Validation report on soil dataset obtained from MRSAC and field experiment

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PoCRA - IITB phase 1 project has involved development and delivery of a scientific village level water budgeting and planning framework based on water balance approach. Phase 1 was envisaged to promote optimum intervention and crop planning within the village through water balance exercise. To do this, generic GIS tools, datasets, and scientific procedures were developed and transferred to PMU, PoCRA. These tools provide zone level water balance outputs for micro-watershed zones within the village which measure seasonal agricultural water deficit, water availability in form of various water balance components - soil moisture, groundwater and runoff to enable demand-supply based zonal planning methodology. To get the basic idea about the tool and framework and the tool two reports can be referred (https://www.cse.iitb.ac.in/~pocra/1MonthUpdate.pdf , https://www.cse.iitb.ac.in/~pocra/Phase%20III%20Plugin%20description%20document.pdf).

Zone and village level water budgeting framework was developed based on these outputs and deployed to the field through PoCRA micro planning app. This water budgeting framework enables understanding the current situation of village in terms of water supply and demand parameters, based on its cropping pattern and existing interventions. It also enables scientific planning, by allowing the user to plan only for available runoff. The water budget part of PoCRA micro-planning app has been designed such that it allows the user to generate post intervention and post crop planning scenarios to see the change in water budget with respect to pre-project implementation state and modify the planning based on that.

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

This report has been divided into three parts.

1. First part gives the description of soil texture values being used in the plugin and its comparison with soil texture values obtained from the soil series data.
2. Second part gives the description about the texture results obtained from the field and its comparison with the texture results obtained from the MRSAC shapefile.
3. Third part discuss about the impact of texture values on the model output.

Comparison of soil texture values used in Plugin with Texture obtained from soil series data

MRSAC has provided the soil shapefile for the project area which is at 1:50000 scale. With the shapefiles separate database in arc info format has been given. The database contains the soil series and its horizon wise information. This contains various physical and chemical soil properties including soil texture and soil composition. The concept regarding soil survey and process of soil map preparation is given in the

Appendix 1. The database provided by MRSAC has link codes which can be used to connect the data with soil polygons in shapefile. We want to compare the soil texture values obtained from the soil series database with the values being tested at few locations in the project region. Table 1 gives the detail of the soil composition for various soil types obtained from literature. These are the values being used in the plugin to run the point level model. Table 2 gives an idea of the properties derived from the soil composition values and being used for various soil types for running the plugin model.

Table 1 Soil composition of different types of soil being used in plugin

SN	Soil Type	HSG	Sand %	Silt %	Clay %	Gravel %
1	Clay loam	D	32	34	34	0
2	Clayey	D	28	21	51	0
3	Gravelly clay	D	23	29	48	10
4	Gravelly clay loam	D	31	35	34	10
5	Gravelly loam	B	41	42	17	10
6	Gravelly sandy clay loam	B	49	25	26	10
7	Gravelly sandy loam	B	63	27	10	10
8	Gravelly silty clay	C	7	46	47	10
9	Gravelly silty loam	C	21	64	15	10
10	Loamy	B	42	38	20	0
11	Loamy sand	A	82	10	8	0
12	Sandy	A	91	4	5	0
13	Sandy clay	D	51	7	42	0
14	Sandy clay loam	C	57	15	28	0
15	Sandy loam	A	65	24	11	0
16	Silty clay	D	9	45	46	0
17	Silty clay loam	D	11	55	34	0
18	Silty loam	B	19	65	16	0

Table 2 Soil properties for different types of soil being used in plugin

SN	Soil Type	WP	FC	Saturation	Ksat mm/hr	Bulk Density	AWC
1	Clay loam	0.21	0.34	0.44	2.70	1.48	0.14
2	Clayey	0.30	0.43	0.49	0.52	1.36	0.12
3	Gravelly clay	0.29	0.42	0.49	0.83	1.36	0.12
4	Gravelly clay loam	0.21	0.34	0.44	2.32		0.12
5	Gravelly loam	0.11	0.02	0.41	10.83	1.57	0.12
6	Gravelly sandy clay loam	0.16	0.27	0.41	5.83	1.56	0.1
7	Gravelly sandy loam	0.07	0.16	0.40	33.29	1.58	0.08
8	Gravelly silty clay	0.28	0.42	0.51	1.70	1.29	0.13
9	Gravelly silty loam	0.10	0.28	0.42	6.80	1.55	0.16
10	Loamy	0.13	0.26	0.41	10.20	1.56	0.13
11	Loamy sand	0.05	0.11	0.41	69.09	1.56	0.06
12	Sandy	0.03	0.07	0.42	108.06	1.53	0.04

13	Sandy clay	0.25	0.36	0.43	0.73	1.51	0.11
14	Sandy clay loam	0.17	0.27	0.41	6.09	1.57	0.1
15	Sandy loam	0.17	0.26	0.40	6.67	1.59	0.09
16	Silty clay	0.27	0.42	0.51	1.90	1.31	0.14
17	Silty clay loam	0.21	0.37	0.47	2.65	1.41	0.17
18	Silty loam	0.11	0.29	0.42	6.97	1.54	0.19

For entire state, 544 soil series were established by MRSAC. Brief description of the soil mapping process is given in the annexure 1. There are broadly 18 soil texture classes provided by MRSAC for the entire state. Within these established soil series there is variation in composition of soils belonging to similar textural classes. This variation is explained in fig 2. Table 3 provides the average soil composition values for various soil types. These values have been computed from the soil series data for the top layer. Fig 1 gives the strong correlation between the values used for plugin and values calculated from the soil series data. The % clay content values used in plugin on x axis is plotted against % clay content obtained from the top layer for different textural classes.

Table 3 Average soil composition for Top layer for different soil types obtained from 544 soil series data

SN	TEXTURE	SAND_PER	SILT_PER	CLAY_PER
1	Clay loam	42.11	22.92	34.97
2	Clay	26.47	23.22	50.30
3	Gravelly clay	27.27	23.29	49.44
4	Gravelly clay loam	42.10	22.84	35.07
5	Gravelly loam	51.75	24.00	24.25
6	Gravelly sandy clay loam	56.24	17.44	26.33
7	Gravelly sandy loam	66.65	16.73	16.62
8	Gravelly silty clay	18.85	48.40	32.75
9	Gravelly silty loam	20.20	51.85	27.95
10	Loamy	38.03	37.11	24.86
11	Loamy sand	84.67	6.67	8.67
12	Sandy	90.00	5.00	5.00
13	Sandy clay	54.60	14.63	30.77
14	Sandy clay loam	57.06	16.57	26.37
15	Sandy loam	64.16	18.92	16.92
16	Silty clay	13.81	42.68	43.51
17	Silty clay loam	20.07	46.28	33.65
18	Silty loam	23.44	50.88	25.69

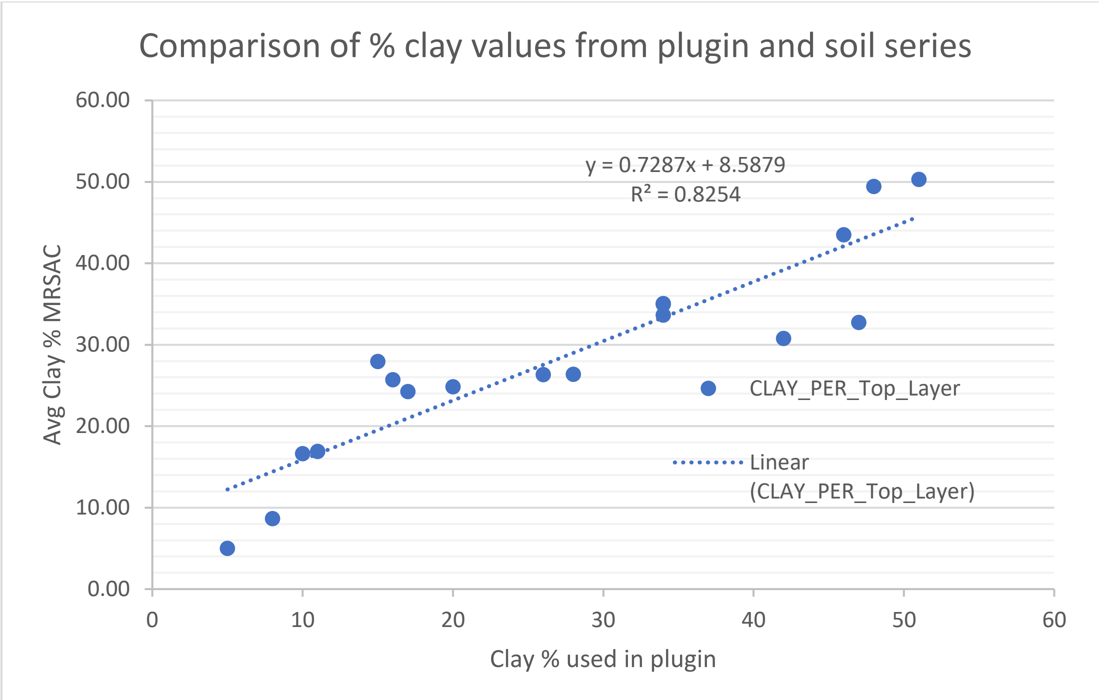

Fig 1 Comparison of % clay values from plugin and soil series

Out of 544 soil series 182 of them identify their soil texture as clayey, 71 as clayey loam, 34 as gravelly clay, 50 as gravelly clay loam, 42 as gravelly sandy clay loam, 27 as gravelly sandy loam, 48 as sandy clay loam, 31 as sandy loam. This shows that most the soil series which have been identified have high clay content. Their distribution is shown via box plot diagram given in fig 2. Orange dot tells us the value being used in plugin for various soil textures. This has been plotted on the distribution of clay content in different soil series with in same texture class. In most of the cases the value being used in plugin falls within the range of values obtained from soil series. These are closer to mean except two cases which is gravely sandy loam and sandy loam where value is much lower than distribution.

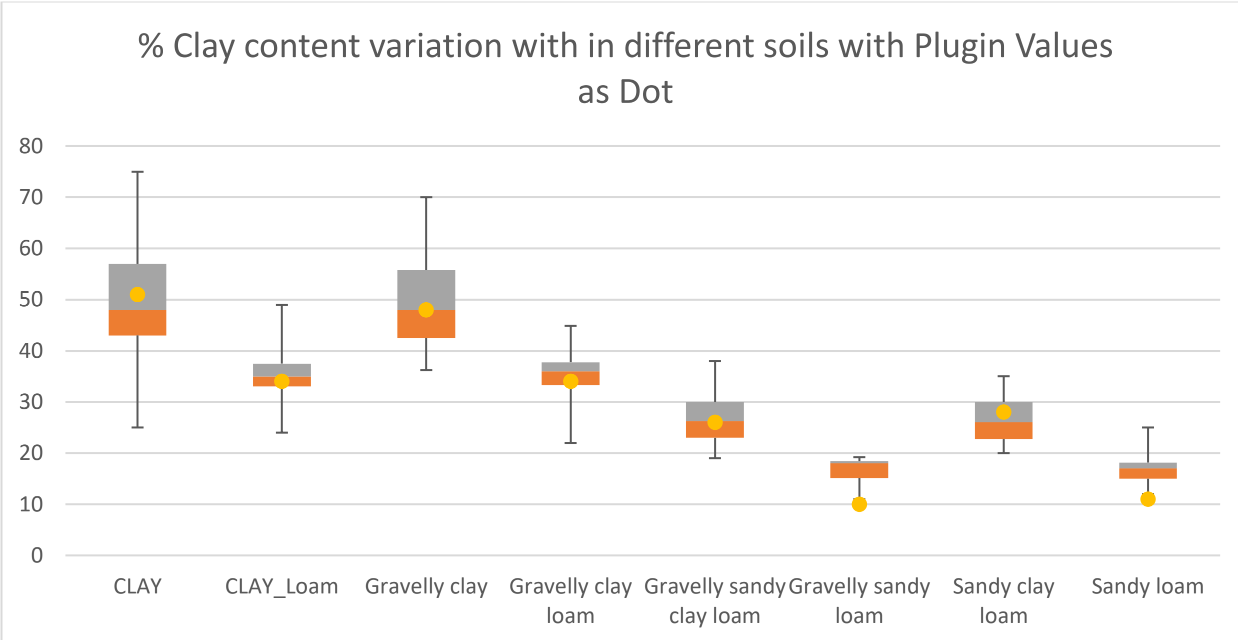

Fig 2 Clay content variation with in different soils with Plugin Values as Dot

Results of soil texture values for selected village

To have confidence in the values being used in the plugin and check the values provided by MRSAC, 5 villages were randomly selected for soil textural analysis with in the POCRA region where Micro level planning process has been completed. These villages are Gondala & Jamdaya in Hingoli district, Paradgaon in Jalna district, Janori, Yeulkhed, Pimpri Gawli in Buldhana district with Janori and Yeulkhed in saline track and Pimpri Gawli in non-saline track. Minimum 5 samples were collected from each village and texture analysis was done on each of them. Location of these villages are shown in the Fig 3. The soil texture triangle is one of the tools that soil scientists use to visualize and understand the meaning of soil texture names. The textural triangle is a diagram which shows how each of these textures is classified based on the percent of sand, silt, and clay in each. these percentages are based on the USDA definition of sand and silt only. For each village a separate table is given which shows the comparison of sample texture given in shapefile and actual texture value tested in field. Rows in orange color are values tested in field where as in grey color values belongs to shapefile database. Location of these samples is shown on the soil map for each village. these samples for each village are also represented on the soil texture triangle separately village wise.

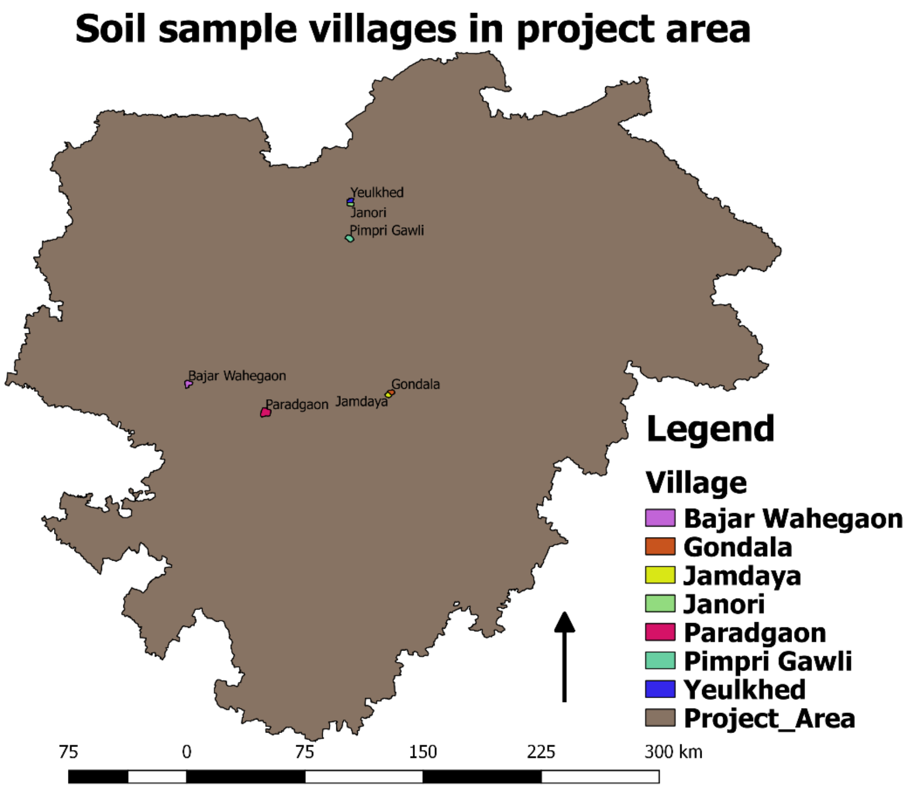

Fig 3 Villages selected for soil sampling in POCRA region

Paradgaon

Within Paradgaon various soil polygons from MRSAC shapefile, were analyzed carefully and from different types of soil polygons 10 soil samples were collected randomly in such a way that whole village and different soil types were covered completely. Fig 4 shows the location of the places where soil sample has been collected. It has been overlaid over the soil map.

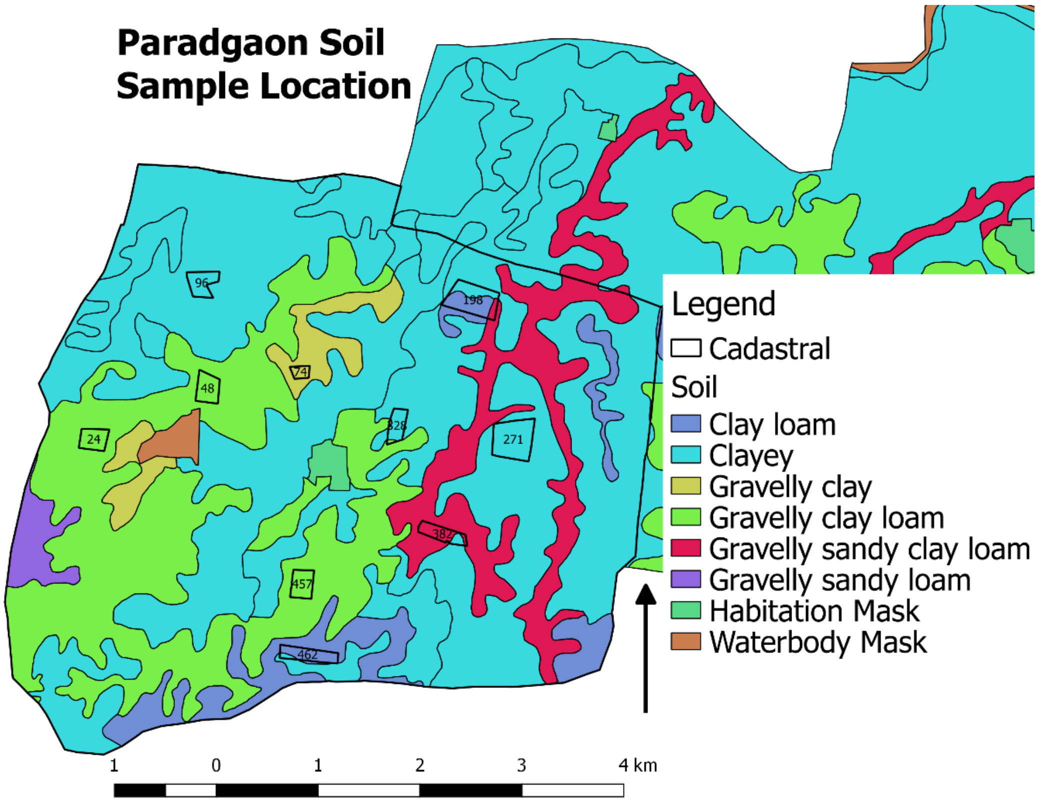

Fig 4 Soil samples location in Paradgaon Village

Table 4 gives us the result of values tested in the laboratory and extracted from the soil series data for the locations from where sample has been collected. In table grey color highlight the values from MRSAC soil polygons for the top layer. Values in light orange color represents the results obtained from laboratory testing. From the 10 samples one conclusion can be clearly made that clay content is very less as compared to the MRSAC values and soils are high in silt content.

Table 4 Comparison of soil composition from MRSAC layer and Field tests in Paradgaon

MRSAC Layer	Field Results	**Soil Composition**			**Texture**
Sr. No	**Gat No.**	**Sand (%)**	**Silt (%)**	**Clay(%)**	
1	24	67.22	32.97	0.79	Sandy Loam
		48	18	34	Gravelly clay loam
2	48	76.64	17.96	6.38	Loamy Sand/ Sandy Loam
		48	18	34	Gravelly clay loam
3	96	1.52	85.71	12.75	Silty/Silty Loam
		24	22	54	Clay
4	74	71.6	26.98	1.39	Sandy Clay Loam
		17	27	56	Gravelly clay
5	198	7.53	91.66	0.79	Silty
		42	20	38	Clay loam

6	328	47.6	46	6.4	Sandy Loam/Loam/Silty Loam
		24	22	54	Clay
7	457	63.6	29.9	6.3	Sandy Loam
		48	18	34	Gravelly clay loam
8	271	63.62	27.98	8.39	Sandy Loam
		24	22	54	Clay
9	382	59.6	37.9	2.39	Sandy Loam
		54	13	33	Gravelly sandy clay loam
10	462	3.23	61.97	34.78	Sandy Clay Loam/Sandy Clay
		39	22	39	Clay loam

Soil sample results from field and MRSAC has been represented on USDA Soil taxonomic classification triangle. To indicate the difference soil samples results from the MRSAC and field values have been joined with line. The values have come from table 4 and represented on fig 5. All the texture values fall in different zones. This can be seen from the figure 5. Results Indicate completely different soil texture from the MRSAC values. E.g gat number 462 shows sandy loam which is opposite from clayey given in MRSAC shapefile. Same thing is observed for gat number 24.

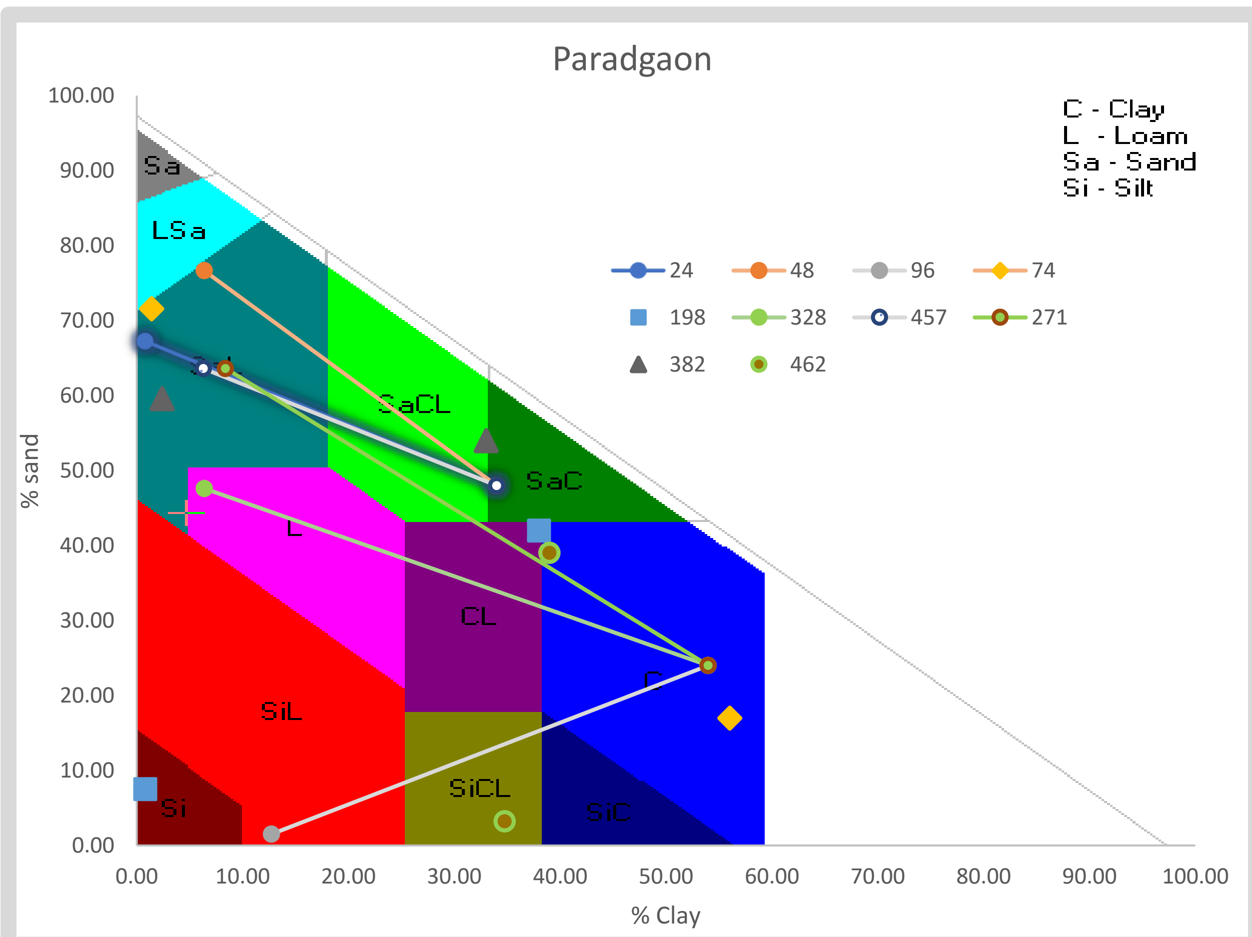

Fig 5 Representation of Soil composition on Soil taxonomic classification triangle

Janori

5 soil samples were randomly collected from the Janori village. This village falls in saline track of Buldhana district. According to MRSAC shapefile the complete village has clayey texture represented in fig 6. Field result here also shows that soils are siltier in nature as compared to clayey given in shapefile.

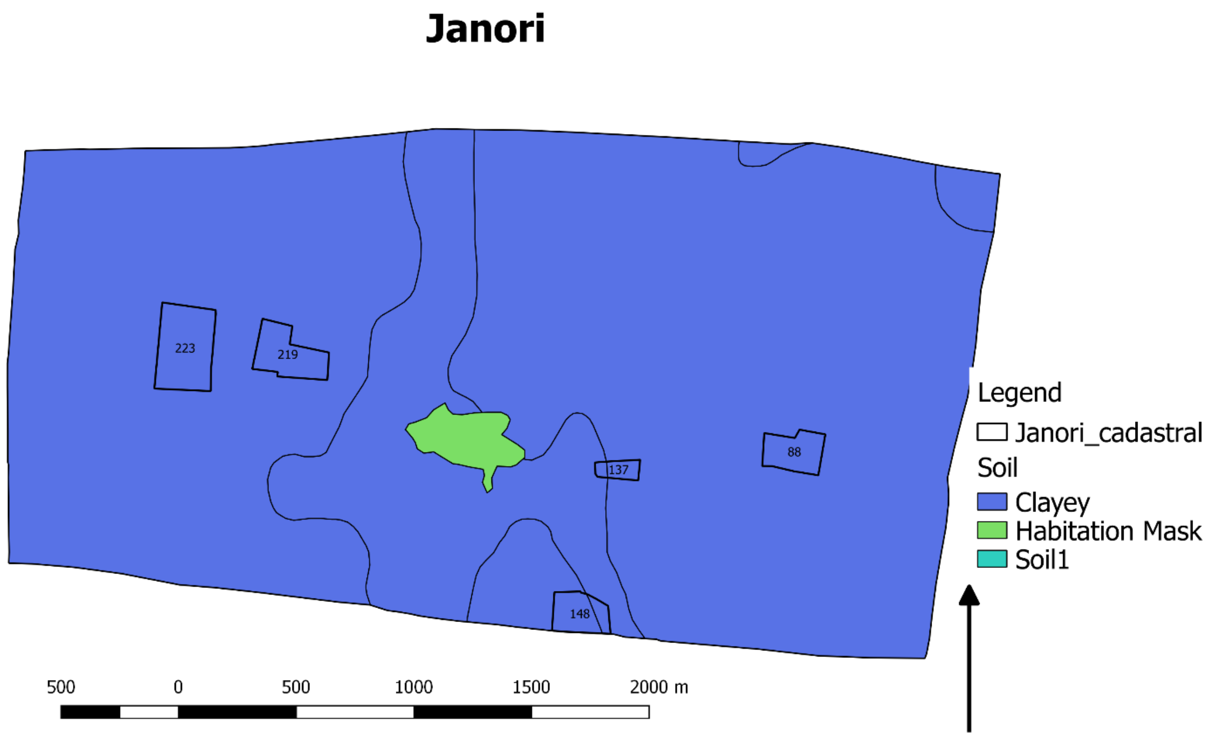

Fig 6 Soil samples location in Janori Village

The results in Janori village shows that soils are having more than 40% of silt content in all the samples tested. The values are given in table 5. Only one sample has shown more sand content than the silt. There is less clay content in the samples tested. Similar observations were observed in paradgaon village as well. Fig 6 also shows the same thing with most of the samples falling in the boundary of clay/sandy clay region and laboratory readings shows the different results.

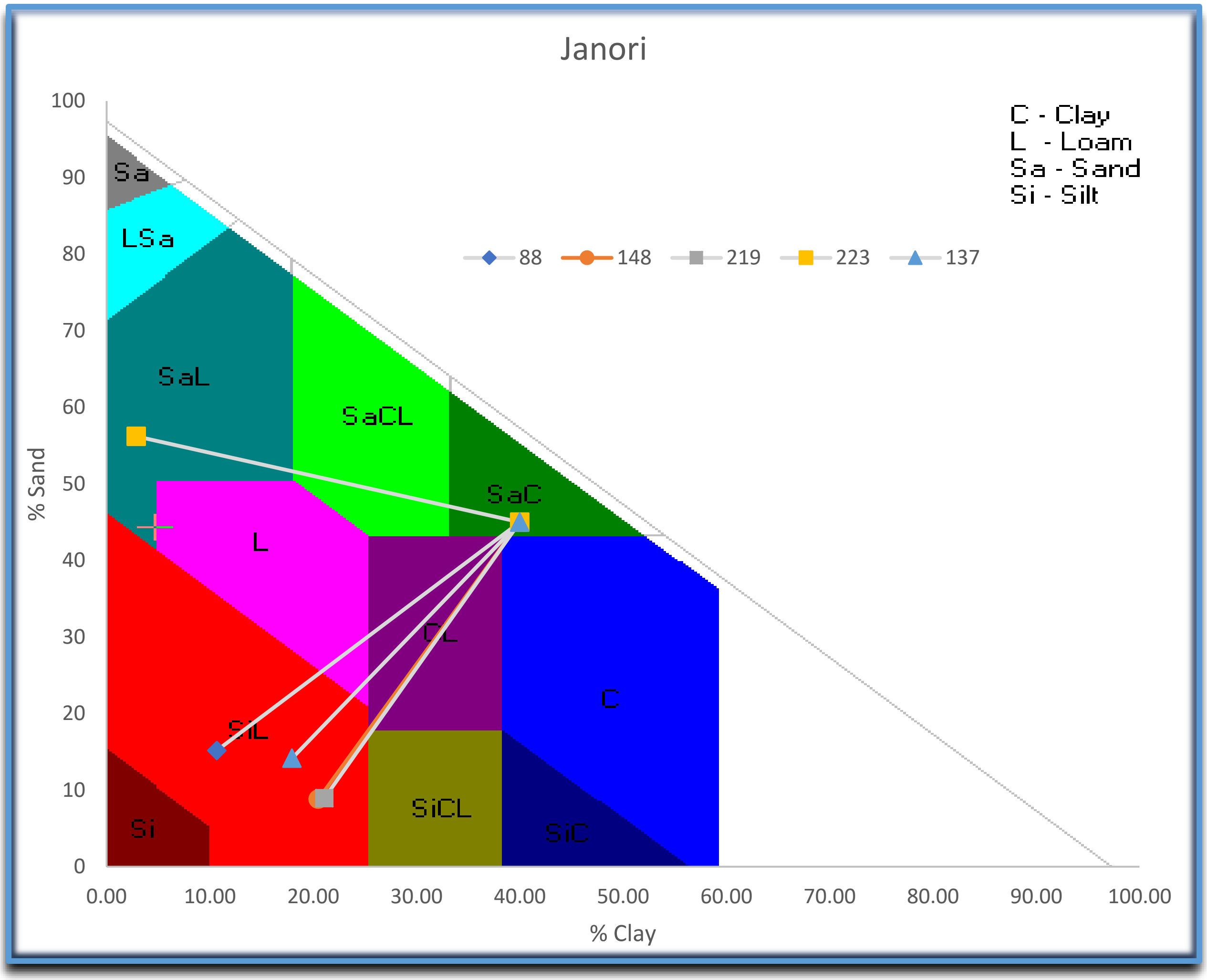

Fig 7 Representation of Soil composition on Soil taxonomic classification triangle

Table 5 Comparison of soil composition from MRSAC layer and Field tests in Janori

MRSAC Layer	Field Results	**Soil Composition**			**Texture**
Sr. No	**Gat No.**	**Sand (%)**	**Silt (%)**	**Clay (%)**	
1	88	15.18	74.14	10.68	Silty Loam
		45	15	40	Clay
2	148	8.82	70.68	20.5	Silty Loam
		45	15	40	Clay
3	219	8.94	69.69	21.08	Silty Loam
		45	15	40	Clay
4	223	56.21	41.01	2.87	sandy loam
		45	15	40	Clay
5	137	14.17	67.86	17.96	silty loam
		45	15	40	Clay

Pimpri Gawli

According to MRSAC shapefile soils are high in clay content in Pimpri Gawli. To test this claim 5 samples were randomly selected and tested for texture analysis in the laboratory.

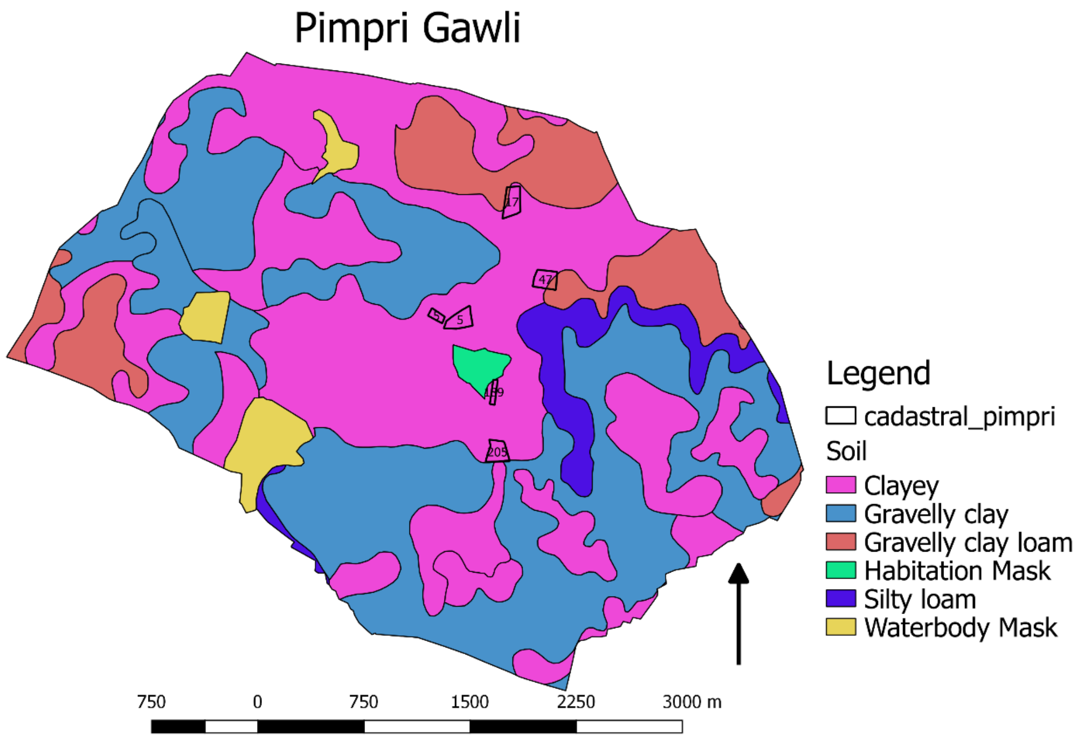

Fig 8 Soil samples location in Pimpri Gawli Village

Except Gat number 17 all the other samples have high silt content. Gat number 17 has more sand content. All the MRSAC values have high clay content, whereas test results show more silty soils. Comparison of this has been given in the table 6. Fig 9 also gives us idea about the different regions where MRSAC results lies as compared to test results. Even if soil samples have been collected from the same soil polygon there is difference in the actual ground level texture values.

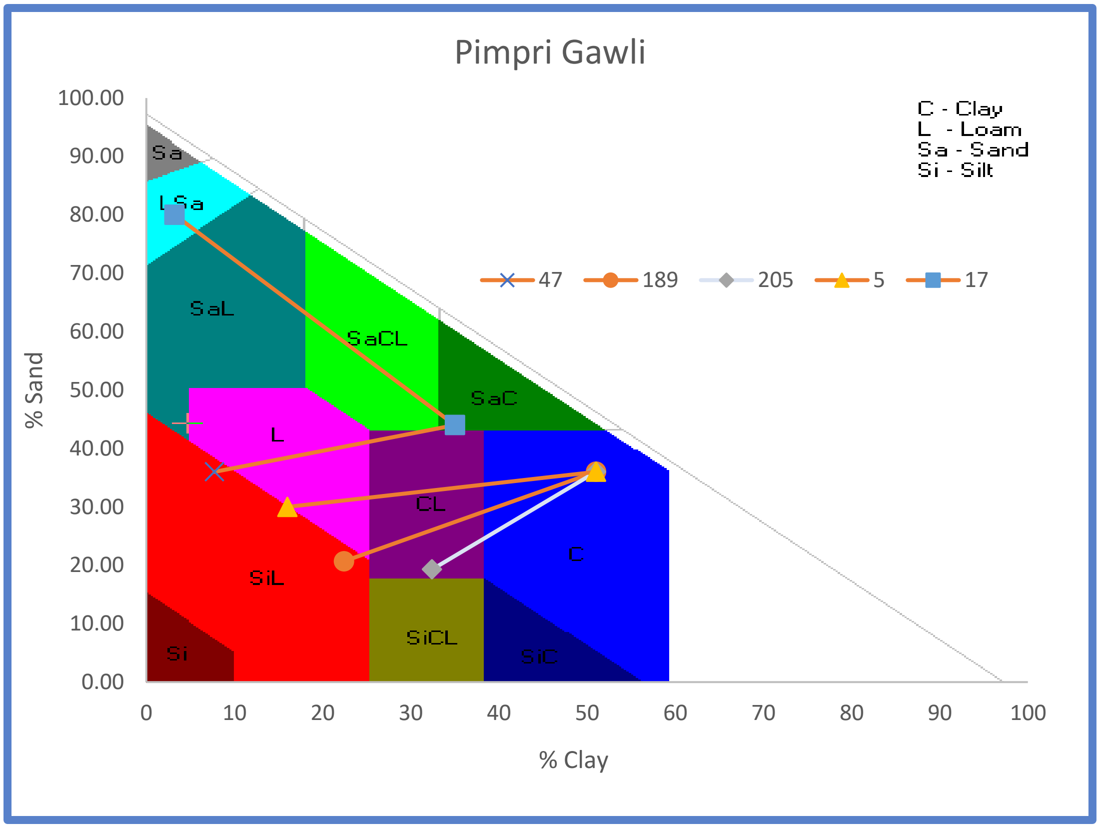

Fig 9 Representation of Soil composition on Soil taxonomic classification triangle

Table 6 Comparison of soil composition from MRSAC layer and Field tests in Pimpri Gawli

MRSAC Layer	Field Results	Soil Composition			Texture
Sr. No	**Gat No.**	**Sand (%)**	**Silt (%)**	**Clay(%)**	
1	47	36	56.28	7.72	Silty Loam/loamy
		44	21	35	Gravelly clay loam
2	189	20.68	56.91	22.41	Silty Loam/loamy
		36	13	51	Clay
3	205	19.27	48.34	32.39	Clay loam
		36	13	51	Clay
4	5	30	54	16	silty loam
		36	13	51	Clay
5	17	80.02	16.78	3.19	loamy sand
		44	21	35	Gravelly clay loam

Jamdaya

5 samples from Jamdaya village were collected randomly from various soil polygons and sent for testing in the laboratory. This is shown in fig 8. Less variation in test results and sample values can be observed in this village as compared to other villages fig 9.

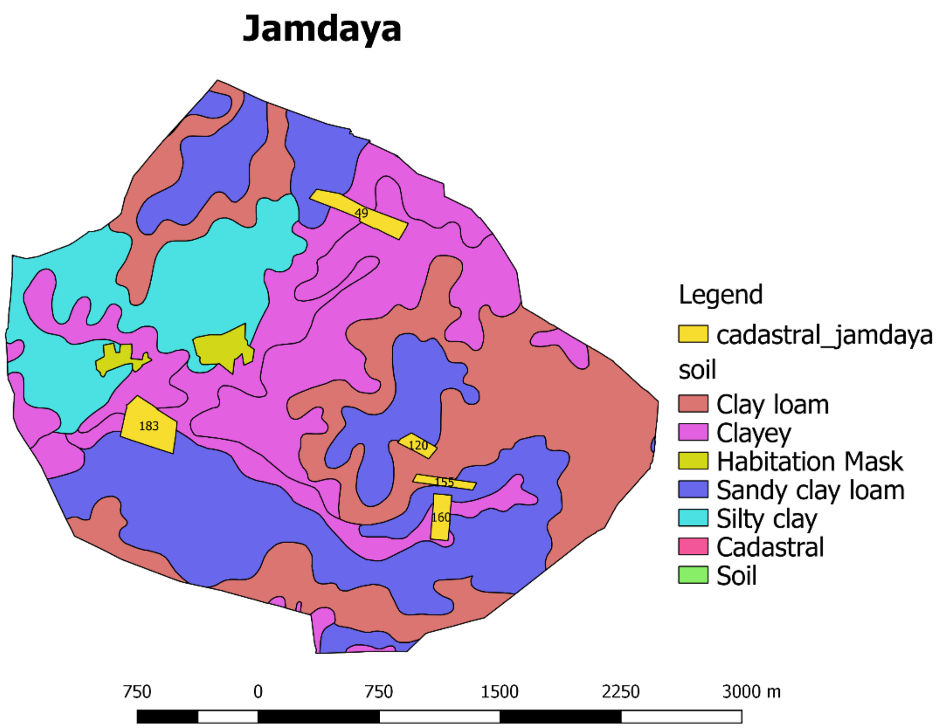

Fig 8 Soil samples location in Pimpri Jamdaya

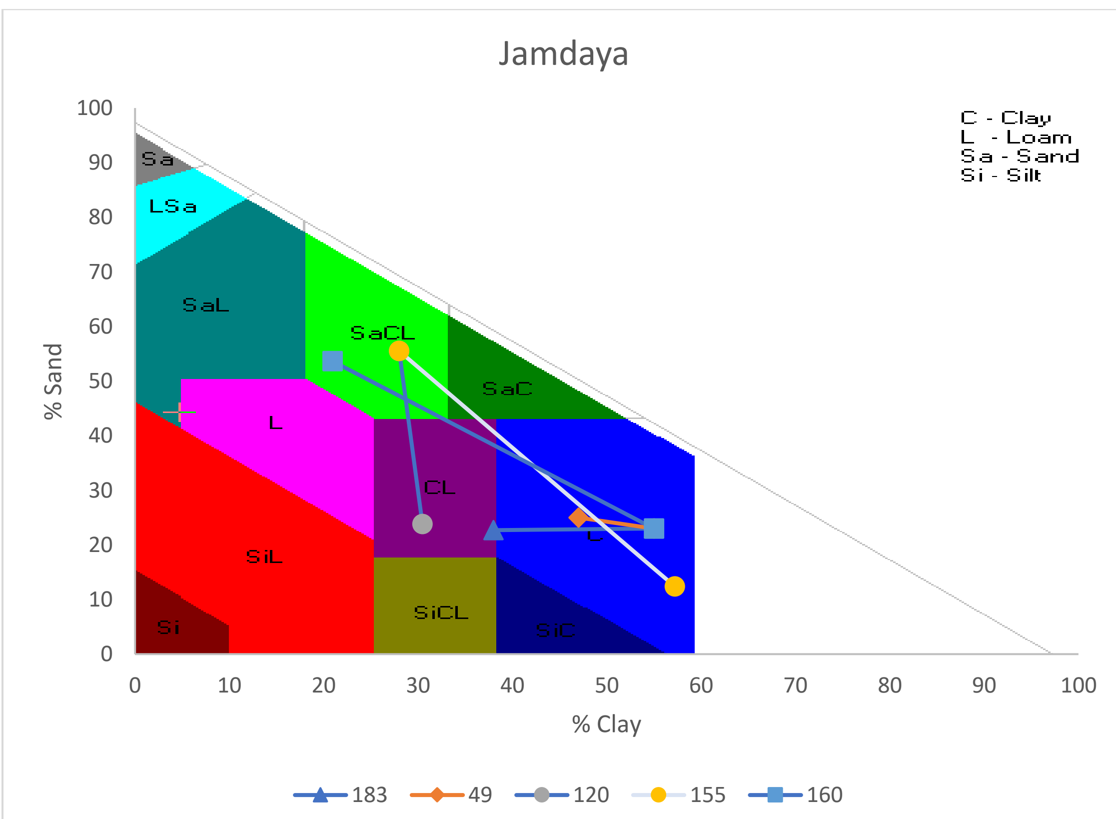

Fig 9 Representation of Soil composition on Soil taxonomic classification triangle

More silt content can be observed in the village as compared to clay content. This can be observed from the table 7 as well while comparing its value with the MRSAC data.

Table 7 Comparison of soil composition from MRSAC layer and Field tests in Jamdaya

MRSAC Layer	Field Results	Soil Composition			Texture
Sr. No	**Gat No.**	**Sand (%)**	**Silt (%)**	**Clay (%)**	
1	183	22.7	39.3	38	Gravelly Clay Loam/Clay
		23	22	55	Clay
2	49	25	28	47	Clay
		23	22	55	Clay
3	120	23.83	45.71	30.46	Clay Loam
		55.5	16.5	28	Sandy clay loam
4	155	12.38	30.39	57.23	Clay
		55.5	16.5	28	Sandy clay loam
5	160	53.63	32.68	20.95	Gravelly Sandy Clay Loam
		23	22	55	Clay

Gondala_Yeulkhed_Wahegaon

4 samples were collected from the Gondala clusters from different soil polygons. Location of these polygons can be seen in the fig 10. Clay, silty clay and sandy clay loam polygons were selected for sample collection.

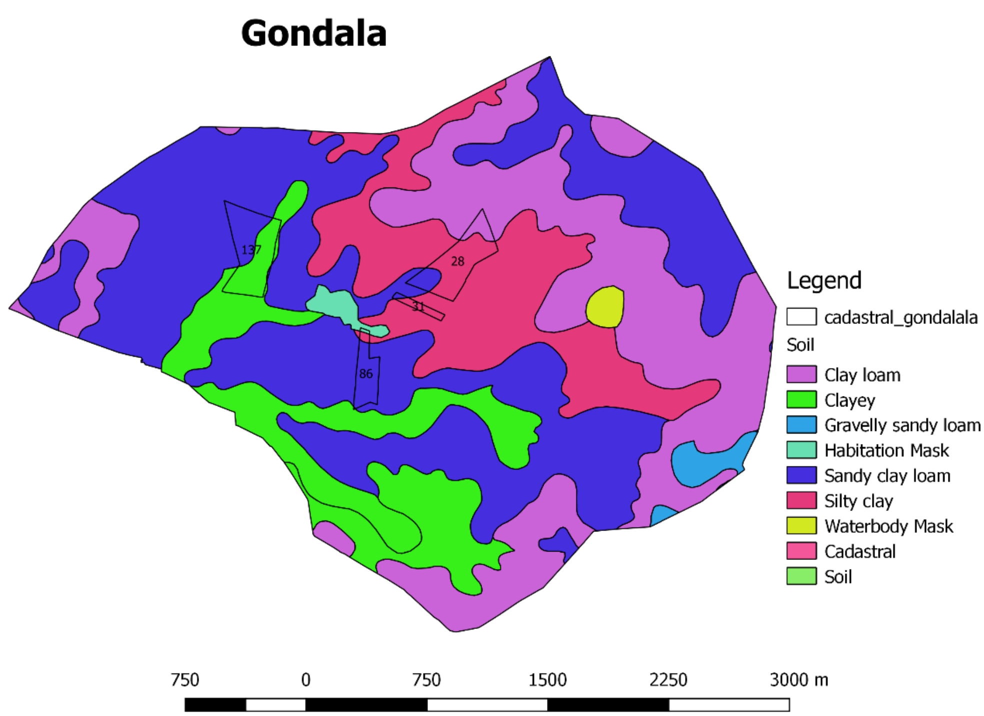

Fig 10 Soil samples location in Gondala

3 samples were collected from the yeulkhed village. One from the farm top layer and second at the 3m depth and third from the river bed. One sample was collected from wahegaon. Sample values and MRSAC values are plotted on the soil taxonomic classification triangle to classify them in different textures and understand the variation. Clearly except one soil sample that is of deep soil, all other samples have fallen in different region. Some are closer and some are quite opposite. This can be seen from the fig 11.

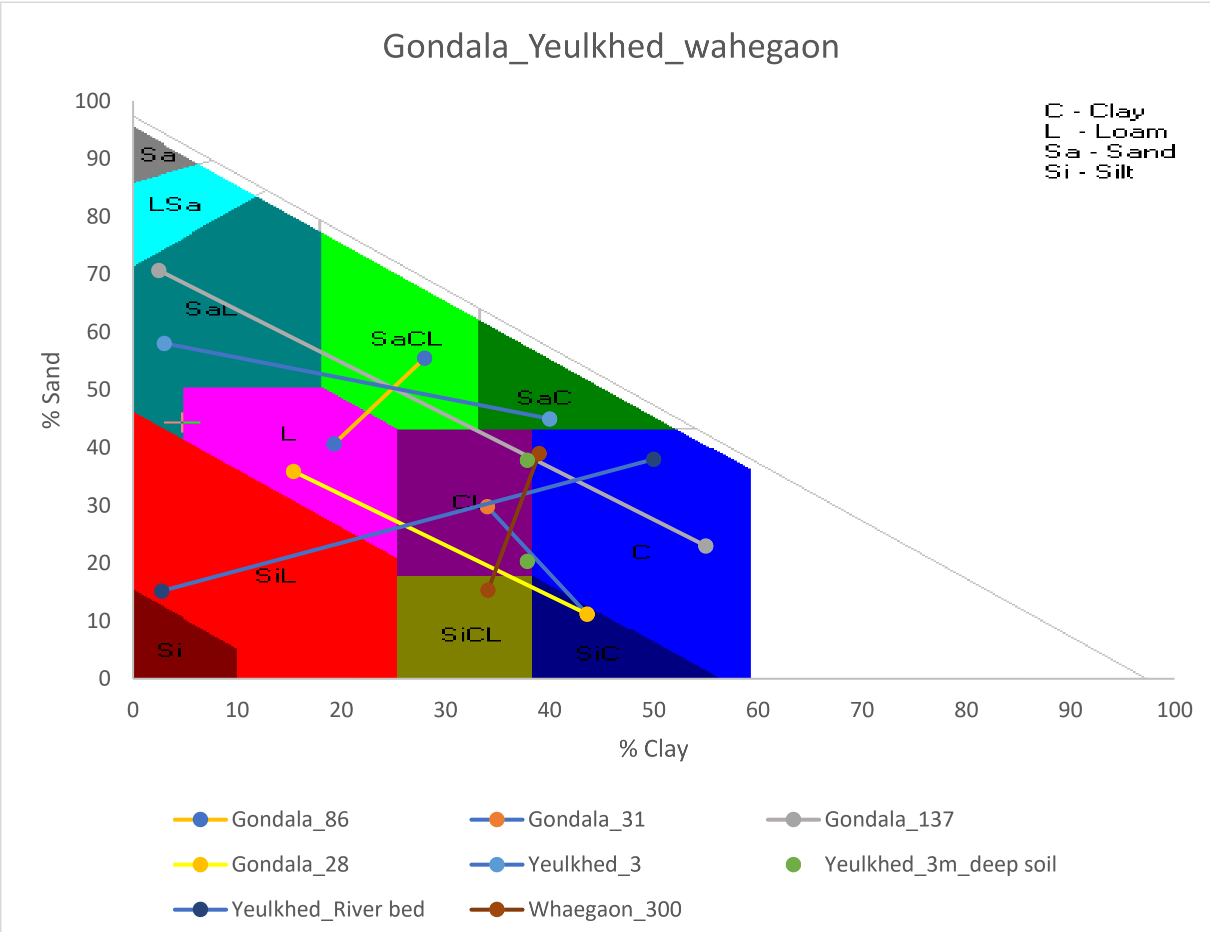

Fig 11 Representation of Soil composition on Soil taxonomic classification triangle

Table 8 gives the composition of 8 samples collected from 3 different villages. Here also we can see that the soils are siltier than being clayey.

Table 8 Comparison of soil composition from MRSAC layer and Field tests in Gondala, Yeulkhed, Whahegaon

MRSAC Layer	Field Results	**Soil Composition**			**Texture**
Sr. No	**Gat No.**	**Sand (%)**	**Silt (%)**	**Clay (%)**	
Gondala					
1	86	40.65	40.05	19.3	Loam
		23	22	55	Sandy Clay loam
2	31	29.8	36.2	34	Clay Loam
		11.2	45.2	43.6	Silty clay
3	137	70.7	26.9	2.5	Sandy Loam
		23	22	55	Clay
4	28	35.9	48.7	15.4	Loam
		11.2	45.2	43.6	Silty clay
Yeulkhed					
5	3	58.07	38.94	2.99	Sandy Loam
		45	15	40	Clay
6	deep soil_3m	20.33	41.82	37.84	Clay Loam
7	River_bed	15.2	82.02	2.76	Silty Loam
		38	12	50	Clay
Bajar Wahegaon					
8	300	15.3	49.6	34.1	Silty Clay
		39	22	39	Clay loam

Impact of texture on model output

Plugin was run at few locations where soil sample has been tested. This was done to analyze the impact of texture values on model output.

In paradgaon village two survey numbers were selected, survey number 328 with cotton plot and survey number 48 with cotton plot. At the locations model was run for tested soil texture and texture obtained from MRSAC value. First, we will investigate the survey number 328 results.

The model was run for two years 2017 and 2018 at location 328. According to MRSAC shapfile soil is very deep and its texture is clay. But, soil depth at the location is 0.5m and texture is sandy loam or silty loam. Model was run for all the scenarios and result is given in table 9. In 2018, there is less rainfall where as in 2017 there is more rainfall. In clay texture obtained from MRSAC shapefile there is hardly any groundwater recharge. This is tested for two depths, 1.5m and actual depth .5m. when depth is more, more water is being stored in the clay soil and is available to plants as it has high water holding capacity. Due to less depth, soil is completely saturated and recharge through it is very slow as it tries to hold water, this does not allow much groundwater recharge. This causes high runoff and more deficit. The model was run for tested texture and actual depth as well which is sandy loam or silty loam. In case of sandy loam there is more groundwater recharge and crop has taken less water due to which deficit is more. In case of silt loam ground water recharge is less as compared to sandy loam and crop has taken more water. Silty loam situation matches to the ground scenario. Same kind of trends have been observed in model output for the year 2018.

Table 9 Model output for cotton plot 328 in paradgaon for year 2017 and 2018

Cotton_328_2017				
	Test		MRSAC	
2017	Sandy_loam_0.5	Silty_loam_0.5	Clay_0.5	Clay_1.5
Rainfall_Monsoon_End	777	777	777	777
Runoff_Monsoon_End	229	230	376	268
AET_Monsoon_End	372	452	386	483
Soil Moisture_Monsoon_End	4	13	6	31
GW_Monsoon_End	172	83	11	0
Deficit_Monsoon_End	131	50	117	20
AET_Crop_End	413	497	425	539
Soil Moisture_Crop_End	4	9	6	11
Deficit_Crop_End	361	227	348	234
Cotton_328_2018				
Rainfall_Monsoon_End	436	436	436	436
Runoff_Monsoon_End	116	93	162	134
AET_Monsoon_End	253	292	260	301
Soil Moisture_Monsoon_End	4	9	6	1
GW_Monsoon_End	62	41	7	0
Deficit_Monsoon_End	283	244	275	235
AET_Crop_End	253	292	260	301
Soil Moisture_Crop_End	4	9	6	0
Deficit_Crop_End	525	485	517	476

In Paradgaon, model was tested on another survey number with a cotton plot. According to MRSAC shapefile this survey number has gravely clay loam texture. Test results shows actual texture is loamy sand or sandy loam. Model was run for 3 scenarios as depth shown in mrsac shapefile is correct. Depth is taken as 0.5m. In 2017, results on gravely clay loam texture showed high amount of runoff and less groundwater recharge which is far from the ground reality. Both loamy sand and sandy loam texture results shows less runoff and high GW recharge. In both the cases crop deficit is also high. This case Is true as farmer has irrigated his cropl many times during monsoon and non-monsoon season using well. Year 2018 also shows the similar trends in terms of runoff, groundwater recharge and crop deficit.

Table 10 Model output for cotton plot 48 in paradgaon for year 2017 and 2018

Cotton_48_2017			
	MRSAC	Test	
	Gravely_clay_loam_0.5	Loamy_Sand_0.5	Sandy_loam_0.5
Rainfall_Monsoon_End	777	777	777
Runoff_Monsoon_End	431	229	287
AET_Monsoon_End	297	214	269
Soil Moisture_Monsoon_End	7	2	4
GW_Monsoon_End	45	347	223
Deficit_Monsoon_End	206	289	233
AET_Crop_End	333	239	298
Soil Moisture_Crop_End	7	1	4
Deficit_Crop_End	441	535	475
Cotton_48_2018			
2018	Gravely_clay_loam_0.5	Loamy_Sand_0.5	Sandy_loam_0.5
Rainfall_Monsoon_End	436	436	436
Runoff_Monsoon_End	199	138	156
AET_Monsoon_End	208	148	179
Soil Moisture_Monsoon_End	7	1	4
GW_Monsoon_End	21	149	96
Deficit_Monsoon_End	327	388	357
AET_Crop_End	208	148	179
Soil Moisture_Crop_End	7	1	4
Deficit_Crop_End	569	630	598

Model was run in village Jamdaya at location or survey number 160 for year 2017 and 2018. According to shapefile the texture at the location is clay and test results shows it to be sandy clay loam. 2018 was low rainfall year and 2017 was average rainfall year in Jamdaya village. In both the cases GW recharge is low. Runoff is slightly higher in case of sandy clay loam. Due to low rainfall in 2018 there is hardly any soil moisture left at the end of monsoon where as in case of 2017 there is soil moisture available at monsoon end. In case of sandy clay loam deficit is slightly higher as compared to clay.

Table 11 Model output for cotton plot 160 in Jamdaya for year 2017 and 2018

Jamdaya_Cotton_Gat_No_160_depth_1m				
Year	2018		2017	
	Test	MRSAC	Test	MRSAC
Soil Type	Sandy Clay Loam	Clay	Sandy Clay Loam	Clay
Rainfall_Monsoon_End	434	434	641	641
Runoff_Monsoon_End	78	66	168	151
AET_Monsoon_End	356	368	436	452
Soil Moisture_Monsoon_End	0	0	37	38
GW_Monsoon_End	0	0	0	0
Deficit_Monsoon_End	256	253	170	154
AET_Crop_End	356	368	516	536
Soil Moisture_Crop_End	0	0	0	0
Deficit_Crop_End	522	510	359	340

In Gondala village model was run at survey number 86 having shallow soil thickness. According to MRSAC soil shapefile the texture is sandy clay loam where as actually it is loamy in nature. In table 12 model result is given for two years 2018 and 2017. Sandy clay loam soil shows more runoff as compared to loamy soil. Groundwater recharge is more and crop deficit is less in case of loamy as compared to clay texture.

Table 11 Model output for cotton plot 160 in gondala for year 2017 and 2018

Gondala_Cotton_Gat_No_86_depth_0.25m				
Year	2018		2017	
	Test	MRSAC	Test	MRSAC
Soil Type	Loamy	Sandy Clay Loam	Loamy	Sandy Clay Loam
Rainfall_Monsoon_End	434	434	641	641
Runoff_Monsoon_End	74	128	149	224
AET_Monsoon_End	238	214	321	295
Soil Moisture_Monsoon_End	7	5	32	25
GW_Monsoon_End	116	87	139	97
Deficit_Monsoon_End	384	407	285	311
AET_Crop_End	238	214	373	340
Soil Moisture_Crop_End	117	5	7	5
Deficit_Crop_End	641	664	502	536

Result and Discussion

Currently soil maps being used are at 1:50000 scale and soil texture results for 5 villages shows that there is scope of improvement. Model output results at five locations shows that there is difference in texture values being used directly from the shapefile and field-tested results. The soils have more silt content as compared to clay content. Due to this difference model output results varies significantly. At some places there is huge variations in runoff, groundwater recharge, soil moisture values and hence in crop deficit. Improved input data to any model will result in better output. Soil maps can be brought down to 1:10000 scale. This will improve the land-based planning as well as farm level water budget results. Efforts should be made towards bringing the down the scale of the map.

Annexure 1 Summary of Soil Mapping Process

Terminologies

Physiographic location A named geographic area is specified with a defined location. Geographic and physiographic information primarily addresses the question “Where is it?”

Geomorphic description A discrete land surface feature (a separate entity) or an assemblage of features is identified. Features are categorized by dominant process of origin or geomorphic setting. Geomorphic description attempts to answer the questions “What is it?” and “How did it occur?” Earth surface features can be partitioned into any number of scale ranges, but three general levels have proven consistently effective: landscapes, landforms, and microfeatures.

Landscapes features at the coarsest scale, are collective groups or families of related landforms and typically cover large areas. Examples are a mountain range.

Landforms are discrete, individual features that are related to one another within the context of the larger landscape and can be mapped at conventional mapping scales, such as order 2 (1:12,000 to 1:31,680). They are typically local in size, but some can be quite large.

Microfeatures are discrete, individual, earth surface features that are readily identifiable on the ground but are too small or intricate to display or capture at conventional mapping scales.

Geomorphic Environment A geomorphic environment is a natural setting dominated by a geomorphic process of formation and modification and the resultant behavioral dynamics. For example, a fluvial geomorphic environment consists of landforms and associated sediments created directly by, or in response to, channel water flow (fluvial processes). In such a setting, present-day environmental dynamics, such as ground-water and water table dynamics, are likely to be largely controlled by the fluvial system that formed the area’s landscape.

Surface morphometry Land surface shape or geometry is described. A discrete portion of a geomorphically defined land feature, area, or slope segment is identified. Microrelief, drainage patterns, and other surface features are also described. Surface morphometry uses various terms to describe land surface shape or geometry, discrete portions of a geomorphic entity or slope segment, and miscellaneous features that are fundamental to soil and natural resource inventory. Several terms are discussed in the following paragraphs.

Elevation is the height of a point on the Earth’s surface, relative to mean sea level. This information is widely available from common GIS databases and historically from topographic maps. Elevation conveys the important climatic context and reflects the relative potential and kinetic energy available at a location.

Soil slope has a scale connotation. It refers to the ground surface configuration for scales that exceed about 10 meters and range up to the landscape as a whole. It has gradient, complexity, length, and aspect. The scale of reference commonly exceeds that of the pedon and should be indicated. It may include an entire map unit delineation, a soil component within the map unit delineation, or an arbitrary area. Most commonly, slope is recorded in pedon descriptions for the segment of the landscape extending a few tens of meters above and below the site of the soil profile described and is representative for the landscape segment occupied by the soil component at that site.

Slope aspect is the compass bearing that a slope faces looking down slope. It is recorded either in degrees, accounting for declination, or as a general compass orientation. The direction is expressed as an angle between 0 and 360 degrees (measured clockwise from true north) or as a compass point, such as east or north-northwest.

Soil mapping is the process of delineating natural bodies of soils, classifying and grouping the delineated soils into map units, and capturing soil property information for interpreting and depicting soil spatial distribution on a map.

Soil Taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile (Soil Survey Staff, 1999). Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically.

A **pedon** is the smallest body of one kind of soil that is large enough to represent the nature and arrangement of horizons and the variability in the other properties. It lacks boundaries with neighboring pedons (Soil Survey Staff, 1999). It is a unit of observation, sampling, and classification. A pedon by itself is too small to be the unit of soil mapping because it cannot account for features such as slope and surface stoniness. In addition, it is too small to embody the full range of variability occurring within a soil series.

The **polypedon** is used to define a soil series and is the unit of soil mapping. It is the three-dimensional soil body or soil individual that is homogeneous at the soil series level of classification. It is big enough to exhibit all the soil characteristics considered in the description, classification, and mapping of soils.

The **series** represents a three-dimensional soil body having a unique combination of properties that distinguish it from neighboring series. As a class, a series is a group of soils or polypedons that have horizons similar in arrangement and in differentiating characteristics. The soils of a series have a relatively narrow range in sets of properties. The soil series is not the object mapped in soil survey. Natural soil bodies are mapped and then described and classified. Each map unit soil component is correlated to a soil series or other taxonomic class. Soil series serve as a bridge between real soil bodies and conceptual taxonomic classes

Soil map units are designed to efficiently deliver soil information to meet user needs for management and land use decisions. Map units can appear as individual areas (i.e., polygons), points, or lines on a map. A map unit is a collection of areas defined and named the same in terms of their soil components, miscellaneous areas, or both. Each map unit differs in some respect from all others in a survey area and is uniquely identified on a soil map. A map unit description is a written characterization of the component within a map unit and the relationship of one map unit to another. A delineation of a map unit generally contains the major (dominant) components included in the map unit name, but it may not always contain a representative of each kind of minor component.

Component Within the context of a map unit, a component is an entity that can be delineated at some scale. It is commonly a soil but may be a miscellaneous area. Components consisting of soil are named for a soil series or a higher taxonomic class. Those that are miscellaneous areas are given an appropriate name, such as “Rock outcrop” or “Urban land.”

family the first level above the series is the family. Components mapped to the family level match the classification of a series, but not the series criteria. The name of a representative series belonging to the component taxonomic classification is used as the component name.

Taxadjuncts are polypedons that have properties outside the range in characteristics of any recognized series and are outside higher category class limits by one or more differentiating characteristics of the series. A taxadjunct is given the name of an established series that is most similar in characteristics.

Phase terms added to map unit component names convey important information about a map unit and differentiate it from other map units on the map unit legend. Common phases are slope, surface texture, flooding and ponding, surface fragments, degree of erosion, and climate.

Soils differ in size and shape of their areas, in degree of contrast with adjacent soils, and in geographic relationships. Four kinds of map units are used in soil surveys: consociations, complexes, associations, and undifferentiated groups.

In a **consociation**, delineated areas are dominated by a single soil component (or miscellaneous area). Commonly, at least one-half of the pedons in each delineation are of the same soil taxa as the named soil. The remainder of the delineation mostly consists of soil so similar to the named soil that major interpretations are not significantly affected.

Complexes consist of two or more dissimilar major components that occur in a regularly repeating pattern or in an unpredictable pattern. The major components of a complex cannot be mapped separately at a scale of about 1:24,000. Typically, each major component occurs in each delineation, although the proportions may vary appreciably from one delineation to another. The major components are sufficiently different from each other in morphology or behavior that the map unit cannot be a consociation.

Associations consist of two or more dissimilar major components occurring in a regular and repeating pattern on the landscape. The major components of an association can be separated at a scale of about 1:24,000, but due to land use or user needs, the map unit design integrates the predictable and repeating pattern of soil occurrence. Many general soil maps use soil associations because they are at scales much smaller than 1:24,000 and can depict only the characteristic landscapes of associated soils, not the individual soils. The major components are sufficiently different in morphology or behavior that the map unit cannot be a consociation.

An undifferentiated group is a map unit of dissimilar soils that are not consistently associated geographically and, therefore, do not always occur together in the same map unit delineation. These components are included in the same named map unit because use and management are the same or very similar for common uses.

Traverses are used to identify different components on a landform. The observation points along a traverse can be any distance apart. The distance is adjusted to the direction and scale of the soil boundaries and the variability of the important properties in each component.

Transects are used to determine the composition and design of map units. They have fixed length intervals between observation points. Observations made at points along a transect are typically identified as belonging to a particular taxon, or soil component, but can also be a combination of properties, such as depth, thickness, color, or vegetation.

Soil Mapping Process

Land resource inventory (LRI) on 1:10000 scale provides site specific information needed for farm/ village level planning. LRI involves systematic survey of soils (agricultural land) on 1:10000 scale and collection of other collateral data needed for scientific land use planning in GIS environment. The detailed database generated at farm level and its subsequent abstraction to village, mandal, taluka, district, state and country will form the basis needed for prioritizing, initiating and executing any land-based developmental programmes. At present, the soils information available in the country is of general nature (1:250000 scale soil maps for the entire country and few district maps at 1: 50000 scale) and is suitable up to district or taluka level planning. These maps have limited application at the farm level due to scale limitations. Few pilot studies on 1:10000 carried out in various parts of the country have proved conclusively the importance of such site-specific database. Land resource inventory (LRI) on 1:10000 scale is expected to provide site-specific information needed for farm/ village level planning(NBBSS&LUP, 2016).

A DEM can provide data that can assist the soil surveyor in mapping and deriving quantitative attributes of landform which is first step for preparation of soil maps at various scales. The terrain attributes like contours, drainage, slope and hill shade are treated as input layer for landform delineation. The landform classification process is hastened taking into consideration the slope class zone, hill shade, contour and auto-drainage pattern.

Soils are formed on different landforms as per soil-physiographic relationships. Soils are mapped at different levels and a soil mapping unit represents the soil properties acquired over time. It assumes that if landform, slope and land use are identical, there is high possibility of getting similar kind of soils. The properties of soil vary from place to place, but this variation is not random. Natural soil bodies are the result of *climate*, and *vegetation including living organisms* acting on *parent material*, with *topography* or local relief exerting a modifying influence and with *time* required for soil forming processes to act. For the most part, soils are the same wherever all elements of the five factors are the same.

Field studies are conducted to establish Soil-Mapping unit relationship by studying profiles, minipits and auger observation in well-defined strips. Numbers of strips are marked for covering entire Mapping unit. During the traverse of the area, most of delineated boundaries are checked and confirmed. After extensive field work and soil correlation, soil series is established; phases of each soil series are defined. Phases of series include soil depth, surface texture, slope, erosion, gravelliness, salinity/sodicity and any other feature influencing management. Intensive field traversing is done to check and verify the pre-field landform or physiographic boundaries delineated in the laboratory through interpretation of satellite image. Based on soilsite variations (for example, landform, slope, aspect, geology, vegetation/land use, etc.), profiles/ mini-pits are excavated and examined for the detailed morphological properties(USDA, 2017).

A soil survey describes the characteristics of the soils (such as depth, colour, texture, structure, internal drainage, parent material, depth to groundwater, topography, degree of erosion, stoniness, and salinity etc.) and their spatial distribution over a landscape in each area. Soils are grouped into similar types and their boundaries are delineated on map. Each soil type has a unique set of physical, chemical and mineralogical characteristics and has similar response to use and management. The general methodology of soil survey comprises prefield interpretation using cadastral map, Survey of India toposheets, aerial photograph and satellite data (depending upon their availability) for delineation of various physiographic units, ground truthing for verification of physiogphic units, soil profile study, developing physiography-soil relationship and extrapolation of this relationship to other similar areas. Depending on the similarity of the pedons in the surveyed area, soil series are tentatively established. The soil surveyor, then attempts to establish the relationships between the landforms and the soils so that it can be depicted on the map. A soil survey tries to answer the following type of questions.

(i) What types of soils are present and in what proportions? (ii) What is the soil type at any site of interest? (iii) Where can soil of a particular type or particular range of soil properties be found?

Questions of the first type can be answered most efficiently by identifying the soil. However, most soil surveys also aim to answer questions of the second and third types by the production of a soil map showing how and where the soil varies.

The soil bodies contain a sequence of identifiable horizons and layers that occur in repeating patterns in the landscape as a result of the factors of soil formation as described by Dokuchaev and Jenny (USDA, 2017). The repeating patterns formed by these natural bodies of soil in the landscape allow soil scientists to develop predictive soil-landscape models, which serve as the scientific foundation for making soil

The basic objective of soil surveys is the same for all kinds of land, but the number of map units, their composition, and the detail of mapping vary with the complexity of the soil patterns and the specific needs of the users. Thus, a soil survey is designed for the soils and the soil-related problems of the area.

landforms (such as glacial moraines, alluvial plains, loess plains, and marine terraces).

For many soils, the information obtained from a small sample amply describes the pedon from which it is taken. For other soils, however, important properties of a pedon are not observable in a smaller sample and detailed studies of the entire pedon are needed. Complete study of an entire pedon requires the exposure of a vertical section and the removal of horizontal sections layer by layer. Horizons are studied in both horizontal and vertical dimensions. The kind of exposure (e.g., bucket auger, push tube, small hand-dug pit, backhoe pit, road cut, etc.) should be identified in the soil description.

The soils and miscellaneous areas (e.g., Rock outcrop) in a survey area are in an orderly pattern that is related to the geology, landforms, topography, climate, and natural vegetation. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. Soil scientists delineate these repeating patterns of landform segments, or natural bodies, on a map. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they formed. Thus, during mapping, these models enable the soil scientist to predict with considerable accuracy the kind of soil or miscellaneous area on the landscape (Hudson, 1992).

After the soil scientists identify and describe the properties of landscape components, or natural bodies of soils, the components are correlated to an appropriate taxonomic class, which is used for naming map units. Correlation, or comparison of individual soils with similar soils in the same taxonomic class in other areas, confirms data and helps the staff determine the need to assemble additional data.

The mapper essentially is predicting the soil beforehand and only making an observation to confirm the prediction, rather than discovering the soil only after each observation is made. As long as the model is accurate, relatively few observations are required to make an accurate map

The relationships between patterns of soil and patterns of images on photographs for an area can be determined. These relationships can be used to predict the location of soil boundaries and the kinds of soil within them.

While a soil survey is in progress, samples of some of the soils in the area are collected for laboratory analyses. Soil scientists interpret the data from these analyses and tests as well as the field observed characteristics of the soil properties to determine the range of values for key soil properties for each soil. They also use these data to determine the expected behavior of the soils under different uses.

The landscape is partitioned either in the field or using remotely sensed data. The first step is to group areas having the same soil-forming factors known as conceptual models of related soils. This premapping step groups defined landscapes, landforms, geology, vegetation, and climatic areas. Areas that have these same repeating patterns are delineated and labeled as the same map unit. It is recommended that broad groupings are established first. The lines can be adjusted as the survey team completes fieldwork to verify map units and refine concepts.

Designing map units to indicate significant differences in behavior among soils is particularly important for meeting the current objectives of a survey. Map units separated according to differences in geomorphic processes (e.g., parent material, relief, and time) are considered the most important soil lines on the landscape. These lines should be the first delineated on a map. Indicating differences in geomorphic processes is important, even if no immediate differences in interpretations are known. Differences in soil properties that do not affect current interpretations may be important in the future. Too many delineations may greatly reduce the immediate usefulness of a soil map. The potential benefit of extra delineations (the value of the additional information) must be weighed carefully against the costs incurred in making additional separations. Every soil survey is designed to record knowledge about soils; however, this does not mean that the soil map must show the location of every kind of soil in a survey area or that the publication must record everything that is known about the soils. Capturing and managing all observations of soil data on maps, even if the data is not used for publication, is invaluable in later analysis to develop new maps or update soil information.

Soil mapping uses the scientific method, in which the scientist must: (1) develop questions, (2) generate hypotheses that answer those questions, (3) test the hypotheses, and (4) confirm or reject the hypotheses. After a tentative delineation of a soil body is drawn on an aerial photo or digital image, the soil mapper (step 1) questions what type of soil exists within that delineation. Typically, the delineation follows a landscape feature, such as a large flood plain or a ridge summit. Based on previous knowledge about the soils of the region, the mapper (step 2) develops hypotheses, such as the Alpha and/or Beta series occurs within the delineation. The mapper (step 3) tests those hypotheses by augering, backhoe trenching, or observing natural exposures and (step 4) confirms or rejects each hypothesis. After documenting the results, the mapper returns to step 1 (develops questions) and repeats the process for a neighboring area. This process allows the soil scientist to map soils efficiently. Rather than making a large number of observations on a regular grid pattern to discover the kind of soil present, the mapper selects a limited number of strategically located points in the landscape to make observations. The observations confirm or reject the previously developed model. The mapper essentially is predicting the soil beforehand and only making an observation to confirm the prediction, rather than discovering the soil only after each observation is made. As long as the model is accurate, relatively few observations are required to make an accurate map (Hudson, 1992).

The concept of the polypedon is, from a practical standpoint, more or less equivalent to the *component* in soil mapping, but with one technical difference. Since the polypedon is defined as being homogenous at the series level of classification, each pedon making up the polypedon must fall within the class limits for all the properties (texture, color, reaction, thickness, etc.) of that series. When the limits of taxa are superimposed on the pattern of soil in nature, areas of taxonomic classes rarely, if ever, coincide precisely with mappable areas. In contrast, the map unit component represents a miscellaneous area or a natural soil body that includes all of the pedons making up the polypedon, as well as other very similar pedons within the mapped area that are just slightly outside the property ranges assigned for the series.

The correlation process is an integral part of soil survey. It is carried out on a continuing basis throughout the course of the project. Soil correlation can be described by the following steps: (1) design of map units, (2) characterization of map unts, (3) classification of map unit components, (4) correlation of map units, and (5) certification.

Annexure 2 Model result for different soil texture

	Model Result - Paradgaon – Gat – 48 – Cotton -2018						
2018	Sandy loam 0.5	Silty loam 0.5	Clay 0.5	Clay 1.5	Gravely clay loam 0.5	Loamy Sand 0.5	Sandy Loam 0.5
Rainfall_Monsoon_End	436	436	436	436	436	436	436
Runoff_Monsoon_End	116	93	162	134	199	138	156
AET_Monsoon_End	253	292	260	301	208	148	179
SM_Monsoon_End	4	9	6	1	7	1	4
GW_Monsoon_End	62	41	7	0	21	149	96
Deficit_Monsoon_En	283	244	275	235	327	388	357
AET_Crop_End	253	292	260	301	208	148	179
SM_Crop_End	4	9	6	0	7	1	4
Deficit_Crop_End	525	485	517	476	569	630	598

	Model Result - Paradgaon – Gat – 48 – Cotton -2018 – depth - 0.25m					
2018	clay loam	clay	gravely clay	gravely clay loam	gravely loam	gravely sandy clay loam
Rainfall_Monsoon_End	436	436	436	436	436	436
Runoff_Monsoon_End	202	207	203	200	150	160
AET_Monsoon_End	206	207	209	208	213	199
SM_Monsoon_End	7	6	7	7	7	6
GW_Monsoon_End	20	15	17	21	66	70
Deficit_Monsoon_End	329	329	327	328	323	336
AET_Crop_End	206	207	209	208	213	199
SM_Crop_End	7	6	17	7	7	6
Deficit_Crop_End	571	570	569	569	564	578

	Model Result - Paradgaon – Gat – 48 – Cotton -2018 – depth - 0.25m					
2018	gravely sandy loam	gravely silty clay	gravely silty loam	loam	loamy sand	sandy
Rainfall_Monsoon_End	436	436	436	436		
Runoff_Monsoon_End	162	180	150	153	139	150
AET_Monsoon_End	178	219	236	210	148	132
SM_Monsoon_End	5	7	9	7	1	0
GW_Monsoon_End	91	30	40	67	148	155
Deficit_Monsoon_End	358	317	299	326	388	404
AET_Crop_End	178	219	236	210	148	132

Soil Moisture_Crop_End	5	7	9	7	1	0
Deficit_Crop_End	600	558	541	568	630	646

	Model Result - Paradgaon – Gat – 48 – Cotton -2018 – depth - 0.25m					
2018	sandy clay	sandy clay loam	sandy loam	silty clay	silty clay loam	silty loam
Rainfall_Monsoon_End	436	436	436	434	436	436
Runoff_Monsoon_End	211	193	156	192	175	145
AET_Monsoon_End	197	184	179	214	226	239
SM_Monsoon_End	6	5	4	7	8	9
GW_Monsoon_End	23	54	96	23	26	42
Deficit_Monsoon_End	339	352	357	322	310	296
AET_Crop_End	197	184	179	214	226	239
Soil Moisture_Crop_End	6	5	4	7	8	9
Deficit_Crop_End	581	594	598	563	551	538

	Model Result - Paradgaon – Gat – 328 – Soyabean -2018 – depth - 0.5m						
2018	Clay 0.5	Clay 1.5	Clay Loam	Gravely clay	Gravelly clay loam	gravelyloam	gravely sandy clay loam
Rainfall_Monsoon_End	436	436	436	436	436	436	436
Runoff_Monsoon_End	164	133	172	166	171	106	117
AET_Monsoon_End	246	270	241	245	242	258	255
SM_Monsoon_End	19	33	20	19	20	21	17
GW_Monsoon_End	6	0	3	5	2	50	47
Deficit_Monsoon_End	120	96	126	121	125	108	112

	Model Result - Paradgaon – Gat – 328 – Soyabean -2018 – depth - 0.5m					
2018	gravely sandy loam	Gravely silty clay	gravely silty loam	loam	loamy sand	sandy
Rainfall_Monsoon_End	436	436	436	436	436	436
Runoff_Monsoon_End	139	135	132	108	111	121
AET_Monsoon_End	229	259	263	257	186	163
SM_Monsoon_End	14	22	31	20	12	11
GW_Monsoon_End	53	19	9	51	127	140
Deficit_Monsoon_End	137	108	103	109	181	204

	Model Result - Paradgaon – Gat – 328 – Soyabean -2018 – depth - 0.5m					
2018	Sandy clay	sandy clay loam	sandy loam	silty clay	silty clay loam	silty loam
Rainfall_Monsoon_End	436	436	436	436	436	436

Runoff_Monsoon_End	173	160	116	166	160	94
AET_Monsoon_End	237	230	236	246	253	271
SM_Monsoon_End	16	15	14	22	23	33
GW_Monsoon_End	9	31	69	2	0	38
Deficit_Monsoon_End	129	136	130	120	114	95

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