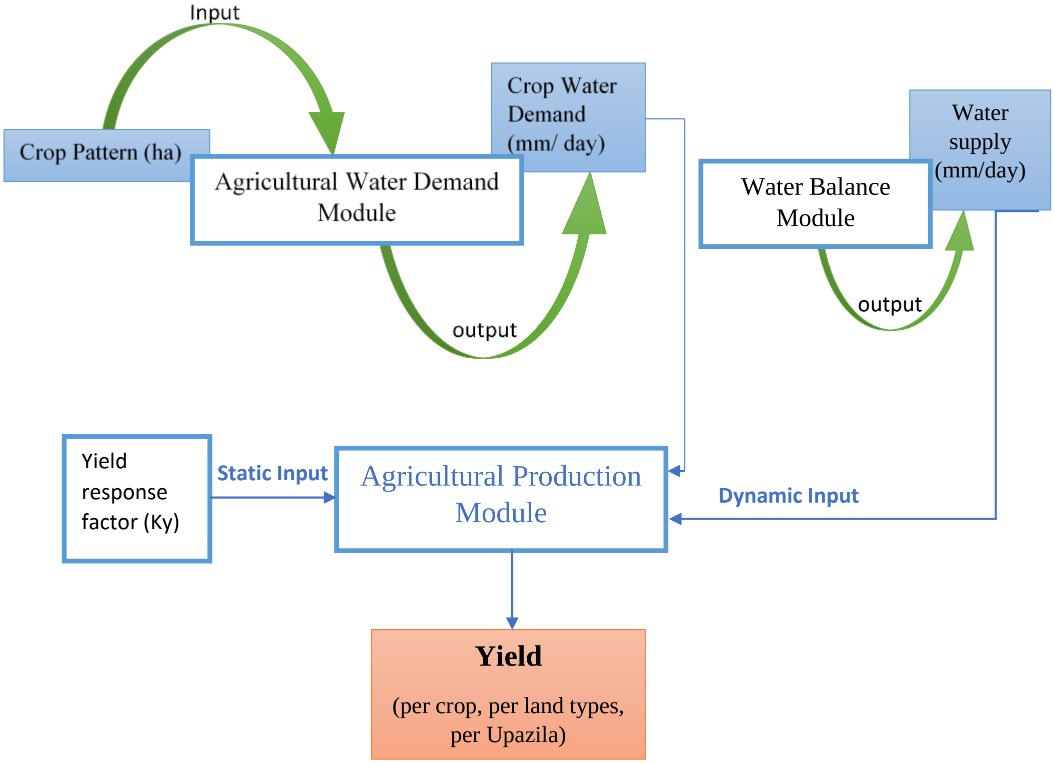
Drought



A (l, u, c)	= Cropping area	(ha)
D (l, u, t)	= Water demand	(mm/ha), obtained from water balance module
S (l, u, t)	= Water supply	(mm/ha), obtained from water balance module
Yp (c)	= Yield potential	(tonnes/ha)
Ky (c)	= Yield response factor for drought	
T (c)	= Planting season	(number of decade)
Ya (l, u, t, c)	= Yield actual	(tonnes/ha)
Y (u, t, c)	= Total yield	(tonnes)
t	= time	(decade)
c	= crop	
u	= upazila	
l	= land type, F0, F1, F2, F3, F4	

Agriculture production module requires inputs from other modules: water demand module (water demand, cropping area) and water balance module (water supply). Attributes of each crop, such as potential yield, yield response factor and planting season were obtained from (Hassan, Ahmadul and Parsons, Luke, 2015). Actual yield was estimated using function below (FAO, 2012)

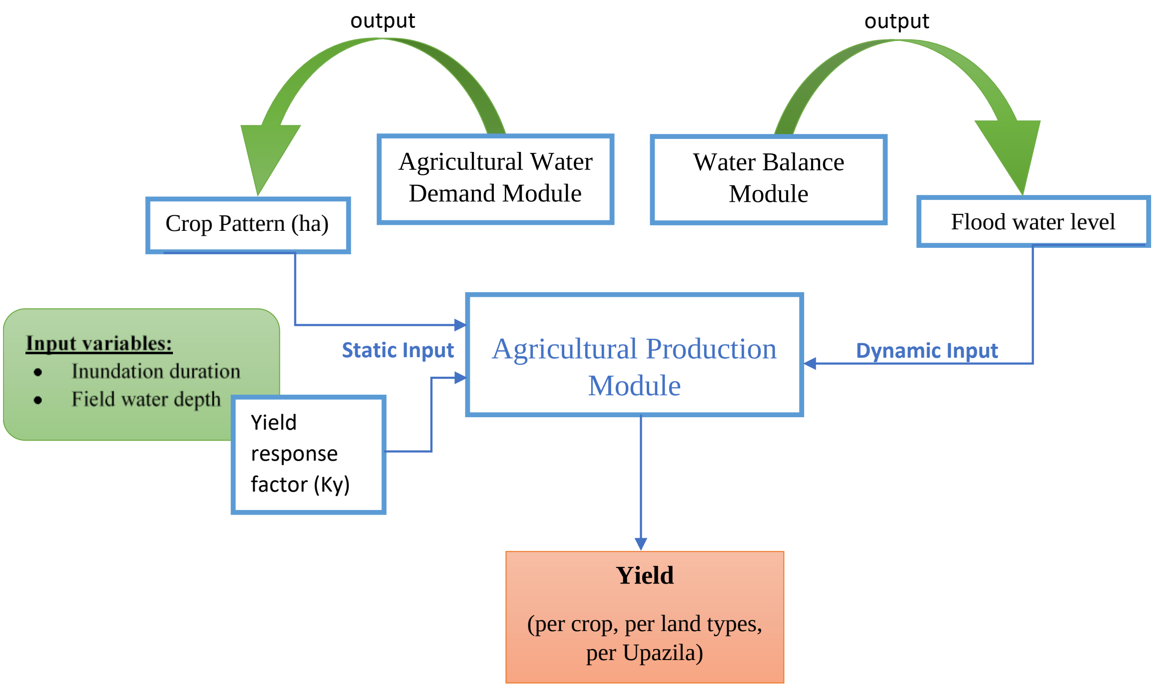
$$Ya/Yp = 1 - Ky * \Sigma D / \Sigma S$$
$$Y = Ya * A$$

Table 1 presents the yield response factor, which was assumed as an average of ky values in different stages for each crop. The water demand and supply were aggregated over the planting period. The actual yield was calculated at the end of harvest time.

Table 1. Drought damage factor ky for each crop

Crop ID	Crop	ky	Plant timestep	Harvest timestep
1	Aus	0.75	13	21
2	T Aman	0.75	21	31
3	B Aman	0.75	21	31
4	Boro	0.75	3	14
5	Wheat	0.35	33	7
6	Pulses	0.35	32	6
7	Maize_Rabi	0.35	31	9
8	Maize_Kharif	0.35	13	27
9	Jute	0.75	12	23
10	Spices	0.2625	35	8
11	OilSeeds	0.275	31	3
12	Potato	0.475	32	4
13	Sugarcane	0.475	35	34
14	Vegetables_S	0.475	13	25
15	Vegetables_W	0.475	32	7

Flood



A (l, u, c)	= Cropping area	(ha)
H (u, t)	= Flood water level	(m), obtained from water balance module
N (l, u, t)	= Length of flood event	(decade)
Z (l, u)	= Land elevation	(m)
Yp (c)	= Yield potential	(tonnes/ha)
Ky (c)	= Yield response factor for flood	

T (c)	= Planting season	(number of decade)
Ya (l, u, t, c)	= Yield actual	(tonnes/ha)
Y (u, t, c)	= Total yield	(tonnes)
t	= time	(decade)
c	= crop	
u	= upazila	
l	= land type, F0, F1, F2, F3, F4	

Flood depth is calculated as the difference between flood level and land elevation. By comparing the flood depth and the plant's height (assumed as 1.2 m), percentage of submerged plant height can be estimated. The percentage of submerged plant height determines the value of yield response factor (Hassan, Ahmadul and Parsons, Luke, 2015). As the metamodel uses decadal time step, only two ky values can be included in the model:

- ky value for 10-14 days of submerged or plant is inundated for 1 timestep
- 15 days or more of submerged can be taken or plant is inundated for 2 timesteps.

In Table 2, Yield response factor was assumed as an average of ky values in different stages. The maximum value of ky during the planting period of a crop was taken to estimate the actual yield as below (FAO, 2012).

Ya/ Yp = 1 – Ky
Y = Ya * A

Table 2. Flood damage factor ky for each crop

ky	% submerged lower range	% submerged upper range	Time step submerged 1 = less than 10 days 2= more than 10 days
0	0	25	1
29.17	25	50	1
55	50	75	1
90	75	100	1
0	0	25	2
38.33	25	50	2
65	50	75	2
100	75	100	2

Combined damage coefficient

The coefficient of flood damage and drought damage are multiplied to get a combined damage coefficient to obtain the crops' actual yield.

Calibration

The maximum value of yield (Y) per district (d) was obtained from Chapter 3 Yearbook of Agricultural Statistics (http://bbs.portal.gov.bd/site/page/3e838eb6-30a2-4709-be85-40484b0c16c6/-) from 2011 to 2018. Most tables in the report shows values in yield per hectare. If the yield per hectare is not available, the value is obtained by dividing yield in tonnes (Y) by crop area (a).

$$y (c, d) = \max(Y_{2010}/A_{2010}, \ldots, Y_{2018}/A_{2018} (c, d)))$$

Chapter 4 Yearbook of Agricultural Statistics records the results of survey on agricultural damage caused by various events (wind (tornado), cyclone, hailstorm, heavy fog, flooding, and others). Unfortunately, agricultural damage survey results due to drought are unavailable. The survey provides damages of different crops (e.g. rice, kharif maize, jute, ginger, green papaya, and chili) at the district level. As Agricultural Production module only includes damage due to flood (D) and drought to rice production, only survey results of damage related to flood are added into the module.

$$Y_{actual}(c, d, t) = Y_{potential}(c, d) – D(c, d, t)$$

Figure 1 presents the percentage of agricultural area damaged by flood of the total agricultural area for rice crops based on the Yearbook of Agricultural Statistics. From the chart, it can be seen that the crop damage due to flood was insignificant in comparison to its potential yield. The survey results also show that the yield reduction is mostly less than 5% in a district. This number seems to be underestimated. A possible explanation for these low damages may be the lack of survey data (not all flooding events were surveyed).

Table 3 shows that, for most crops, the actual yield per hectares is applied on district level. For some crops, which their yields are the results of aggregation from many different crops (Pulses, Spices, OilSeeds, Vegetables_S, Vegetables_W), maximum potential yield of crop is taken from national figures and assumed to be the same for all districts.

Table 3. Maximum potential yield for each crop

ID	Crop Type	Crop Name	Aggregation level
1	Aus	Aus (Local), Aus (HYV)	District
2	T Aman	Aman (LT), Aman (HYV)	District
3	B Aman	B Aman	District
4	Boro	Local Boro, HYV Boro, Hybrid Boro	District
5	Wheat	Wheat	District
6	Pulses	Arhar, Gram, Kheshari, Maskhalai, Motor, Mung, Mushur, Other pulses	Bangladesh
7	Maize_Rabi	Rabi Maize	District
8	Maize_Kharif	Kharif Maize	District
9	Jute	Jute	District
10	Spices	Chilli_Kharif, Chilli_Rabi, Coriander, Garlic, Ginger, Onion, Turmeric	Bangladesh
11	OilSeeds	Castor, Groundnut, Linseed, Other Oil Seeds, Rape & Mustard, Till	Bangladesh
12	Potato	Local Potato, HYV Potato	District
13	Sugarcane	Sugarcane	District
14	Vegetables_S	Kharif Pumpkin, Kharif Brinjal, Patal Lady's Finger, Ridge Gourd (Jhinga), Bitter Gourd (Karolla), Arum (Kachu), Ash Gourd (Chalkumra), Cucumber, Long bean (Barbati), Indian Spinach (Puishak), Snake Gourd (Chichinga), Amaranth (Danta), Karala (Kakrol), Sponge Gourd (Dundul) Colocacia (Kachur Lati), Other kharif Vegetable s	Bangladesh
15	Vegetables_W	Rabi Brinjal, Cauliflower, Cabbage, Gourd/Water Gourd, Rabi Pumpkin, Tamato, Radish, Bean, Bengal Spinach (Palong Shak), Red Amaranth (Lal Shak), Carrot, Laushak, Other Winter Vegetables	Bangladesh

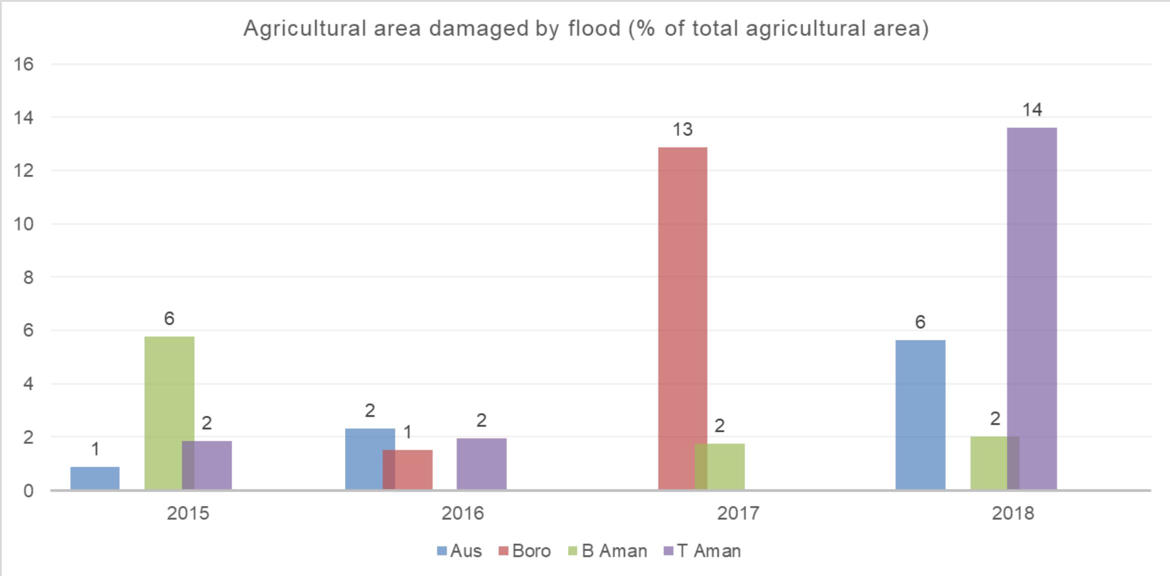


Figure 1. Percentage of agricultural area damaged by flood of the total agricultural area for rice crops (Yearbook of Agricultural Statistics 2015, 2016, 2017, sand 2018)

Validation

The results obtained from the metamodel is compared to the data from Yearbook of Agricultural Statistics from 2011 – 2018. The rice crops production data (R) from the book at district level (d) is aggregated to division level (v) and averaged over years.

$$R_{2011}\ (v) = R_{2011}\ (d_1) + R_{2011}\ (d_2) + \ldots + R_{2011}\ (d_{n,})$$
$$R_{annual} = R_{2011}\ (v) + R_{2012}\ (v) + \ldots + R_{2018}\ (v)\ /\ 8\ \text{years}$$

Currently, two out of seven divisions have been calibrated (50 Rajshahi and 55 Rangpur). The resulting rice crop production from the metamodel are calibrated and validated to actual rice production (including its damage from flood) from Yearbook of Agricultural Statistics data is available (2011-2018). Table 4 shows that the yield calculated by the metamodel is slightly lower than the yield obtained from Yearbook of Agricultural Statistics (BBS). A possible explanation for this might be that survey results recorded by Yearbook of Agricultural Statistics might not cover the whole flood events as they have limited points (<300 points at the district level over 8 years). Table 5 presents the complete rice crops production from the metamodel, including average flood and drought coefficients for rice crops which are dependent on water demand, water supply, and damage factor during the crops' planting season.

Table 4. Validation of rice crops production indicator

Division		Actual yield (million tonnes)			
ID	Name	MM flood & drought (1988-2018)	MM flood (2011-2018)	BBS flood (2011-2018)	Difference MM&BBS flood (2011-2018)
10	Barisal	2.9	na	2.26	
20	Chittagong	1.2	na	4.63	
30	Dhaka	3.1	na	7.77	
40	Khulna	1.6	na	4.55	
50	Rajshahi	5.4	5.8	5.8	-0.52 %
55	Rangpur	5.0	5.4	5.6	-3.93 %
60	Sylhet	0.6	na	2.32	

Table 5. Results of rice crops production indicator

ID	Name	K flood	K drought	Yield (tonnes/ha)		
				Potential MM input	Actual BBS	Actual MM
10	Barisal	0.46	1.00	2.33	2.13	1.08
20	Chittagong	0.32	1.00	2.63	2.48	0.67
30	Dhaka	0.39	1.00	2.76	2.14	1.01
40	Khulna	0.50	1.00	2.76	2.28	1.31
50	Rajshahi	0.90	0.99	2.86	2.46	2.57
55	Rangpur	0.75	0.99	3.32	3.01	2.50
60	Sylhet	0.41	1.00	2.38	2.03	0.87

These results must be interpreted with caution because:

- Metamodel are calibrated and validated based on the eight years available data from Yearbook of Agricultural Statistics.
- In addition to flood, Metamodel include agricultural damage from drought. Agricultural damage due to drought are not calibrated as data are not available in Yearbook of Agricultural Statistics.
- Metamodel only include agricultural damage from flood and drought while there are many factors contributing to crop yield reduction, e.g. pest, heat, wind damage, and others
- Metamodel assumes similar yield per hectares for the whole Bangladesh for pulses, spices, oil seeds, summer vegetables, and winter vegetables