Interim Report on Model Validation: Kharif

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1. Introduction

1.1 Motivation

The core objective of the model validation exercise is to test and enhance the soundness of the model. This has been achieved partly over the last two years, through continuous engagements and interactions with PMU, World Bank experts, external agencies and farmer narratives. During the last year, validation exercise for surface runoff was attempted in the kharif (Monsoon 2020) season in selected catchments of Hingoli and Washim districts. However model validation was not the core focus of the third MoU and it was further met with many challenges such as Covid-19 outbreak and the consequent restrictions on travel, limitations on holding meetings in the villages, difficulties in procurement and installation of equipment etc. The limited results achieved for the surface runoff were termed as satisfactory by the World Bank (WB) experts and PMU. It was further suggested by the experts from WB and the PMU that the model validation exercise may be extended to a few more locations and should be one of the important components of MoU IV.

1.2 Background

The deliverables planned for the model validation component of MoU IV consist of three reports viz. Interim Report on fieldwork for Model Validation, Interim Report on Model Validation (Kharif), and Closure (Final) Report on Model Validation. Out of these reports, first report i.e. Interim Report on fieldwork for Model Validation was submitted to the PMU at the end of phase II of this MoU. It has covered the motivation, objectives, tentative plan and methodology for the overall model validation exercise. The focus however was to discuss the methodology and its execution in terms of selection of study area, installation of different instruments and fieldwork conducted during the monsoon in detail.

1.3 Scope of the report

This report, titled ‘Interim Report on Model Validation: Kharif’ is the second one in the model validation series which will be followed by the final closure report on model validation. This report builds on the previous report and is aimed at focusing on the model results in the study area at the end of kharif season. The first chapter provides background, details out the scope and organization of this report.

The second chapter covers the conceptual validation framework and the strategy for execution of validation methods proposed for different model components at appropriate scale. It further summarizes key information and attributes of the different instruments installed and subsequent processing required for the data obtained from these measuring systems. The third chapter discusses data handling primarily for the data from different instruments including the data formats, data cleaning and data processing.

The fourth chapter documents the model results for both at farm-level as well as at the regional level, and the comparison of the same with the corresponding field measurements and calculations carried out by the IITB. The fifth chapter summarizes the findings of the exercise, future work and recommendations.

2. Validation Methodology

The overall strategy for the model validation was to simultaneously measure and monitor model outputs such as runoff, groundwater recharge, soil moisture and actual evapotranspiration (AET) with reasonable accuracy and satisfactory standards. The detailed methodology and its rationale is documented in the first report on model validation titled ‘Interim Report on Fieldwork for Model Validation’, submitted to PMU in Phase II of MoU IV. In this chapter we discuss the method proposed for validation of each of the four model outputs at an appropriate scale.

2.1 The water budget model

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 based on the following mass-conservation equation –

$$P(t) = Q(t) + GW(t) + AET(t) + [SM(t) - SM(t-1)] \qquad \text{- eqn 1}$$

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 is the actual evapotranspiration and [SM(t) - SM(t-1)] is the change in soil moisture stock during the time-step t.

Equation 1 computes water balance for a single point and is computed for each hour based on the hourly weather data and other input datasets such as soil, land-use, terrain, crop-properties etc. This equation is run in an iterative manner for the whole monsoon season to compute the total surface runoff, total crop water uptake, total groundwater recharge and soil moisture stock left at the end of monsoon. This hourly point-wise model is run as a plugin on the GIS (Geographical Information Systems) platform on a grid of points (200mx200m resolution) to aggregate the point-wise results to regions of choice (which may be zones, villages or clusters). Thus, the above equation, when aggregated temporally (over the whole Kharif season) and spatially (over the whole region) gives,

$$P = Q + GW + kharifAET + delSM \qquad \text{- eqn 2}$$

$$Qout = Q - Qi \qquad \text{- eqn 3}$$

$$\text{surplus or deficit} = (delSM + GW + Qi) – (rabiPET + summPET) \qquad \text{- eqn 4}$$

The output of the model is the total water balance for the region for the kharif season. 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 the region boundary, GW is total groundwater recharge during the monsoon, kharifAET is the total amount of water leaving the region through evapotranspiration and delSM is the change in soil moisture during monsoon.

(GW + delSM + Qi) in equation 4 is the total water available at the end of the kharif season. (rabiPET + summPET) is the total water demand for the rabi and summer seasons.

Thus, equations 3 and 4 are very important for the local planners and the VCRMC at the village level for planning supply-side and demand-side interventions.

2.2 Conceptual validation framework

In order to design the validation framework for the PoCRA water budget model, it is important to divide the model into its two main computational components:

1. The core model i.e. point-wise water balance computation for the monsoon season
2. Regional aggregation i.e. running the model on a grid of points over the region of interest and producing the regional water balance

The core point model is essentially a 1-dimensional mass conservation equation as shown above in eqn 1. which is widely used all over the world in different geographies and its scientific basis has already been proven in the SWAT framework. The equation considers the most important phenomena which control the infiltration, movement and availability of water below the soil layer at different times. Thus, if all the input datasets required to compute the equation are fairly accurate, the results of the water balance equation would reasonably simulate the reality.

The point model results are simply arithmetically aggregated to compute regional water budgets for zones / villages. While computing the regional water budget, the key input datasets apart from the ones used for the point model are the ones which correctly provide the spatial geography in terms of differences in soil texture, depth, land-use, crops, land-cover and weather. Thus, the results of the regional water budget depend primarily on these spatial inputs.

Regarding translation of point model results to a region, there are few points which need to be considered. While soil moisture and crop water uptake (i.e. AET) are point-level (or farm-level) stocks which typically do not move laterally, groundwater and surface runoff act as stocks as well as flows i.e. they move laterally and across farms / villages. So, hydrologically speaking, the simulation of these movements is necessary while aggregating the stocks for a region.

In the current aggregation, this is not considered. However, this has been tackled in the MoU IV and work is under progress to incorporate models for surface water and groundwater movements across zones and villages within the cluster. At the same time, improvements in the point model to incorporate aquifer properties and to simulate the saturation of aquifers are being carried out in the current MoU.

Our validation strategy is to first validate the point model. This would ideally mean comparing each and every estimated component of the point water balance equation shown in eqn 1 with the observed / measured value on the ground for a specified period.

[Henceforth in the validation exercise, we treat different farm plots considered in the study as single points in the point model. This entails an assumption that all the properties such as soils, soil depths, crop, rainfall etc. for a given farm plot are the same throughout the farm.]

In the farm-level water balance as shown in equation 1, the left-hand side i.e. rainfall for the given period is the input data, along with other input data such as soil properties, crop parameters, crop, terrain etc. while all the components on the right hand side i.e. surface runoff, groundwater recharge, change in soil moisture and crop water uptake (i.e. crop AET) are the key outputs which need to be observed / measured for the specified farm of specified size.

2.3 Validation strategy

Now let us devise the strategy for measuring the output components.

i. Surface runoff for the point model will be measured at the outlet of the farm by installing a v-notch with a water level sensor for continuous monitoring of the stage. The water level (stage) for each time interval will be converted to discharge (volume of water flowing out of the farm) for the respective interval by using the standard equation for the v-notch. This will be then aggregated over the total operational period to compute runoff from the farm.

ii. The soil moisture will be monitored by installing soil moisture sensors in the farm. Soil moisture will be measured at regular intervals and different depths according to soil and root depths in the farm. The percent saturation values provided by the soil moisture sensors will be converted to volumetric mm values to compare with the soil moisture values estimated by the model.

iii. The proxy for groundwater recharge may be taken as the water levels in the nearby well. The groundwater recharge may be computed using the water-table fluctuation (WTF) method used by GSDA for the given period.

iv. AET measurement requires more elaborate methods and costly equipment. Also, the crop PET and crop AET values for different geographies in the PoCRA region have already been verified by the experts from the State Agricultural University, Rahuri and have been accepted to fall in the reasonable range. Hence, AET values will not be measured at the farm level and only farmers' narratives on crop stress during the dry spells will be considered as the proxy for AET measurement.

Now, in order to accurately simulate the farm conditions, the inputs to the point balance equation need to accurately represent the farm conditions. Following are the key input datasets for the point model.

Table 1: Point model input summary

Input	Source	Soundness of input data
Soil parameters - Field Capacity, - Wilting Point, - Saturation Point, - Saturated hydraulic conductivity, - Bulk density	FAO for the given soil texture class	Globally accepted values. However not tested for local soils.
Soil layer depth	Soil depth class for given point as per MRSAC soil map	MRSAC soil maps were found to be reasonably correct at some of the locations and incorrect at some other locations in the PoCRA region.
Crop parameters - crop duration, - crop growth stages and corresponding Kc values - Depletion factor - root depth	FAO	Globally accepted values. Fairly suit local conditions. PET and AET values for different crops using these values have been approved by SAUs.

Hourly weather data - rainfall, - temperature, - wind velocity, - relative humidity etc.	Skymet weather stations	Fairly high density of skymet AWS i.e. around 1500 in PoCRA region provide reasonable accuracy of weather data. However, for some of the weather stations, the problem of missing weather data has been reported by the IITB team.
Slope at the given point	Terrain data comes from DEM provided by SRTM.	SRTM data resolution is 30m x 30m which is reasonable.
SCS Runoff Curve number	USDA	Runoff Curve numbers not available for local conditions.
Land-use and Land-cover	MRSAC land-use land-cover map	Latest Land-cover data is available for the year 2015-16.

So, with all these various input datasets, the task of validating the point model essentially is to demonstrate that if all the input datasets are fairly accurate, the outputs i.e. individual components of the equation 1 above, reasonably replicate the reality.

Among all the inputs, weather data and the soil properties are the most sensitive inputs. Within soil properties, the key data is of the soil layer depth, saturated hydraulic conductivity, field capacity, permanent wilting point, saturation point and available water content of the soil. Furthermore, as these properties vary according to the soil texture class, the accuracy of the soil maps which provide the spatial expanse of different soil texture and depth classes also turn out to be very critical and sensitive.

Gaps and inaccuracies in the secondary data such as soil texture and soil depth from the MRSAC maps have been already reported during earlier MoUs. Thus, this time it was decided to use all the relevant soil properties as per the lab soil tests for the samples in farms selected for point model validation. It was decided to perform these tests at NBSS, Nagpur.

Also, during the previous validation exercise, it was noticed that the Skymet weather data was missing for a few hours on several days during the monsoon season. Such gaps in the rainfall data lead to inaccurate model results. Hence, a rain gauge was installed in the selected catchment to get more accurate rainfall data. Other input data such as runoff curve numbers, various crop properties etc. were to be taken directly from the existing secondary data.

Thus, the key steps to be followed while formulating the validation plan are as follows:

1. Point model validation –

a. Devise plan for measurement of inputs [rainfall, soil texture, soil properties, soil depth, crop sown, sowing date].

b. Devise plan for measurement of outputs [surface runoff generated on the farm, soil moisture, crop stress by visual inspection and farmer narratives, well levels as proxy to groundwater recharge].

c. Clean, consolidate and process the measured data for output components [convert the sensor output data to formats suitable for comparing the model results].

d. Run the hourly point model using the primary data for the inputs measured and the existing secondary data for the remaining inputs.

e. Compare the estimated values with the measured values for the output components.

f. Check key trends in the measured outputs and verify them with the trends in the model results.

2. Regional water balance validation –

a. Select a regional unit for validation [catchment in this case].

b. Devise a plan for specifying inputs for the decided regions [existing MRSAC maps].

c. Devise a plan for measurement of water balance components at the regional level [water level sensors at the outlet of the catchment (on a CNB) for surface runoff, monitoring of well levels of selected wells as a proxy for groundwater recharge].

d. Run the regional water budget model (i.e. aggregation of point model) at the regional level with the specified inputs.

e. Compare the estimates for the model outputs with the measured ones for the specified episodes during monsoon season.
f. Check key trends in the measured outputs and compare them with the trends in the model results.

The table below lists all the important water balance model components along with the measurement strategy for point as well as regional model validation.

Table 2: Water balance model components and strategy for validation

Component	Type	Point model	Regional model
Soil	Input	Collect soil samples for farms selected for point model validation. Get all the critical soil properties tested from NBSS lab in Nagpur.	Extrapolate the soil properties to existing soil-texture class polygons as indicated by MRSAC maps. Use soil depth as observed on the field.
Crop	Input	Use FAO properties as they are for the crop sown on the selected farm	Use FAO properties as they are for the observed cropping pattern in the catchment
Weather	Input	Use the Rain Gauge data for rainfall and skymet AWS data for the other weather data	Use the Rain Gauge data for rainfall and skymet AWS data for the other weather data
Terrain	Input	Use DEM and slope and existing SCS runoff curve numbers	Use DEM and slope and existing SCS runoff curve numbers
Surface runoff	Output	Measured at the farm outlet through V-notch	Measured at the catchment outlet using water level sensors installed over CNBs

GW recharge	Output	Nearby well water level to be used for computation of GW recharge by WTF method as proxy	Average well water levels in the catchment to be used for computation of GW recharge by WTF method as proxy
Soil moisture	Output	Measured at the farm level for different depths through soil moisture sensors	Not estimated for the catchment. The moisture measured at the farm level is not extrapolated to catchment level.
AET	Output	Not measured. Farmer narratives used as proxy for crop water stress	Not measured. Farmer narratives used as proxy for crop water stress

2.3.1. Expected results from validation

- The model results for different water balance components at different scales such as surface runoff and soil moisture at farm level and surface runoff at catchment level should reasonably match (i.e. +/- 20%) the observed /measured values.
- The model should demonstrate the ability to explain certain climate-related and biophysical phenomena (such as impact of rainfall patterns and dry spells / wet-spells on different soil types and terrain) which are critical in terms of planning and management of water resources required for improving climate resilience at the village / farm level.
- The model results, especially the crop PET, AET and crop water deficit values should be consistent with the farmer narratives.

2.4. Operational framework

This section discusses the execution part of the methodology. It covers the procedures followed for selection of the study areas, site selection for installation of different instruments, preparatory and installation works involved for the same.

2.4.1 Selection of study areas

The main focus while selecting the study areas was to ensure that the selected areas fairly represented the PoCRA region. This representativeness was based on the coverage of the different attributes used as inputs for the model which includes rainfall, soil texture and depth, terrain and land use. The coverage of these attributes is also important because they affect different model outputs especially runoff, groundwater recharge and soil moisture. The selection of the study area for the model validation exercise firstly involved selection of the potential PoCRA clusters and then selecting appropriate catchments from these clusters.

2.4.2 Cluster selection

Based on the past experience of the IITB team on model validation and the feedback from the PMU, about 40 potential clusters from the PoCRA region were shortlisted. These clusters were paired up in about 28 groups using different combinations with two clusters in each group which can be operated from the same base location for the IITB team. The pairing was primarily based on the logistics for the fieldwork to be conducted in these clusters. Given the uncertainty associated with the restrictions imposed due to the pandemic and considering factors like connectivity between the clusters and time required for the travel, an attempt was made to pair those clusters which are not far away from each other. These clusters however needed to be from different taluka and preferentially from different districts to have better administrative coverage.

One of the key factors considered for cluster selection was rainfall received by these clusters wherein normal rainfall and rainfall for the last 5 years were compared to check if the clusters in a pair complement each other and do not show similar pattern. These selected clusters were checked for adequate diversity and coverage of the key attributes such as soil types, and land use. Considering above points and a suggestion of PMU to have study areas from both Marathwada and Vidarbha region, two clusters each from the respective regions were selected. Table 4 lists the selected clusters and Figure 1 shows location of these locations in the project region. Ahmedpur and Karnja were the base locations for the clusters from Marathwada and Vidarbha region respectively where two field teams stayed for about four months for the fieldwork during the kharif season.

Table 3 : Selected clusters for Model Validation

Cluster	District	Taluka
511_gv-101_03	Nanded	Loha
524_mr-47_05	Latur	Ahmedpur
510_wrb-1a_01	Yavatmal	Ner
502_ptkp-1_03	Washim	Karanja

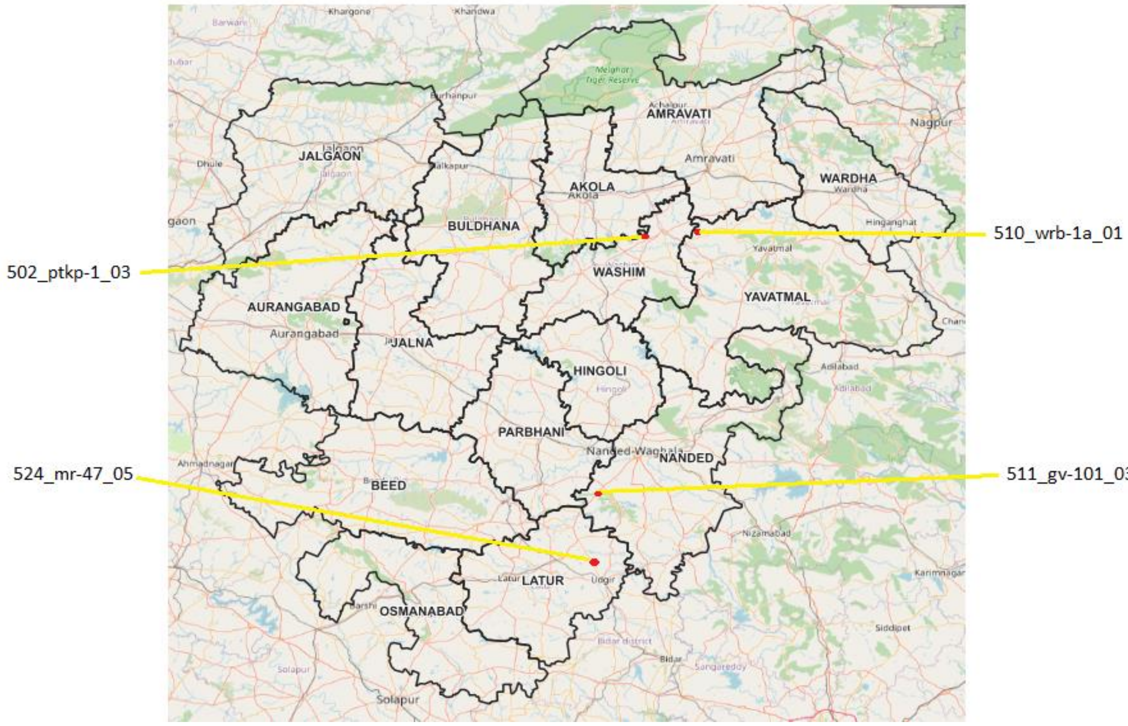

Figure 1: Location of the selected clusters in PoCRA region

2.4.3 Selection of the catchments

Given the large size of the clusters (more than ten thousand hectares in most of the cases) and complications associated with the model validation exercise, it was not possible to select a complete cluster as the study area. Therefore, only part of the cluster was selected for the model validation. This selection was based on the attributes of soil, slope, drainage and land use. The objective was to strike an appropriate balance of the combination of these attributes ensuring representativeness of the study area and considering various practical limiting conditions. Table 4 lists the attributes and their respective variations considered for the catchment selection among the available options.

Based on study of different regions in the clusters for the aforementioned attributes, catchments were selected. Although the idea was to select four main catchments and a few subcatchments for the respective catchments, suitable main catchment could not be finalized in Karanja cluster considering various constraints on the field. Instead, two independent small catchments which can be considered equivalent to subcatchments were selected. The details for the selected catchments such as soil maps, drainage and LULC are documented in the previous report titled 'Interim Report on Fieldwork for Model Validation'.

Table 4: Catchment attributes considered while selection

Catchment Attribute	Variation Considered
Rainfall	High, Moderate and Poor rainfall
Soil Type	Different soil textures with combinations of different soil depths such as clayey very deep, clayey deep, clay loam shallow, gravelly clay deep etc.
Land use and land cover	Different combination of land use and landcover in terms of completely agricultural area and mix of agricultural and non agricultural area, percentage of only kharif crop and 2-3 crops
Terrain	Relatively flat, moderately hilly terrain

Once catchments were finalized the next task was to select suitable locations for installation of different instruments. The details of all the instruments installed, along with their need and importance, their working principle, provisions for data logging and visualization, overall number and location of the instruments installed along with the preparatory work required for installation, challenges faced have been explained in a detailed manner in the 'Interim Report on Fieldwork for Model Validation' submitted during the Phase II in the current MoU. Table 5 summarizes the number of instruments installed in different study clusters.

Table 5: Clusterwise summary for installed instruments

Cluster (Taluka)	Villages	No. of rain gauges	No. of water level monitoring systems	No. of soil moisture monitoring systems	No. of V-notches
511_gv-101_03 (Loha)	Mangrul, Polewadi, Berali Kh.	1	7	4	2
524_mr-47_05 (Ahmedpur)	Morewadi, Chobali, Gadewadi	1	6	2	2
510_wrb-1a_01 (Ner)	Adgaon, Karkheda, Bhalki, Umartha	1	6	4	2
502_ptkp-1_03 (Karanja)	Wai Pr. Karanja, Lohara	0	2	2	1

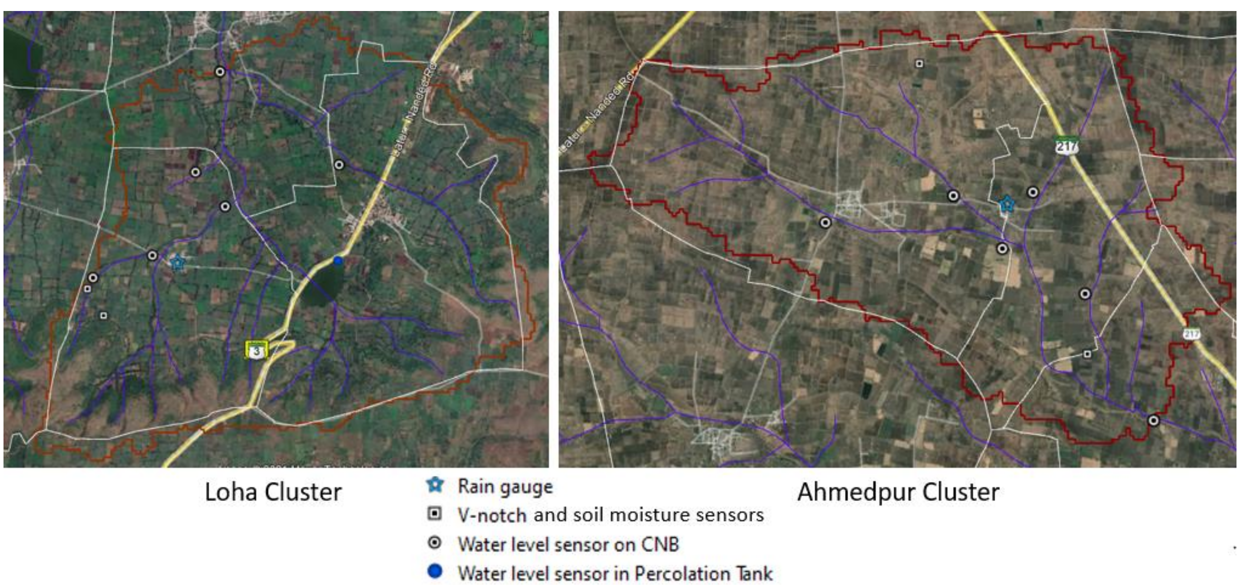

Figure 2: Catchments and sensor locations for clusters from Marathwada region

Figure 2 and Figure 3 show locations of the different instruments installed in the Marathwada and Vidarbha region respectively.

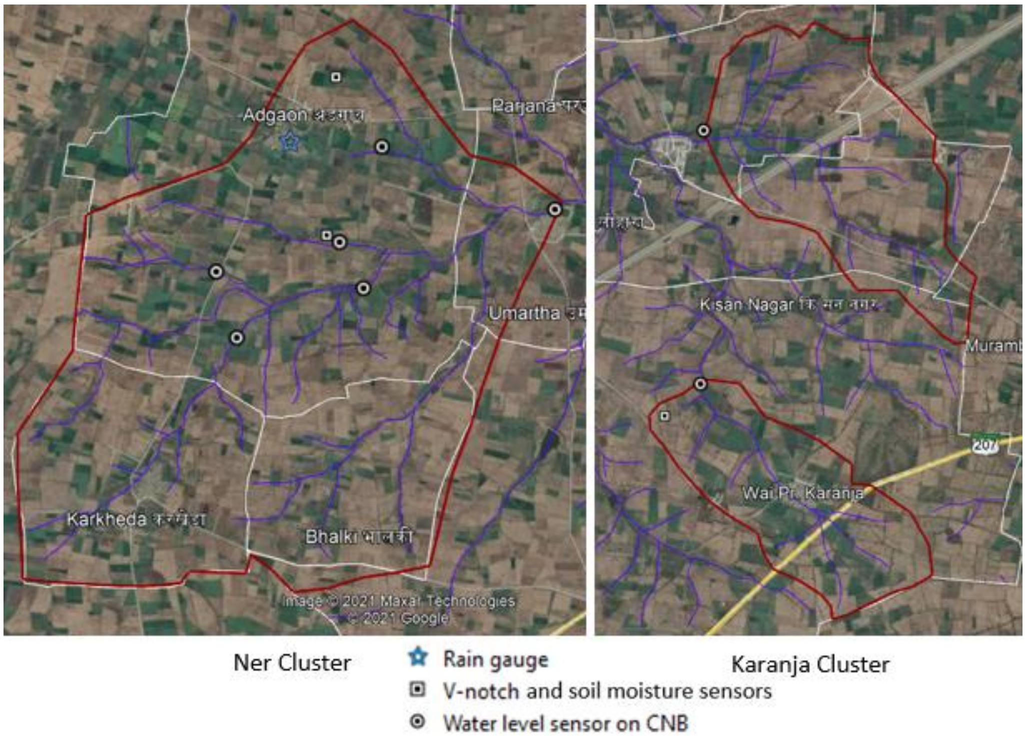

Figure 3: Catchments and sensor locations for clusters from Vidarbha region

3. Data Handling

This chapter covers data handling and data analysis for the data from different instruments installed in the field such as rain gauge, water level sensors and soil moisture monitoring system.

3.1 Rain gauge

3.1.1. Data formats and processing

The rainfall data fetched from the rain gauge have a time stamped record of temperature and rainfall received for the set logging interval. A record (in the form of a unique row) is maintained at the end of logging interval and also for every tipping of the bucket (or the cup, as may be the case). However, to use this data as an input, it needs to be converted in the hourly rainfall data format where a unique row indicates the rainfall received during that hour.

A	B	C	D	E
data2	data1	loggerUid	logDateTime	dateTime
24.19	0	E6DB517E5734	1629333000	19,08,21 6:00
24.19	0	E6DB517E5734	1629333900	19,08,21 6:15
24.13	0	E6DB517E5734	1629334800	19,08,21 6:30
24	0	E6DB517E5734	1629335700	19,08,21 6:45
24	0	E6DB517E5734	1629336600	19,08,21 7:00
24	0	E6DB517E5734	1629337500	19,08,21 7:15
24	0	E6DB517E5734	1629338400	19,08,21 7:30
24	0	E6DB517E5734	1629339300	19,08,21 7:45
23.94	0	E6DB517E5734	1629340200	19,08,21 8:00
23.94	0	E6DB517E5734	1629341100	19,08,21 8:15
23.94	0	E6DB517E5734	1629342000	19,08,21 8:30
24	0.2	E6DB517E5734	1629342582	19,08,21 8:39
24	0.2	E6DB517E5734	1629342900	19,08,21 8:45
24	0.2	E6DB517E5734	1629343036	19,08,21 8:47
24	0.4	E6DB517E5734	1629343489	19,08,21 8:54
24	0.4	E6DB517E5734	1629343800	19,08,21 9:00
24	0.2	E6DB517E5734	1629344368	19,08,21 9:09
24	0.2	E6DB517E5734	1629344700	19,08,21 9:15
23.94	0	E6DB517E5734	1629345600	19,08,21 9:30
24	0.2	E6DB517E5734	1629346339	19,08,21 9:42
24	0.2	E6DB517E5734	1629346500	19,08,21 9:45
24	0	E6DB517E5734	1629347400	19,08,21 10:00

(a)

A	B	C
Date	Hour	Hourly_rainfall
8,19,21	0	0
8,19,21	1	0
8,19,21	2	0
8,19,21	3	0.4
8,19,21	4	1.2
8,19,21	5	1
8,19,21	6	0
8,19,21	7	0
8,19,21	8	0.2
8,19,21	9	0.8
8,19,21	10	0
8,19,21	11	0
8,19,21	12	0
8,19,21	13	0.2
8,19,21	14	0
8,19,21	15	0.2
8,19,21	16	0.2
8,19,21	17	0
8,19,21	18	0
8,19,21	19	0
8,19,21	20	0
8,19,21	21	0

(b)

Figure 4: Snippets of sample rainfall data fetched from the rain gauge and ready to use for model

The fetched data was converted to required format by aggregating the rainfall recorded for the set interval (which was fifteen minutes in our case) at each hour. Figure 4 shows the sample snippets of the data fetched from the rain gauge and processed data which can be used as input for the model.

3.1.2 Timeline

Although three rain gauges were successfully installed in the study areas as explained in the previous report, one of the rain gauges got damaged (located in the Ahmedpur cluster). This rain gauge did record data for a couple of rain events however the data was very inadequate and hence the data from the nearest skymet automatic weather station was used for this catchment. For the rest of the two rain gauges, after installation they were operational throughout the study period except for a day which was not the rainy day in either case. The only limitation being these rain gauges were installed in the second week of July owing to administrative and logistic delay due to prevailing pandemic as explained earlier.

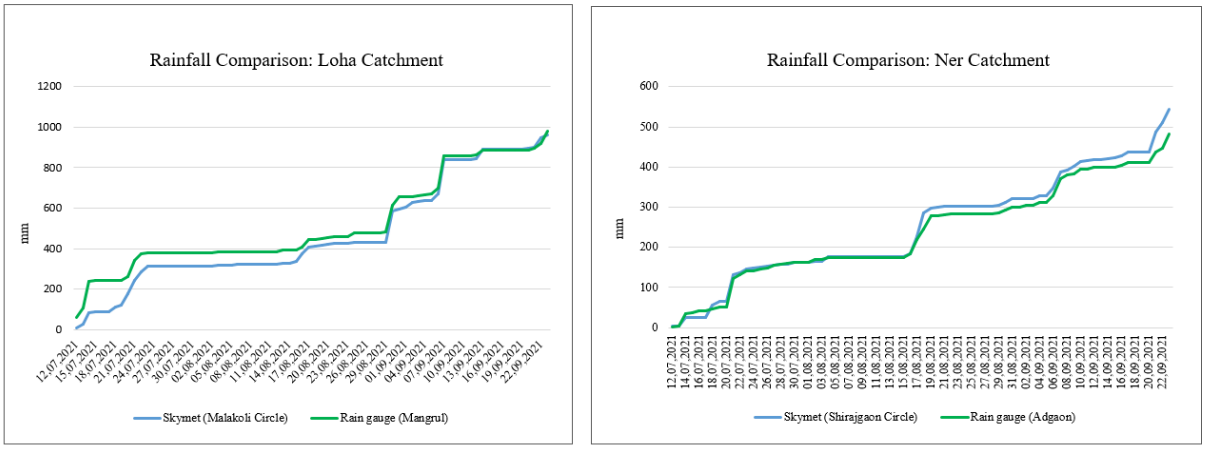

Figure 5: Comparison for the installed rain gauges with the nearest skymet weather stations for Loha and Ner catchments

Figure 5 shows the comparison of the rainfall recorded by these installed rain gauges and the nearest skymet weather station for the period starting from the date of installation till the last date considered for analysis of this study. As can be seen, from the graph, for the Loha catchment the total rainfall very much matches with the corresponding skymet weather station, however for the Ner catchment there is considerable variation of about 100 mm for the said period.

3.2 Water level sensors

The water level sensors were used at CNBs (and percolation tank) for measurement of runoff from the catchment and at V-notches for measurement of the farm runoff. For both the types of locations, the data cleaning process followed was the same. The only slight difference being in the processing of the data where the formula used for the computation of water flown was different.

3.2.1. Data format and data cleaning

The water level sensor data fetched from the sensors have a time stamped record of water height, change in water height after the previous record, depth to water, change in depth to water after the previous record (all in meters) and percentage full. The sensor records the water level at regular intervals and in case of the change in water level as may be the case depending on the logging settings. Ultrasonic water level sensors deployed with the regular sensors at the selected locations also provide the data in the same format.

For our use, the only important parameter from this data is water height along with its timestamp. Thus we use two columns from the fetched data viz. time and water height. This data was first cleaned to remove any abnormal spikes recorded during maintenance, repair and testing of the sensors, due to rodents and other obstacles etc. while selecting appropriate records of higher and lower sensors. This was done based on the field observations by the team members during regular visits to the site for monitoring and maintenance, farmers narratives on the runoff events and checking consistency of the sensor data with the rainfall. It was observed that the data recorded during the runoff events was reasonably accurate for almost all of the sensors and it was during lean period that the unusual spikes were recorded which needed the cleaning

3.2.2. Timeline

For CNBs

After the exercise of data cleaning was performed for all the 21 sensor sites, some of these sensors were excluded from the analysis. Given the need for repair and maintenance for K1 and K2 sites which were frequently down after a couple of weeks from installation, requirement of regular visits to these sites for regular monitoring and repair, and limiting conditions of optimizing runoff measurements during runoff events both the sensor sites in the Karanja cluster were eventually dropped from the further analysis due to poor data. This was also because the IITB team could not install the rain gauge in this cluster as discussed in the earlier report and this posed challenges in validating different farmers' narratives on the rainfall and selected runoff events.

Similarly, in the case of Ahmedpur cluster, A8 and A3 were not considered for the analysis. For A8, which was the gated CNB and also happened to be the final outlet of the catchment, the sensor RTU was stolen. It took about a month’s time to reinstall the RTU after the replacement was available. It was planned to conduct multiple current meter readings at this location to get the stage discharge relation for a fixed reference point as for this site broad crested weir formula could not be used owing to gated structure of CNB. However, due to the difficulties in accessing the site (due to heavy water logging not just in the neighboring farms but also the connecting earthen road) for flow measurements, it was not possible to conduct measurements using the current meter. Thus A8 was not considered for the analysis owing to data inadequacy.

Whereas for A3, the data fetched was found to be of poor quality especially during the time of runoff event. This site did not witness any runoff event[1] except the one in June prior to sensor installation and in September when the site was partly down due to technical issues. The data fetched during the main event also showed some inconsistencies possibly due to damage by rodents and other weather conditions.

Similarly, for the Loha cluster, sensor site L4 was not considered due to poor data. The site was down multiple times and even repeated repair works could not yield reliable data. Thus out of the 21 sites 5 sites were dropped from the further analysis either due to inadequate data or poor data. The rest 16 systems were considered for further data processing out of which 15 were located on the CNB and one was in a percolation tank in Loha catchment.

Table 6: Summary for water level monitoring instruments considered for analysis at catchments

Sr No.	Catchment	Cluster Catchment	Village Location	Start Date	End Date
1	A2	Ahmedpur	Chobali	25/06/21	23/09/21
2	A4	Ahmedpur	Morewadi	05/07/21	23/09/21
3	A5	Ahmedpur	Morewadi	25/06/21	23/09/21
4	A6	Ahmedpur	Morewadi	25/06/21	23/09/21
5	L1	Loha	Mangrul	23/06/21	23/09/21
6	L2	Loha	Mangrul	23/06/21	23/09/21
7	L3	Loha	Mangrul	23/06/21	22/09/21
8	L5	Loha	Polewadi	23/06/21	23/09/21
9	L6	Loha	Mangrul	23/06/21	23/09/21
10	N1	Ner	Adgaon	24/06/21	23/09/21
11	N2	Ner	Adgaon	20/06/21	23/09/21
12	N3	Ner	Adgaon	20/06/21	23/09/21

[1] This was attributed to the presence of the percolation tank on the upstream of this site which did not allow runoff to flow in the stream over CNB by temporarily arresting runoff generated from the catchment. However this arrested runoff was not stored in the tank for longer duration and it used to get emptied in a short period of time say in less than a span of four five days due to very high percolation rate unlike the percolation tank located on the upstream of site A2.

Sr No.	Catchment	Cluster Catchment	Village Location	Start Date	End Date
13	N4	Ner	Adgaon	24/06/21	23/09/21
14	N5	Ner	Adgaon	07/09/21	23/09/21
15	N6	Ner	Umaratha	24/06/21	23/09/21

The most of these 16 sites considered for the analysis were functional after the installation throughout the study period (upto last week of September) and accordingly the rainfall data during this period was considered for analysis. In a couple of cases such as N5 (where sensor was washed away), and L7 (where the sensor got damaged when water entered RTU after the percolation tank started overflowing) the rainfall was considered only for the period when these sites were operational.

For V-notches

Unlike CNBs, the water level sensors installed on V-notch were significantly delayed. It was partly because of the unavailability of the sensor but mainly due to the challenges in finding an appropriate site for the V-notch installation which can be reasonably representative and with desired attributes. Also, the fabrication of V-notch as per the norms and actual installation posed many challenges. Ideally, V-notch should be installed in the cemented channel to ensure stability of the structure, however given the overall delay in delivery of the instrument and fabrication, the monsoon was almost midway. This meant we could not execute the V-notch in the cemented channel as curing could have been an issue and farmers who agreed for the installation were also hesitant for any cement construction especially in the mid season after sowing.

Although all of the six installed V-notches could withstand a couple of minor runoff events, later due to high pressure exerted by the flowing water during peak runoff events and lack of rigid support the water started leaking from the sideways. Therefore even though data was recorded by the sensors, it could not be used for the analysis and hence discarded. Thus data for only V3, and V5 sites were considered for the analysis out of the six V-notch sites which could withstand the farm runoff without letting water seep through sideways.

3.2.3. Data processing

For the CNB sites, once the data was cleaned, the water height data recorded by the sensor was used to calculate height of the water flowing above the CNB. The water flowing above CNB was computed using simple calibration based on the distance between the sensor bottom and that of the CNB wall (water flowing above CNB = water height recorded by sensor - sensor bottom below CNB wall). This distance was decided at the time of the installation of the overall setup based on the range of the sensor, site specific conditions and farmers' narratives on the maximum water height that may reach during peak runoff events.

The height of water flowing above CNB was used in a broad crested weir formula to compute discharge corresponding to this water height as below.

$$Q = 1.705 * C_d * L * H^{\wedge(1.5)}$$

where, Q = Discharge in expressed in m^3/s,

C_d = Coefficient of discharge,

L = Length of the CNB in meters, and

H = Height of the water flowing above CNB in meters

This discharge for the corresponding water height was aggregated over a period of time to compute the water flown in two steps. First, for each water height, a time period (in seconds) was considered to compute the water flown during that time. This period was computed as a time difference between two consecutive time records for the water levels were recorded by the sensor. Therefore, for a given time step, water flown was calculated as multiplication of the discharge (in m^3/s) for a particular height and time period (in seconds). In the second step, the water flown for the corresponding water height of all the entries was added up to get total water flown. This was then converted to thousand cubic meters (TCM) and finally to mm based on the catchment area.

F2729 =IF(E2729>0, (0.62*1.705*15*(E2729)^(1.5)), 0)

	A	B	C	D	E	F	G
1	Sr. No.	DateTime, GMT+05:30	Time (s)	Water Height (m)	Water level height above CNB (m)	Discharge (m3/s)	Water Flown or Runoff (m3)
2710	2709	21 Aug 2021 12:38:31 PM	1169	0.25	-0.02	0	0
2711	2710	21 Aug 2021 01:00:53 PM	1342	0.25	-0.02	0	0
2712	2711	21 Aug 2021 01:42:37 PM	2504	0.25	-0.02	0	0
2713	2712	21 Aug 2021 02:04:56 PM	1339	0.25	-0.02	0	0
2714	2713	21 Aug 2021 02:26:50 PM	1314	0.25	-0.02	0	0
2715	2714	21 Aug 2021 02:48:39 PM	1309	0.25	-0.02	0	0
2716	2715	21 Aug 2021 03:32:16 PM	2617	0.25	-0.02	0	0
2717	2716	21 Aug 2021 04:24:59 PM	3163	0.25	-0.02	0	0
2718	2717	21 Aug 2021 04:33:52 PM	533	0.25	-0.02	0	0
2719	2718	21 Aug 2021 05:13:04 PM	2352	0.25	-0.02	0	0
2720	2719	21 Aug 2021 05:26:08 PM	784	0.25	-0.02	0	0
2721	2720	21 Aug 2021 06:03:37 PM	2249	0.3	0.03	0.0823928	0
2722	2721	21 Aug 2021 06:31:34 PM	1677	0.3	0.03	0.0823928	138.1727104
2723	2722	21 Aug 2021 07:17:26 PM	2752	0.3	0.03	0.0823928	226.7449605
2724	2723	21 Aug 2021 08:01:35 PM	2649	0.3	0.03	0.0823928	218.2585031
2725	2724	21 Aug 2021 08:46:01 PM	2666	0.3	0.03	0.0823928	219.6591805
2726	2725	21 Aug 2021 09:10:58 PM	1497	0.3	0.03	0.0823928	123.3420079
2727	2726	21 Aug 2021 09:55:11 PM	2653	0.3	0.03	0.0823928	218.5880743
2728	2727	21 Aug 2021 10:53:44 PM	3513	0.3	0.03	0.0823928	289.4458744
2729	2728	21 Aug 2021 11:14:52 PM	1268	0.3	0.03	0.0823928	104.4740589

Figure 6 : Snippet of the data processing for A2 site

Except in case of L1 site, where the CNB had a V cut, the broad crested weir formula could not be used. Instead, current meter readings were used to compute the stage discharge relationship for the cut which was 80 cm in height. This relationship was used upto the CNB wall i.e. 80 cm and above that, the broad crested weir formula was used in addition to stage discharge at 80 cm. This discharge computed for each of the water heights recorded was then aggregated over the time period as was done for the other sites.

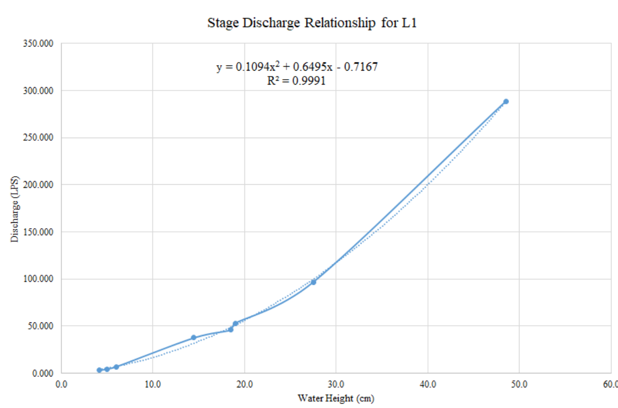

Figure 7 : Stage Discharge Relationship for L1

In case of V-notch sites, the height of water water flowing from the notch was calculated using sensor readings and distance between the the point of notch (also known as neck of the V-notch which is lowest point of the weir opening) and sensor bottom below the point of notch. This height of water flowing from the notch point was then used to compute the discharge for the corresponding water height using the following formula.

$$Q = 2.36 * C_d * L * H^{(2.5)}$$

Where,
Cd is the coefficient of discharge,
L is the width of the stream channel in meters,
H is the water column flowing above the top of the notch point (in meters)
(source- Flow in Open Channels – Subramanya 2019)

This discharge for the corresponding water height was aggregated in the same manner as done for the water level sensors on CNB, explained earlier in this section and expressed in mm.

For CNBs and V-notches, the water flown expressed in mm was later used for comparing the runoff estimates by the IITB water balance model. For further understanding of the event wise runoff with respect to the rainfall, the water flown from the catchment expressed in mm, was appropriated to the time period of the corresponding event.

3.3. Soil moisture monitoring systems

The soil moisture probes were procured from two different vendors as explained in the earlier report and hence the data fromats for them were also different. However, in case of soil moisture probes, there was no scope for data validation and hence data cleaning using primary observations.

As explained earlier, for water level sensors data cleaning was performed using primary observations and alternate measurements (for example manual measurement of water height above CNB in case of water level sensors) as the system was accessible for such monitoring which was not the case for soil moisture probes. Thus even after the data issue such as repeated abnormal spikes of the same magnitude were reported they could not be rectified to get the cleaned data. Hence the data from such sensors was discarded and only those systems without any such issue were considered for the analysis.

Further, since both the types of the sensors were sophisticated and procured from outside the country, their repair was not possible and replacement was not feasible. Therefore, out of the soil moisture systems installed at the five farm locations, the data from three locations were used for the analysis which were installed in the first week of August due to various delays explained earlier in the report.

3.3.1. Data formats and processing

In case of soil moisture probes procured from the Data Flow, the data fetched was available in both percentage saturation as well as in mm. Therefore, for these sensors, soil moisture expressed in mm was directly used. Since there were multiple sensors located at different heights of the probe, based on the model parameters used for the particular point such as soil and root depth, the results for soil moisture were appropriated by considering data from only the sensors at relevant height. For example, for the shallow soil which are assumed to be 10 - 25 cm deep, the soil moistures located at 10 and 30 cm were considered whereas for moderately deep soil (25 - 50 cm), the sensors located at 10, 30 and 40 cm were considered.

For the soil moisture probes procured from RiOT, there was no provision for fetching the data in the mm. For these sensors, the data was expressed in the percentage saturation. This was then converted to mm using volumetric conversions and the results for different soil properties such as bulk density and available water content received from NBSS for the respective sensor locations. For these probes as well the data considered for analysis was only from the relevant sensor locations on the probe as explained in the previous paragraph.

For both the types of soil moisture monitoring systems, the instantaneous soil moisture measurement calibrated as per the model inputs were compared with the soil moisture estimates from the model to the corresponding time. Further, the trend as per the model estimates and as per the results of sensor probes over a period of time were compared.

Before we carry out the data analysis from the above measurement devices, let us first point out some of the key limiting conditions posed[2] during the monsoon season which affected smooth data collection and monitoring.

3.4 Challenges in data collection

3.4.1. Logistic and administrative delay

The component of model validation was part of MoU IV however the signing of the MoU was delayed due to various reasons. However, to meet and match monsoon timeline, the work for the model validation exercise was started prior to signing of MoU after in-principle agreement by the PMU for the start of the work.

The study areas to be selected from PoCRA clusters for the fieldwork were finalized after considering different aspects of the study and discussions with PMU by April end and fieldwork was scheduled to begin in the first week of May. This however was met with a request from PMU to accommodate clusters from Vidarbha region just before the team was scheduled to leave for the field. This necessitated selection of clusters from Vidarbha region which required about a week's time, this was later shared with the PMU for approval. This led to a delay of a couple of weeks. This delay also meant that we were required to negotiate with the vendors accordingly for procurement of the instruments.

The water level sensors vendor Green Pyramid Energy, needed a number of items and utility specifications from IITB as these were hardware heavy instruments parts of which were to be sourced from other vendors. The tentative lead time for all of this was conveyed to be a month by GPE. Because of the change in the study area and subsequent change in the number of instruments to be procured there was delay in the delivery of the instrument to the field[3]. All this collectively resulted in delay in the beginning of the fieldwork for finalization of sites for installation of the

[2] The challenges faced specifically during the installation of the instruments are already documented in the previous report.

[3] This was also affected by the second wave of covid-19 which posed limitations due to restrictions imposed on transportation.

instruments and later to the installation of the instruments. Some of the instruments such as rain gauge and soil moisture monitoring systems which did not require much hardware support were available in limited quantities with the respective vendors and since they were sourced from outside the country, took time to get delivered.

The delay in installation of instruments was the result of the late delivery of the instrument which was further exaggerated due to early onset of the monsoon with heavy rains. This posed challenges in accessing field locations as streams and CNBs started flowing and early sowing meant difficulties in carrying machinery for installation from the farm lands. This was more crucial for installation of V-notches in the farms.

3.4.2. Poor CNB infrastructure

Water level installation which was one of the most important tasks of the instrument installation was met with the challenge of poor CNB infrastructure[4]. Many of the CNBs were either damaged naturally due to aging and extreme runoff events or by the neighboring farmers to avoid water logging in their farm. In the absence of any regular maintenance, the damage was exaggerated. Some of the CNBs which were not damaged were largely silted. This meant there were limited options of CNBs available to choose from.

Further, the selection of sites for installation was to be planned considering coverage of the catchment and to suit the accounting of runoff from the catchment. This meant selection of these sites were not necessarily made not in isolation but with respect to other subcatchments and considering features of the differential catchments as well. In such cases, it was a challenge to have these combinations right on the field. In some cases, especially in the catchments from the Ner and Karnaja, we could not get the best possible selection that team would have liked due to rejection of either or multiple CNBs in pairs or groups.

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[4] This is documented in detail along with the photos in the previous report..

3.4.3. Damage to the instruments

Even after the instruments were successfully installed, some of them were damaged due to different reasons. In Ahmedpur and Loha catchments, a water level sensor was stolen from each of the catchments from CNB site and a V-notch site respectively. Apart from this, there were multiple incidents of snatching and cutting of the instruments wires resulting in the site being down till it got repaired by the IITB team.

Apart from human interference, stray animals and rodents also caused damage in a couple of cases. A rain gauge in the Ner catchment was down for a day as one of the monkeys took away a data logger installed with the rain gauge on the rooftop of the gram panchayat office which was later recovered from the nearby farm. Similarly, a rat which got inside the installation setup from a nearby climber, chewed the wires making that system non functional for a couple of days.

3.4.4. Extreme rainfall events

Though none of the instrument was washed away in Loha cluster which witnessed extreme rain event of cloud burst wherein more than 100 mm of rainfall was received within couple of hours. In the Ner cluster, a couple of sensors were washed away in one of such extreme events where not just the sensors but the side wall of the CNB also got washed away. In another such event, a sensor on the bank of the stream was washed away as the stream channel expanded, eroding the bank and hence also the sensor.

As mentioned earlier in this chapter, all of the clusters especially those in Marathwada received very high rainfall events on the very onset of monsoon. So much so that in Loha cluster, all the CNBs and streams were not just full but overflowing in only one such event and there was water logging in the gaothan area of the village as well. Similarly, in Ahmedpur cluster until till last week of August there was almost no water in the streams and they were completely dry except for the first week in June where a single rainfall event of high intensity led to flowing streams for about a couple of days. These uncharacteristic and extreme events posed multiple challenges in installation and measurements especially for V-notches as explained in the earlier sections.

Considering the last year’s experience of the IITB team where a couple of instruments were damaged due to extreme and unforeseen events, this year a number of instruments were finalized for installation. This was to ensure that even in case of any damage to some of the instruments, we would get sufficiently meaningful data from the rest of the instruments.

4. Validation Results

4.1. Point model validation

The main objective of this chapter is to match the point model results with the measured values of surface runoff and soil moisture for the selected farm plots.

Although we selected six farm plots in four villages with different soil types for monitoring soil moisture, due to the issues discussed in Chapter 3, we could process data for only four farms. The final selected farm plots are listed below in Table 7.

Table 7: Summary for instruments considered for analysis at farm level

Village, Farm ID	V-notch data	Soil moisture sensor data
Mangrul, VL1	Not considered	09/08/21 To 30/09/21
Mangrul, VL2	Not considered	04/08/21 To 30/09/21
Adgaon, VN3	04/07/21 To 05/09/21	Not considered
Adgaon, VN5	05/07/21 To 30/09/21	10/08/21 To 30/09/21

Thus, we could obtain clean and processed data for both soil moisture sensor and v-notch for only the Adgaon N5 farm plot. For Mangrul plots (L1 and L2) we have clean soil moisture sensor data while for the Adgaon N3 plot we have only the v-notch data. Now, we will analyze the sensor data and compare the sensor values with the model results for the above farm plots as follows:

4.1.1 Mangrul L1– Soil moisture sensor data

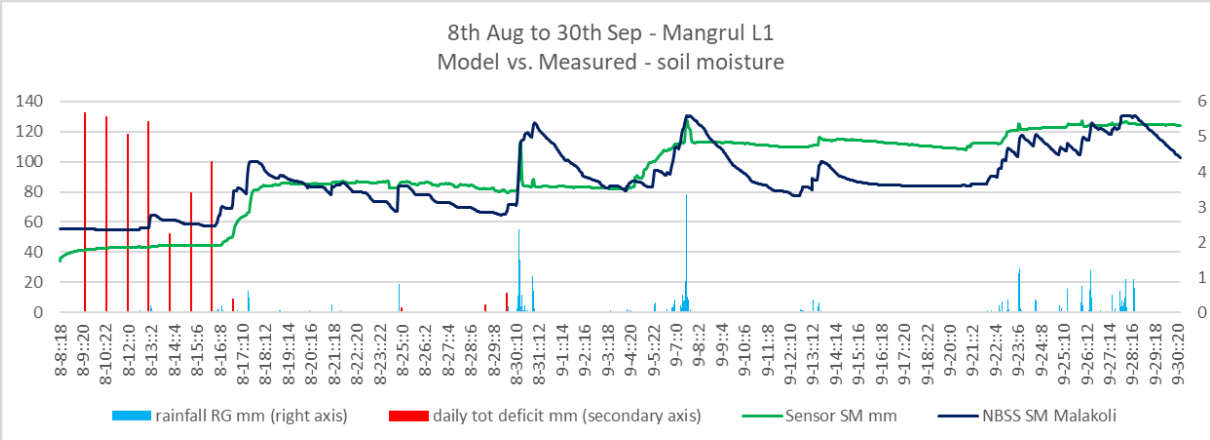
Input soil data

	MRSAC	Soil sample testing at NBSS
Soil texture	Gravelly Clay Loam	Silty Clay Loam
Soil depth (cm below ground)	50 cm	25 cm (observed in the field)
Hydrologic Soil Group For SCS curve number	D	D
Bulk density	1.47	1.8
Field capacity	34.3	28
Wilting point	20.6	15.8
Available Water Content	12%	12.1%
Saturated hydraulic conductivity (mm/hr)	2.32	27.2

Rainfall

Period	8th August 6 PM – 23rd September 11PM
Skymet Malakoli circle Rainfall (mm)	900
Rain gauge installed in Mangrul (mm)	856.8

Comparing predicted and measured soil moisture values



The x-axis indicates the time axis i.e. day and hour of the day. For example, 8-8::18 denotes 8th August 6 PM. It shows the complete measurement period i.e. from 8th August to 30th September. The primary Y-axis i.e. the one on the left hand indicates soil moisture stock and hourly rainfall values in mm. The "green" plot gives the soil moisture values as monitored by the soil moisture sensor and the "dark blue" plot gives the soil moisture values as predicted by the model. The "light blue" column graph gives the hourly rainfall values. The secondary Y-axis i.e. the one on the right hand indicates the daily crop water deficit values as simulated by the model.

As is seen in the rainfall graph in chapter 3, there was a long dry spell in and around Mangrul from around last week of July to around 3rd week of August. As is seen in the above plots, the soil moisture sensors were installed at the end of 1st week of August. Thus, the last 10 days of the dry spell were monitored by the soil moisture sensor.

The wilting point for the soil in the plot L1 as per soil tests carried out at NBSS is 15.8% i.e. 37.5 mm, considering 25 cm of the soil depth. The soil moisture sensor as well as the model correctly show very low soil moisture values getting close to wilting point in the period from 8th August to 16th August.

The increase in soil moisture (around 30 mm) due to events of 16th August and 18th August is correctly simulated by the model. The spikes in soil moisture values on 30th August and 7th September are also correctly simulated by the model.

In general, the modeled soil moisture values reasonably match the actual soil moisture values for the period 8th August to 30th September in Mangrul L1 plot.

4.1.2 Mangrul L2 – Soil moisture sensor data

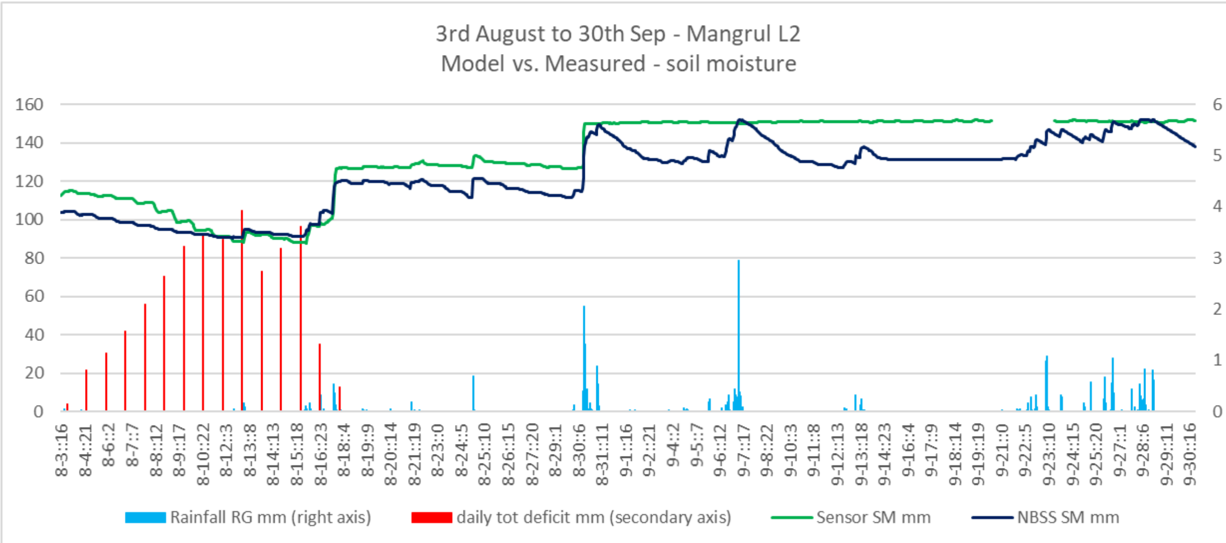
Input soil data

	MRSAC	Soil sample testing at NBSS
Soil texture	Clayey	Clayey
Soil depth (cm below ground)	25 cm	30 cm (observed in the field)
Hydrologic Soil Group	D	D
Bulk density	1.36	1.75
Field capacity	42.7	43.8
Wilting point	30.3	26
Available Water Content	12%	17.8%
Saturated hydraulic conductivity (mm/hr)	0.51	4.8

Rainfall

Period	3rd August 4 PM – 23rd September 11PM
Skymet Malakoli circle Rainfall (mm)	905.25
Rain gauge installed in Mangrul (mm)	859.8

Comparing predicted and measured soil moisture values



Here too, the x-axis indicates the time axis i.e. day and hour of the day. It shows the complete measurement period i.e. from 3rd August to 30th September.

4.1.3 Adgaon N3 – V-notch

Input soil data

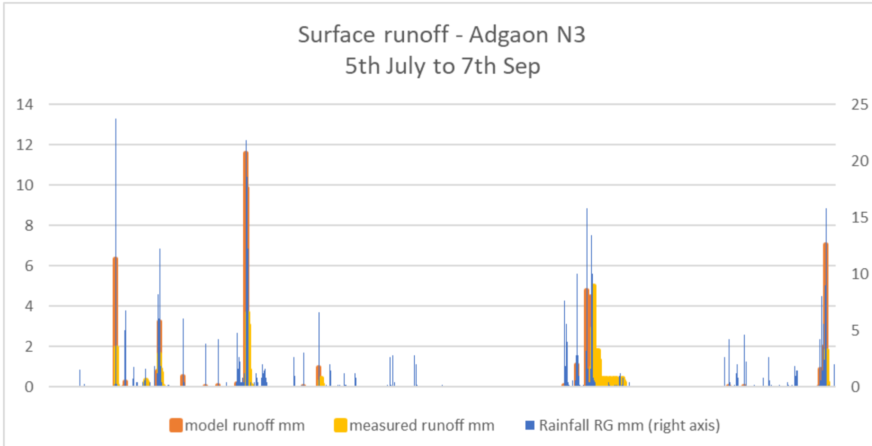
	MRSAC	Soil sample testing at NBSS
Soil texture	Clayey	Clayey
Soil depth (cm below ground)	150	150
Hydrologic Soil Group	D	D
Bulk density	1.36	1.7
Field capacity	42.7	49.7
Wilting point	30.3	39.6
Available Water Content	12%	18.1%
Saturated hydraulic conductivity (mm/hr)	0.51	5.9

Results

Period	5th July 5 PM – 7th September 11PM
Skymet Shirajgaon circle Rainfall (mm)	411.25
Rain gauge installed in Adgaon (mm)	423.05
NBSS runoff mm (for Adgaon rainfall)	65.39
MRSAC runoff mm (for Adgaon rainfall)	71.31

Measured runoff mm	65.83

Following plot shows the comparison between predicted and measured farm runoff values:



As can be seen from the graph, the measured runoff and the model runoff fairly matches with each other. This is true for the estimates of the quantities as well as the timeline for the occurrence of the runoff events.

4.1.4. Adgaon N5 – V-notch and soil moisture sensor

Input soil data

	MRSAC	Soil sample testing at NBSS
Soil texture	Clay loam	Silty clay
Soil depth (cm below ground)	50	50 (as observed in the field)
Hydrologic Soil Group	D	D
Bulk density	1.48	1.7
Field capacity	34.1	39.6
Wilting point	20.6	24.1

Available Water Content	14%	15.5%
Saturated hydraulic conductivity (mm/hr)	2.7	2.6

Rainfall

V – notch – 4th Jul 6 PM to 30th Sep 11PM		Soil moisture sensor – 10th Aug 5 PM to 30th Sep 11 PM	
Skymet Shirajgaon circle rainfall mm	625.5	Skymet Shirajgaon circle rainfall mm	427
Adgaon Rain gauge rainfall mm	550.25	Adgaon Rain gauge rainfall mm	323.6

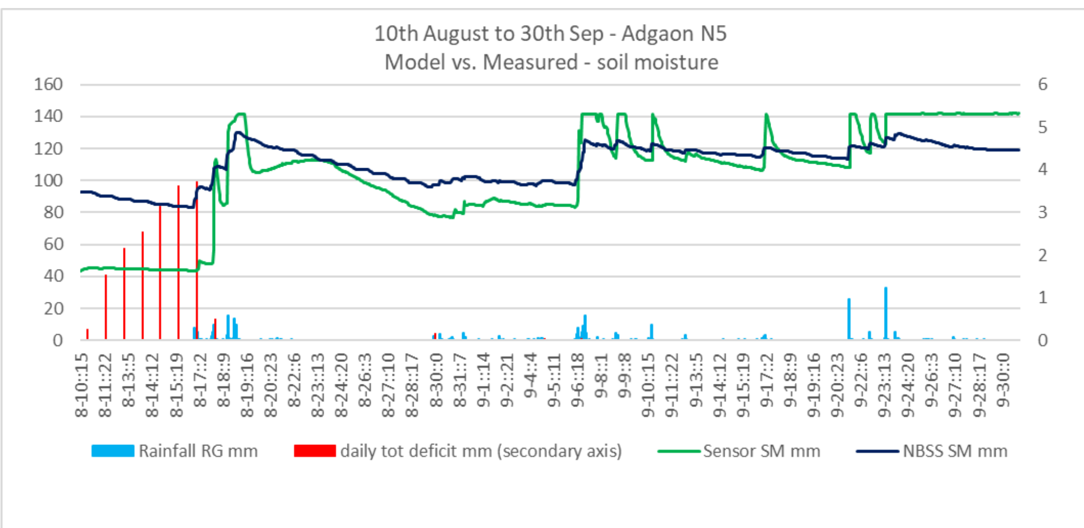
V-notch data:

Period	4th July 6 PM – 30th September 11 PM
Skymet Shirajgaon circle Rainfall (mm)	625.5
Rain gauge installed in Adgaon (mm)	550.25
NBSS runoff mm (for Adgaon rainfall)	119
MRSAC runoff mm (for Adgaon rainfall)	124
Measured runoff mm	116

Soil moisture sensor data:

Period	10th Aug 3 PM – 30th September 11PM

Skymet Shirajgaon circle Rainfall (mm)	427
Rain gauge installed in Adgaon (mm)	324
NBSS runoff mm (for Adgaon rainfall)	69
NBSS del SM (for Adgaon rainfall)	26
MRSAC runoff mm (for Adgaon rainfall)	73
MRSAC del SM mm (for Adgaon rainfall)	25
Measured runoff mm	79
Measured change in soil moisture mm	98



Key explanations:

1. End of a long dry spell (from last week of July to 3rd week of August). Lower soil moisture values near the end of the dry spell i.e. from 8th August to 16th August. Higher crop deficit values during this period.

2. Sudden increase in soil moisture after the rainfall events are shown by sensor as well as model.
3. Surface runoff not generated upto 18th August due to very low antecedent soil moisture. Correctly predicted by model.
4. Spikes and trends in soil moisture values during rainfall events have been correctly simulated by the model.

Following is the comparison of model results and sensor values for the key event of 16th August to 20th August:

Component	Measured	Model (using NBSS data)
Runoff mm	27.2	15.4
Change in soil moisture mm	63.8	36.9
GW recharge mm	11.5 (model)	11.5
AET mm	15.5 (model)	15.5
Total mm	117.1	104
Rainfall (Adgaon RG) mm	104	104
Difference mm	13.1	0

Key phenomenon:
As there is a preceding dry spell of more than 2 weeks, the initial rainfall on 16th and 17th August, which is around 50 mm, does not generate any surface runoff, as seen by the V-notch readings. This is perfectly simulated by the model.

4.2. Regional water budget validation

4.2.1 Input data and selected catchments

As discussed in Chapter 2, the unit of validation chosen for the regional water budget is a catchment. The key component of the water budget equation to be validated is the surface runoff, which was measured by installing water level sensors on the cement bunds in these villages.

The input data required for running the model for the given catchment consists of soil texture and soil depth polygons, the land-use (cropping pattern) and land-cover polygons, the crop properties, the DEM and slope maps and the hourly weather data. As already mentioned in Chapter 2, it is very difficult to measure and accurately provide each and every input dataset to the water budget equation. The most critical input dataset to the soil-water balance model is the soil data and its key properties. Keeping this in mind, representative soil samples from almost all the catchments were tested and key properties were measured at the NBSS soil lab in Nagpur. The same soil data was used to validate the point-level water balance model as shown in Chapter 4.

The soil-test results showed significant variation in soil properties used currently in the water budget model through MRSAC soil texture and depth maps and through FAO database. The new properties were given as input for the point model which showed a reasonable match between the measured values and predicted results for soil moisture and runoff.

However, when it comes to input data for the regional model, spatial pattern and variation in soil texture and depth classes becomes critically important. This is currently provided by the MRSAC soil and depth maps which have been proven incorrect through the above soil sampling and testing method. Thus, although we got accurate values of soil properties at a few selected locations, we did not have the spread of different soil types at the catchment level. Hence, the decision was made to replace the FAO soil properties being currently used by the NBSS soil test results conducted during the survey. These values would then be extrapolated to the whole catchment using the existing MRSAC soil polygons. Thus, although we are using improved soil properties, we have sampled only a few locations for soil samples. Also, we have used the same soil texture and depth polygons as indicated by the MRSAC maps. This would retain the gaps and errors in the MRSAC maps and may give incorrect results.

In total, 21 catchments in 7 villages were selected for validation during the monsoon of 2021. As explained in Chapter 3, due to various issues faced, right from instrument related errors to data related problems to tampering by rodents, out of 21 catchments, some catchments could not be selected for validation due to lack of valid / clean data. Eventually, 15 catchments were selected for the validation purpose. The process of data collation, cleaning, consolidation and processing has been explained already in Chapter 3.

4.2.2 Baseflow separation:

The total discharge measured over a given time interval is the total water flowing out of the catchment during that interval. This flow is the total water flowing out of the catchment through the outlet. This flow contains direct surface runoff as well as delayed flows (generally termed as baseflows).

These delayed flows are due to the infiltrated/percolated water oozing out on the surface and joining the streams. This happens because, once the aquifers get fully saturated and cannot hold more groundwater recharge coming from the soil layer, the excess percolation below the soil layer is rejected by the aquifer. Thus, essentially, this is the groundwater recharge which is converted to surface water flow which flows through the stream network. As far as our model is concerned, this cannot be termed as direct surface runoff.

The amount of rejected groundwater recharge / baseflow depends primarily on the aquifer properties, i.e. the aquifer thickness and the water holding capacity of the aquifer (which is indicated by the "specific yield" of the aquifer). The aquifer thickness typically varies from 6-7 m in the ridge areas of hilly regions to around 12-15 m in the flat valley regions. The specific yield for the basaltic terrain is very low and ranges from 0.7% in poor aquifers to about 3% for very good basalt aquifers, as per GSDA data. Thus, the amount of baseflows is high in regions which are hilly and have poor aquifers while it is very low in flat regions with good aquifer thickness and specific yield.

Thus, with regards to model results, the total water flowing out at the catchment outlet is essentially the addition of direct surface runoff and the rejected groundwater recharge during the validation period. This value needs to be used while comparing the model results with the measured discharge at the outlet of the catchment. The validation process using computation of baseflows and separation of baseflows from the surface runoff was explained in detail in the final closure report of validation in the MoU III.

(https://docs.google.com/document/d/1duksraV8icPp8mu9vlDPon9Bf03IvSWC/edit?usp=sharing&ouid=101157203687689908755&rtpof=true&sd=true)

The formula for rejected groundwater recharge is as follows:

rej_GWR = GWR_val_period - available_capacity — if GWR_val_period > available_capacity

= 0 — if GWR_val_period <= available capacity

Where –

GWR_val_period (mm) *is the total groundwater recharge simulated by the model during the validation period (mm)*

Available_capacity (mm) *= total aquifer capacity (mm) - groundwater recharge at the beginning of the validation period as per the model (mm)*

total aquifer capacity (mm) *= (aquifer_thickness in m * 1000) * (specific yield in % / 100)*

Table 8 shows the above values for all the selected catchments:

Table 8: Summary for rejected groundwater at catchment level

Sr. No.	Catchment	Validation Start Date	Validation End Date	GWR beginning (mm)	GWR val period (mm)	Rejected GWR (mm)
1	A2	25/06/21	23/09/21	39	126	5
2	A4	05/07/21	23/09/21	38	122	0
3	A5	25/06/21	23/09/21	27	165	2
4	A6	25/06/21	23/09/21	70	146	16
5	L1	23/06/21	23/09/21	108	325	263
6	L2	23/06/21	23/09/21	113	335	278
7	L3	23/06/21	22/09/21	103	319	222
8	L5	23/06/21	23/09/21	74	299	213
9	L6	23/06/21	23/09/21	69	276	145
10	N1	24/06/21	23/09/21	47	97.8	0
11	N2	20/06/21	23/09/21	140	276	116
12	N3	20/06/21	23/09/21	96	195	71
13	N4	24/06/21	23/09/21	74	143.7	17.7
14	N5	07/09/21	30/09/21	61	73.5	0
15	N6	24/06/21	23/09/21	59	119.2	0

The table clearly shows that the modeled groundwater recharge is very high for all the catchments in the Loha cluster and for some catchments in the Ner cluster (N2 and N3). This is due to the presence of a thin and poor soil layer with very high hydraulic conductivity values. Thus, the rate of percolation of infiltrated water below the soil layer is very high in these catchments.

However, as the aquifers in these regions do not have the capacity to store the percolated water, this translates to high amounts of rejected groundwater recharge / baseflows. This was evident from the observations on the field as the cement bunds used to overflow for many days after the rainfall event. Similar phenomena was observed in the Lingdari and Gondala catchments during the monsoon of 2020.

4.2.3. Validation results

Thus, the input data for running the regional model for all the selected catchments was corrected and fixed. At the same time, the aquifer properties were incorporated into the model in order to compute the rejected groundwater recharge / baseflows. The next task was to compare the measured flow at the outlet of the catchment with the corrected model surface runoff.

The stage of water flowing above the cement bund was regularly monitored by the water level sensors and was converted to discharge using standard equation for flow over the broad crested weir as explained in Chapter 3. This flow computed using theoretical methods was validated through actual measurement of flow in the stream channel using cup/pigmy type current meters for some of the events. The methodology has been explained in detail in the interim report in MoU III.
(https://docs.google.com/document/d/1GjSiGmbt7B12mqTV_47QVWhNGCB0AFMY/edit?usp=sharing&ouid=101157203687689908755&rtpof=true&sd=true).
Such measurements were carried out at 8 locations during the monsoon of 2021. The discharge measured using current meter matched with the flow estimated using the broad-crested weir formula.

This total discharge was compared with the corrected model surface runoff. This corrected runoff is simply the addition of model surface runoff and rejected groundwater recharge for the validation period.

Table 9 shows the details of comparison between model results and the values of runoff / water discharge actually measured by the sensors at the outlets of the above catchments.

Table 9: Comparison of measured and corrected model runoff

Sr No.	Catchment	Area (ha)	Rainfall (mm)	Measured Runoff (mm)	Model Runoff (mm)	Model GWR (mm)	Rejected GWR (mm)	Corrected Model Runoff (mm)	% Error
1	A2	201	550.5	108.7	95	126	5	100	8.00%
2	A4	487	499	100.0	82	122	0	82	18.00%
3	A5	168	550.5	121.4	114	165	2	116	4.45%
4	A6	78	550.5	99.0	92	146	16	108	9.09%
5	L1	114	1090	745.4	545	325	263	808	8.40%
6	L2	26	1090	713.9	536	335	278	814	14.02%
7	L3	245	1031.2	773.6	531	319	222	753	2.66%
8	L5	219	1090	779.6	498	299	213	711	8.80%
9	L6	714	1090	714.4	511	276	145	656	8.17%
10	N1	323	566	164.3	125.9	97.8	0	125.9	23.37%
11	N2	113	583	191.0	105	276	116	221	15.71%
12	N3	98	583	194.0	98	195	71	169	12.89%
13	N4	807	566	158.6	118.4	143.7	17.7	136.1	14.19%
14	N5	246	323.6	78.6	69.6	73.5	0	69.6	11.45%
15	N6	2042	566	150.0	118.6	119.2	0	118.6	20.93%

5. Conclusions

1. The point model was validated by comparing point model results for selected farm plots with the runoff and soil moisture values measured using v-notches and soil moisture sensors. The model results matched reasonably with the measured values.
2. The key input data required for the point model validation (such as soil depth, soil properties, crop data, rainfall data etc.) was collected through primary data collection. The soil data was tested at the NBSS lab in Nagpur. It was found that the soil properties as per NBSS lab tests were more accurate than the FAO soil properties used currently.
3. The regional model was validated in the 15 catchments in three villages. The measured values of runoff reasonably matched with the model results. The gap between model results

and measured values was more in the regional model than the point model. This may be due to high dependence of and inaccuracies in the secondary data used (such as MRSAC soil texture polygons, GSDA data on specific yield etc.).

4. The model demonstrated the ability to show variations in runoff generated, soil moisture trends and groundwater recharge in different soil types and depths. At the same time, the impacts of rainfall distribution on runoff, soil moisture and AET have also been significantly demonstrated by the model. Thus, the model can be used to understand the temporal and spatial variations in soil moisture availability and crop stress within the village. This is an important achievement with regards to identification of vulnerable farmers and planning with respect to climate variability. This has been a significant achievement over the existing Strange's table method to estimate runoff.
5. The phenomenon of rejected groundwater recharge / baseflows during the monsoon was correctly simulated by the model.
6. The model can be further upgraded and modified so as to incorporate other important phenomena such as ponding and water logging in the fields, routing / movement of surface / ground water across zones / villages etc.

6. Recommendations

1. The validation exercise must be carried out in an incremental manner over the next few years in various geographies and for different rainfall patterns.
2. Conceptual framework and methodology for validating the water budget model has been further extended and is now established. This methodology may be used by the third-party agencies or engineering colleges to carry out the validation exercise in different geographies.
3. The Department of Agriculture and Water Conservation Department may install and monitor water level sensors over CNBs and soil moisture sensors in different soil types across the state. The rich data generated may be used to validate the model further, to incorporate newer phenomena in the model and to promote more scientific and evidence-based planning of water resources in the rainfed regions.

4. The changes to the model for incorporating baseflows have been made for the selected clusters and tested during the validation exercise. The data (aquifer thickness and specific yield) required for incorporating baseflows for the whole PoCRA region should be requested from GSDA. Aquifer thickness data may be fetched from the well depth of the newly chosen GSDA observation wells (one observation well per village). With regards to specific yield data, currently one value per elementary watershed (of about 20-30 K ha) is available with GSDA. Village level studies for estimating specific yield values need to be conducted by GSDA to have more realistic and accurate values.