International Water Management Institute

ITC Limited

CGIAR

Drought Proofing Tool

Case study exercise

Innovative water solutions for sustainable development

Food • Climate • Growth

Acknowledgement

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1. Introduction

Drought proofing tool is developed to operationalize the Drought proofing framework (**Figure 1**). In the framework, drought proofing in a watershed is conceptualized as an interaction between water availability for crop and water productivity or use efficiency (figure 1). In the framework, 'drought proofing' is conceptualise as an interaction between water availability for crop (% of crop water need met) and how efficiently available water is used (**Figure 1**). Across a simple 2*2 plane, we can identify four distinct quadrants with water availability for crop on y-axis and crop water productivity on x –axis. Quadrant 1 is the ideal quadrant where water availability is sufficient to meet crop water needs and available water is used efficiently. In other quadrant, there has to be focus on increasing water availability (quadrant 4) or water use efficiency (Quadrant 2) or both (Quadrant 4). By analysis where watershed crops lies in different rainfall years, user can identify the type and intensity of required interventions. Water availability can be increased with supply augmenting practices (storages, recharge and soil moisture conservation) whereas water use efficiency can be increased by increasing yield or reducing non-beneficial evaporation and increasing irrigation application efficiency.

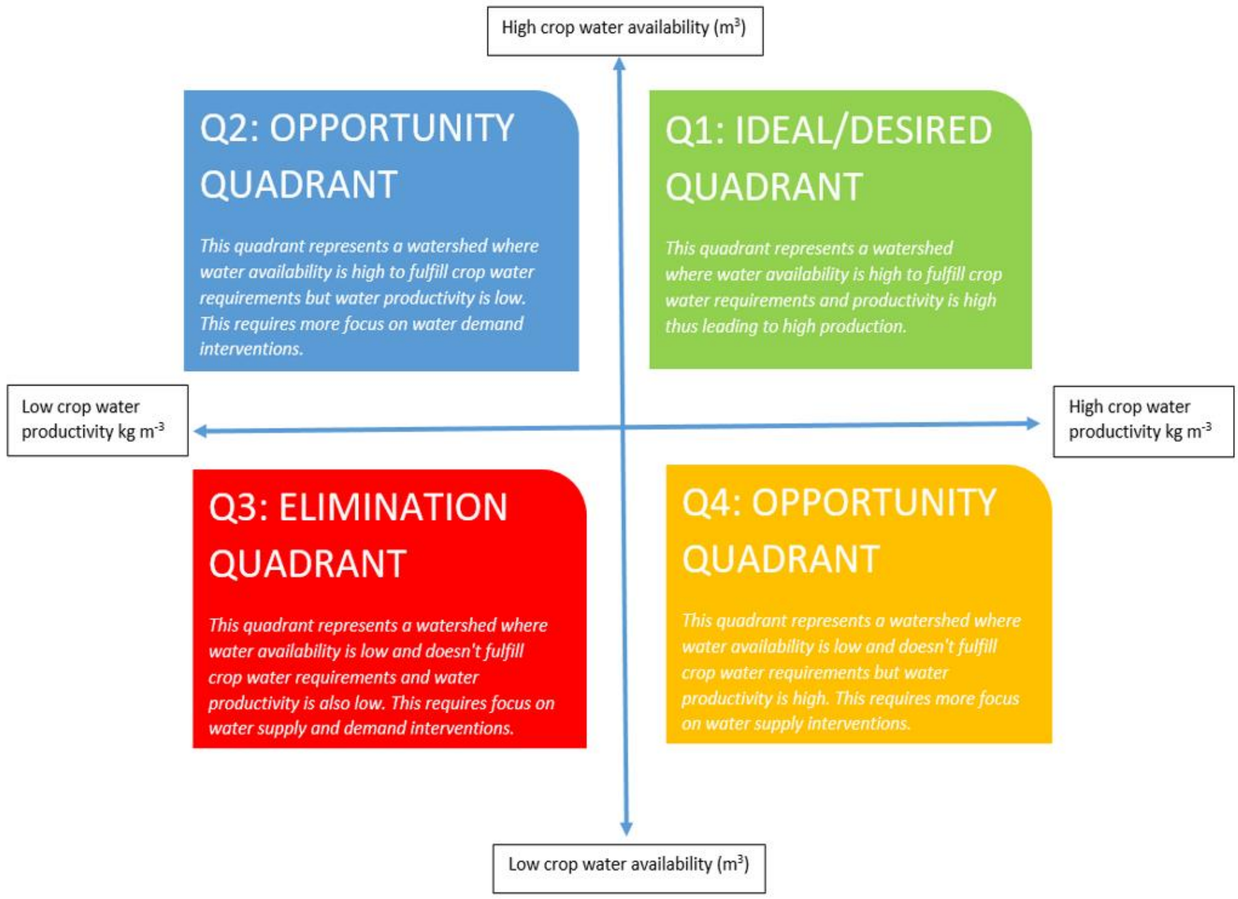

Figure 1: Conceptual physical drought proofing framework

With water as the key input to the drought proofing framework (**Figure 1**), a drought proofing tool is developed to operationalize the framework. Water balance tool helps in site specific water balance, crop yield and crop requirement assessments.

The two-key function of the tool are as follows:
1. To assess water balance of study area under different conditions (dry, normal and wet year)
2. To assess the impact of proposed land and water interventions on water balance for study area.

The water balance results from before and after the interventions are plotted in the same drought proofing framework plot to monitor the change in crop yield and productivity. The tool is modelled in excel spread sheet with minimum input data requirements for simplifications. Drought Proofing Tool is developed in MS Excel + Visual Basic Editor (VBA) platform.

This case study examples provides a brief guide on running the model and analysing the results. To see detailed step by step instructions on setting up and running the tool, please read the user manual.

2. Study area

Jhalarapatan Watershed is located in the Jhalarapatan Block of Jhalawar District in Rajasthan, India (**Figure 2**). Watershed is part of Chambal basin. The study area has Tropical Savanna climate bordering on a hot semi-Arid climate under Koppen climate classification. South-West monsoon covers most of the annual precipitation. The average annual rainfall is 827 mm. Average rainfall of watershed is 890 with more than 90 % of rainfall occurring during monsoon season (Jun-Sep).

Kharif season (overlapping monsoon season) is the main cropping season followed by Rabi season and Zaid. Soyabean and Maize are the main crops during Kharif, wheat and Mustard during Rabi season and Green gram in Zaid season There are some horticultural crops such as vegetables (garlic, onion) and fruits (orange) grown in the watershed

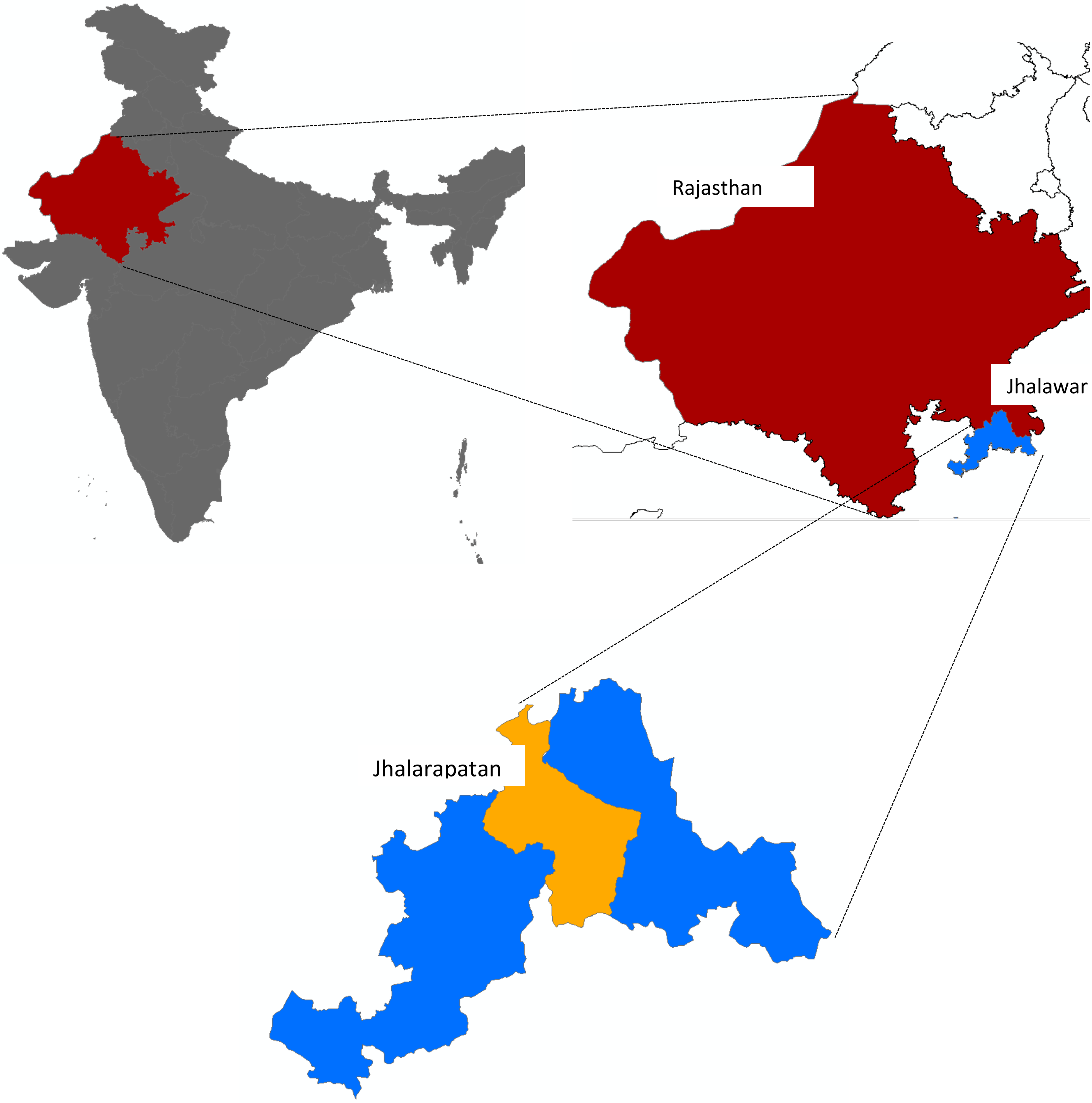

Figure 2: Study area map

3. Input data

3.1 Land Use & Soil

Watershed is predominantly cultivated with agricultural area occupying ~ 70 % of watershed area. Enter the details in Table 1 in the tool *Land & Soil* section. Clay loam is the predominant soil type in the area covering 86 % of in the area. Enter the soil details in Table 2 in the tool *Land & Soil* section. For details of parameters or step by step instructions on how to add data, please see user manual.

Table 1: Land use details

S.no	Description	Area (ha)
	Total Agri catchment Area (ha)	7663.3
1.	Agriculture Area (Net cultivated sown area)	5417.7
2.	Fallow	338.7
3.	Built-up / Settlements	370.9
4.	Waterbodies	13.0
5.	Pasture	338.0
6.	Forest	1185.0
7.	Other	0

Table 2: Soil details

S.no	Soil Type	Soil Depth (m)	Soil Distribution (%)	Infiltration Rate (mm/hr)	Hydrological condition
1.	Clay Loam	0.70	86	5-10	Poor
2.	Loam	0.65	14	10-20	Good

3.2 Crop Details

In the kharif, major crops grown are Soyabean and Maize. In the rabi, major crops grown are Wheat and Mustard. Enter the details in Table 3 in the tool *Crop Details* section. For details of parameters or step by step instructions on how to add data, please see user manual.

Table 3: Cropping pattern details

Area	Crop name	Area Sown (ha)	Irrigation (ha)		Crop Duration (days)	Crop Sowing Date	
			Irrigated	Rainfed		Month	Week
Kharif							
Area 1	Soyabean	4624	3500	1124	100	June	4
Area 2	Maize	793	600	193	120	June	4
Rabi							
Area 1	Wheat	1803	1500	303	130	Nov	1
Area 1	Mustard	1287	1000	287	110	Nov	1

Now in the *Crop Details* section, update the crop details (clicking update crop details button) as given in Table 4. For details of parameters or step by step instructions on how to add data, please see user manual.

Table 4: Update Crop details

Crop name	Crop yield (tonne/ha)	Price (Rs/Tonne)
Soyabean	2.25	32000

Maize	3.45	19000
Wheat	4.45	20000
Mustard	1.97	34000

3.3 Rainfall & Temperature

Add Rainfall and temperature data that should be stored in an external excel file in your computer. File is shared with the case study material or available at link.

- The rainfall and temperature excel file layout must not be changed (i.e. modifying, adding or deleting new rows or columns in excel file).
- Only the file containing the rainfall and temperature data should be select. Name the pre-prepared file always under same formation ("Location name" Rainfall_Temperature_Data").

3.4 Irrigation & Domestic

Enter the irrigation and domestic data as given in Table 5. Keep the River/canal WA empty. For details of parameters or step by step instructions on how to add data, please see user manual.

Table 5: irrigation & domestic details

Irrigation Source	**Area (%)**	**Irrigation efficiency**	**Residual storage**	**Non-Renewable storage**
		Irrigation		
Groundwater	95	0.5	0	No
Surface water	5	0.5	0	-
		Domestic		
Population	Daily water usage (LPD)	GW dependent	SW dependent	
2810	60	90	10	

4 Run baseline scenario

Before running the scenarios, reset 

tool to remove any previous results.

Once all the input data is entered in tool and tool is reset, procced to click on icon without adding any interventions. Name the scenario *Baseline.* For details of parameters or step by step instructions on how to run scenarios, please see user manual.

4.1 Analyse results

4.1.1 Water balance

Check water balance for average (overall), mild and moderate drought years. Table 6 gives the water balance results for the watershed. Analyse the results. Some key points are:

- The water balance varies due to variability in rainfall. What is the rainfall for different drought years?

- What is the percentage of rainfall converted to runoff and recharge?

- Compare the results of runoff and recharge to observed values in your study area? Are they similar? And if not, why? Some key points to remember:
    - Runoff and groundwater recharge is influenced by land use classification, crop types, soil type and hydrological condition of soil.

- Water balance results can tell you how much runoff is available for harvesting and recharge.
    - But is there enough runoff in moderate drought year to capture?

Table 6: Water balance results (in mm)

Year	Rainfall	Runoff	recharge	ET
Overall	911	248	152	511
Mild	741	154	86	502
Moderate	623	51	81	492

4.1.2 Crop water requirement and irrigation water requirement

- Check the second plot which gives Crop water requirement (CWR) and Irrigation water requirement (IWR) for each crop.

- CWR of crop is calculated based on reference evapo-transpiration (ET). As the temperature difference between different drought years is small, therefore CWR is shown to be same for different drought years.
    - What will happen if temperature is high for a year?

- IWR varies across different drought years. Why does it vary?
    - IWR is the difference between CWR and rainfall in the crop growing period. So in years with low rainfall, IWR will be high.
    - This is the reason IWR is less for kharif crops relative to rabi season because of more rainfall during crop growing season in monsoon.

- IWR depends on rainfall during crop growing season. It is possible that despite of higher annual rainfall, IWR remains high.
    - Can you identify this is Table 7. (Hint: mild vs moderate drought year).

Table 7: CWR & IWR of crop (in mm)

	Overall		Mild		Moderate	
	CWR	**IWR**	**CWR**	**IWR**	**CWR**	**IWR**
Kharif						
Soya bean	365	51	365	60	365	49
Maize	510	106	510	95	510	113
Rabi						
Wheat	443	315	443	317	443	297
Mustard	250	228	250	231	250	234

4.1.3 Crop water requirement met and crop yield

- Check the third plot which gives crop water requirement met (CWR met in %). This shows how much of CWR of a crop (Table 7) is met.
    - CWR is met by rainfall and soil moisture in case of rainfed crops.
    - CWR in met by rainfall, soil moisture and irrigation storage in case of irrigated crops.
    - This is why CWR met of irrigated crop is higher than the rainfed crops (Table 8).

- Kharif crops (Soyabean & Maize) have higher CWR met due to higher rainfall during the crop growth period. Why? (Hint: Monsoon rainfall).

- For Rabi crops (Wheat & Mustard), CWR met for rainfed is very low due. Why? (Hint: post monsoon crops).
    - What it shows is that irrigation is needed to support rabi crops.
    - Is irrigated crop water requirements completely met? If it is not, that means more storage and recharge is required to meet crop irrigation water needs.

Table 8: CWR met & IWR met

	Overall		Mild		Moderate	
	Irrigated	**rainfed**	**Irrigated**	**rainfed**	**Irrigated**	**rainfed**
Kharif						
Soyabean	93%	86%	93%	84%	92%	86%
Maize	94%	79%	94%	81%	94%	78%
Rabi						
Wheat	69%	29%	50%	29%	56%	33%
Mustard	67%	9%	44%	7%	48%	8%

- Check the fourth plot now. This gives crop yield (in terms of % of potential yield). Crop yield is more or less directly proportional to CWR met. You can check the technical manual to see how this is calculated.

- Crop yield of rainfed and irrigated kharif crops is higher due to higher CWR met.

- Crop yield of rainfed rabi crop (Wheat & Mustard) is significantly less due to low CWR met.

- Crop yield is a direct reflection of CWR met. Hence interventions are focussed on increasing the CWR met for kharif and rabi crops.

Table 9: Crop yield

	Overall		Mild		Moderate	
	Irrigated	**rainfed**	**Irrigated**	**rainfed**	**Irrigated**	**rainfed**
Kharif						
Soyabean	94%	88%	94%	86%	93%	89%
Maize	93%	74%	92%	77%	92%	72%
Rabi						
Wheat	66%	22%	45%	21%	52%	26%
Mustard	71%	12%	44%	3%	43%	0%

4.1.4 Drought proofing and Quadrant

- You can plot CWR met and efficiency of irrigated crops in drought quadrant plot and identify the type of interventions required to improve CWR met and crop yield.

- Based on the drought plot, the interventions for kharif crop (Soyabean and maize) needs to be focussed on improving efficiency and relatively less on supply as CWR met is already on the higher end.

- For rabi crops (wheat & mustard), interventions need to be focussed on both supply and demand to improve both the CWR met and irrigation efficiency.

- Why is irrigation efficiency higher than 0.5? (Hint: Return flow). See technical manual to see how this is calculated.

Table 10: CWR met & efficiency results

Scenario	Soybeans		Wheat		Maize		Mustard	
	CWR met	**Eff**	**CWR met**	**Eff**	**CWR met**	**Eff**	**CWR met**	**Eff**
Baseline	93%	0.60	69%	0.60	94%	0.60	67%	0.60

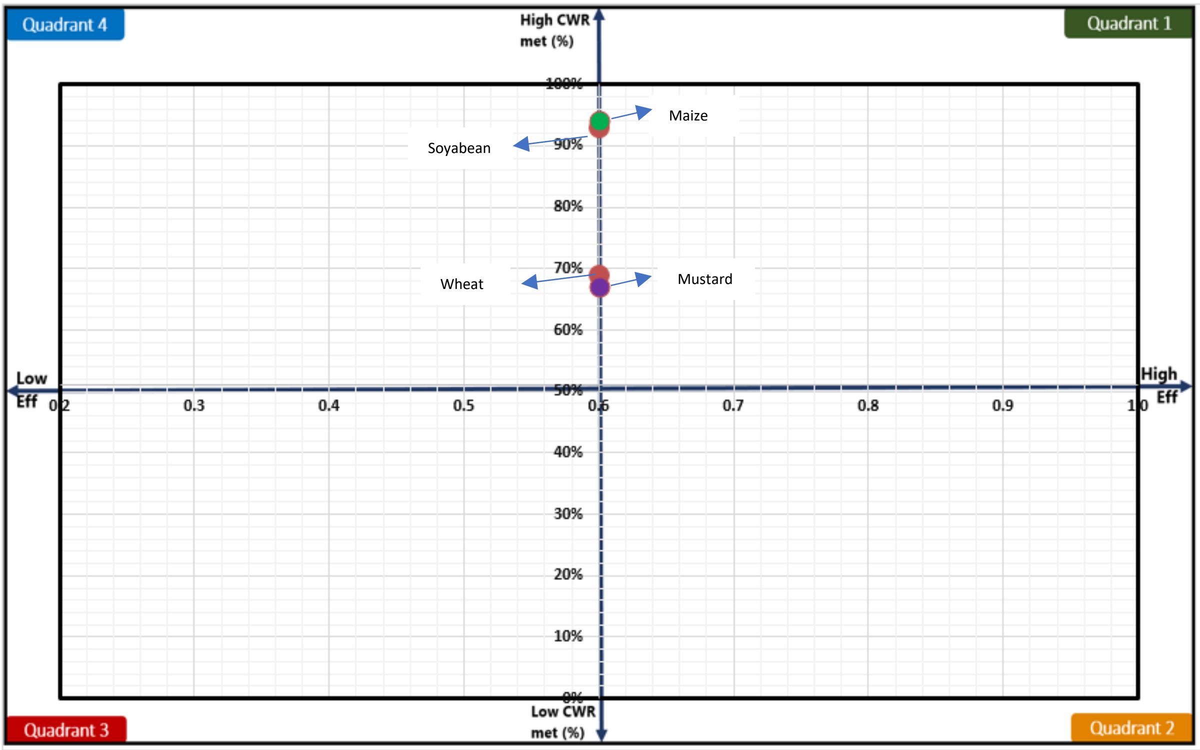

Figure 3: Drought quadrant (Baseline scenario)

5 Plan Interventions Scenarios

- Interventions are planned based considering how much water is available (See water balance) and crop deficits (see CWR, IWR and CWR met).

- You can check how much is the deficit for each crop based on results of CWR, IWR and CWR met. See Table 11 below.

    - Which crop has the highest deficit?
    - Absolute deficit (in m^3) is combination of crop area and deficit per area (mm).
    - Deficit (in m^3) can give idea of how much additional storage to plan or how much area should be covered with improved irrigation measures.

Table 11: CWR met & deficit

Crop	Drought type	Crop Area (ha)	CWR (mm)	CWR met (%)[a]	CWR met (mm)	Deficit (mm)	Deficit (m^3)
		Input date	Plot 2	Plot 3	CWR met (%) * CWR	CWR (mm) - CWR met (mm)	Deficit * crop area
Soyabean	Overall	4624	365	91%	333.2	31.7	1,468,614
	Mild	4624	365	91%	331.4	33.5	1,550,666
	Moderate	4624	365	91%	330.4	34.5	1,596,364
Maize	Overall	793	510	90%	460.7	49.2	390,303

	Mild	793	510	91%	463.2	46.7	370,617
	Moderate	793	510	90%	459.5	50.4	400,146
Wheat	Overall	1803	443	62%	275.8	167.1	3,012,975
	Mild	1803	443	46%	205.8	237.1	4,275,525
	Moderate	1803	443	52%	230.96	212.0	3,823,134
Mustard	Overall	1287	250	54%	135.17	114.8	1,477,925
	Mild	1287	250	36%	89.37	160.6	2,067,275
	Moderate	1287	250	39%	97.70	152.3	1,960,100

[a] Average of rainfed and irrigated area.

- In addition to deficit, check how much water is available for capture i.e runoff. See table 12 below.
  - To reduce the runoff and increase the recharge, supply side interventions such as check dam, farm pond, infiltration pond, etc. are planned and simulated.
  - Check how does available water compare with deficit? Is available water enough to cover the deficit for all years?

Table 11: Runoff & available water

	Runoff (mm)	Watershed area (ha)	Available Water (m^3)
Overall	248	7663	19,004,240
Mild	154	7663	11,801,020
Moderate	51	7663	3,908,130

- In addition to supply, you can also save water by increasing efficiency. See table 13 below to check rough estimate on saving in water under different efficiency improvements.
  - Check if savings with high irrigation efficiency is more than enough to cover the deficit or not?

Table 12: Potential savings through increase efficiency

Crop	Drought type	Irrigated Area (ha)	Efficiency	IWR met (mm)[a]	IWR (m^3)	Applied IWR (m^3)	Water saved (if eff=0.75)	Water saved (if eff=0.9)
				IWR*IWR met (%)	IWR met*area	IWR/efficiency(0.5)	Applied water – IWR/0.75	Applied water – IWR/0.9
Soyabean	Overall	3500	0.5	47.43	1660050	3320100	1106700	1475600
	Mild	3500	0.5	55.80	1953000	3906000	1302000	1736000
	Moderate	3500	0.5	45.08	1577800	3155600	1051867	1402489
Maize	Overall	600	0.5	99.64	597840	1195680	398560	531413

	Mild	600	0.5	89.30	535800	1071600	357200	476267
	Moderate	600	0.5	106.22	637320	1274640	424880	566507
Wheat	Overall	1500	0.5	217.35	3260250	6520500	2173500	2898000
	Mild	1500	0.5	158.50	2377500	4755000	1585000	2113333
	Moderate	1500	0.5	166.32	2494800	4989600	1663200	2217600
Mustard	Overall	1000	0.5	152.76	1527600	3055200	1018400	1357867
	Mild	1000	0.5	101.64	1016400	2032800	677600	903467
	Moderate	1000	0.5	112.32	1123200	2246400	1106700	1475600

5.1 Check deficit and plan interventions accordingly

To plan interventions, now consider:

- Which crop needs it (Table 8-11)
  - Crop with highest deficit needs more focus (Rabi crops)
  - What type of interventions are need. See the drought proofing quadrant.

- How much water is available (Water balance and Table 12)
- How much potential savings can be achieved with increasing efficiency (Table 13)

Based on above consideration, we here simulate three scenarios:

- Scenario 1: Supply side [25 % of deficit is covered through supply side intervention]
  - Check dam – 19,45,000 m^3

- Scenario 2: Demand side: [Sprinkler irrigation is added to 25 % of irrigated area of all crops]
  - Sprinkler irrigation is considered for total irrigated area of 1650 ha.

- Scenario 3: Combined: Supply and demand side interventions are combined.

For details of parameters or step by step instructions on how to run scenarios, please see user manual.

Table 13: Intervention details

	Supply		**Demand**	
	Check dam		**Sprinkler**	
Scenario	**m^3**	**Cost/ m^3**	**ha**	**Cost/ha**
Baseline	0	0	0	0
1	1945000	80	0	0
2	0	0	1650	25000
4	1945000	80	1650	25000

5.2 Analyse results

5.2.1 Water balance

- Check how water balance change and why it changes.

- The change in water balance in scenario 1 is due to additional storage capacity created. The interventions captures the runoff and in-turn added as groundwater recharge based on the infiltration rate.

- Why there is no change in recharge and runoff in scenario 2?
  - As only efficiency improvement technology is applied, tool only considers its impact on how efficiently the irrigation storage is change but doesn't influence runoff and recharge processes.

Table 14: Water balance results (mm)

Scenario	Recharge (mild)	Runoff (mild)	Recharge (mod)	Runoff (mod)	Recharge (overall)	Runoff (overall)
BL	86	154	81	51	152	248
Supply	102	94	92	13	169	191
Demand	86	154	81	51	152	248
Supply + Demand	103	94	92	13	170	192

5.2.2 CWR met and yield

- Check how CWR met has changed after interventions?
  - There will be no change in CWR and IWR as that is governed by temperature and rainfall which interventions don't change.

- Why there is no impact on rainfed CWR met?
  - Supply and efficiency improving interventions can only support irrigated areas.

- How much improvement is there in CWR met under different scenarios?
- Check the corresponding improvement in Yield.

Table 15: CWR met & IWR met

	Overall		*Mild*		*Moderate*	
Scenarios	*Irrigated*	*rainfed*	*Irrigated*	*rainfed*	*Irrigated*	*rainfed*
Soyabean						
BL	93%	86%	93%	84%	92%	86%
Supply	97%	86%	98%	84%	97%	86%
Demand	94%	86%	93%	84%	92%	86%

Supply + Demand	97%	86%	98%	84%	97%	86%
Maize						
BL	94%	79%	94%	81%	94%	78%
Supply	98%	79%	98%	81%	97%	78%
Demand	95%	79%	94%	81%	94%	78%
Supply + Demand	98%	79%	98%	81%	98%	81%
Wheat						
BL	69%	29%	50%	29%	56%	33%
Supply	80%	29%	68%	29%	63%	33%
Demand	72%	29%	53%	29%	58%	33%
Supply + Demand	82%	29%	72%	29%	67%	33%
Mustard						
BL	67%	9%	44%	7%	48%	8%
Supply	81%	9%	71%	7%	65%	8%
Demand	69%	9%	47%	7%	53%	8%
Supply + Demand	84%	9%	77%	7%	74%	8%

Which crops still need more interventions to make them drought proof?

- Kharif crops are drought proof with most of the CWR being met.
- Rabi crops performs better but still need more interventions to make them drought proof
- Rainfed crops either need to be converted to irrigated areas or need soil & moisture interventions.

You can make more scenarios to simulate and make rabi crops drought proof:

- Increase the intensity of interventions. Example: Make sprinkler irrigation in 50 % of area.
- Increase irrigated area of crops.
- Can reduce wheat area to less water consuming crops such as mustard or pulses.

Make these scenarios and see what the results are.

5.2.3 Drought quadrants

- Again Plot CWR met and efficiency of irrigated crops after considering interventions in drought quadrant plot.

- The desired position of a crop should be top right end of quadrant 1 and all the interventions should be designed by aiming to reach that position in the drought quadrant.

- In which quadrants are the crops now?

5.2.4 Drought Proofing

- Check the overall plot on Drought proofing results. Plot show overall drought proofing is achieved with all the scenarios leading to drought proofing greater than 80%

- For both mild and moderate drought, scenario 4 (supply + demand) leads to drought proofing (if drought proofing threshold is 80 %).

- Check what the drought proofing results are if you plan further interventions.

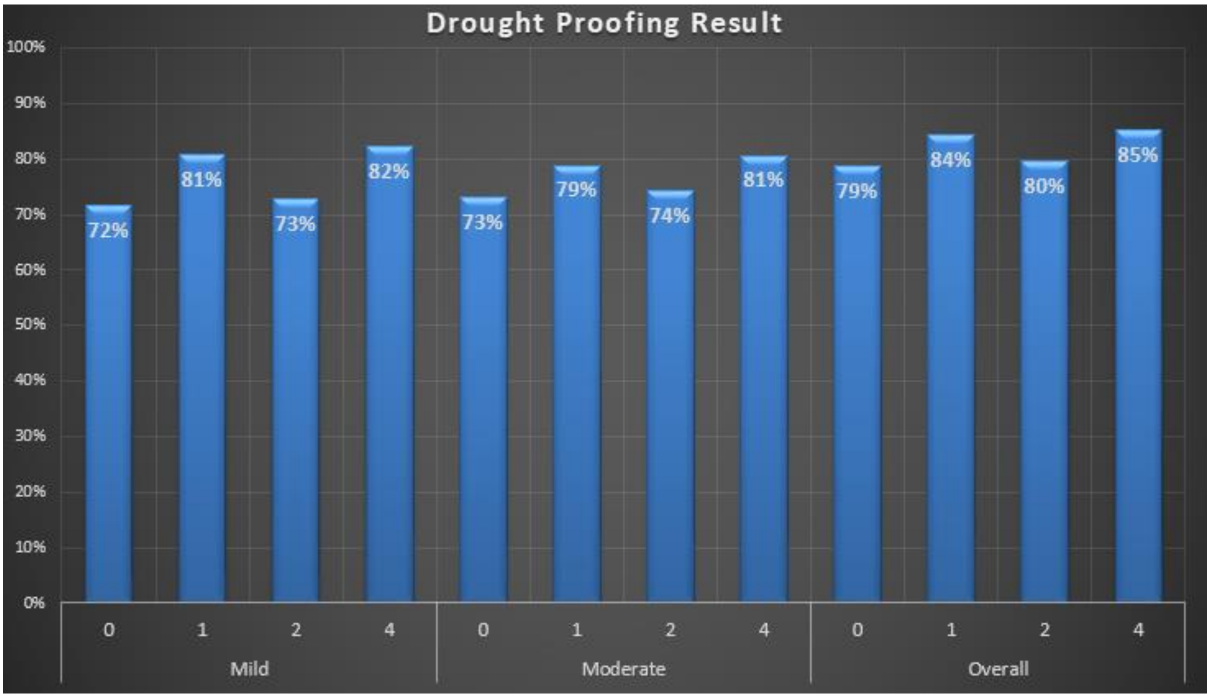

Figure 4: Drought proofing result

5.2.5 Economics

- Check the last plot cost and benefits.
- See technical manualto see how this is calculated.
- This BCR is based on investment horizon of 20 years with interest rate of 4.5 %. You can change it based on your need. See user manual on how to change it.
- Enter in the table below total cost, benefits and BCR of three scenarios.
- What does it tell you? How will you make decisions based on this? Is the total cost within your project budget?

	Total cost	Total benefits	BCR
Supply			
Demand			
Supply + Demand			