48- IITB daily, IITB hourly and GSDA GW recharge comparison

GWR IITB Daily < GWR GSDA < GWR IITB Hourly (GSDA recharge <u>falls in between</u> daily and hourly IITB estimates)	7
GWR GSDA < GWR IITB Daily < GWR IITB Hourly (Both daily and hourly IITB estimates are <u>higher</u> than GSDA recharge)	7
GWR IITB Daily < GWR IITB Hourly < GWR GSDA (Both daily and hourly IITB estimates are <u>lower</u> than GSDA recharge)	14

As can be seen from the table above, for about half the number of clusters, groundwater recharge estimates are still lower than the GSDA estimates. One of the possible reasons is the effect of soil type (and also the soil depth) on the groundwater recharge estimation in case of the IITB model. As far as these 14 clusters are considered, where IITB estimates for groundwater recharge is lower than the IITB model, most of these clusters have clayey soil as dominant soil type which generally yields lower groundwater recharge in IITB water balance model. The IITB team is hopeful about the further improvements in the recharge estimates for such clusters when the phenomenon of ponding will be incorporated in the model. Similarly, for the rest of the clusters where IITB model estimates for recharge are considerably more than that of GSDA, incorporation of base flows and limiting the recharge by aquifer capacity (aquifer thickness) would positively reduce the gap in the estimates. Since the overall strategy for IITB water balance model refinement is discussed separately in another document, it is not the focus of this section and hence only briefly mentioned.

In this chapter, it has come out very clearly that the results of groundwater estimates by GSDA and IITB did not seem to be in reasonable range even after incorporating hourly time steps for computation instead of the daily time step. While investigating the possible explanations for this gap in the estimates of many of the clusters, it was found that the results for groundwater recharge estimates were not necessarily reliable for all the clusters. The detailed account of some of the key issues with GSDA recharge estimates is covered in the next chapter of this report. It is suspected that the issues raised by the IITB team may significantly change the groundwater recharge estimates in many clusters. It is therefore proposed that further comparison and analysis of the groundwater recharge estimates by GSDA and IITB may be done only after clarifications on the issues raised by the IITB team are received from GSDA. The IITB team will continue to work on the proposed improvements in the IITB model to incorporate different phenomena like base flows, stream flows and ponding. This analysis will be helpful for further calibration and integration of GSDA groundwater recharge estimates in IITB water balance model.

5.6 Issues in GSDA Recharge Plan

This chapter of the report discusses some of the key issues encountered by the IITB team while studying and analyzing recharge plans prepared by GSDA. These issues also have consequences on the results as estimated by GSDA for surface runoff, groundwater recharge and groundwater extraction.

5.6.1 Related to Specific Yield Calculation

The most important issue that has come up while studying groundwater recharge plans prepared by GSDA is that of specific yield. Specific yield is one of the key factors used in computation of rainfall recharge during monsoon, the main contributor to overall groundwater recharge. As per the recharge plans, GSDA has calculated specific yield for all the 28 clusters using dry season specific yield approach. Following sections discuss the issues with the execution method used by GSDA for calculation of specific yield.

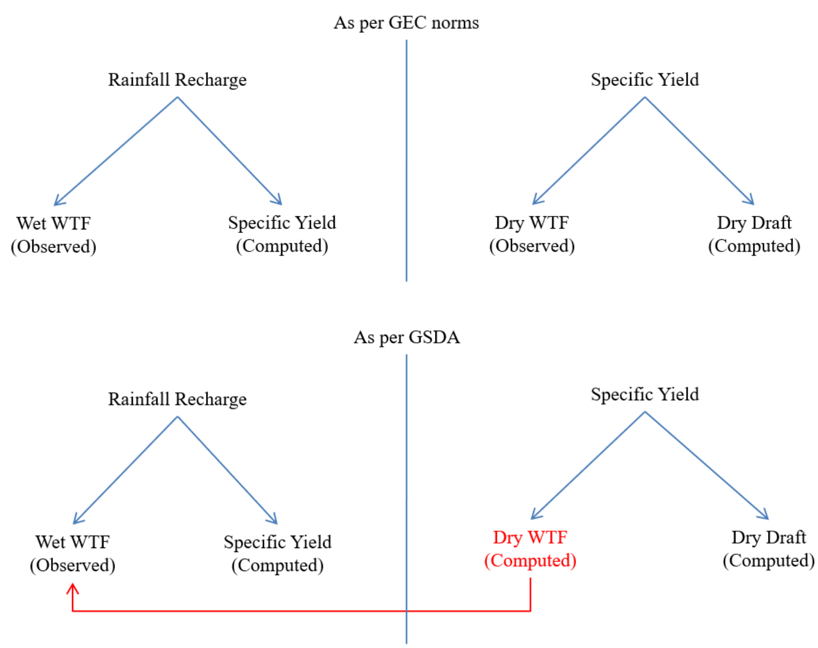
i. Missing water table level required for computing dry WTF

As per the GEC norms, dry WTF is calculated using water level at the end of monsoon i.e. post monsoon when aquifer is recharged and water level at the end of dry season i.e. pre monsoon water level for the next year when the groundwater that has got recharged gets extracted. The difference in these two water table levels is essentially the dry WTF. This dry WTF is supposed to be used for calculation of specific yield which then is used in calculation of rainfall recharge. Thus in totality, to compute recharge using this method, one would require records of three water levels viz. pre-monsoon water level for the concerned year, post-monsoon water level for the same year and pre-monsoon water level for the next year. But GSDA has recorded only two water levels instead of these three required water levels. The WTF obtained from these two water levels are supposedly used for rainfall recharge calculation. In the absence of the third water level required for calculation of dry WTF, GSDA has assumed a relationship between dry WTF and wet WTF (simply referred to as WTF earlier which essentially means WTF which is to be used for rainfall recharge calculation). The equation used by GSDA for calculating dry WTF is,

Dry WTF = (5/8) * Wet WTF

Out of 23 clusters for which specific yield calculation data was made available to the IITB team, for 15 clusters the factor used for calculation of dry WTF from wet WTF is 5/8. Likewise, factor

4/8 and 2/6 have been used once and 3/6 has been used twice for calculation of dry WTF from wet WTF. For the remaining 4 clusters, either the source of the dry WTF is not clear or the fraction used is not consistent. No explanation is provided by GSDA for any of the above cases, nor does any such method is mentioned in the GEC norms. It is not clear how we may fix a relationship between two observed entities which otherwise are independent of each other. Ideally, dry WTF is to be taken from the observed water levels and not based on a certain relationship. GSDA may have some reasoning for the same which needs to be further investigated.



Further, GSDA has considered draft during the period of January to May i.e. of 5 months only instead of complete dry season. This may be fine when the corresponding dry WTF is to be used i.e. WTF between January and May. But as explained earlier, GSDA has simply used an assumed relationship to calculate dry WTF instead of actual observations of required water table levels. Another issue with this relationship is that GSDA has ended up assuming that dry WTF for a concerned year can never be more than or even equal to the WTF i.e. wet WTF. This may not be necessarily true and as such no such relationship can be established.

Since GSDA has not recorded requisite water levels necessary for specific yield calculation in any of the clusters, it is suspected that this error in specific yield calculation persists for all 28 clusters. Given the importance of the accuracy of specific yield to be used in groundwater recharge calculation, this error also raises questions on the groundwater recharge estimates.

ii. Equation used for calculating specific yield

As per the GEC norms, specific yield is computed by dry season specific yield approach using following equation,

Specific Yield= (Dry GW Draft - Recharge from Dry GW Draft + base flows)/(dry WTF * area)

Whereas GSDA has computed specific yield using following equation, Specific Yield = Dry GW Draft / (dry WTF * area)

As can be seen from the above equations, GSDA has not considered the recharge from groundwater draft in dry season and base flows while computing specific yield. The possible reason could have been the small quantities of these two parameters. But given the sensitivity of the specific yield towards recharge calculation, both of these quantities should have been considered. In clusters where quantities of base flows are negligible it could have been neglected but at least for the clusters where base flows are observed, it should have been considered. Similarly, in the clusters where the dry draft is high, the corresponding recharge from application of this extracted water would also be comparatively higher and hence should have been considered.

iii. Inconsistency in area considered for calculating specific yield

While considering the area for specific yield calculation GSDA has used cultivable area in some cases whereas total cluster area in the cluster in other cases. Out of the 23 clusters for which specific yield calculation data was received, for 15 clusters only cultivable area was used whereas for rest 8 clusters total area (i.e. cultivable area as well as other land use) was used. Assuming that there should be consistency in area considered (whether of total land use or only cultivable), in any case this inconsistency would possibly have introduced an error in either type of the clusters.

iv. Issues with the dry draft calculation

With regards to dry draft calculation, GSDA has considered draft for both dug wells as well as bore wells. Since specific yield to be calculated is for shallow aquifer, corresponding WTF and draft should have been used. If the numbers reported by GSDA for average aquifer depth, average aquifer thickness, average depth of dug wells and average depth of bore wells are to be believed, it seems that the shallow aquifer for which specific yield is being calculated, is tapped largely by dug wells only and not the bore wells. Though the effect of bore well draft on the WTF of shallow aquifers is not certainly known, it would have been more appropriate to consider draft of dug wells. GSDA may clarify this further.

v. Issues with the averaging method used

While calculating specific yield for the cluster, GSDA has first calculated specific yield for the individual villages in the cluster which is then averaged out for the cluster. In doing so, GSDA has used a simple average and not the weighted average. This may introduce an error in computation of specific yield where distribution of village area in the cluster is not uniform. A sample case of 499_ PT-13_01 cluster from Mukainagar, Jalgaon can be referred to, where the error introduced due to this averaging method is of about 25 mm if the same WTF is used.

Based on the above observations discussed in this section for specific yield calculations, we must consider the accuracy and the reliability of specific yield values and hence the groundwater recharge estimates. Apart from the above key issue, other issues which are not necessarily true for all the clusters at the same time but may affect the estimates of groundwater recharge are discussed in the following sections.

5.6.2 Related to WTF

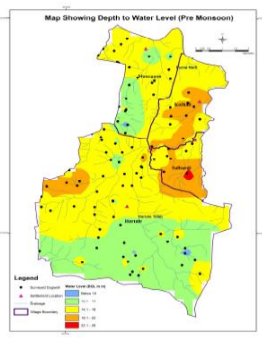
i. Incorrect reference used for WTF

As indicated in GEC methodology, WTF considered for recharge calculation has to be the rise in water level in monsoon i.e. water table fluctuation from pre-monsoon and post monsoon for the same year. This rise in water level is a mark of net positive change in groundwater storage (availability) indicating groundwater recharge. The first water level to be considered is that of pre-monsoon when the water table has gone down due to natural discharge and extraction for agriculture and domestic use for the previous year. The other water level to be considered is that of post monsoon where the water table rises due to water received by an aquifer in Monsoon through rainfall. The difference in these two water table levels is the desired WTF to be used for the groundwater recharge calculation.

Case I: Use of Correct reference to calculate WTF for Recharge -

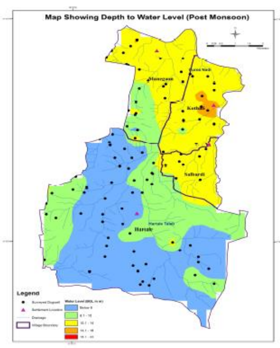
iv) **Depth to groundwater level map – Pre-monsoon (Summer) (Fig-10):**

Depth to groundwater level in summer varies from 8 to 21 mbgl; however the depth to GW level between 11 to 18 mbgl is more common.



v) **Depth to groundwater level map – Post-monsoon (Winter) (Fig-11):**

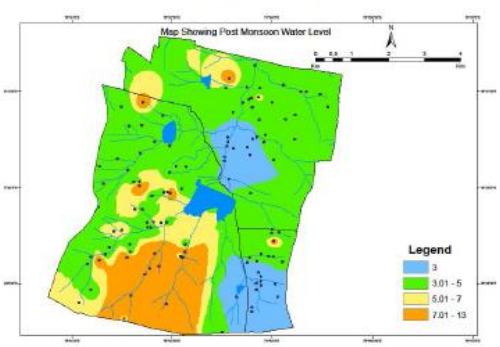
Depth to groundwater level in winter varies from 2 to 15 mbgl; however the depth to GW level between 3 to 14 mbgl is more common



Pre-monsoon To Post-monsoon

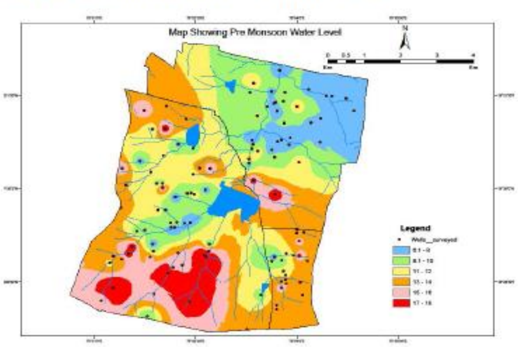
Depth to groundwater level map – Post-monsoon (Winter 2018) (Fig-11):

Depth to groundwater level in winter 2018 varies from 3 to 13 m bgl. However the depth to GW level between 3 to 7 m.bgl is more common.



Depth to groundwater level map – Pre-monsoon (Summer 2019) (Fig-12):

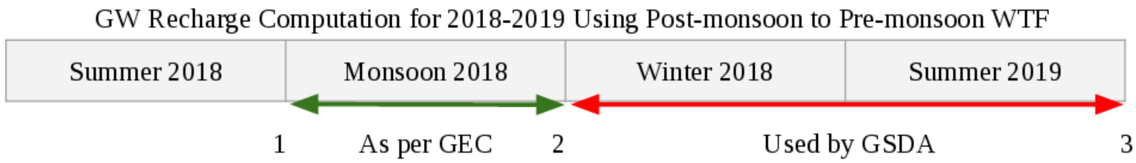
Depth to groundwater level in summer 2019 varies from 6 to 18 m bgl. However the depth to GW level between 8 to 12 m.bgl is more common.



Case II: Use of Incorrect reference to calculate WTF for Recharge -
Post-monsoon To Pre-monsoon

Figure 53- Incorrect reference used for WTF

Though GSDA has used this correct i.e. pre-monsoon to post-monsoon WTF for some clusters, in some of the cases the reference used for calculating WTF is not correct. In such cases, instead of ‘rise in water level in monsoon’, GSDA has used annual water table fluctuation from post-monsoon (winter 2018) and pre-monsoon (summer 2019). This WTF does not indicate net positive but the negative change in water availability of an aquifer. This negative change in groundwater storage indicates groundwater extraction during Rabi and summer season of the concerned monsoon year. Thus, this WTF on multiplication with specific yield and area would give extraction and not recharge as suggested by GSDA. A summary sheet is attached in Annexure which details the reference used for WTF and comment by the IITB team on the same. In some cases, it cannot be said conclusively if the reference used for WTF is incorrect or not but at least for 5 clusters, the reference WTF used is incorrect.



Following case better explains the issue with the use of such WTF.

Table 49- Incorrect reference used for WTF

	Case I (GW Draft > 100%)	Case II (GW Draft = 100%)	Case III (GW Draft < 100%)
GW level Pre-monsoon 2018 in mgl (@ end of summer 2018)	8	9	10
GW level Post-monsoon 2018 in mgl (@ start of winter of 2018)	3	3	3
GW level Pre-monsoon 2018 in mgl (@ end of summer 2019)	9	9	9
WTF which should have been used as per GEC method	5	6	7
WTF used by GSDA	6	6	6
Recharge computation	x	✔	x

As can be seen from the table above, this error will not show up for the clusters where the stage of groundwater development is exactly 100 % for monsoon year 2018. But this seems a rare case where the groundwater used in the concerned year is exactly equal to the recharge for the same monsoon year. Based on the 28 recharge plans of GSDA as received by the IITB team from PMU, in most of the cases the groundwater extraction is on a higher side than that of recharge. Therefore, the possibility of elimination of this error on its own wherever incorrect WTF has been used is very less.

ii. Inconsistency in WTF for values reported and those used for calculation

In some of the cases, WTF mentioned in the section of annual groundwater level fluctuation is different from the ones used for calculation of rainfall recharge. A summary sheet is attached in Annexure which compares the WTF values as reported in the section 4. vi.f of the recharge plan with those which are actually used for calculation of rainfall recharge in section 8 of the report.

iii. Inconsistency in WTF used for calculation and those calculated from Raw Data

The IITB team calculated WTF from the raw data received for the 16 clusters and compared these WTF with those used by GSDA while calculating groundwater recharge. Out of 16, for 5 clusters WTF used for calculation of rainfall recharge is consistent with the WTF calculated using raw data. While WTF could not be computed for 3 clusters due to lack of required data, WTF was found to be inconsistent for 8 clusters.

Table 50 - Inconsistency in WTF used for computation of recharge

No. of cluster where data is received	No. of clusters where WTF could not be calculated	No. of clusters where WTF used for calculation is consistent with WTF calculated from raw data	No. of clusters where WTF used for calculation is NOT consistent with WTF calculated from raw data
16	3	5	8

The details on the same and approximate error in estimation of the recharge due to WTF is attached in the annexure separately. This error ranges from about 6 mm to 76 mm. Though error of 6 mm can be ignored, out of 8 clusters, this error is around 25 mm and 75 mm for 2 clusters each.

5.6.3 Incorrect Use of Equation for Monsoon Recharge

As per GEC 2015, groundwater recharge during monsoon season is given as,

Groundwater recharge during monsoon
= (Rise in water level in monsoon * Specific yield * Area) + Gross groundwater draft

Whereas GSDA has computed the same using following equation,

Groundwater recharge during monsoon
= (Water table fluctuation * Specific yield * Area) + Recharge from WCS +

Recharge from surface water irrigation + Gross groundwater draft

It can be seen from above two equations that GSDA has used the incorrect equation for computing groundwater recharge during monsoon. In doing so, GSDA has double counted recharge from WCS and recharge from surface water irrigation (if applicable for the cluster). Though the overall error incurred in the computation of the annual groundwater recharge on using this equation is comparatively less, the same error is present in all the 28 recharge plans.

GSDA has provided no explanation on deviation from the GEC method for considering different references while calculating WTF and for using different equation for calculating monsoon recharge.

5.6.4 Related to Raw Data

Apart from the reports, IITB found some issues with the raw data used by GSDA. A summary sheet is attached in the Annexure which briefly comments on the issues relating to raw data as shared with the IITB team by PoCRA PMU. As the data received had varying formats and there was hardly any consistency in the different data formats used, a standard method for analyzing this data could not be used. Hence data was analyzed for only two main components which are important for IITB team viz. WTF used for calculation of groundwater recharge and groundwater extraction during kharif season. These two components are important as they are required in calculation of the monsoon recharge which was to be compared with IITB groundwater estimates.

To calculate Monsoon recharge as is done by GSDA, one would require data on pre and post monsoon groundwater level to calculate WTF and pump discharge, pumping hours and operational pump days in monsoon season. Also, cropping pattern data of surveyed farmers along with the irrigation provided would have been helpful for triangulation of the kharif extraction. As can be seen from the summary table, for none of the clusters all of these data points were available. For all the clusters either of these data points or many in some cases were missing. For example, pumping data was completely missing for 2 clusters, in 10 other clusters pumping data for kharif was not available. Similarly, for 4 clusters data required to calculate WTF was not available. While cropping data was available for only one cluster in usable form along with corresponding irrigation provided, for other clusters it was either missing or incomplete. This data inadequacy did put limitations on the checks that could have been run on the data and further on the positive use of the available data for any kind of validation or calibration.

A summary sheet is attached in Annexure that summarizes comments on the raw data shared with the IITB team.

5.6.5 Other Issues and Observations

Apart from the above issues, some of the important observations are listed below as recorded while studying GSDA recharge plans and the raw data.

- Observation on relationship of specific yield computed and extraction

As can be seen from the chart below, there seems a correlation of extraction reported for the cluster and the corresponding specific yield calculated by GSDA. The specific yield is an intrinsic property of the concerned aquifer and hence is believed to be independent of the extraction. Though extraction is used in the specific yield approach method for calculation of specific yield, a direct relationship or dependency of the specific yield on the extraction is not expected given the other parameters in the equation used are not constant. Therefore, the R squared value of 0.7 looks surprising and GSDA may investigate this and clarify. The only possible explanation is that the (i) well depths are roughly constant across clusters, and (ii) discharge equals recharge.

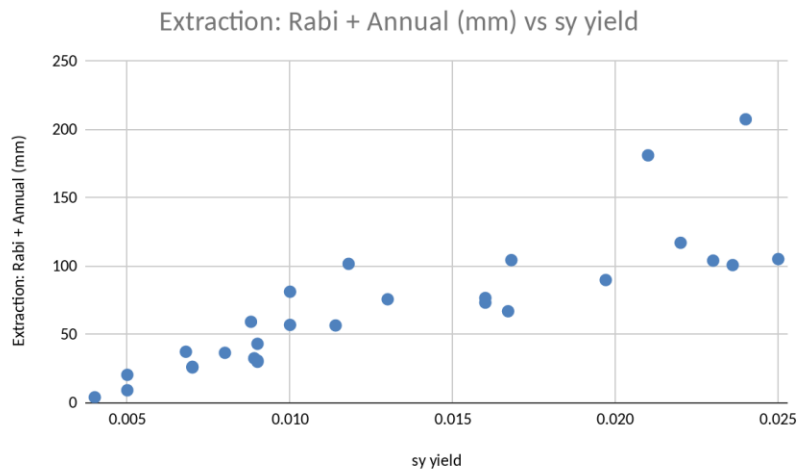


Figure 54- GW extraction vs. specific yield

- GSDA Specific yield values and gap in GSDA and IITB recharge estimates

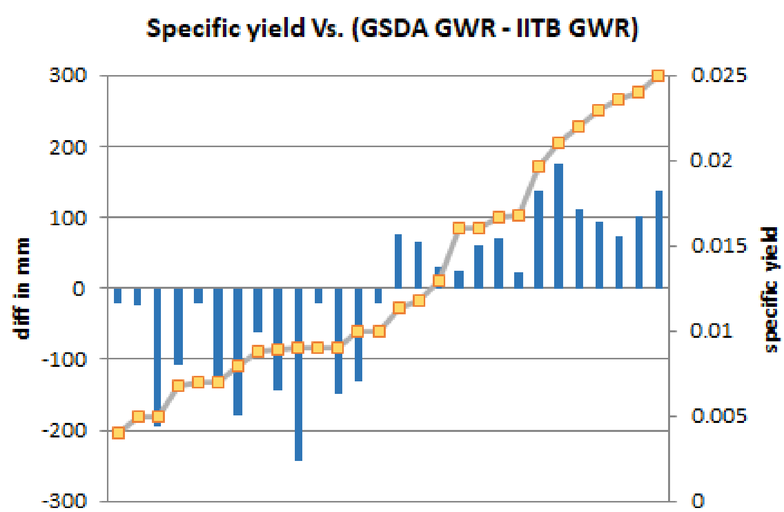


Figure 55 - Difference between IITB and GSDA GW recharge Vs. specific yield

In the above chart, specific yield values of 28 clusters are arranged in increasing order and the difference in the GSDA groundwater estimates and IITB hourly model estimates are plotted against the same. As can be seen for the graph, for the clusters where specific yield value for the cluster is more than 1%, GSDA groundwater recharge estimates are on the higher side than that of IITB groundwater recharge estimates. Whereas for the rest of the clusters groundwater recharge estimates by GSDA are lower than IITB model estimates. For some of these clusters where IITB groundwater recharge estimates are comparatively higher than that of GSDA estimates, it is felt that the specific yield values used for computation of groundwater recharge are on the lower side. This argument is based on the assumption that some of the following observations.

The specific yield values recommended by GEC for the aquifers found in these clusters ranges from 1% to 3% where minimum specific yield is said to be 1% and maximum of 3%. For 14 out of 28 clusters, the specific yield values are less than equal to 1%. Also, field observations from some of these clusters suggest that groundwater recharge estimates by GSDA for these clusters seems on the lower side. Further, when the possible maximum groundwater recharge during monsoon for these clusters is computed based on the specific yield and aquifer thickness reported by GSDA, the numbers seem on the lower side especially when compared with the corresponding extraction for these clusters.

It is therefore believed that the specific yield values for these clusters are not accurate and correction in these specific yield values may positively reduce the gap in the GSDA and IITB estimates if all other factors are assumed to be correct and kept unchanged. (Similarly for clusters where IITB groundwater recharge estimates are on the higher side, the possible reason for the gap can be attributed to un-accounting of base flows in the IITB model.)

- Error in computation of rainfall recharge
    - As is observed in case of specific yield calculations, there is inconsistency in the area used for calculation of rainfall recharge during monsoon. In 3 out of 28 clusters, cultivable area and not the total area is used for the calculation of rainfall recharge. The error introduced in these 3 clusters ranges from 10 to 20 mm.
    - In the 525_MR-07_03 cluster from Washi Osmananbad, though the correct equation and numbers have been used, there is an error of about 930 TCM (~ 20 mm) in the rainfall recharge.
- Error in calculation of groundwater draft for agriculture use
    - In some of the clusters, while computing groundwater draft for agriculture use, GSDA has averaged out some of the components used in groundwater draft calculation like pumping hours and operational pump days of individual villages, to the cluster and then computed groundwater draft considering total operational wells in the cluster. This introduces a computational error in some clusters. Firstly, the draft for the cluster should have been computed by aggregating groundwater draft for all the villages in the cluster as is done in some of the clusters. Secondly, in case averaging was required, it should have been weighted average than the simple average.
- Average unit draft per well: On higher side in many clusters
    - For some clusters, average annual draft of a well was found to be on the higher side (around 8-10 TCM or more, which comes out to be about 15-20 waterings of 50 mm each for one hectare). This draft is multiplied with total operational wells to compute total groundwater draft which may give exaggerated extraction figures especially for non-command dryland regions.
    - This can be possibly because of sampling error in well selection where the majority of wells fall in the stream proximity area.
    - In some cases, this is because of higher pumping data reported for summer months

- Incorrect use of simple average instead of weighted average
    - As discussed earlier in this report, apart from specific yield calculation or for pumping hours and operational pump data, almost in all the cases where GSDA intended to use average values for the concerned data, simple average is used instead of weighted average. This has been done for important parameters like WTF (wet) and dry WTF as well. It is important to note that the issue is not using average values but the method used to arrive at those values.
- Pumping hours data (and hence GW extraction) for April-May as mentioned in the report is not consistent with the raw data for some of the clusters
    - In most of such cases, the pumping data for the these summer months is reported on higher side in the recharge plans than that of raw data used
- Method used for aggregation of farmers level data
    - Farmer level data such as crops sown, area under crops, type of irrigation used, and number of irrigations provided was either found to be missing or has many inconsistencies in reporting in most of the clusters. The method used for aggregation of this farmer level data at the cluster level is not clear. Also, it is not clear how this dataset was used in computation of groundwater extraction.
- Error while using spreadsheet formulae
    - Because of missing entries in the spreadsheet for parameters like pumping hours, operational days, etc. in raw data, in a cluster or two, error is introduced while using average formula.

This sums up some of the key observations of the IITB team on recharge plans prepared by GSDA.

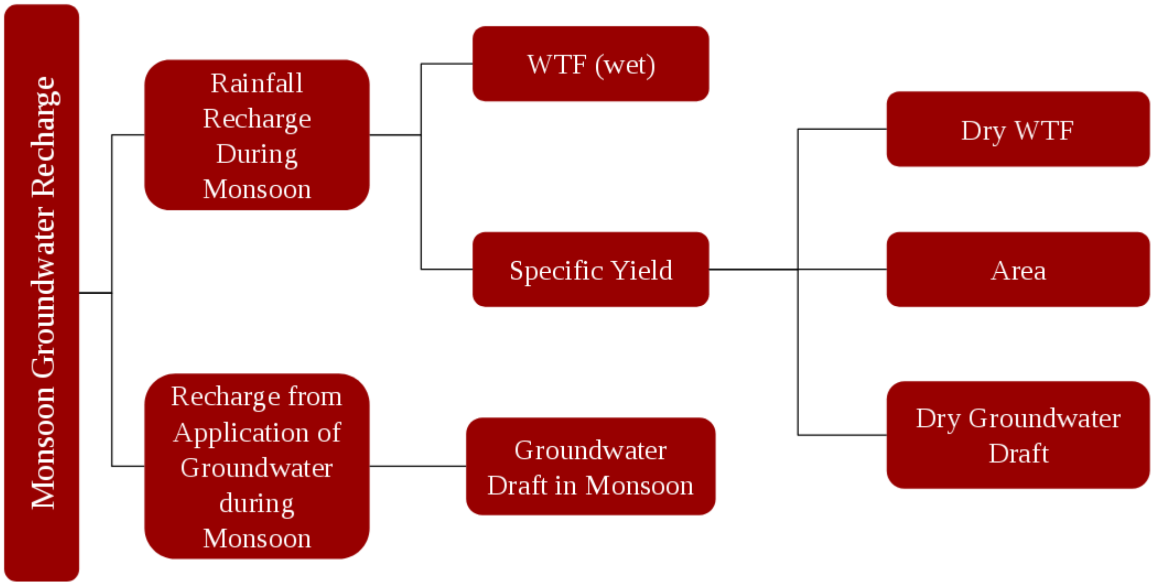


Figure 56 - GSDA computation schematic

Lastly, the above schematic highlights how error in the above discussed components leads to error in the computation of the monsoon groundwater recharge which is a key contributor to the gross groundwater recharge.

5.7 Proposed Plan for Calibration of IITB GW Recharge Estimates

The broader objective of this study was to evolve a strategy to integrate GSDA results for groundwater recharge in IITB water balance model. As is evident from the summary table, IITB results for groundwater recharge estimated using the daily model were indeed lower. The IITB team was thus entrusted with the task to positively improve these estimates using GSDA results for groundwater recharge. For this, groundwater recharge plans prepared by GSDA for 28 clusters and the data for 16 clusters as used by GSDA for preparation of these recharge plans was shared by PMU with the IITB team. The idea was to use these reports, raw data and their results so as to calibrate the groundwater recharge estimates of the IITB water balance model which can be then integrated in the water balance model and scaled up for all the villages accordingly. This had an assumption that the GSDA estimates for groundwater recharge are reliable. This however does not seem to be necessarily true as can be seen from the various issues discussed in the report.

5.7.1 Calibration of IITB GW Estimates with Corrected GSDA Estimates as Reference

A suggestion from PMU for calibration of IITB model estimates was to correct errors found in computation of groundwater recharge in GSDA recharge plan by IITB team and then use these corrected results for calibration of the IITB groundwater recharge. This suggestion was not implemented by the IITB team as it was not possible to quantify all of the issues / errors found out by the IITB team in GSDA recharge plans. An error of considering incorrect reference is an example of such error where it commenting on the corrected values is not possible. Similarly, for kharif extraction, corrected figures were difficult to calculate as there was no way for ground truthing or triangulation. This was also because the data used for most of these calculations is dynamic in nature i.e. subject to change every year based on the other conditions for the concerned year like rainfall, kharif cropping pattern and occurrence of dry spell if any etc. Hence the idea to calibrate IITB model based on the corrected GSDA results for 2018 / 2019 was dropped considering unsuitability of the same as far as feasibility of execution and reliability of results were concerned.

Considering the issues found in the GSDA groundwater recharge plan reports and the raw data used for preparation of the same, it was opined that IITB water balance model should not be calibrated based on the GSDA results. Rather it was decided that the IITB team will be using the GSDA method for estimation of groundwater recharge for the catchments of the clusters where fieldwork for water balance model validation is underway. Simultaneously, the IITB team will work on to strategize use of GSDA data shared with all its limitations to the maximum possible extent.

5.7.2 Calibration of IITB Estimates Based on the Fieldwork

A plan is proposed for calibration of IITB GW estimates based on the observations and measurements from the field as recorded during fieldwork. This is covered separately in the water balance model validation report. The key points of the validation plan are briefly discussed in the following section.

- Adopt GSDA method in the selected catchments (4-5) to estimate GW recharge
    - Select wells for recording measurements and observations
    - Use cluster area and specific yield (corrected specific yield values obtained from GSDA) to calculate recharge from WTF
    - Use recharge from WCS and other sources as estimated by GSDA
    - Compute kharif GW extraction using pump discharge, pump hours, operating days etc as observed in the field
    - Use equation for Monsoon groundwater recharge

- Compare our model GW recharge (hourly) and GW recharge calculated using GSDA method

- Reduce gaps in these two estimates by incorporating appropriate changes in IITB water balance model
    - Stream flow model - accounts for GW recharge in the stream proximity regions
    - Modifying conductance to aquifer and accounting for aquifer thickness
    - Incorporating concept of ponding in the water balance model
    - Modifying base flows
    - Updating kharif availability / use of groundwater in the model

- Positively correct the water balance model so as to match with the GW recharge as calculated (GSDA method) and observed runoff (stream flow measurement)

This report thus sums up the overall methodology and execution methods used by GSDA for preparation of recharge plans, observations by the IITB team on these recharge plans and way forward for the convergence of the groundwater estimates by GSDA and IITB.

6. Report on Comparison of water budget for three villages using GSDA balance and soil data from MRSAC, NBSS

Prepared by

Parth Gupta

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6.1 Introduction

This document is in the submission of task A3 under PoCRA-IITB MOU-III. It involves coordination with external agencies and work for the improvement of the water balance framework. Results of water balance for 2 clusters were prepared using MRSAC and NBSS soil layer and compared against GSDA.

PoCRA had signed an MoU with NBSS&LUP for the preparation of the high-resolution (1:10,000) soil maps for the 70 clusters. This was done to improve the existing resolution of soil maps available from the MRSAC at 1:50,000 resolution. This was to be done using multiple trial pits at the village level, a laboratory sample analysis of samples obtained from these trial pits combined with landforms identified using the digital elevation model. Out of the 70 clusters, results for 8 clusters were shared by the NBSS&LUP team. Out of 8 clusters, 4 of these clusters are in Jalna, and 4 are in Amravati district of the project area. Results obtained were based upon the hand feel based textural class identification. Laboratory analysis of different samples is going on.

The water balance model developed by IITB team uses soil layers along with other GIS layers to model the soil water balance at the hourly or daily. The model uses various soil properties for its computation like field capacity, wilting point, saturation point, bulk density, hydraulic conductivity, etc. It is expected that the NBSS&LUP will provide these properties along with the soil shapefiles. Currently, we are using these properties, which are provided by the SPAW hydrological model.

NBSS had shared soil layers for comparison with few clusters. Out of these clusters, GSDA also submitted its report for 2 clusters. For these 2 clusters, the model was run using MRSAC soil layer and NBSS soil layer. It includes results for the Paradgaon (Ghansawangi taluka), Bajar Wahegaon (Badnapur taluka), and Malegaon (Badnapur taluka) villages in Jalna district. Results obtained from these clusters are compared against the results obtained from the GSDA.

6.2 Description of soil Maps for Paradgaon village, Bajar Wahegaon Malegaon Village

Paradgaon Village

Soil polygons for texture are different from each other. Soil polygons for depth are different from each other. This can be seen from Figures 1 and 2. Texture classes, as well as polygon boundaries are different from each other. NBSS soils for paradgaon village are dominant in clay and sandy clay where as MRSAC soils are dominant in clay and gravelly clay loam. Depth classification as well as Polygons boundaries are different for both the clusters. NBSS soils are dominant in a deep and moderately deep class whereas MRSAC is dominant in a very deep and shallow category.

Bajar Wahegaon Malegaon Village

Soil polygons for texture are different from each other. Soil polygons for depth are different from each other. This can be seen from Figures 3 and 4. Texture classes, as well as polygon boundaries, are different from each other. NBSS soils for Bajar Wahegaon and Malegaon Village are dominant in clay. MRSAC soil for the same cluster has two dominant categories clayey and clay loam. Depth classification as well as Polygons boundaries, are different for both the clusters. NBSS soil has three dominant categories which are deep, moderately deep and shallow whereas MRSAC is dominant in very deep and moderately deep category.

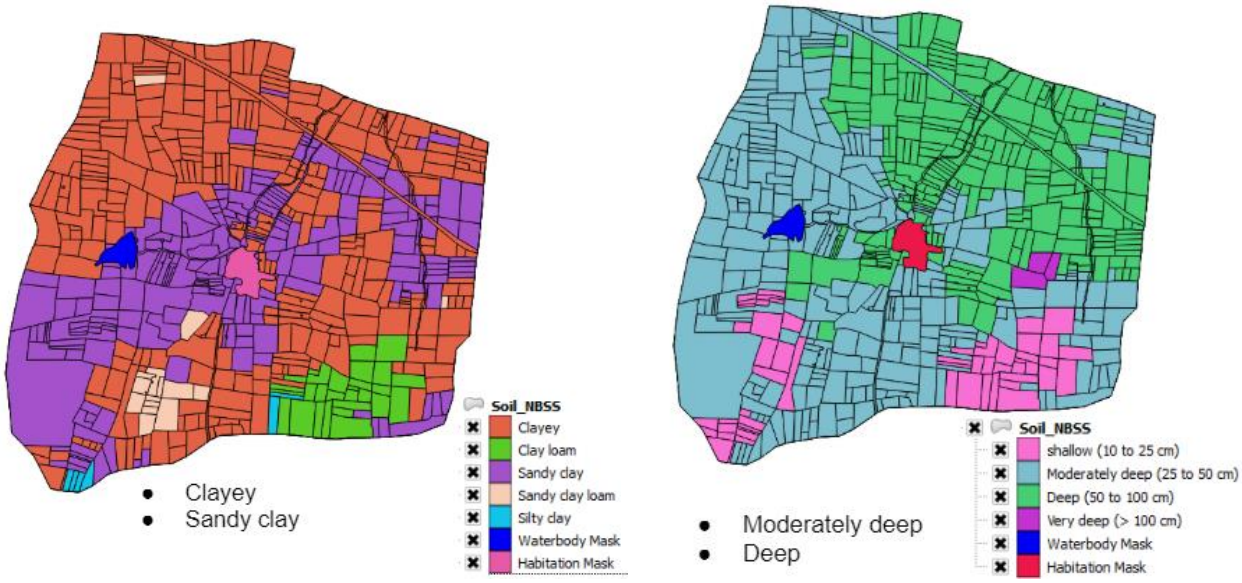


Figure 57 - NBSS Soil texture and depth layer for Paradgaon

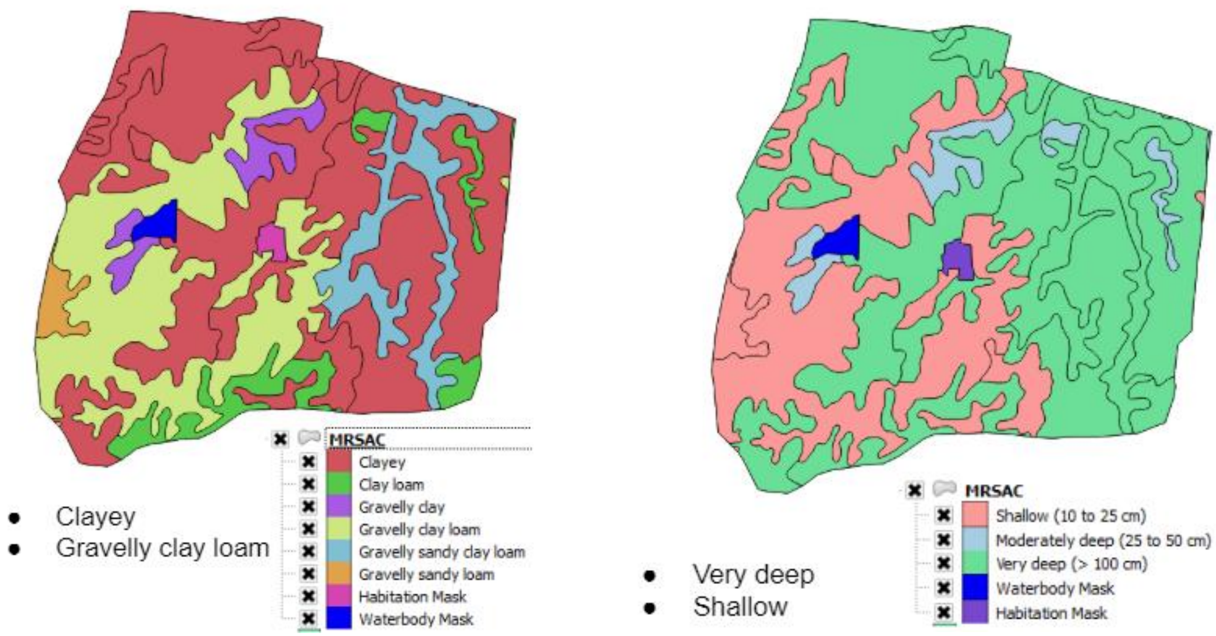


Figure 58 - MRSAC Soil texture and depth layer for Pardgaon

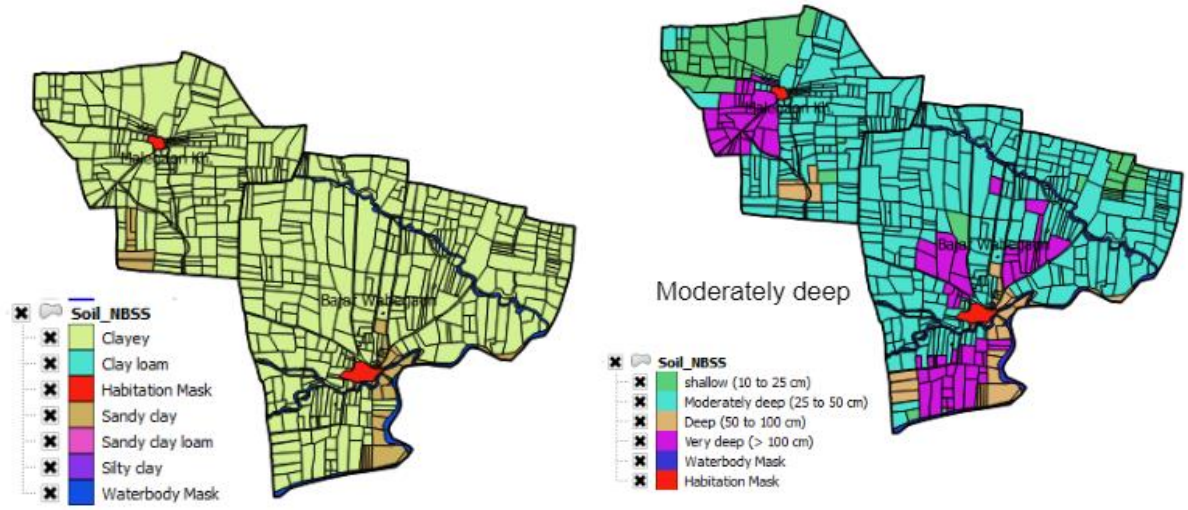


Figure 59 - NBSS Soil texture and depth layer for Bajar Wahegaon and Malegaon

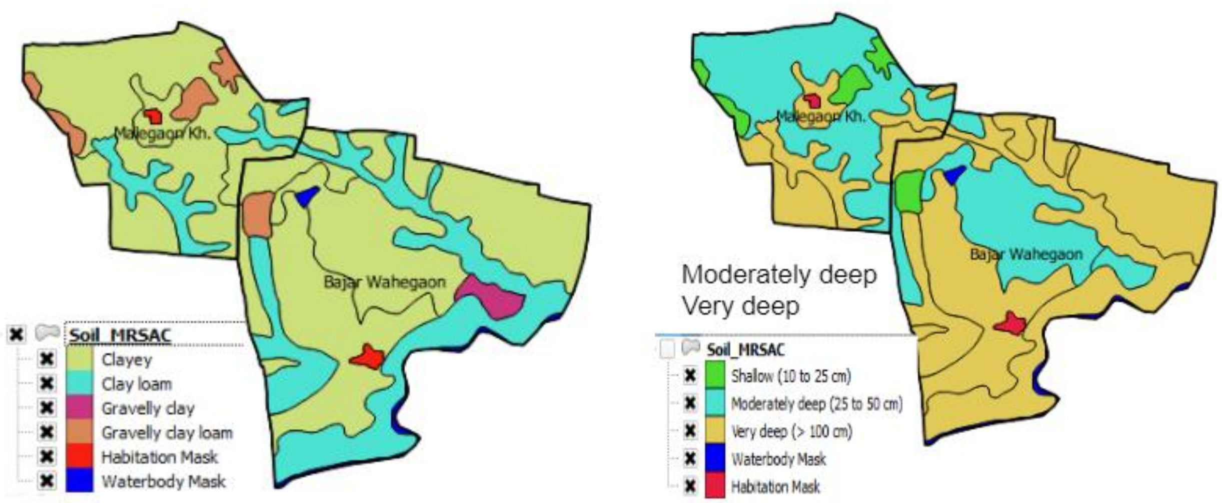


Figure 60 - MRSAC Soil texture and depth layer for Bajar Wahegaon and Malegaon

6.3 Water Balance Comparison for Paradgaon Village

For water budget calculation, the year 2019-20 was used by GSDA. The same year was used for running the water balance model using MRSAC and NBSS soils. Ranjani (Gansawangi) circle is closest to the Paradgaon. Data for this circle was used to run the model. GSDA used Partur circle for its analysis, which is the taluka circle. Rainfall for the year 2019 for both the circles were well spread and can be seen from figure 5 and6. By the end of the year 2019, Partur circle received around 747mm, whereas Ranjani circle received around 800m. Total rainfall for one year from 2019-20 for partur circle was around 800mm, whereas for ranjani circle it was 868mm.

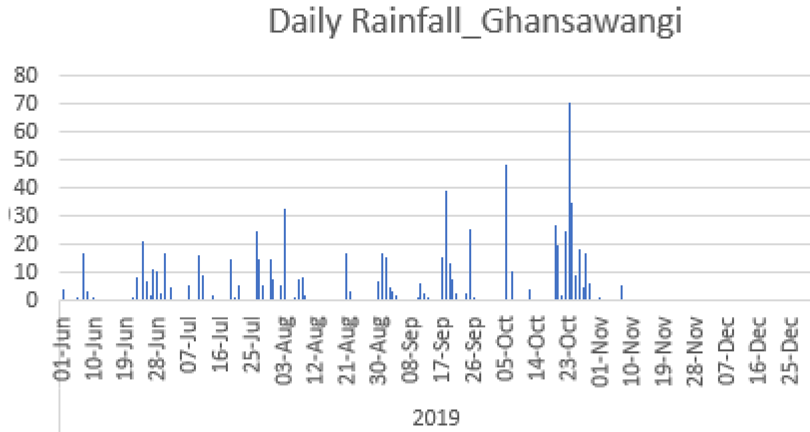


Figure 61 - Rainfall Ranjani (Ghansawangi)

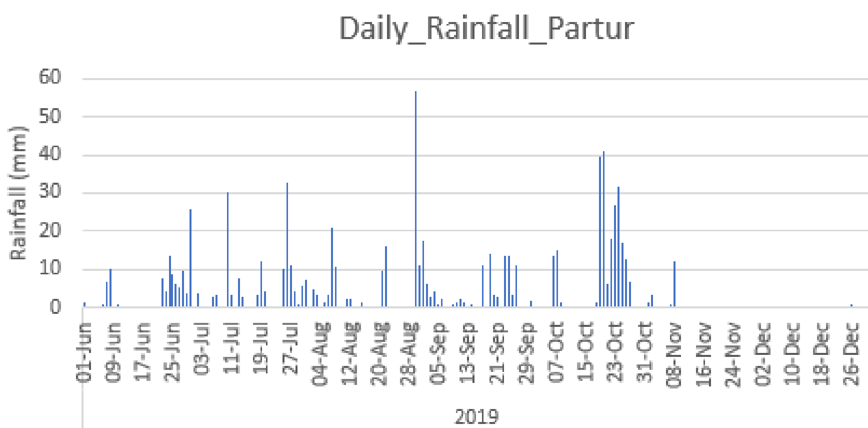


Figure 62 -Rainfall Partur

Half of the Village area was under Cotton as per the data extracted from MLP database, followed by soybean, tur, and moong. Around 75 ha in the village under annual crops like sweetlime, lemon, sugarcane etc. gram sorghum and wheat were major crops in the Rabi season.

Table 51- LULC for Paradgaon

Sr. No	Landuse	Area (Ha)
1	cotton	1392.5
2	soybean	507.5
3	tur	306
4	moong	271
5	bajra	139.5
6	sorghum	136
7	sweetlime	34
8	lemon	18.5

9	udid	15
10	sugarcane	12.5
11	vegetables	5
12	small_vegetables	3
13	grapes	1.5
14	current fallow crop	19
15	scrub	16.5
16	wasteland	33.5
17	permanant fallow crop	11
18	rabi_sorghum	187
19	rabi_maize	13
20	gram	330.5
21	rabi_wheat	272.5

In Table 2, results for the hourly water balance for the village are given. Pre-Monsoon Rainfall was 550mm in the year 2019. Water demand for most of the crops was fulfilled during the monsoon period. MRSAC soils are deeper and have more soil moisture and less runoff as compared to NBSS. Groundwater recharge is similar in both cases. In 2019, there were late monsoon showers. In this case, around 317mm. Post monsoon GW and runoff are on the higher side as compared to monsoon. This is because in the model after Kharif seasons, fields were empty. If we look only at Long Kharif and annual crop land-use, there is reasonable GW and runoff. We should only consider half the runoff and recharge from the Kharif land for the post-monsoon scenario. This will give more clarity while understanding the water budget. There is a minor monsoon crop deficit in both cases. Significant storage capacity exists in paradgaon due to three percolation tanks, farm ponds, compartment bunding, etc. Groundwater recharge from Kharif land is more as compared to long Kharif due to standing crops in the long Kharif and annual Kharif fields.

Table 52 - Hourly water balance results for Paradgaon village 2019

Sr.No	Item	NBSS(mm)	MRSAC(mm)
1	Rainfall_monsoon_End	551.25	551.25
2	Monsoon_cropwater_requirement	395.46	395.46
3	Monsoon_AET	365.59	359.38
4	monsoon_crop_deficit	29.86	36.08
5	storage_capacity	29.32	29.32
6	Monsoon_Gw	53.23	50.71
7	Monsoon_Runoff	75.03	51.8
8	post_monsoon_soil_moisture_available	51.21	82
9	Loss from Non-Ag land	6.19	6.19
10	Post_Monsoon_rainfall	317	317
11	Post_Monsoon_Gw_Total	68.28	88.6
12	Post_Monsoon_Runoff_Total	120.9	85.17
13	Post_Monsoon_Gw(Long_kharif+annual)	23	33.7
14	Post_Monsoon_Runoff(Long_kharif+annual)	60.4	39.82
15	Post_Monsoon_Gw(kharif)	45.28	54.91
16	Post_Monsoon_Runoff(kharif)	60.5	45.35

GSDA, in its report, has mentioned it has used Partur circle rainfall, which was 747mm in 2019 till the time of the survey given in table 3. There is a difference of 120mm between Ranjani (skymet) and partur circle (GSDA). Rainfall used by them in the calculation was 547mm. Skymet has reported 796mm rainfall at partur circle in 2019. This is a difference of 70mm with the Ranjani circle. As can be seen from table 3, GSDA used a strange table method for calculating the runoff coefficient, which is .09 for rainfall of 547mm. It will give us higher results if we use the actual rainfall value of the year 2019. Groundwater recharge was computed with the Questionnaire-based approach of asking water level measurements. Using dry season water table fluctuation, GSDA calculated specific yield. There was no actual pump test conducted to obtain specific yield values. Specific yield values can make a massive difference while calculating the recharge. More on this is explained in the GSDA Recharge Plan Analysis Report.

Table 53 - GSDA budget for paradgaon

Year for Budget	2019-2020
Village Area	2926
Rainfall Actual Year(Partur Circle)	747.5
Rainfall used for runoff calculation	591
Runoff coefficient used	0.09
Runoff generated in mm	54.38
% Runoff of actual rainfall	7.27%
% Runoff of rainfall used for calculation	9.20%
Gross GW Recharge in mm	68.87
% GW Recharge of actual rainfall	9.21%
% GW Recharge of rainfall used for calculation	11.65%

Comparison between NBSS, MRSAC and GSDA is given in table 4. GSDA recharge and runoff values are very low as compared to the result obtained from the NBSS and MRSAC. One reason is due to low rainfall considered in GSDA calculation. Another reason is ambiguity in the calculation of specific yields. MRSAC soil map has both deep as well as the shallow category whereas NBSS has a deep and moderately deep category. Due to this, the recharge is more in MRSAC soil as compared to NBSS.

Table 54 - Comparison between NBSS, MRSAC and GSDA

Sr.No	Item	NBSS (mm)	MRSAC (mm)	GSDA(mm)
1	Rainfall	868	868	591 (747)
2	Recharge	121	139	54
3	Runoff	195	136	68

6.4 Water Balance Comparison for Bajar Wahegaon and Malegaon

Cotton, soybean, and tur are the main crops in both the villages given in table 5 and 6. Bajar wahegaon have significant area under sweetlime. GSDA used the year 2018 for water balance computation. The same year was used for running the water balance model. Badnapur circle was used by GSDA, which is the taluka circle. However, the nearest circle is Roshangaon circle. Rainfall received by the Roshangaon was 318mm, which is significantly lower as compared to the taluka circle(482mm). To understand the result in comparison to GSDA, the model was run using the same circle and year as used by GSDA.

Table 55 - Bajar Wahegaon cropping pattern

Sr. No	Crop Name	Area Ha
1	cotton	822
2	soybean	171
3	sweetlime	123
4	tur	113.5
5	moong	80
6	maize	66.5
7	bajra	59.5
8	small_vegetables	54.99
9	udid	52
10	fodder_crop	39
11	pomegranate	25.2
12	groundnut	12
13	grapes	7
14	rabi_wheat	43
15	rabi_fodder	8
16	gram	85
17	rabi_vegetables	8
18	rabi_sorghum	210

Table 56 - Malegaon Cropping Pattern

Sr. No	Crop Name	Area Ha
1	cotton	561.72
2	soybean	84
3	tur	48
4	sweetlime	36.99
5	maize	29.5
6	bajra	24
7	moong	22.5
8	small_vegetables	17.5

9	udid	10
10	pomegranate	5.7
11	groundnut	2.5
12	grapes	2
13	fodder_crop	0.655
14	rabi_sorghum	139
15	gram	16
16	rabi_wheat	7
17	rabi_vegetables	3

There was a single rainfall event of 150mm on 16^{th} august, which led to a considerable runoff generation. This event can be seen in figure 7 for badnapur circle level rainfall.

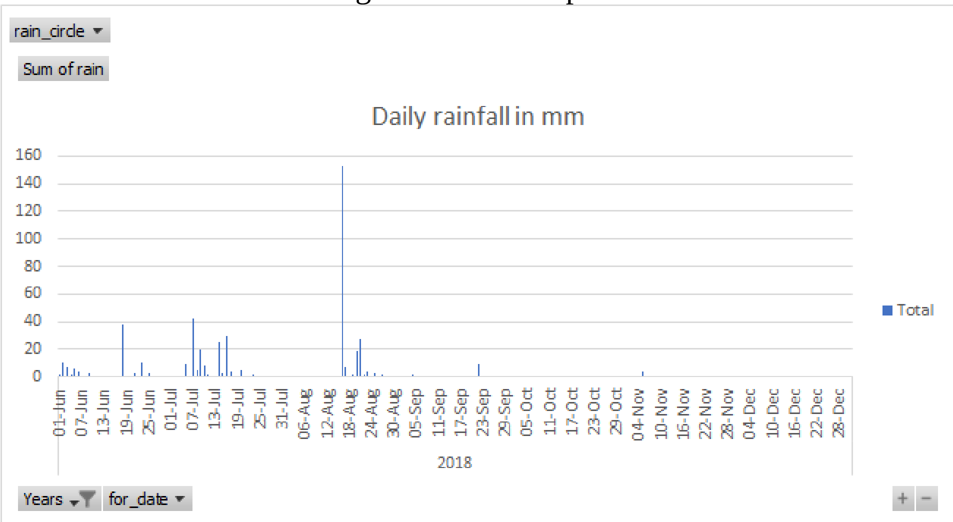


Figure 63 - Badnapur circle Rainfall 2018

Crop water deficit is higher for nbss soil as compared to the mrsac. Total groundwater recharge is more for nbss than mrsac. Runoff generated is significantly higher for the nbss as compared to mrsac. In 2018 there was not sufficient runoff to fill the structures. MRSAC Soil in Bajar Wahegaon is deep, due to which less percolation and runoff. More water is added to soil moisture and available to crops through AET. Hence less crop water deficit. MRSAC soil in Malegaon are moderately deep. Soils get saturated and lead to an increase in percolation and runoff rate. NBSS soils are moderately deep and clayey. Soils get saturated and lead to an increase in percolation and runoff rate.

Table 57- Water Balance of Bajar wahegaon and Malegaon using hourly model

Description	MRSAC		NBSS	
	Bajar Wahegaon (mm)	Malegaon (mm)	Bajar Wahegaon (mm)	Malegaon (mm)
rainfall_mm	482.75	482.75	482.75	482.75
monsoon_cropwater_requirement	443.63	468.51	443.63	469.06
monsoon_crop_deficit	128.04	188.74	178.99	220.15
monsoon_storage_available	17.78	37.59	17.78	37.63

monsoon_groundwater_available	8.4	13.29	13.34	14.83
monsoon_balance	-101.87	-137.86	-147.87	-167.69
monsoon_index	-0.26	0.27	0.17	0.24
post_monsoon_crop_water_requirement	254.03	259.24	254.03	259.54
post_monsoon_drinking_water_requirement	6.2	5.3	6.2	6.2
post_monsoon_storage_available	17.78	37.59	17.78	37.63
post_monsoon_groundwater_available	16.79	26.58	26.68	29.65
post_monsoon_soil_moisture_available	55.72	25.36	18.89	15.73
post_monsoon_balance	-169.93	-175.02	-196.87	-182.72
post_monsoon_index	0.35	0.34	0.24	0.31
runoff_generated	70.32	135.28	153.4	171.73
runoff_available	35.16	67.64	76.7	44.6
runoff_available_for_impounding	-0.4	-7.53	41.14	-30.66

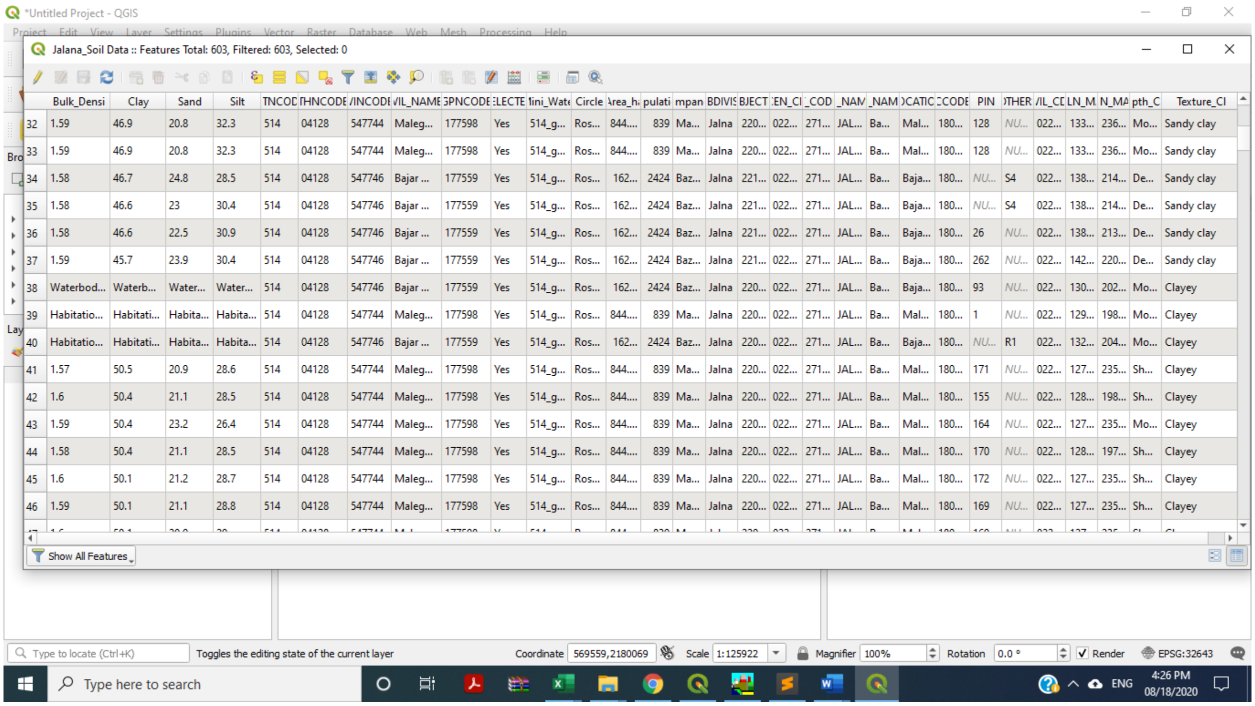
Runoff is low incase of GSDA as it is based upon the strange table method and considered only aggregated runoff. As can be seen from the circle rainfall, there was a single rainfall event of 150mm on 16th august. The single runoff event from the rainfall itself would have generated more runoff than calculated by the GSDA. GSDA has shown considerable recharge, whereas the model has shown less recharge as compared to the GSDA.

Table 58 - Comparison of result between MRSAC, NBSS and GSDA,

	MRSAC (mm)	NBSS (mm)	GSDA (mm)
Bajar Wahegaon			
Rainfall	482.75	482.75	487
Runoff	70.32	135.28	34.5
Groundwater	25.19	39.86	74.4
Malegaon			
Rainfall	482.75	482.75	487
Runoff	135.28	171.73	34.5
Groundwater	39.86	44.47	74.4

6.5 Numerical data shared by NBSS and issues

NBSS shared a numerical dataset for Bajar wahegaon and Malegaon. The dataset includes % sand, %silt, %clay and bulk density. The field capacity, wilting point, and saturation point, etc. are missing from the shared dataset. One issue with the shared dataset is sandy clay soil has the same value of % sand, %silt, %clay, and bulk density as clay soil. This is not correct as per USDA textural classification.



	Bulk_Densi	Clay	Sand	Silt	TNCOD	THNCODE	/INCODE	VIL_NAME	GPNCODE	ELECTE	lini_Wate	Circle	Area_ha	pulati
32	1.59	46.9	20.8	32.3	514	04128	547744	Maleg...	177598	Yes	514_g...	Ros...	844....	839
33	1.59	46.9	20.8	32.3	514	04128	547744	Maleg...	177598	Yes	514_g...	Ros...	844....	839
34	1.58	46.7	24.8	28.5	514	04128	547746	Bajar ...	177559	Yes	514_g...	Ros...	162...	2424
35	1.58	46.6	23	30.4	514	04128	547746	Bajar ...	177559	Yes	514_g...	Ros...	162...	2424
36	1.58	46.6	22.5	30.9	514	04128	547746	Bajar ...	177559	Yes	514_g...	Ros...	162...	2424
37	1.59	45.7	23.9	30.4	514	04128	547746	Bajar ...	177559	Yes	514_g...	Ros...	162...	2424
38	Waterbod...	Waterb...	Water...	Water...	514	04128	547746	Bajar ...	177559	Yes	514_g...	Ros...	162...	2424
39	Habitatio...	Habitati...	Habita...	Habita...	514	04128	547744	Maleg...	177598	Yes	514_g...	Ros...	844....	839
40	Habitatio...	Habitati...	Habita...	Habita...	514	04128	547746	Bajar ...	177559	Yes	514_g...	Ros...	162...	2424
41	1.57	50.5	20.9	28.6	514	04128	547744	Maleg...	177598	Yes	514_g...	Ros...	844....	839
42	1.6	50.4	21.1	28.5	514	04128	547744	Maleg...	177598	Yes	514_g...	Ros...	844....	839
43	1.59	50.4	23.2	26.4	514	04128	547744	Maleg...	177598	Yes	514_g...	Ros...	844....	839
44	1.58	50.4	21.1	28.5	514	04128	547744	Maleg...	177598	Yes	514_g...	Ros...	844....	839
45	1.6	50.1	21.2	28.7	514	04128	547744	Maleg...	177598	Yes	514_g...	Ros...	844....	839
46	1.59	50.1	21.1	28.8	514	04128	547744	Maleg...	177598	Yes	514_g...	Ros...	844....	839

	mpan	BDIVIS	BJECT	EN_CI	_COD	_NAM	_NAM	OCATIO	CCODE	PIN	OTHER	VIL_CD	LN_M	N_MA	pth_C	Texture_Cl
32	Ma...	Jalna	220...	022...	271...	JAL...	Ba...	Mal...	180...	128	NU...	022...	133...	236...	Mo...	Sandy clay
33	Ma...	Jalna	220...	022...	271...	JAL...	Ba...	Mal...	180...	128	NU...	022...	133...	236...	Mo...	Sandy clay
34	Baz...	Jalna	221...	022...	271...	JAL...	Ba...	Baja...	180...	NU...	S4	022...	138...	214...	De...	Sandy clay
35	Baz...	Jalna	221...	022...	271...	JAL...	Ba...	Baja...	180...	NU...	S4	022...	138...	214...	De...	Sandy clay
36	Baz...	Jalna	221...	022...	271...	JAL...	Ba...	Baja...	180...	26	NU...	022...	138...	213...	De...	Sandy clay
37	Baz...	Jalna	221...	022...	271...	JAL...	Ba...	Baja...	180...	262	NU...	022...	142...	220...	De...	Sandy clay
38	Baz...	Jalna	220...	022...	271...	JAL...	Ba...	Baja...	180...	93	NU...	022...	130...	202...	Mo...	Clayey
39	Ma...	Jalna	220...	022...	271...	JAL...	Ba...	Mal...	180...	1	NU...	022...	129...	198...	Mo...	Clayey
40	Baz...	Jalna	220...	022...	271...	JAL...	Ba...	Baja...	180...	NU...	R1	022...	132...	204...	Mo...	Clayey
41	Ma...	Jalna	220...	022...	271...	JAL...	Ba...	Mal...	180...	171	NU...	022...	127...	235...	Sh...	Clayey
42	Ma...	Jalna	220...	022...	271...	JAL...	Ba...	Mal...	180...	155	NU...	022...	128...	198...	Sh...	Clayey
43	Ma...	Jalna	220...	022...	271...	JAL...	Ba...	Mal...	180...	164	NU...	022...	127...	235...	Mo...	Clayey
44	Ma...	Jalna	220...	022...	271...	JAL...	Ba...	Mal...	180...	170	NU...	022...	128...	197...	Sh...	Clayey
45	Ma...	Jalna	220...	022...	271...	JAL...	Ba...	Mal...	180...	172	NU...	022...	127...	235...	Sh...	Clayey
46	Ma...	Jalna	220...	022...	271...	JAL...	Ba...	Mal...	180...	169	NU...	022...	127...	235...	Sh...	Clayey

Figure 64- Numerical dataset shared for one cluster

6.6 Future Actions

1. NBSS to share a full numerical dataset for few clusters so that results can be analyzed to develop a better understanding regarding the impact of new properties received vis a vis existing property used.
2. Appropriate changes to code to read properties from shapefile once a full set of properties received from NBSS.
3. Chart out plan and give recommendations regarding use of NBSS shapefile for other project clusters once sufficient number of shapefiles are received.

7. Report on Case Study Report - Water Balance in two clusters and extension methodology

Hemant Belsare and Vidyadhar Konde, Chirag MM

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Preamble

This report primarily addresses MoU component A3 and partly addresses components E2 and D3. It includes update on field work for runoff measurements, validation of the PoCRA water budget model, insights from the field towards its extension and improvements and methodology for integration of GSDA's GW recharge into IITB model. The final delivery for these components will be done at the end of Phase 4. This is an interim report and an update on the activities done during Phase 3.

The outline of this report is as follows. Section 1 sets up the background and the motivation for the validation and on-field measurements. Section 2 lists the primary objectives of the field work. Section 3 describes the validation plan and its methodology. Section 4 gives a detailed account of the execution of the validation plan in the selected clusters of Gondala and Mop. Section 5 lists the issues encountered while executing the validation plan and gives the current status as well as pending work in the field. Section 6 provides preliminary analysis of the validation, section 7 points out few observed phenomena which would provide insights for the model improvement and section 8 provides some recommendations from the point of view of making changes to the model so as to refine it.

7.1 Background

The PoCRA water budget model is based on the soil water balance method which is based on the SWAT (Soil and Water Assessment Tool) methodology as explained in the Plugin Description document (https://www.cse.iitb.ac.in/~pocra/Phase%20III%20Plugin%20description%20document.pdf). The core of the model depends on the daily soil-water balance which is based on the following mass-conservation equation –

P(t) = Q(t) + GW(t) + AET(t) + [SM(t) - SM(t-1)] - Eqn 1

where P(t) is the total rainfall during the time step t, Q(t) is the total surface runoff generated, GW(t) is the groundwater recharge, AET are the actual evapotranspiration and [SM(t) - SM(t-1)] is the change in soil moisture stock during the time-step t. The time-step can be an hour or a day.

Eqn 1 computes water balance for a single point and is computed daily in the current working model. This equation is run in an iterative manner for the whole monsoon season to compute the total surface runoff, total crop water uptake during monsoon season, total groundwater recharge and soil moisture stock left at the end of monsoon. This daily point-wise model is run as plugin on GIS (Geographical Information Systems) platform to aggregate the point-wise results to regions of choice (zones, villages or clusters). Thus, the above equation, when aggregated temporally (over whole Kharif season) and spatially (over whole village) gives,

P = Q + GW + kharifAET + ΔSM - Eqn 2
Qout = Q - Qi - Eqn 3
surplus or deficit = (delSM + GW + Qi) – (rabiAET + summAET) - Eqn 4

P is the total rainfall during monsoon, Q is total surface runoff generated, Qi is the runoff obstructed/impounded due to NRM activities, Qout is the total amount of water leaving village boundary, GW is total groundwater recharge during monsoon, kharifAET is the total amount of water leaving the village through evapotranspiration and delSM is the change in soil moisture during monsoon.

The output of the model is the total water balance for the region for the kharif season. Eqn 3 gives total runoff flowing out of the village / cluster by subtracting the impounded runoff from total runoff generated. This is used by the planners i.e. cluster assistants and agriculture assistants to plan the NRM (Natural Resource Management) activities such as Cement Bunds, Percolation Tanks, Contour Trenches etc.

(GW + delSM + Qi) in the Eqn 4 is the total water available at the end of the kharif season. (rabiAET + summAET) is the total water demand for the rabi and summer seasons.
This is the water available for the coming Rabi and Summer seasons. If the total crop water requirement during these seasons is higher than the water available, then there is crop water deficit and stress.

All these outputs are published for a PoCRA village in a chart which is displayed in the village. These model outputs are crucial as far as planning and expenditure are concerned. The water budget is expected to be used by the local planners (cluster assistants, krushi sahayaks) to plan the NRM activities so as to reduce the deficits. At the same time PMU expects the community to use the water budget results in making crucial cropping decisions. Thus, the water budget needs to reflect the ground reality as closely as possible.

But it has been noticed in the past that the runoff estimated by the current PoCRA water budget is on the higher side and at the same time, the estimated groundwater recharge is on the lower side. This has been discussed in the meetings between PMU, IITB and World Bank experts. This requires work to be done on following fronts – i) to validate the model and to know the actual gap between the model estimates and actual measurements / observations on the ground, ii) to incorporate natural phenomena (such as stream flow routing, regional flows etc.) in order to improve the model framework, iii) to coordinate with the external agencies such as GSDA, SAUs to validate and calibrate the model and iv) to improve the quality of input data, such as soil maps, soil properties, crop characteristics etc.

Thus, it was decided to include “model improvement and validation” as an important component in the MoU III. Accordingly work on the same has been initiated by IITB on following threads –

A. Model improvement –

- As more high resolution temporal data is now available i.e. hourly weather data as well as rainfall data, it was decided to shift from daily computation of water balance to hourly time-step. With higher resolution of rainfall intensity and ETo values, the computation of runoff, recharge and other components would improve. This was seen through preliminary results of the hourly model. Please see chapter 1 and 3 of this report.
- Stream flow model – The single point model computes point-wise runoff and groundwater recharge for the whole season. The GIS plugin simply aggregates these quantities spatially and computes zone and village level water balance. This however may

not be true in reality. There may be transmission losses and recharge occurring between the farm and the outlet of the micro-watershed. This would require modeling of stream channels which convey the runoff from farm to watershed outlet. Thus, a model refinement in order to improve estimation of regional runoff is required. Please see chapter 2 of this report.

B. Calibration with GSDA recharge into IITB model

- It was decided that IITB will coordinate with GSDA in order to improve the GW recharge estimation methodology. As per MoU between PMU and GSDA, GSDA is supposed to estimate groundwater recharge in 70 clusters in the PoCRA region. As GSDA methodology of recharge estimation is based on already proven empirical methods (water levels in the wells), it was decided that the recharge estimated by GSDA will be used to calibrate the IITB model and a plan to incorporate the GSDA results into IITB model need to be devised so as to improve the model. Please see chapter 5 of this report.

C. Model validation and runoff measurements

- With regards to runoff estimation, it was decided that IITB will carry out runoff measurements on the ground for few selected clusters and calibrate the model using measured runoff. To this end, six catchments in three PoCRA clusters were selected to carry out the runoff measurements. The runoff would be measured by installing water level sensors at the outlets of the catchments. Cumulative runoff flowing out of the catchment would be computed using stage-discharge relationships for each of the catchment outlets. Runoff thus measured will be compared with the runoff estimated by daily and hourly models.
- At the same time, groundwater recharge for the catchment will be computed using the GSDA methodology and the same will be compared with the GW recharge by daily and hourly models and will be used to calibrate and improve the model.

Thus, the main aim of this report is

- To carry out on-field measurements of key components of the water balance such as runoff, groundwater etc. and test/validate the new / ongoing model refinements such as daily-to-hourly shift, corrections to soil data etc. against observed / measured data.
- To document/observe the phenomena such as baseflows, stream flow etc. in order to inform the other improvements to the model such as stream-flow simulations, inclusion of baseflows etc. to the model.
- To devise a plan to implement GSDA methodology in the selected catchments to estimate GW recharge and use it to calibrate and improve the water budget model.

7.2. Objectives of field work

- To devise validation plan for the PoCRA water budget
    - To select clusters and catchments for validation during monsoon 2020
    - To devise validation methodology
    - To set up required infrastructure and logistics required for measurements and validation

- To execute the validation plan during monsoon of 2020
    - To carry out measurements, collect data and analyze and compile the results
    - To compute water budgets for the selected catchments using the above results
    - To document farmer narratives and various phenomena (such as ponding, baseflows etc.) on the field which would provide insights for model improvements.
- To compare the results with current i.e. daily model, hourly model etc. and provide explanations for the gaps if any.
- To recommend changes to the model so as to minimize the gaps and suggest model improvements.

7.3. Validation plan

The validation of the water budget model is essentially validating individual components of the water balance equations mentioned above. Validation plan would involve methods for measuring these individual components and matching them with the estimated / computed values by the model for the same rainfall. This would require setting up the area for measurement and validation. The model computes point-level runoff, recharge, AET and soil moisture and then aggregates them to zone / village / cluster. Soil moisture and AET are essentially farm-level attributes and can be measured or observed at farm level. But entities like runoff and groundwater are essentially regional in nature and are typically measured / computed for a region i.e. mostly for a catchment or a watershed.

Thus, we propose the unit of validation as catchment. Runoff would be measured at the outlet of the selected catchment. Groundwater recharge would be estimated for the catchment using empirical Water-Table Fluctuation (WTF) method as was used by GSDA during their cluster studies. These regional values will be compared with the model results for the whole catchment for specific time periods or rainfall events.

Soil moisture and AET would be measured / observed for few sample points within the catchment so as to cover different soil types and crops. The model would be run by entering the soil texture, soil depth, root depth, slope etc. for these sample points and the results such as soil moisture and AET will be compared with the measured (soil moisture) and observed (i.e. crop height, growth stage etc.) values.

Following table shows the planned measurements and their methods –

Component	Scale	Measurable on field?	Proxy	How?
Runoff	Regional	Yes		Measuring discharge at the outlet of the selected catchment
GW recharge	Regional	No	Well levels	GSDA Water table fluctuation method

Soil moisture	Farm level	Yes		Soil moisture measurement for selected points at regular intervals
AET	Farm level	No	Farmer narratives + crop height	Questions such as - Was there need to irrigate the crop during dry spell? Did the crop suffer stress? Is crop growth adequate? What is the expected yield?
GW recharge	Farm level	No	Farmer narratives and well levels	Well levels in the individual fields
Runoff	Farm level	No	Farmer narratives	Questions such as - Was runoff generated on the field? How long did it last? Was there any ponding? etc.

Component-wise measurement methodology

1. Runoff – For the selected catchment, all the runoff generated within the catchment will flow out of the catchment through the outlet. Thus, if we measure the discharge Q/sec at the outlet continuously and aggregate it over time t, say 1 month, we get the total water flowing out of the catchment during that time period.

We propose following methodology –

a. Identify a CNB (Cement Nala Bund) at the outlet of a catchment.

b. Monitor the stage (water level) at this CNB during the whole monsoon season at regular intervals, say every 15 mins.

c. If, after a rainfall event, the water level rises, but water does not flow over the CNB, runoff generated in the catchment by the rainfall event is the change in volume of water in the CNB

d. If, after the rainfall event water flows over the CNB, the discharge may be computed by using the formula for discharge over broad-crested weir. The discharge is proportional to the height of water column above the CNB. (ref).

e. For some heights of water column over CNB, the discharge would be manually measured in order to validate the above formula and calibrate the discharge coefficient in the formula.

f. Once this is validated, we will get the stage-discharge relationship for that specific CNB. This will be repeated for all the catchments.

2. Groundwater recharge – The groundwater recharge for the whole catchment can be computed using the GSDA methodology. This methodology is based on the CGWB's GEC methodology of 1997 i.e. Water Table Fluctuation method, which is being used to estimate groundwater recharge throughout the country. The basic formula is –

GW recharge by WTF method = [post_mon_wl – pre_mon_wl] x A x sp

where post_mon_wl is the height of water table in meters below ground level (mbgl) in October i.e. after the monsoon and pre_mon_wl is the height of the water table in mbgl in May i.e. before the monsoon started. Thus, the difference in the water levels indicates the rise in the water table during monsoon due to GW recharge. A is the area of the catchment, sp is the specific yield (denotes water holding capacity of the aquifer, and the values will be taken from GSDA for the particular catchment).

As we are conducting these measurements in the clusters where GSDA has already conducted studies under PoCRA, we will select the wells selected by GSDA for this method.

3. Soil moisture – The soil moisture will be measured using oven-dry method for the soil samples for the selected farms. The samples will be selected such that all soil-crop combinations will be covered in the catchment. The samples will be collected at regular intervals or after key monsoon events.

4. Actual Evapotranspiration (AET) – AET will be estimated on the field through farmer interviews and through direct assessment (i.e. crop height, flowering etc.).

7.4. Execution of the validation plan

7.4.1 Selection of clusters

- Clusters were selected based on following criteria
    - Clusters where GSDA has completed their study and prepared report
    - Rainfall
    - Soil types
    - Land use
    - Slope
    - Logisitics (minimum travel during lockdown)

Following clusters were selected.

Table 59 - Selected clusters

Cluster	District	Taluka
502_pg-6_02	Washim	Risod
512_gp-47_04	Hingoli	Sengaon
514_gp-35_03	Jalna	Partur
512_ppg-3_03	Hingoli	Goregaon

Jalna cluster was dropped after the team reached the field, and instead the Goregaon cluster was added. The reasons are explained later in the report.

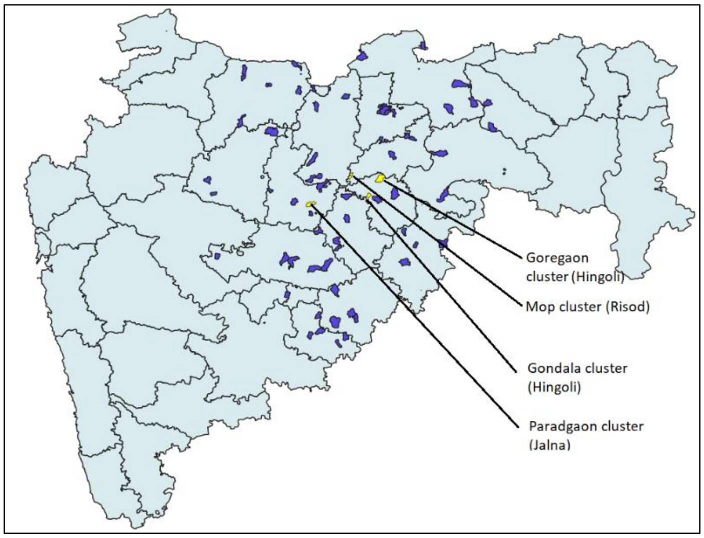


Figure 65- Map showing selected clusters

7.4.2 Selection of catchments within clusters

Catchments were selected based on these criteria

- Catchment size
- Presence of good non-leaking CNBs at the outlet of the catchment
- Representativeness of the cluster with respect to soil types, slopes, land-use

Following CNBs and catchments were identified.

Table 60- Selection of catchments within clusters

Village	Catchment size ha	Agri. Area ha	Forest area.	Dominant soil types	Terrain	Dominant vegetation
Lingdari	224	100	126	Clay loam- shallow	Slopes	Scrub, soyabean
Gondala	538	250	228	Clay loam- shallow, sandy clay loam-shallow	Slopes	Scrub forest, soyabean
Mop	55	50	0	Gravelly sandy loam, shallow	Gentle slope	Soyabean
Mop	455	455	0	Clayey-deep	Flat	Soyabean
Paradgaon	431	431	0	Gravelly clay loam	Flat	Cotton, soyabean
Paradgaon	1285	1285	0	Clayey-very deep	Flat	Cotton, soyabean

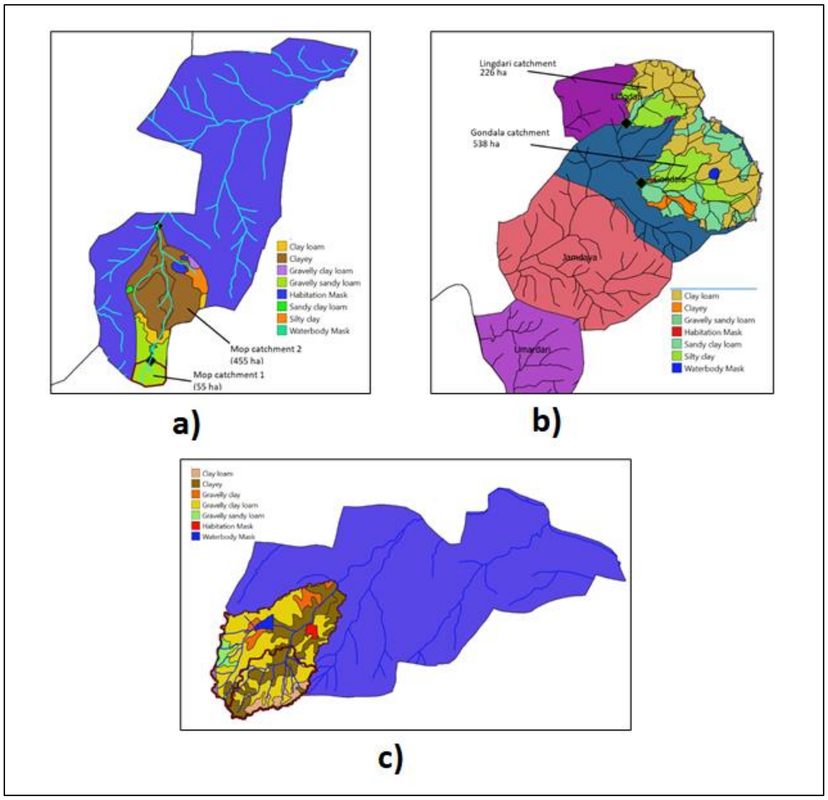


Figure 66 - Selected catchments: a) Mop, b) Gondala, c) Paradgaon

7.4.3 Installation of water level sensors at the selected CNBs

A detailed document was submitted regarding selection of water level sensors and their installation on the field ("Final_streamflow measurement" - https://docs.google.com/document/d/1rehUUeMHTf8_2p0OHnJiq6HmfpK4KQEHXZUI4Ds-2Qo/edit#). The document described 2 methods for installation of water level sensors – i) Stilling well method and ii) direct installation of sensor in the stream channel.

Stilling well is a small diameter, shallow well (upto the depth of stream bed) which is installed at the stream banks in which the water level sensor is mounted. The stilling well is connected to the stream through inlet pipes which maintain the stilling-well water level at the same head as in the stream channel. This is as shown in the figure 5a). The stage is then measured by the water level sensor inside the stilling well with the help of float-type sensor which is connected to an electronic device or data logger which records the stage at regular intervals.

Direct installation is another way where the perforated PVC pipe is installed directly in the stream channel (figure 5b), or alongside the walls of CNB in our case. The sensor will be mounted inside the pipe and will record the stage of fluctuating water level.
Both methods are shown in the following figure.

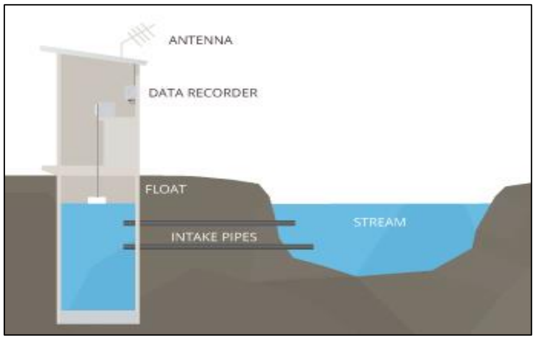


Figure 67 - a) Stilling well, b) Direct installation

Both these methods were discussed well before and the "Stilling well method" was finalized for the installation of water level sensors. But due to COVID-19 pandemic and lockdown issued across Maharashtra, the team could not reach the field on time and the required infrastructure could not be set for the stilling well. Eventually, the team reached the field on 27th June when more than 200 mm rainfall had occurred in all the clusters, and the CNBs in most of the locations were already overflowing. Considering time and labour availability, it was decided to directly install the sensors on the Cement Bunds i.e. without the stilling well.

First three sensors were installed directly on the CNB. Two in Paradgaon and one in Gondala.

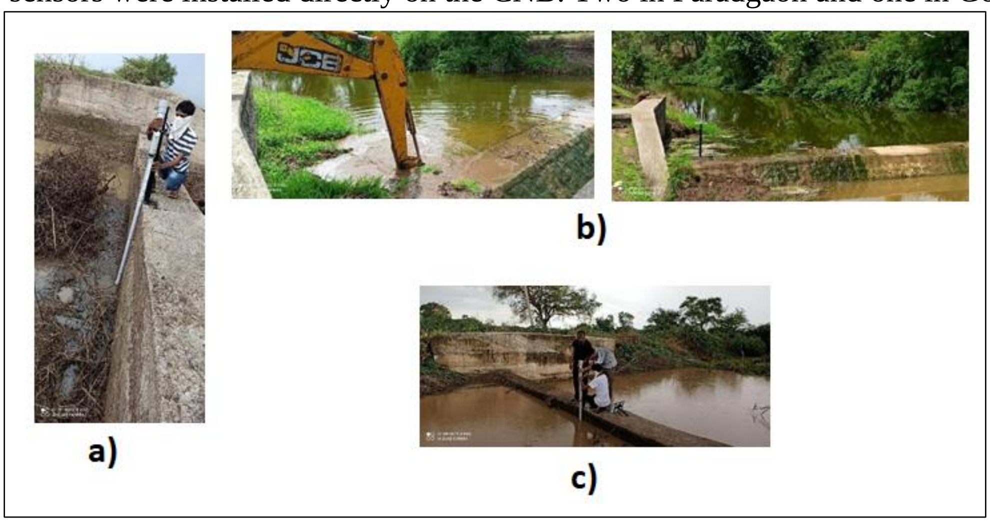


Figure 68 - Sensors installation - direct method: a) Paradgaon 1 –b) Gondala c) Paradgaon 2

The sensors were installed on the CNB in the middle of the stream as there was considerable silt deposited near the side walls of the CNB. But the sensors in Paradgaon got washed away in first two days itself due to very heavy rains followed by exceptionally high flow through the streams. The rainfall on two days between 27th and 29th June was around 165 mm. The height of water column over the CNB was recorded to be over 1.2 m before the sensors washed away in Paradgaon. Following are the sensor readings before the sensors stopped giving readings.

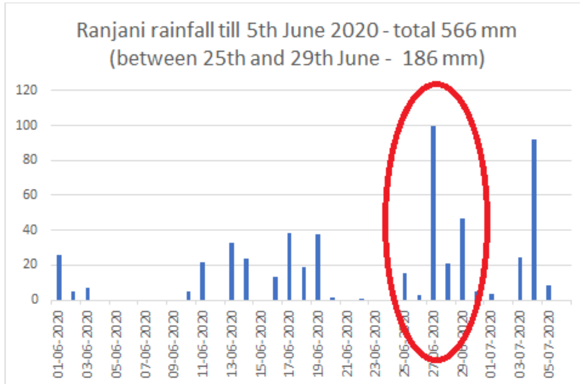


Figure 69 - Ranajani circle rainfall around 28th June

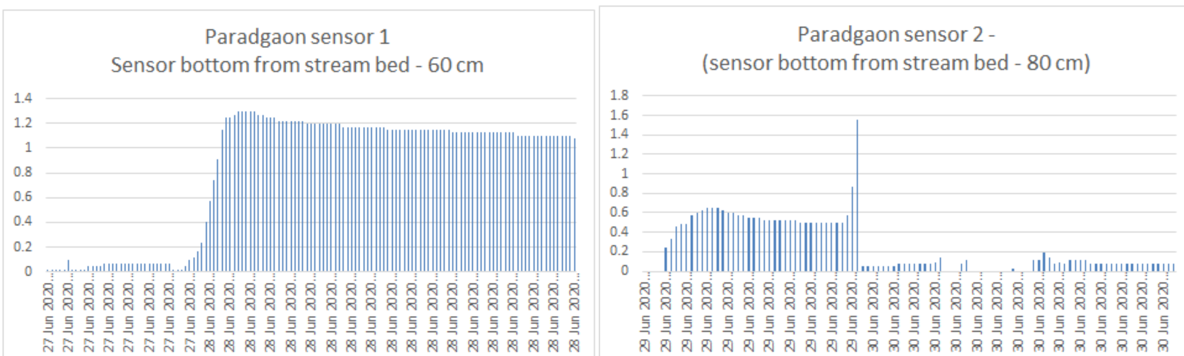


Figure 70 - Paradgaon sensor readings before getting washed away

This prompted us to go back to the stilling well method. The remaining three sensors were installed using stilling well. This involved exploration for design of stilling well, its location near the CNB, the material required (i.e. PVC pipes or cement pipes), labour requirement for digging pits and excavation and other logistics. Detailed steps in the design and execution of the stilling well and sensor installation will be provided in the final report.

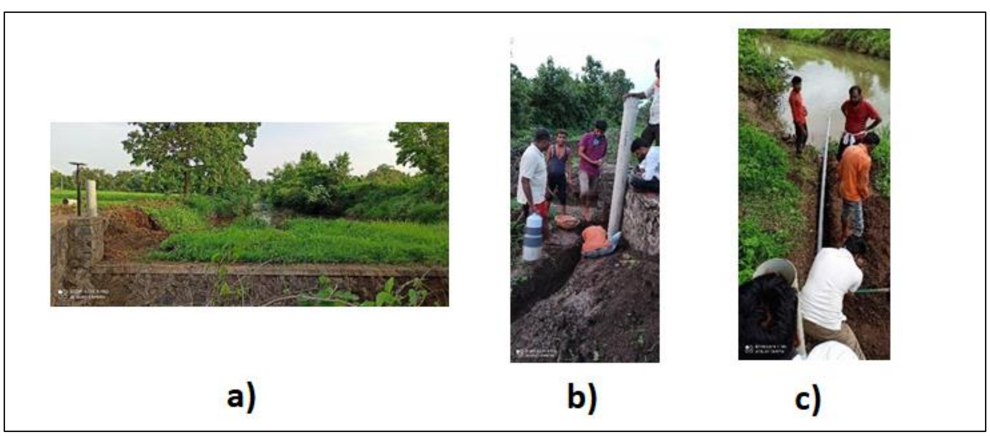


Figure 71 - Sensors installation - stilling well a) Mop 1, b) Lingdari, c) Mop 2

As the sensors got washed in Paradgaon cluster, and as the cluster was a little far (around 100 km) from our base location in Sengaon, the cluster was dropped. It is now replaced by Goregaon cluster in Sengaon. We plan to install the new sensor in this cluster at the following location. Several CNBs were visited and checked for suitability of installing the sensor. Finally, following location was identified.

Figure 72 - a) Goregaon catchment, b) CNB location decided for sensor installation

7.4.4 Water level sensor schematic and functioning

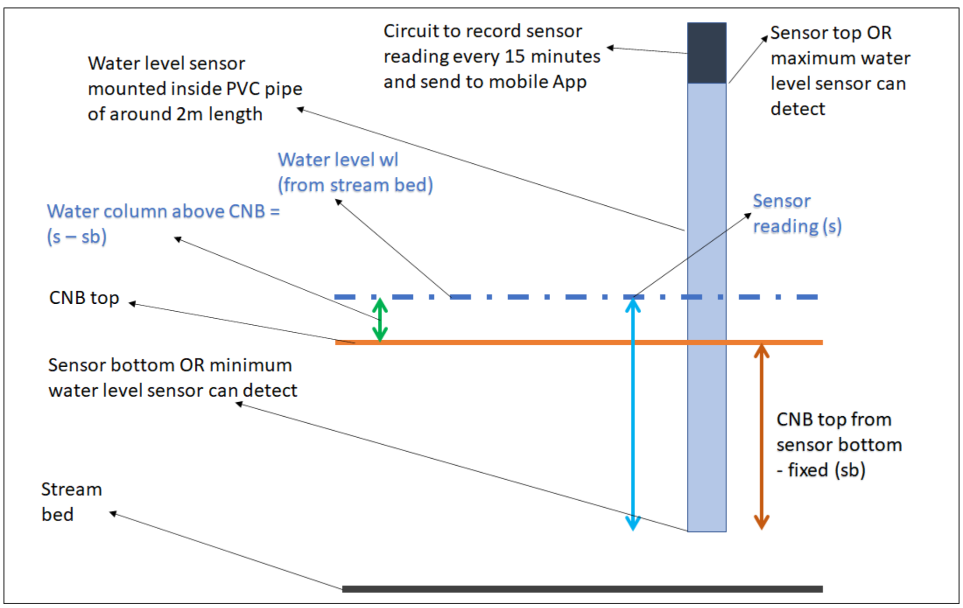


Figure 73 - Water level sensor schematic

The sensor is mounted inside a long PVC pipe of around 2m in length and is installed vertically as shown in the above schematic. The sensor may be installed directly on the horizontal CNB wall or on the vertical side-walls such that the sensor will directly come in contact with the water in the stream, as in the case of Paradgaon and Gondala sensors. The sensor may also be installed in a stilling well (a bigger pipe or a small well with casing which is to be dug away from stream channel). In the case of stilling well, a horizontal pipe has to be fit near or below the sensor bottom so as to connect with the water in the stream such that the water level in the stilling well will

always be the same as in the stream channel. Such type of sensor installation was done in Lingdari and both the locations in Mop.
In any case, the sensor position is fixed with respect to stream bed and CNB crest. This position is decided such that the water levels typically do not cross the sensor top or sensor bottom. The sensor cannot detect water levels if the water level goes above sensor top or goes below sensor bottom. Thus, the sensor position is to be carefully decided, through consultation with the local farmers. For example, in case of Lingdari and Gondala sensors, it was confirmed by the farmers that the CNBs overflow till the months of November or December. Thus, the sensor bottom can be kept as close to the CNB top as possible, so as to capture maximum water column above the CNB top in case of peak runoff events.

The sensor is designed so as to record the water level every 15 minutes and send it to the server which then logs and sends it to Mobile App, My Water. The reading given by the sensor is the height of the water column from the sensor bottom. If we subtract the length of the sensor below CNB top from this reading, we get the height of water column flowing over the CNB top. It will be negative in case the water is not flowing over the CNB.
Following is a snapshot of the excel file showing sensor readings for Lingdari sensor –

Date-Time	Sensor reading (m)	Sensor bottom from CNB top (m)	Water column above CNB top (m)
23 Jul07:08:21 AM	0.24	0.21	0.03
23 Jul07:22:20 AM	0.24	0.21	0.03
23 Jul07:36:19 AM	0.24	0.21	0.03
23 Jul07:50:36 AM	0.24	0.21	0.03
23 Jul08:04:31 AM	0.696	0.21	0.486
23 Jul08:18:25 AM	0.864	0.21	0.654
23 Jul08:34:51 AM	0.648	0.21	0.438
23 Jul08:50:00 AM	0.48	0.21	0.27
23 Jul09:06:24 AM	0.408	0.21	0.198
23 Jul09:23:31 AM	0.36	0.21	0.15
23 Jul09:37:29 AM	0.336	0.21	0.126
23 Jul09:52:46 AM	0.336	0.21	0.126
23 Jul10:06:56 AM	0.312	0.21	0.102
23 Jul10:20:54 AM	0.312	0.21	0.102
23 Jul10:34:53 AM	0.312	0.21	0.102
23 Jul10:50:29 AM	0.312	0.21	0.102
23 Jul11:06:06 AM	0.312	0.21	0.102
23 Jul11:20:05 AM	0.288	0.21	0.078
23 Jul11:35:23 AM	0.288	0.21	0.078
23 Jul11:49:22 AM	0.288	0.21	0.078
23 Jul12:05:05 PM	0.288	0.21	0.078

Figure 74 - Excel file snapshot showing sensor readings

There have been some issues regarding data retrieval and network connectivity in Gondala and Lingdari due to which some sensor readings could not be received at expected time intervals in the first few weeks after installation. But the issues have been resolved by installing a separate data-logger over the sensor on top of the existing HTTP signal sending unit which will log each and every reading at the sensor and can be retrieved manually at any point of time.

7.4.5 Current meter readings and stage-discharge relationship

The sensors are supposed to monitor the water levels every 15 minutes as described above. This will give us continuous stage of water with respect to CNB top. In order to get how much water flowed over the top of the CNB, i.e. the discharge, there needs to be a stage-discharge relationship which will convert the stage acquired from the sensor to actual flow/discharge in the form of cum/sec. Such discharge can then be aggregated over the time duration of our choice (say, a day, a rainfall event, months etc.). This will give us the total water flowed out of the catchment during that time period. This will help us in matching the runoff estimated by the model with the observed runoff from the catchment.

The stage-discharge relationship varies with the size and dimensions of the CNB, the dimensions of the stream channel and catchment properties. It is different for different CNBs and their catchments. Thus, the stage-discharge relationship needs to be established for all the catchments under study.

One method to find out the stage-discharge relationship is to measure the actual just discharge downstream of the CNB for different heights (h) of water column over the CNB top. Then the h for different readings is plotted on the x-axis and the measured discharge is plotted on y-axis and the curve is plotted. The equation of the curve will give the stage-discharge relationship. Thus, using the curve we can get value on y-axis for any h on the x-axis.
In order to measure the discharge we used the pigmy current meter, which measures the velocity of the running water.

Figure 75 - Current meter readings: a) Gondala stream, b) Lingdari stream

Taking readings with the help of pigmy current meter –

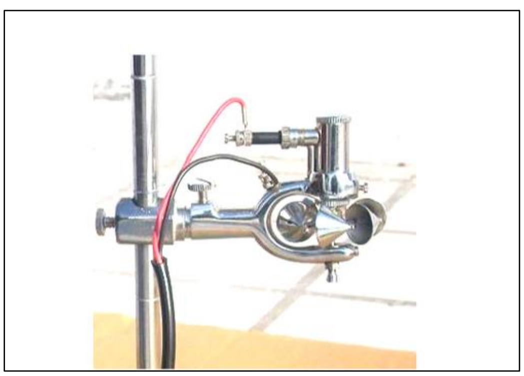


Figure 76 - Cup type pigmy current meter

A cup-type pigmy-sized current meter is as shown in the above figure. The current meter when submerged in the flowing stream, the cups rotate just as turbines due to the water current or flow. The inbuilt counter records the number of rotations per unit time. This can be converted to the

velocity of the water current using the calibration equation. Thus, velocity at different points across the width of the stream can be recorded with the help of current meter.
In order to compute the total discharge of water in the stream, the total cross section area of the stream needs to be multiplied with the average velocity of flow at that cross section. As the stream bed is not uniformly horizontal, the depth as well as the cross-section differs across the width. Thus, velocity needs to be measured for different sections as per the variation in the depth. This is done as per the FAO norms as follows –

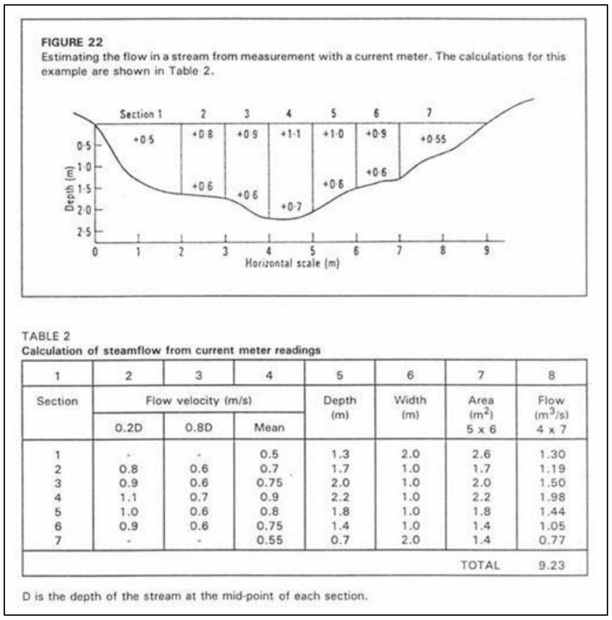


FIGURE 22
Estimating the flow in a stream from measurement with a current meter. The calculations for this example are shown in Table 2.

TABLE 2
Calculation of steamflow from current meter readings

1	2	3	4	5	6	7	8
Section	Flow velocity (m/s)			Depth (m)	Width (m)	Area (m^2) 5 x 6	Flow (m^3/s) 4 x 7
	0.2D	0.8D	Mean				
1	-	-	0.5	1.3	2.0	2.6	1.30
2	0.8	0.6	0.7	1.7	1.0	1.7	1.19
3	0.9	0.6	0.75	2.0	1.0	2.0	1.50
4	1.1	0.7	0.9	2.2	1.0	2.2	1.98
5	1.0	0.6	0.8	1.8	1.0	1.8	1.44
6	0.9	0.6	0.75	1.4	1.0	1.4	1.05
7	-	-	0.55	0.7	2.0	1.4	0.77
						TOTAL	9.23

D is the depth of the stream at the mid-point of each section.

Figure 77 - Procedure for taking current meter readings in a stream - source (FAO)

Depth, width and the velocity as per the current meter reading are recorded for all the sections. This gives discharge of water for each section. Finally, the total discharge is the sum of discharge for all the sections.

The location for measurement of discharge using current meter needs to be chosen such that there is minimum turbulence in the stream, slopes are minimum and the stream channel is fairly straight. Following are the current meter readings recorded just to the downstream of Gondala and Lingdari sensors. The table also mentions the corresponding height of the water column flowing over the CNB for those points.

Table 61- Current meter readings and computed discharge

For sensor	Water column over CNB (cm)	Discharge downstream of CNB (lps) Measured by current meter	As per formula for broad crested weir (lps)
Gondala	1	12	21
Gondala	5	272	236
Gondala	7	430	391
Lingdari	1	9	10.5

Lingdari	4	61.4	84

If the height of the water column above CNB i.e. h (cm) and the discharge measured downstream of CNB i.e. Q (litres per second) from the above table are plotted for Gondala, we get the following stage-discharge relationship –

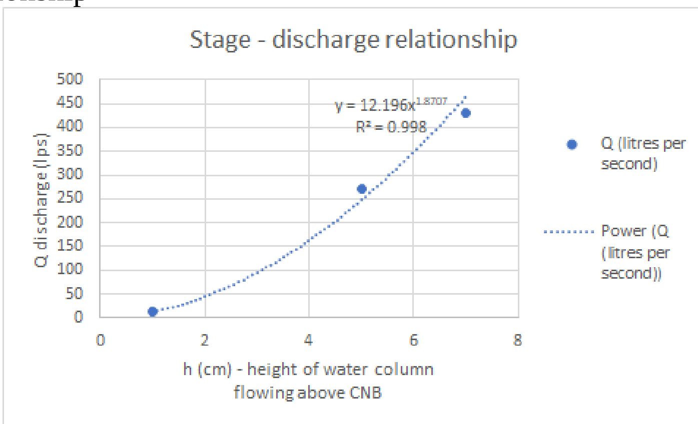


Figure 78- Stage discharge relationship computed from current meter readings Gondala

With more current meter readings, the stage-discharge relationship will become more representative, and can be used to derive discharge from given stage.

Stage-discharge relationship from theoretical method - Flow over broad-crested weir

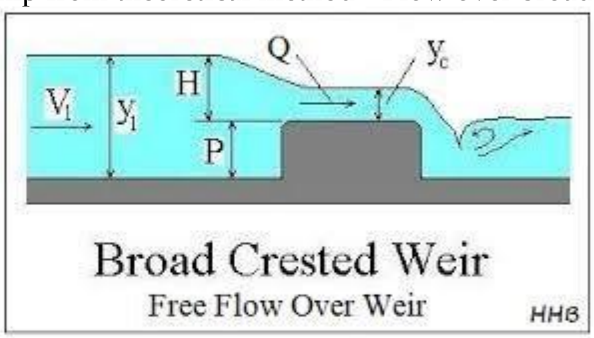


Figure 79 - Flow over broad-crested weir

The flow of water over a Cement Bund on the stream can also be computed using the formula for flow over broad-crested weir. This formula is given as –

$$Q = C \times b \times H_1^{\frac{3}{2}}$$

Where Q is the total discharge in cum/sec, C is the coefficient of discharge which depends on the material of the weir, its roughness etc. It is generally taken as 0.62, b is the width of the weir across the stream flow and H1 is the height of the water column above the weir just before it drops down. In our case, the H1 is monitored by the water level sensor every 15 minutes. Thus, the discharge can be computed continuously using the above equation. The values of discharge as computed by the formula were compared with the discharge calculated using current meter. The values roughly match as seen in the above table. More current meter readings need to be taken in order to calibrate the above formula, so that it can be used for computation of continuous discharge over the CNB.

7.4.6 Installing rain gauge

Out of the three clusters finalized for validation, the Gondala cluster does not have an Automatic Weather Station (AWS) within the cluster. The nearest AWS for Gondala cluster is in Sengaon which is around 8 kms from Lingdari village and more than 10 kms from Gondala village. As per the narratives from the local farmers, the rainfall significantly varies between Sengaon and Lingdari, Gondala villages. Thus, it was decided to install a rain gauge in Gondala village. A tipping-bucket rain gauge with data-logger was installed above the Gram Panchayat office of Gondala. Following are the images taken during the process of installation –

Figure 80 - Rain gauge installation at Gondala GP office

But the hourly rainfall data from the rain gauge could not be retrieved due to an issue with the data logger which has not been resolved till date. The USB pen-drive when inserted into the data-logger shows some error message "nCon" due to which the data cannot be retrieved. There have been multiple interactions with the vendor. The issue would be resolved in next few days hopefully and the vendor has guaranteed no loss of rainfall data.

7.4.7 Sampling of wells and farmers

Monitoring of water levels in the wells is being done at regular intervals. This will help in computing the groundwater recharge as per the GSDA's methodology.

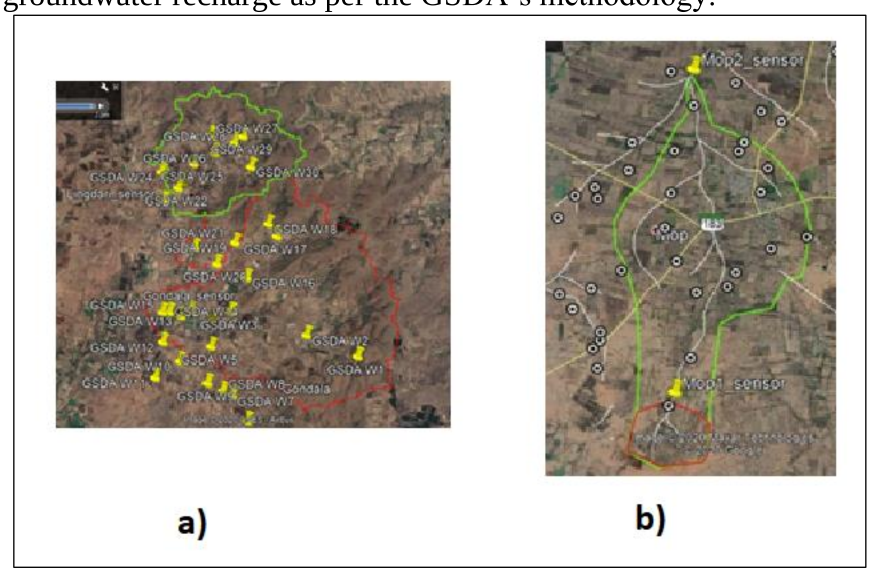


Figure 81 - Locations of wells as per GSDA report : a) Lingdari, Gondala, b) Mop

The wells selected for monitoring are the ones selected by GSDA for their study and which fall in the selected catchments. Above figure shows the locations of wells selected for study by GSDA. Similarly, farmer interviews are also being carried out to understand cropping area, crop growth, soil type, soil depth, crop yields, runoff generated at farm-level, historical and yearly variation in groundwater levels in the wells, contingencies during this season (such as double sowing, damage due to excess rainfall etc.). These narratives will further help in understanding farm-level attributes such as soil moisture, AET, grounwater and runoff.

7.4.8 Soil moisture measurements

The main objective of soil moisture measurements is to compare the soil moisture predicted by the model with the measured soil moisture at selected points in the catchment for specific moments in time.

The points will be selected so as to cover all the soil-crop combinations in the catchment as per the MRSAC maps.

The soil moisture will be measured using oven-dry method. The samples will be taken by digging pits near the crop. The depth of the pit would be such that it goes below the root depth of the crop. The samples would be collected in air-tight containers and immediately taken to Soil Laboratory in Hingoli. The wet-weight of the container will be noted and the container will be kept in oven at 105 degrees temperature for atleast 24 hours. Once all the moisture in the container is evaporated, the weight of the dry soil sample is noted again. The difference in the weight is the moisture content. This is the gravimetric soil moisture.

% gravimetric soil moisture %SMg = (Mw– Md) / Md

Where Mw is the mass of wet-sample in grams, Md is the mass of oven-dried-sample in grams. In order to get the % volumetric soil moisture, the % gravimetric soil moisture content is multiplied with the soil bulk density. The % volumetric soil moisture when multiplied with the soil depth in mm, gives soil moisture in mm.

% volumetric soil moisture %SMv = %SMg x BD

where BD is the soil bulk density which is computed as

BD = mass / volume = Md / Vd

Where Vd is the volume of soil in the container.

Soil moisture in mm = total soil depth in mm x %SMv

The point-wise water budget model will be run for the same crop and soil characteristics and the soil moisture will be compared for the exact time when sample was collected. The model is validated if the predicted and observed soil moisture match for different points in time and space.

7.5. Execution summary

7.5.1 Current status

- 4 sensors installed and functioning.
- Goregaon sensor to be installed before 30th August.
- 6 current meter readings done. More to be taken in last week of August and 1st two weeks of September
- 6 soil samples taken in Lingdari, 5 in Mop. 6 more to be taken in Lingdari, 7 more in Mop and 12 in Gondala. Some samples in Goregaon also to be taken.
- Farmer interviews and well level monitoring is in progress. 2 rounds done in all the four catchments.

7.5.2 Issues faced

- The field work was only restricted to 3 clusters due to COVID-19 pandemic and restrictions on travel due to lockdown issued across the whole state. Moreover these clusters were selected as close to each other as possible so as to minimize the travel between the clusters. This may have compromised the representativeness of the clusters.
- The original plan was to reach the field before the onset of the monsoon for selection of sites, installation of sensors etc. But due to restrictions on travel due to lockdown, the team could only reach the field by the end of June when already more than 200 mm rainfall had occurred in the selected clusters. Most of the selected CNBs were already overflowing by then. This led to many issues such as access to the locations, installation during heavy rainfall, sensors getting washed away etc.
- Installing sensors in Mop cluster was difficult as no suitable location was found in the first two visits. The CNB initially chosen was overflowing, broken in the middle, and was very difficult to reach due to water logging and puddles in the neighboring fields. Eventually a CNB was found in proper condition which required 2 kms of walk through fields from the road. The catchment of this CNB was only 55 ha. This is the Mop 1 sensor. After another 2 visits another CNB was chosen for installing the sensor directly to the side walls of the CNB, but during sensor installation it was found that the cement walls were very weak and brittle due to low quality of construction and were unable to hold the sensor. Eventually this one was cancelled and it was decided to go with the originally chosen broken CNB. This is the Mop 2 sensor.
- The Lingdari and Gondala sensors had data-connectivity issues and were unable to send the signals after every 15 minutes. A separate data logger was ordered for these sensors. These were installed on the sensors in the third week of July and are now recording signals after every 15 minutes. Transport of data logger from Pune to Sengaon costed 10-15 days due to very slowly functioning courier services.
- The pigmy current meter procured from the New Technolab instruments, Nashik stopped working after 5 readings were taken. The instrument was sent to Nashik for repair. The vendor sent a new piece which could not fit the earlier setup (i.e. the rod to which it is meant to be attached). The team had to send the instrument back to Nashik again and get another working piece. This to and fro took many days as the courier services were not working properly during the lockdown.
- The rain gauge was successfully installed in Gondala, but there were problems with the data retrieval. The USB pen-drive could not be detected by the data-logger. There were many interactions with the vendor (Sunsui Process Systems, Pune) and different options

were tried on the field to resolve the problem. The vendor also sent two different pen-drives from Pune but the problem persisted. The problem is still not resolved. But the vendor has guaranteed no loss of data and has promised to resolve the problem.

- As the Paradgaon sensors got washed away, the Goregaon cluster which was closer to team's base location i.e. Sengaon, was selected for installing the sensor. It was decided to install one instead of two sensors in Goregaon catchment. The catchment selection involved multiple visits to different CNBs in the catchment due to problems of access to locations, overflowing (and silted) CNBs. Also, the vendor (i.e. Green Pyramid Energy, Pune) had to design and manufacture new sensor which took considerable time. Transport of new sensor (around 8 feet in length) from Pune to Sengaon also took long time (around 10-15 days) due to lockdown issues. The sensor finally was installed on 29th August. It will be used in validating the runoff if there are few late-monsoon showers in the region.

7.5.3 Pending work

- More current meter readings for establishing the stage-discharge relationships at all the CNBs, especially in Mop and Goregaon
- More soil moisture measurements to be carried out in all the clusters.
- More farmer interviews to be carried out in the month of September.

7.6. Preliminary results, observations and analysis till now

7.6.1 Sensor readings

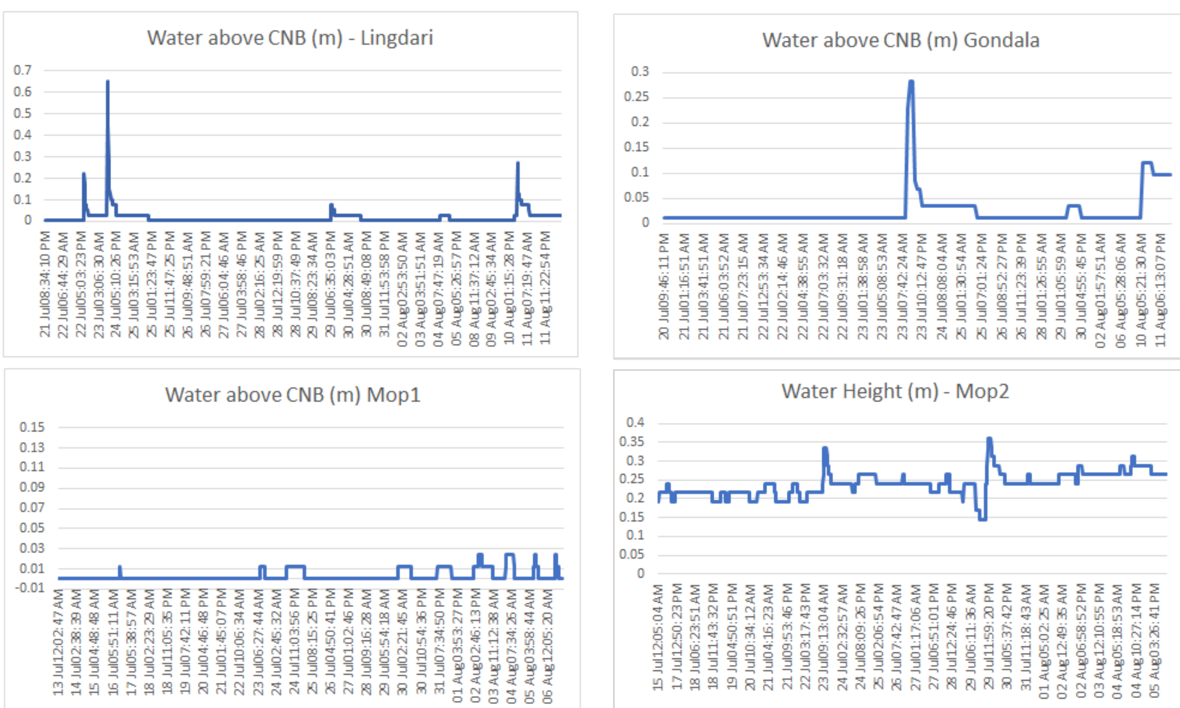


Figure 82 - Sensor readings

7.6.2 Daily and hourly water balance model results

The daily and hourly water budgets for all the four catchments were run for the time period of 1st June to 10th August. The results are as follows –

Table 62 - Daily and hourly water balance results

Catchment	Rainfall mm	Runoff mm daily	Runoff mm hourly	GW mm daily	GW mm hourly	AET mm daily	AET mm hourly	SM mm daily	SM mm hourly
Lingdari	708	316	189	117	227	202	202	74	90
Gondala	708	313	185	136	250	193	194	66	79
Mop1	563	187	58	200	331	152	151	23	23
Mop2	563	210	134	54	108	190	191	108	130

The runoff estimated by the hourly model, as expected, is less than that of daily model. At the same time, the hourly groundwater recharge is higher than the daily. There are only slight differences in the Soil moisture and AET.

7.6.3 Comparison of measured runoff with estimated runoff

Following are some results of the initial validation of the model using the actual measurements of runoff at the outlet of Lingdari catchment. The analysis of sensor readings for other catchments is being done currently, and will be presented in the final field report in Phase 4.
The validation is done for the period between 21st July and 10th August. The total runoff which flowed out of the catchment during this period was computed using the formula for flow over broad-crested weir. The formula still needs to be calibrated using more current meter readings as explained above. Thus, following results may change after correct calibration of the formula with actual readings.

Table 63 - Runoff comparison - estimated and measured

Catchment	Lingdari
Start date	21st July 2020
End date	20th August 2020
Rainfall mm	260
Total water flowed over the CNB (TCM)	156.5
Total water flowed over the CNB (mm)	69
Runoff as per hourly model (mm)	47
Runoff as per daily model (mm)	107

The above table shows that runoff estimated as per hourly model is 47 mm while that estimated by the daily model is more than its double, i.e. 107 mm. The water flowed during the period over the CNB as measured by stage-discharge relationship comes to be around 69 mm.
The measured/observed runoff is more than the estimated runoff. One reason for this may be the water flowing over the CNB during the lean period i.e. after the rainfall and peak-runoff has occurred. Following graphs show the height of water column above CNB for a rainfall event.
The validation can also be done for short rainfall events/episodes such as below –

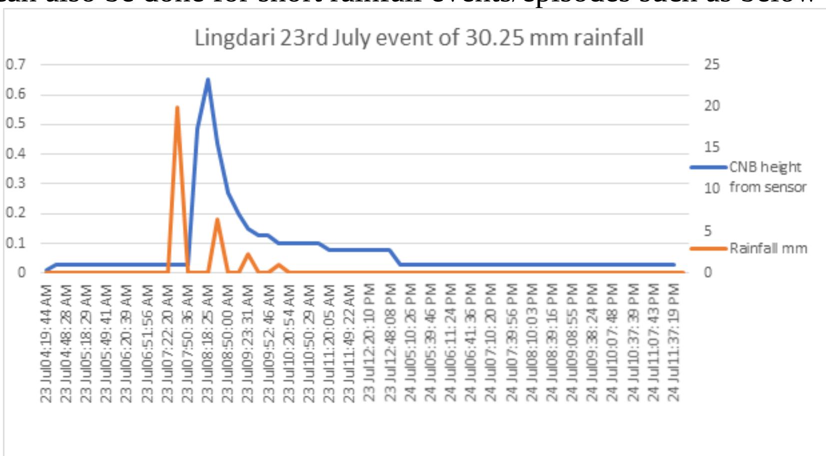


Figure 83 - Runoff event 23rd July - Lingdari

Total rainfall – 30.25 mm (between 7 and 10 am 23rd July)

Runoff as measured – 8.4 mm (computed till 24th July afternoon i.e. including delayed flows OR baseflows)

Runoff estimated by hourly model during this period – 5 mm

The key point to be noted here is the delayed flow after the rainfall event has occurred. Such delayed flows are noted after almost all rainfall events. These flows may be due to rejected recharge i.e. once the soils and the aquifer get saturated, the infiltrated rainfall cannot find space to percolate beneath the soil layer. This may generate baseflows or delayed flows as seen in the graph above. Similar graphs for other events are given below –

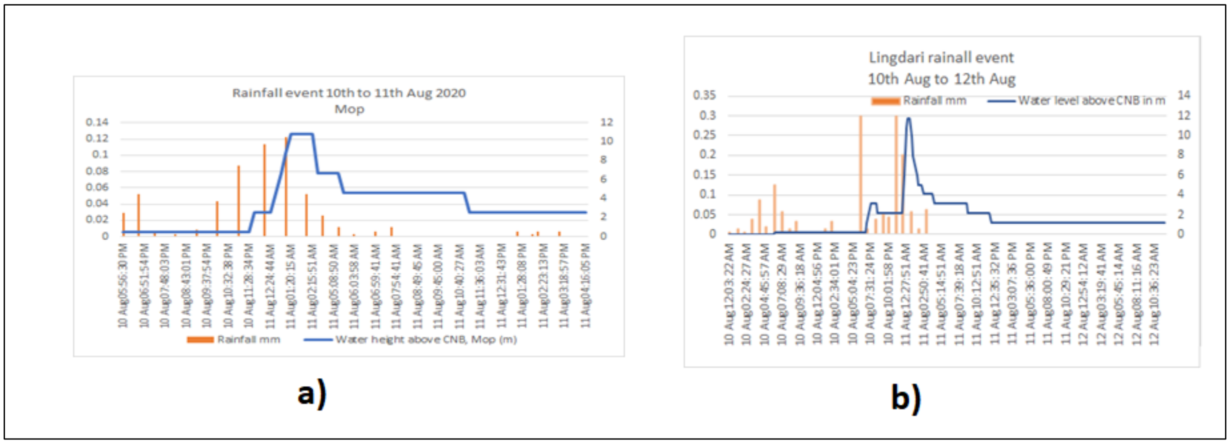


Figure 84 - Rainfall events and water levels over CNB top: a) Mop, b) Lingdari

This needs to be investigated further using hydrograph partitioning. Hydrograph partitioning is used to estimate baseflows after the rainfall event. There are several methods to partition hydrograph between surface runoff and baseflows. The most suitable method will be used to analyze these rainfall events and estimate the baseflows.

Currently the water budget model does not simulate baseflows. The model allows as much water to percolate as is infiltrated, without considering the aquifer storage capacity.

For example, as per GSDA, the aquifer depth in Lingdari is 7 m and the specific yield is 0.8%. Thus, the aquifer storage capacity is 56 mm only, while the total groundwater recharge as estimated by the hourly model is more than 200 mm. This means that once the aquifer is saturated, the remaining recharge is rejected by the aquifer and joins streams as surface runoff.

The specific yield as computed by GSDA also needs to be checked. Please see chapter 2 of this report for analysis of GSDA plans. Thus, it is not yet clear how much is the aquifer storage capacity for Lingdari. Once the aquifer storage capacity is known and the baseflow component of the water flowing out of the catchment is estimated using hydrograph analysis, then the groundwater recharge and runoff can be matched and validated.

This will also help in incorporating baseflows in the model using aquifer depth and specific yield.

7.6.4 Soil moisture measurements

As explained above, soil moisture measurements will be done at selected locations in the catchments. The locations will be selected according to soil - crop combinations. Following map shows locations in Lingdari catchment till now. Around 6 more samples will be taken in this catchment.

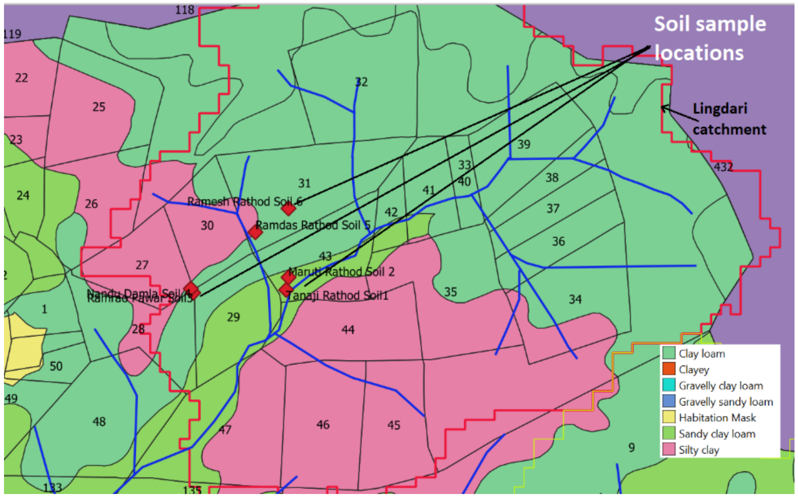


Figure 85 - Map showing soil sample locations, Lingdari

Above map shows the soil moisture measurement locations till now (6 locations in Lingdari).

For each location, the following data is collected.

Table 64 - Soil samples - Location details

Location ID	Village	Location (Lat-Long)	Survey no.	Crop, sowing date	Soil-type, soil depth as per MRSAC	Soil depth as per trial pit	Soil texture (lab)
L1	Lingdari	76.8897, 19.7469	43	Soyabean 13 Jun	Sandy clay loam, shallow		
L2	Lingdari	76.8898, 19.7473	43	Soyabean 18 Jun	Sandy clay loam, shallow		
L3	Lingdari	76.8871, 19.7468	28	Soyabean 7-10 Jun	Clay loam, shallow		
L4	Lingdari	76.887, 19.747	27	Soyabean	Clay loam, shallow		
L5	Lingdari	76.8888, 19.7486	31	Soyabean 20 Jun	Silty clay, deep		
L6	Lingdari	76.8898, 19.7493	31	Soyabean 19 Jun	Clay loam, shallow		

Currently the soil could be dug only about 25-30 cm deep i.e. enough to expose the root depth. But in order to know the real soil depth, soil needs to be dug until soft murum is not encountered. This could not be done currently due to presence of crop. IT will also require a wider pit to be dug which will be done once the crop is harvested.
Also, soil texture analysis is planned to be done in the MIT (Marathwada Institute of Technology) soil laboratory in Aurangabad. This will also be done towards the end of the field work.
Multiple samples will be measured for soil moisture for each location. For each sample, following details will be noted and soil moisture will be measured and compared against the soil moisture predicted by the model for the given soil type and time.

Table 65 - Soil samples - Sample details

Location ID	Sample ID	Date - Time	Crop Height (cm)	Root depth (cm)	Sample weight before drying	Sample weight after drying	Gravimetric Moisture content %	Soil Moisture in mm	Soil moisture model in mm
L1	S1	24 Aug, 12:30	70	13	522.92	416.13	25.66		24.75
L2	S1	24 Aug, 12:50	70	20	523.10	420.95	24.26		24.75
L3	S1	24 Aug, 13:20	85	19	469.85	371.96	26.31		33.75
L4	S1	24 Aug, 13:40	65	20	567.27	416.1	36.33		33.75
L5	S1	24 Aug, 14:10	43	13	532.34	431	23.51		151.23
L6	S1	24 Aug, 14:30	70	20	529.47	428.14	23.66		33.75

Bulk density will be computed using the dry mass of soil sample and the corresponding volume of dry mass. Bulk density will be multiplied with the gravimetric soil moisture percent to get the volumetric soil moisture percent. This when multiplied with total soil depth will give soil moisture in mm. As total soil depth is yet to be measured, observed soil moisture in mm is not available for these samples presently. It will be computed as soon as soil depth is measured through trial pits.
After soil texture analysis is done for the above locations, the hourly model will be run for the exact soil texture, soil depth and Ksat values. The estimated soil moisture for the location and date-time will be compared with the observed soil moisture for validation.
This will be done for more locations as well as soil samples. Work on the same is presently being done.

7.7. Observed phenomena

7.7.1 Ponding

Water logging and ponding in the fields after the rainfall events was observed many times during the field visit. The runoff generated either remained within the field or got ponded into a sink. The water logging remained for a day or two, or sometimes only for hours.

The reasons for such water logging may be poor levelling of the fields, presence of high clay content in the soils, land management practices of farmers or due to natural terrain (i.e. sinks). Such water logging and ponding damaged few sections of the fields and lead to decrease in yields and incomes.

Thus, it was thought that this phenomenon needs to be understood well and incorporated into the water budget model. Please see chapter 8 on incorporation of Ponding.

7.7.2 Well levels and Baseflows –

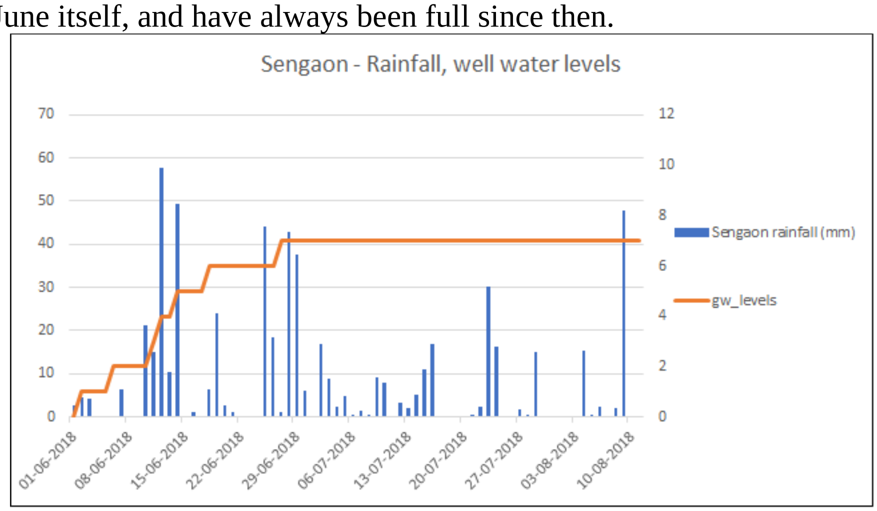
As described above, wells selected by GSDA for their analysis are monitored for water levels. The data on well depth, the well strata, irrigation details, pump details and water levels at regular time intervals is being compiled and will be presented in the final report. Following are some of the wells monitored.

a)

b)

c)

Wells are almost full in all the catchments. As per the farmer interviews and well level monitoring from July 1st week onwards following graph was constructed for Lingdari and Gondala catchments which shows how the well levels increased during the monsoon. It shows that the wells went full in the month June itself, and have always been full since then.



This means that the aquifers in Lingdari and Gondala got saturated in the month of June itlself. As per GSDA, the specific yield in this region is 0.8% which means that 7 m thick aquifer can hold only around 56 mm of water. Total rainfall in this region till now has been 708 mm, and around 350 mm has occurred after 1st July. Thus, as per GSDA there has been no groundwater recharge once the aquifers got saturated i.e. after 1st July which seems unlikely. Thus, going by the WTF method, we would estimate groundwater recharge to be zero. This is not accurate since water has percolated down the soil layer and left the aquifer as baseflows.

Thus, it is important to consider the component of baseflows. It is evident from the continuous over-flowing CNBs that there are significant baseflows.

Also, specific yield data needs to be investigated further to understand how much is the aquifer storage capacity in the region.

7.8. Recommendations for model refinements and extension

- As per the preliminary results, runoff predicted by hourly model roughly matches with the runoff measurements on the ground. More events will be studied in the month of August and September to confirm the observations.

- Overall GW recharge as predicted by the hourly-model is on the higher side, as compared with GSDA recharge estimates. Wells in the region are almost full and hence the aquifer is saturated. All the bunds monitored continuously overflow even during dry spells, indicating significant baseflows. This points towards following analysis to be done –
    - Baseflows need to be estimated using hydrograph analysis
    - Specific Yield values used for computation of groundwater recharge need to be investigated further.
    - Ksat i.e. saturated hydraulic conductivity values need to be investigated. Ksat acts as the interface between soil layer and the aquifer as it decides the speed with which the water percolates beneath the soil layer. Ksat is very high for soils such as sandy loam, sandy clay loam etc. and is very low for soils such as clay. Ksat along with the soil depth plays major role in deciding the amount of groundwater recharge.

- Thus, Ksat and soil depth data from NBSS and, specific yield and aquifer depth data from GSDA would help in tuning or calibrating the groundwater recharge and baseflows in the model.

- Ponding was seen at many places. Ponding was mostly of 3 types - i) within the farms, due to furrows and land management practices, ii) within the farms, due to lack of levelling (here water gets ponded in the corners of the fields and farmers are not able to drain out the water in case of heavy rainfall events), iii) due to natural sinks and depressions in the terrain where water from neighboring fields gets ponded and may cover more areas.
  The first type of ponding may help the crop to some extent as the water slowly infiltrates into the ground over next few hours after the rainfall event and improves recharge and soil moisture. The second and third types of ponding damage the crop. With regards to water

balance, ponding will reduce the runoff and increase soil moisture and recharge. Thus, it is important to understand the phenomenon of ponding and incorporate it into the model.

8. Report on Incorporation of Ponding in Water Balance Framework

Prepared By: Vidyadhar Konde

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8.1 Introduction

The IITB water balance model estimates quantities of different parameters like surface runoff, groundwater recharge, crop AET and change in soil moisture at the end of kharif season. The process of validation of these estimates so as to check if these estimates match with the ground reality is under way. As discussed in the earlier meetings with PMU and is observed from the field visits, runoff estimates by the IITB water balance model are on the higher side whereas those of groundwater recharge on the lower side. It was thus decided that the model should be refined to improve these estimates positively by considering any of the phenomenon missing from the current framework that is being used. One of the important phenomena as observed from the field is that of ponding. This document briefs about the concept of ponding, types of ponding, field observations related to ponding and methods to explore incorporation of the ponding effect in the IITB water balance model.

8.2 Types of the Ponding as observed from the field

Ponding observed on the field can be broadly grouped in three categories:

1. Ponding in furrows :- This type of the ponding majorly depends on the land management practices. If the field has some degree of slope irrespective of the furrow direction, water can move out of the field. But in case the field is almost flat without any slope water can not flow and gets accumulated in furrows. As there is no way out for the water to move, it remains in the furrow. An example of such ponding is shown in the image below.

Appendix 1 shows the series of images for ponding as observed for 30 mm of rainfall.

Figure 86 - Ponding in furrows

2. Ponding near bund :- This type of the ponding majorly depends on the slope and the land management practices. This type of the ponding is observed in the field where in spite of having sufficient slope for water to move out, it gets accumulated near either of the bunds. In order to address this issue of ponding, farmers make an arrangement to move this water out by creating local pathways like clearing part of the bund at suitable locations.

Bund height is an important factor that decides the volume of water that gets accumulated in the ponding.

Figure 87 - Ponding near farm-bunds

3. Ponding due to natural depressions:-

This type of the ponding generally occurs where the concave nature of the slope for that field, results in water accumulation in the middle of the field. As the fields with such slope are more like a saucer the water accumulated cannot move out and results in the ponding.

Figure 88 - Ponding due to natural depressions

8.3 Incorporation of the ponding into the water balance framework

As can be seen from the types of the ponding discussed above, slope and direction of the slope are the key factors that affect the ponding. Annexure II details about slope and direction of slope for Mop (Washim), Gondola (Hingoli) clusters. Main steps to incorporate the ponding discussed above in the water balance framework are i) identifying possible areas of ponding and ii) computation of ponding constant iii) incorporation of ponding constant in present water balance These are explained below.

8.3.1 Identification of possible areas of ponding

In QGIS 3.10, Source is an area where runoff generates and Sink is defined as an area where runoff water accumulates in a watershed. Images below show possible ponding areas as identified using the sink detection tool for Mop and Gondola Cluster.

Gondola Cluster (Hingoli) Mop Cluster(Washim)

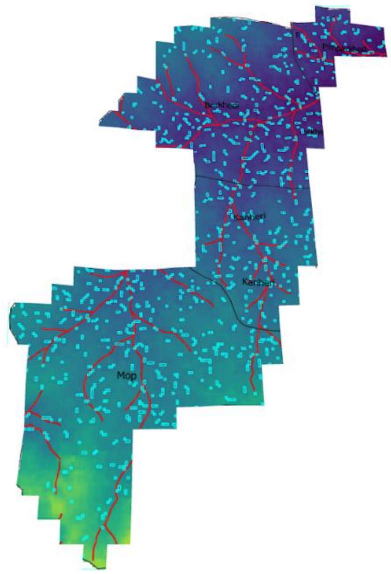


Figure 89 - DEM analysis for identification of ponding - Mop

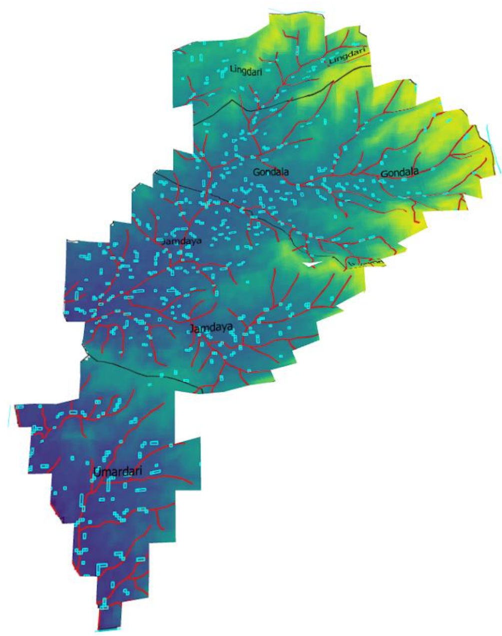


Figure 90- DEM analysis for identification of ponding - Gondala

Results obtained from the above method were compared with actual field locations, they were largely found to be consistent.

8.3.2 Computation of ponding constant

For the computation of ponding constant in mm, for type I ponding, furrow height is important whereas for type II and type III ponding, maximum pond volume is important. Three methods mentioned below can be used for measurement of ponding constant.

A. Based of furrow height from farmers interview:-

- Detailed farmer surveys can be conducted in different parts of the project area to understand cropwise furrow depth. It is observed from the field that maximum furrow height is limited by farm machinery used for land preparation and based on soil depth available in the farm, furrow depth is adjusted by the farmer. Further it is observed that maximum depth in such cases is not more than furrow machinery/pough.
- Apart from furrow depth, an important factor (which is to be investigated) is temporal change in furrow depth due to different factors like rainfall, runoff, crop growth, method of irrigation application etc.
- From field observations in the Hingoli region, furrows were disappeared in the first 2 or 3 rainfall events.
- Important factors to be gathered and analysed from farmers interview are Farm slope, slope direction and furrow depth,furrow direction, Bund Height, Soil Depth, furrow machinery used.

B. Based on sink volume in the cluster area.

- As discussed earlier, possible ponding areas can be identified using QGIS sink, depression, etc algorithms. Using these polygons (surface area) and Digital Elevation Model (DEM) data, volume of local ponding can be computed. Summation of such ponding areas in a particular zone normalized for the the same zone will give ponding constant to the respective zone.

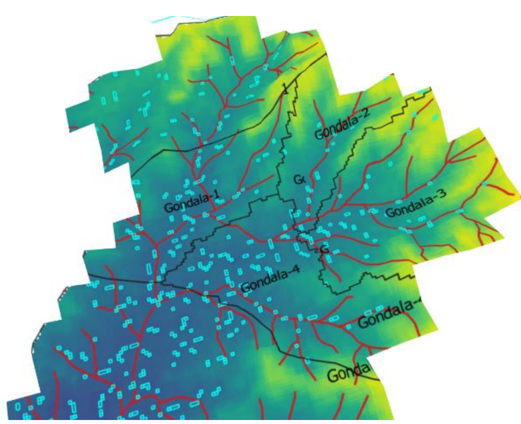


Figure 91 - Zonewise identification of ponding

- Image above shows ponding areas as identified using QGIS for the Gondola village. It can be observed that the ponding in zone 1 and zone 2 is lesser than that of the ponding in zone 3 and zone 4. Such types of variations for ponding in the village can be captured for all the zones with this method..
- If the zone consists of n number of ponding locations with maximum volume of $Vmax_n$, then ponding constant in mm can be computed as below.
-

$$Ponding\ constant(mm) = \frac{Vmax1\ (m3) + Vmax2\ (m3) + Vmax3\ (m3) + .. + Vmax1n(m3)}{Zone\ area(m2)} * 1000$$

C. As per SWAT Theory Documentation 2009:-
   - Appendix III summarizes different variables and formulae used in computation of daily volume of ponding. Appendix IV summarizes the list of variables required and their availability in the present model.
   - In SWAT theory ponds (Type II of ponding mentioned above) and wetlands (Type III of ponding mentioned above) are differentiated based on availability of spillways. It computes the water balance for the pond/wetland. Equation of water balance is as follows:-

The water balance for a pond or wetland is:

$$V = V_{stored} + V_{flowin} - V_{flowout} + V_{pcp} - V_{evap} - V_{seep}$$

- All are the volumetric conversions i.e. in m3.
- For the computational part Maximum Storage of pond/wetland and surface area are two important factors. These can be computed one time and used for daily balance components viz. Vstored,Vflowin,Vpcp,Vevap,Vseep.
- Images below are the wetland identified from QGIS and field observations. From QGIS analysis, the size of the wetland is 1729 m2 and the sub basin for wetland (area from which water comes to the wetland) is 9875 m2.
- Graph below shows daily volumetric computations for mentioned wetland for different soil structures.Also, Appendix IV shows computation in excel

Figure 92- Field location

Figure 93 - Wetland identified through DEM

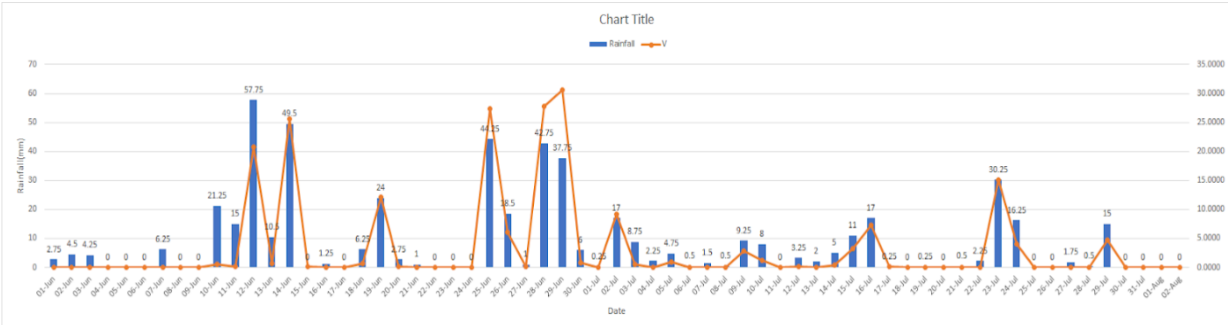


Figure 94 - Ponding for Soil Texture -Clay Loam, Ksat = 2.7 mm/hour

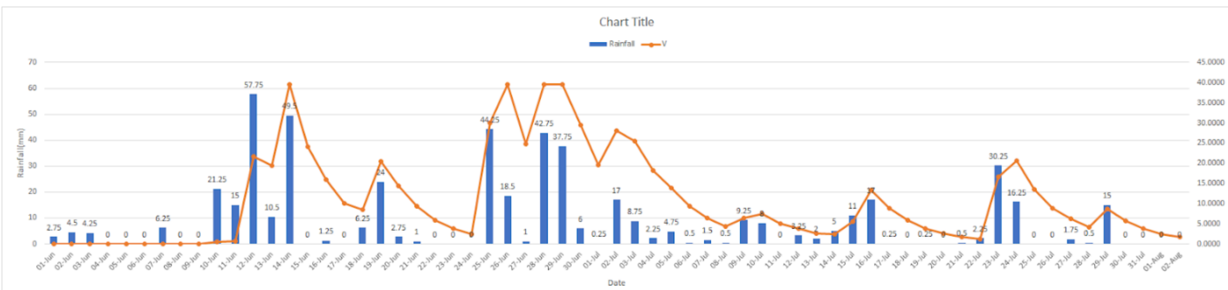


Figure 95 - Ponding for Soil Texture:- Clayey, Ksat = 0.52 mm/hour

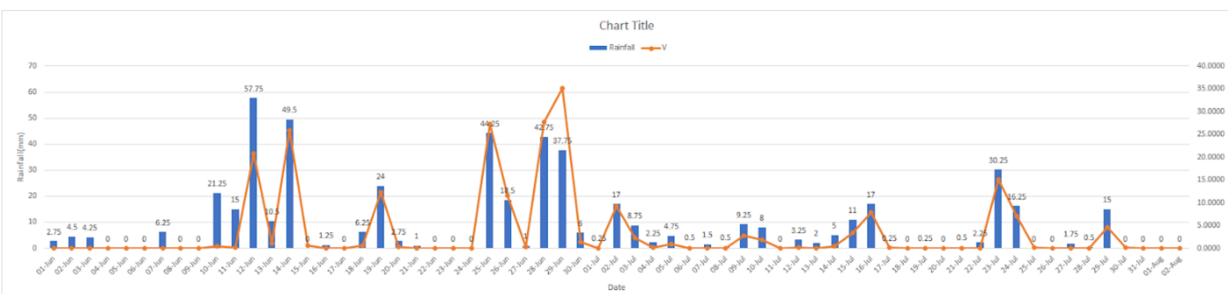


Figure 96 Ponding for Soil Texture:- Gravelly Clay Loam, Ksat= 2.32 mm/hour

- Computation of SWAT based ponding in present plugin:-

i. In the present water balance framework, the cluster area is divided into grid points. Water balance components viz. Groundwater recharge (mm), soil moisture (mm), runoff (mm), AET (mm) for each point are computed daily/hourly.

ii. Results for all the points in a zone are averaged out, and these averaged values are assigned to that particular zone.

iii. For example, the map below shows grid points of size 150m x 150m for the Gondola cluster (Hingoli).

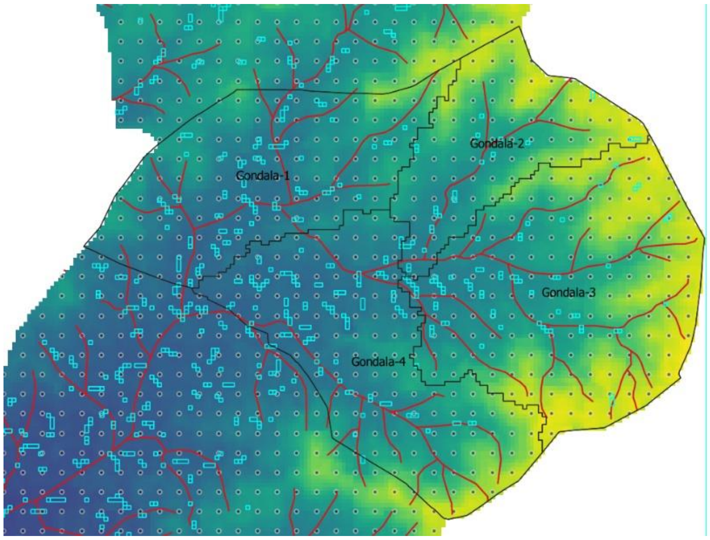


Figure 97 - Grid points and ponding areas for Gondala cluster

iv. List of ponding points in the grid is prepared by assigning each ponding/wetland location to the nearest grid point used for water balance. One time computation parameters like maximum volume (Vmax), Surface Area (SAmax) are also assigned at the same time.
v. While computation of water balance for above selected points, subroutine for the computation of water balance components of pond viz. Vevap, Vseep, Voutflow needs to be executed first. With the help of surface area (SA) in m2 for the day, ponding constant in mm can be computed.
vi. This ponding constant will be used along with the rainfall for computation of infiltration and other water balance components in a regular manner.
vii. Computation of water balance with the help of ponding constant is explained in the next section.

8.3.3 Incorporation of ponding constant in water balance:-

As discussed above, ponding constants can be computed which need further incorporation in the present water balance computation. Following three steps need to be executed for the same.

- If the model generates runoff greater than ponding constant then remove ponding amount from runoff otherwise keep runoff as it is.

if (pri_runoff + sec_runoff) >= Ponding_Constant
then
Ponding_Depth = Ponding_Constant
Else
Ponding_Depth = (pri_runoff + sec_runoff))

- The new runoff generated is lesser than old runoff by the amount of ponding constant (i.e pri_runoff + sec_runoff - ponding)
- Lastly, add this computed ponding constant in next time step rainfall.

present time step rainfall = previous time step's actual ponding + present time step's rainfall

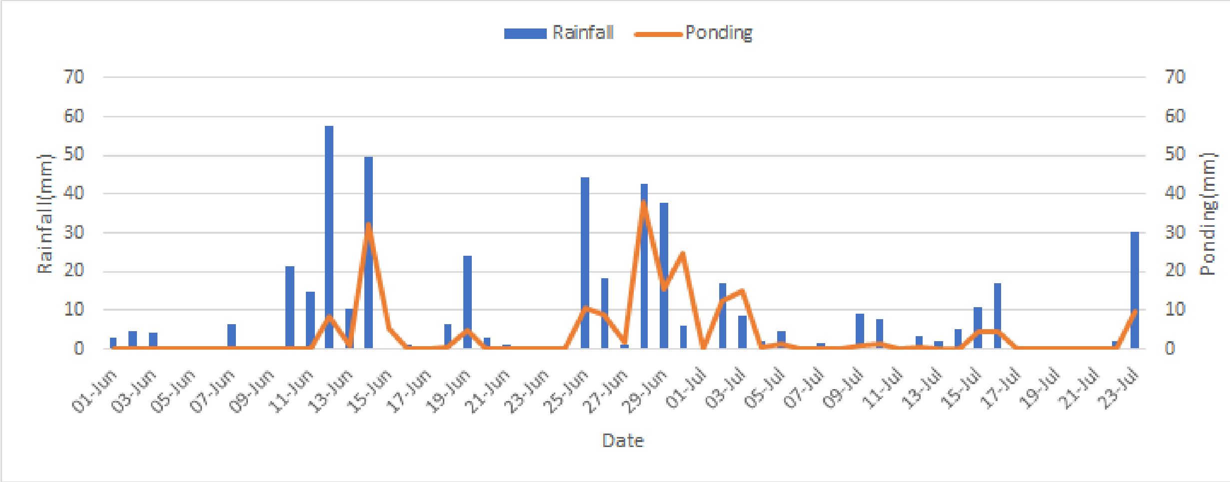


Figure 98 - Ponding with ponding_constant

Above graph shows the rainfall and respective ponding for each day. Ponding constant is assumed to be 4mm. Incorporation of ponding constant resulted in reduction of runoff and increase in ground water recharge. Appendix VI shows the computational part of the same incorporation of ponding constants in water balance with hourly WB model.

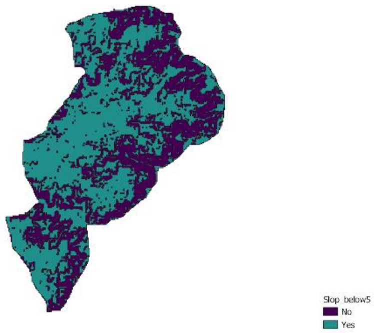
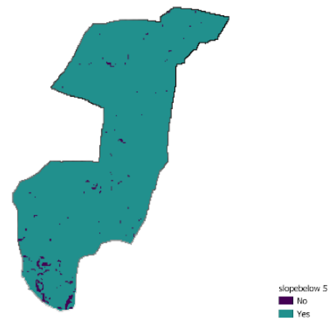
8.4 Appendix I

 2020-07-23 07-11 A.M	 2020-07-23 07-38 A.M

 2020-07-23 07-55 A.M	 2020-07-23 08-11 A.M
 2020-07-23 08-41 A.M	 2020-07-23 08-51 A.M
 2020-07-23 01-29 A.M	 2020-07-24 07-52 A.M

Figure 99 - Ponding in field during rainfall event

8.5 Appendix II

 Gondala Cluster Area below 5 slope:- 1761 Area above 5 slope:- 1157	 Mop Cluster Area below 5 slope:- 2443 Area above 5 slope:- 41

8.6 Appendix III

1 Water Balance equation for pond/wetland

The water balance for a pond or wetland is:

$$V = V_{stored} + V_{flowin} - V_{flowout} + V_{pcp} - V_{evap} - V_{seep}$$

- V = volume of water in the impoundment at the end of the day (m3 H2O)
- V_{stored}=volume of water stored in the water body at the beginning of the day (m3 H2O)
- V_{flowin}=volume of water entering the water body during the day (m3 H2O)
- $V_{flowout}$=volume of water flowing out of the water body during the day (m3 H2O)
- V_{pcp}=volume of precipitation falling on the water body during the day (m3 H2O)
- V_{evap}=volume of water removed from the water body by evaporation during the day (m3 H2O)
- V_{seep}=volume of water lost from the water body by seepage (m3 H2O)

2 SURFACE AREA (SA) for Ponds:-
the surface area of the water body(pond), needed to calculate:-

- the amount of precipitation falling on the water
- the amount of evaporation
- seepage

$$SA = \beta_{sa} \cdot V^{expsa} \qquad \beta_{sa} = \left(\frac{SA_{em}}{V_{em}} \right)^{expsa}$$

$$expsa = \frac{\log_{10}(SA_{em}) - \log_{10}(SA_{pr})}{\log_{10}(V_{em}) - \log_{10}(V_{pr})}$$

- **SA:-** surface area of the water body (ha),
- $\boldsymbol{\beta}_{sa}$ is a coefficient
- **V** is volume of water in the impoundment (m3 H2O)
- **SA_{em}** the surface area of the pond when filled to the emergency spillway
- **V_{em}** volume of water held in the pond when filled to the emergency spillway(m3 H2O)
- **SA_{pr}** surface area of the pond when filled to the principal spillway (ha)
- **V_{pr}** volume of water held in the pond when filled to the principal spillway (m3 H2O)

two known points surface area and volume information provided for the principal and emergency
spillways.

3 SURFACE AREA (SA) for Wetlands:-

the surface area of the water body(pond), needed to calculate:-

- the amount of precipitation falling on the water
- the amount of evaporation
- seepage

$$SA = \beta_{sa} \cdot V^{expsa} \qquad \beta_{sa} = \left(\frac{SA_{mx}}{V_{mx}}\right)^{expsa}$$

$$expsa = \frac{\log_{10}(SA_{mx}) - \log_{10}(SA_{nor})}{\log_{10}(V_{mx}) - \log_{10}(V_{nor})}$$

- SA:- surface area of the water body (ha),
- $\boldsymbol{\beta}_{sa}$ is a coefficient
- V is volume of water in the impoundment (m3 H2O)
- **SA_{max}** surface area of the wetland when filled to the maximum water level (ha)
- **V_{max}** volume of water held in the wetland when filled to the maximum water level (m3 H2O)
- **SA_{nor}** surface area of the wetland when filled to the normal water level (ha)
- **V_{nor}** volume of water held in the wetland when filled to the normal water level (m3 H2O)

the two known points are surface area and volume information provided for the maximum and normal water levels

4 **Precipitation:-** Volume of precipitation falling on pond/wetland

$$V_{pcp} = 10 \cdot R_{day} \cdot SA$$

- **V_{pcp}** volume of water held in the pond when filled to the emergency spillway(m3 H2O),
- **SA** surface area of the water body (ha),

- $\mathbf{R}_{day}$ amount of precipitation falling on a given day (mm H2O)

5 **Evaporation:-** Volume of precipitation falling on pond/wetland

$$V_{evap} = 10 \cdot \eta \cdot E_o \cdot SA$$

- $\mathbf{V}_{evap}$ volume of water removed from the water body by evaporation during the day (m3 H2O),
- $\mathbf{E}_o$ potential evapotranspiration for a given day (mm H2O)
- $\boldsymbol{\eta}$ evaporation coefficient (0.6)

6 **Seepage:-** volume of water lost by seepage through the bottom of the pond or wetland on a given day

$$V_{seep} = 240 \cdot K_{sat} \cdot SA$$

- $\mathbf{V}_{seep}$ volume of water lost from the water body by seepage (m3 H2O),
- $\mathbf{K}_{sat}$ effective saturated hydraulic conductivity of the pond or wetland bottom (mm/hr)

7 Inflows:-
volume of water entering the pond or wetland on a given day

$$V_{flowin} = fr_{imp} \cdot 10 \cdot \left(Q_{surf} + Q_{gw} + Q_{lat}\right) \cdot \left(Area - SA\right)$$

- $\boldsymbol{fr}_{imp}$ the fraction of the sub basin area draining into the impoundment,
- $\mathbf{Q}_{surf}$ the surface runoff from the subbasin on a given day (mm H2O)
- $\mathbf{Q}_{gw}$ groundwater flow generated in a subbasin on a given day (mm H2O),
- $\mathbf{Q}_{lat}$ lateral flow generated in a subbasin on a given day (mm H2O), **Area** subbasin area (ha), **SA** surface area of the water body (ha)

8 **Outflow(Ponds):-** function of target storage
When the month is in between the beginning and end month of flood.

$$V_{targ} = V_{em} \qquad \text{if } mon_{fld,beg} < mon < mon_{fld,end}$$

Before and after flood month

$$V_{targ} = V_{pr} + \frac{\left(1 - \min\left[\frac{SW}{FC}, \quad 1\right]\right)}{2} \cdot \left(V_{em} - V_{pr}\right)$$

$$\text{if } mon \le mon_{fld,beg} \text{ or } mon \ge mon_{fld,end}$$

- $\mathbf{V}_{targ}$ target pond volume for a given day (m3 H2O),
- $\mathbf{V}_{pr}$ volume of water held in the pond when filled to the principal spillway (m3 H2O),
- $\mathbf{V}_{em}$ volume of water held in the pond when filled to the emergency spillway (m3 H2O),

- **mon** the month of the year
- **mon$_{fld,beg}$** beginning month of the flood season
- **mon$_{fld,end}$** the ending month of the flood season
- **SW** the average soil water content in the subbasin (mm H2O)
- **FC** the water content of the sub basin soil at field capacity (mm H2O)

9 Outflow(Wetlands):-
wetland releases water whenever the water volume exceeds
When volume of the water stored in wetland is less than the normal storage volume

$$V_{flowout} = 0 \qquad \text{if } V < V_{nor}$$

$$V_{flowout} = \frac{V - V_{nor}}{10} \qquad \text{if } V_{nor} \leq V \leq V_{mx}$$

$$V_{flowout} = V - V_{mx} \qquad \text{if } V > V_{mx}$$

When volume of the water stored in wetland is greater than the normal storage volume but lesser than maximum storage volume,

$$V_{flowout} = 0 \qquad \text{if } V < V_{nor}$$

$$V_{flowout} = \frac{V - V_{nor}}{10} \qquad \text{if } V_{nor} \leq V \leq V_{mx}$$

$$V_{flowout} = V - V_{mx} \qquad \text{if } V > V_{mx}$$

When volume of the water stored in wetland is greater than the maximum storage volume,

$$V_{flowout} = 0 \qquad \text{if } V < V_{nor}$$

$$V_{flowout} = \frac{V - V_{nor}}{10} \qquad \text{if } V_{nor} \leq V \leq V_{mx}$$

$$V_{flowout} = V - V_{mx} \qquad \text{if } V > V_{mx}$$

- **V$_{flowout}$** volume of water flowing out of the water body during the day (m3 H2O),
- **V$_{nor}$** volume of water held in the wetland when filled to the normal water level (m3 H2O),
- **V$_{mx}$** volume of water held in the wetland when filled to the maximum water level (m3 H2O)

8.7 Appendix IV

Table 66 - SWAT parameters used for ponding volume computations

Sr.No	Variable	Description	Required for	Availability	Source For computation
1	SA	surface area of the water body (ha)	Pond /Wetland	Need to compute	from qgis
2	SA_{em}	the surface area of the pond when filled to the emergency spillway	Pond	Need to compute	from qgis
3	SA_{mx}	surface area of the wetland when filled to the maximum water level (ha)	Wetland	Need to compute	from qgis
3	V_{em}	volume of water held in the pond when filled to the emergency spillway(m3 H2O)	Pond	Need to compute	from qgis
4	V_{mx}	volume of water held in the wetland when filled to the maximum water level (m3 H2O)	Wetland	Need to compute	from qgis
5	SA_{pr}	surface area of the pond when filled to the principal spillway (ha)	Pond	Need to compute	from qgis
6	SA_{nor}	surface area of the wetland when filled to the normal water level (ha)	Wetland	Need to compute	from qgis
7	V_{pr}	volume of water held in the pond when filled to the principal spillway (m3 H2O)	Pond	Need to compute	from qgis
8	V_{nor}	volume of water held in the wetland when filled to the normal water level (m3 H2O)	Wetland	Need to compute	from qgis

9	β_{sa}	coefficient	Pond /Wetland	Need to compute	From 1-9
10	R_{day}	amount of precipitation falling on a given day (mm H2O)	Pond/ Wetland	Available	-
11	V_{pcp}	volume of water held in the pond when filled to the emergency spillway(m3 H2O)	Pond/ Wetland	Need to compute	From 1 and 10
12	E_o	potential evapotranspiration for a given day (mm H2O)	Pond/ Wetland	Available	Weather data
13	η	evaporation coefficient	Pond/ Wetland	Available	Constant (0.6)
14	V_{evap}	volume of water removed from the water body by evaporation during the day (m3 H2O),	Pond/ Wetland	Need to compute	From 1,12,13
15	K_{sat}	effective saturated hydraulic conductivity of the pond (mm/hr)	Pond/ Wetland	Available	Constant from model lookups
16	V_{seep}	volume of water lost from the water body by seepage (m3 H2O)	Pond/ Wetland	Need to compute	From 1 and 15
17	fr_{imp}	the fraction of the sub basin area draining into the impoundment	Pond/ Wetland	Need to compute	From Qgis
18	Q_{surf}	the surface runoff from the sub basin on a given day (mm H2O)	Pond/ Wetland	Available	From WB model
19	Q_{gw}	groundwater flow generated in a subbasin on a given day (mm H2O)	Pond/ Wetland		

20	Q_{lat}	lateral flow generated in a sub basin on a given day (mm H2O)	Pond/ Wetland		
21	Area	subbasin area (ha)	Pond/ Wetland	Need to compute	from qgis
22	V_{flowin}	volume of water entering the pond or wetland on a given day	Pond/ Wetland	Need to compute	From 1 and 17 to 21
23	V_{em}	volume of water held in the pond when filled to the emergency spillway (m3 H2O)	Pond	Need to compute	from qgis
24	V_{pr}	volume of water held in the pond when filled to the principal spillway (m3 H2O)	Pond	Need to compute	from qgis
25	SW	the average soil water content in the subbasin (mm H2O)	Pond	Available	From WB model
26	FC	the water content of the sub basin soil at field capacity (mm H2O)	Pond	Available	From WB model
27	V_{nor}	volume of water held in the wetland when filled to the normal water level (m3 H2O)	Wetland	Need to compute	from qgis
28	V_{mx}	volume of water held in the wetland when filled to the maximum water level (m3 H2O)	Wetland	Need to compute	from qgis
29	$V_{flowout}$	volume of water flowing out of the water body during the day (m3 H2O)	Pond/ Wetland	Need to compute	From 23 to 27

8.8 Appendix V

Date	Rainfall(mm)	Runoff(mm)	V(m3)	Vstored(m3)	SA(Ha)	Vpcp(m3)	Vflowin_Runoff(m3)	Vseep(m3)	Vevp(m3)	Voutflow(m3)
07-Jul	1.5	0	0.0457	0.0588	0.0001	0.0019	0.0000	0.0137	0.0013	0.00
08-Jul	0.5	0	0.0457	0.0457	0.0001	0.0005	0.0000	0.0005	0.0000	0.00
09-Jul	9.25	3.262290961	2.8177	0.0457	0.0001	0.0093	2.8216	0.0557	0.0032	0.00
10-Jul	8	2.496812294	1.8309	2.8177	0.0062	0.4930	2.1462	3.4316	0.1945	0.00
11-Jul	0	0	0.0734	1.8309	0.0040	0.0000	0.0000	1.6311	0.1264	0.00
12-Jul	3.25	0.136147518	0.1019	0.0734	0.0002	0.0052	0.1177	0.0894	0.0051	0.00
13-Jul	2	0	0.0457	0.1019	0.0002	0.0045	0.0000	0.0554	0.0052	0.00
14-Jul	5	0.569414419	0.4844	0.0457	0.0001	0.0050	0.4925	0.0557	0.0032	0.00
15-Jul	11	3.9344709	3.3772	0.4844	0.0011	0.1165	3.3997	0.5899	0.0334	0.00
16-Jul	17	8.899057977	7.9268	3.3772	0.0074	1.2558	7.6399	4.1130	0.2331	0.00
17-Jul	0.25	0	0.1825	7.9268	0.0173	0.0433	0.0000	7.2404	0.5472	0.00
18-Jul	0	0	0.0457	0.1825	0.0004	0.0000	0.0000	0.1250	0.0118	0.00
19-Jul	0.25	0	0.0457	0.0457	0.0001	0.0003	0.0000	0.0002	0.0000	0.00
20-Jul	0	0	0.0457	0.0457	0.0001	0.0000	0.0000	0.0000	0.0000	0.00
21-Jul	0.5	0	0.0457	0.0457	0.0001	0.0005	0.0000	0.0005	0.0000	0.00
22-Jul	2.25	0	0.0457	0.0457	0.0001	0.0023	0.0000	0.0021	0.0002	0.00
23-Jul	30.25	17.42071112	15.0845	0.0457	0.0001	0.0303	15.0674	0.0557	0.0032	0.00
24-Jul	16.25	7.27006314	7.1117	15.0845	0.0330	5.3614	6.0776	18.3706	1.0413	0.00
25-Jul	0	0	0.1647	7.1117	0.0156	0.0000	0.0000	6.4560	0.4909	0.00
26-Jul	0	0	0.0457	0.1647	0.0004	0.0000	0.0000	0.1087	0.0103	0.00
27-Jul	1.75	0	0.0457	0.0457	0.0001	0.0018	0.0000	0.0016	0.0002	0.00
28-Jul	0.5	0	0.0457	0.0457	0.0001	0.0005	0.0000	0.0005	0.0000	0.00
29-Jul	15	5.410923845	4.6819	0.0457	0.0001	0.0150	4.6800	0.0557	0.0032	0.00
30-Jul	0	0	0.1227	4.6819	0.0102	0.0000	0.0000	4.2360	0.3232	0.00
31-Jul	0	0	0.0457	0.1227	0.0003	0.0000	0.0000	0.0703	0.0066	0.00
01-Aug	0	0	0.0457	0.0457	0.0001	0.0000	0.0000	0.0000	0.0000	0.00
02-Aug	0	0	0.0457	0.0457	0.0001	0.0000	0.0000	0.0000	0.0000	0.00
03-Aug	0	0	0.0457	0.0457	0.0001	0.0000	0.0000	0.0000	0.0000	0.00

Figure 100 - Volume computations for ponding - excel model

8.8 Appendix VI

date-time	rain	sec_rain	temp_daily_min	temp_hourly_avg	temp_daily_max	rh_hourly_avg	wind_hourly_avg	et0	pet	pri_runoff	infil	aet	sec_runoff	ponding	new_runoff	gw_rech	avail_s
14-06-2018 18:00	0	4	24.6	26.03	32	98	0.2	0.03	0.01	0.31	3.69	0.01	3.34	3.65	0	0	127.
14-06-2018 19:00	0	3.65	24.6	26.1	32	98	0.58	-0.01	0	0.22	3.43	0	3.09	3.31	0	0	127.
14-06-2018 20:00	0	3.31	24.6	25.93	32	98	0.22	-0.01	0	0.15	3.16	0	2.83	2.97	0	0	127.
14-06-2018 21:00	0	2.97	24.6	25.75	32	98	0.13	-0.01	0	0.09	2.89	0	2.56	2.64	0	0	128.
14-06-2018 22:00	0	2.64	24.6	25.57	32	98	0.22	-0.01	0	0.04	2.6	0	2.27	2.31	0	0	128.
14-06-2018 23:00	0	2.31	24.6	25.42	32	98	0.18	-0.01	0	0.01	2.3	0	1.97	1.98	0	0	128.
15-06-2018 00:00	0	1.98	25.3	25.62	33.4	98.1	0.42	-0.01	0	0	1.98	0	1.66	1.66	0	0	129.
15-06-2018 01:00	0	1.66	25.3	25.82	33.4	98	0.93	-0.01	0	0	1.66	0	1.34	1.34	0	0	129.
15-06-2018 02:00	0	1.34	25.3	26.17	33.4	98.1	1.48	-0.01	0	0	1.34	0	1.02	1.02	0	0	129.
15-06-2018 03:00	0	1.02	25.3	25.93	33.4	98	0.98	-0.01	0	0	1.02	0	0.7	0.7	0	0	130.
15-06-2018 04:00	0	0.7	25.3	25.95	33.4	98	1.68	0	0	0	0.7	0	0.38	0.38	0	0	130.
15-06-2018 05:00	0	0.38	25.3	25.95	33.4	98	2.07	0	0	0	0.38	0	0.07	0.07	0	0	130.
15-06-2018 06:00	0	0.07	25.3	25.93	33.4	98	1.67	0.09	0.03	0	0.07	0.03	0	0	0	0	130.
15-06-2018 07:00	0	0	25.3	26.85	33.4	98	1.92	0.22	0.07	0	0	0.07	0	0	0	0	130.
15-06-2018 08:00	0	0	25.3	28	33.4	98	2.57	0.33	0.11	0	0	0.11	0	0	0	0	130.
15-06-2018 09:00	0	0	25.3	29.33	33.4	97.5	2.65	0.44	0.14	0	0	0.14	0	0	0	0	130
15-06-2018 10:00	0	0	25.3	30.57	33.4	92.3	2.8	0.54	0.18	0	0	0.18	0	0	0	0	130.
15-06-2018 11:00	0	0	25.3	31.68	33.4	85.8	3.32	0.61	0.2	0	0	0.2	0	0	0	0	130.
15-06-2018 12:00	0	0	25.3	32.73	33.4	82.5	3.62	0.64	0.21	0	0	0.21	0	0	0	0	130.
15-06-2018 13:00	0	0	25.3	31.95	33.4	83.2	3.55	0.61	0.2	0	0	0.2	0	0	0	0	129.
15-06-2018 14:00	0	0	25.3	27.32	33.4	98	3.72	0.44	0.14	0	0	0.14	0	0	0	0	129.
15-06-2018 15:00	0	0	25.3	27.08	33.4	98	2.28	0.39	0.13	0	0	0.13	0	0	0	0	129.
15-06-2018 16:00	0	0	25.3	27.72	33.4	98	1.57	0.3	0.1	0	0	0.1	0	0	0	0	129.
15-06-2018 17:00	0	0	25.3	27.65	33.4	98	2.03	0.17	0.06	0	0	0.06	0	0	0	0	129.
15-06-2018 18:00	0	0	25.3	27.03	33.4	98	2.07	0.04	0.01	0	0	0.01	0	0	0	0	129.

Figure 101 - Hourly Water balance with ponding constant