Econometric Analysis of Cropland use decisions in India

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Student's Declaration

I hereby declare that the work presented in the report entitled **"Econometric Analysis of Cropland use decisions in India"** submitted by me for the fulfillment of the requirements for the degree of *Bachelor of Technology* in *Computer Science & Social Sciences* at Indraprastha Institute of Information Technology, Delhi, is an authentic record of my work carried out under guidance of **Dr. Gaurav Arora**. Due acknowledgements have been given in the report to all material used. This work has not been submitted anywhere else for the reward of any other degree.

.... **Place & Date: ....**
Anirudh Ramalingam

Certificate

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

.... **Place & Date: ....**
Dr. Gaurav Arora

Abstract

Satellite land use land change (LULC) data and district-level administrative data indicate an intensification of cropland usage (single to multi-crop transition) in India between 2005-06 to 2018-19. This study attmepts to compare the two data sets and utilizes administrative data at district level to model the impact of various factors on crop intensification and understand the decisions of the farmer driving the same.

Keywords: Agriculture, Land use, Land change, crop intensification, irrigation, policy.

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I would also like to acknowledge the work of Gargi Gupta and Tushita Rathore (Batch of 2019) which laid the foundations for this project.

Work Distribution

The focus of the previous semester was collecting the All-India district wise data for the various parameters required in the regression model. The quasi-binomial regression model captured data for around 600 districts in India.

In this semester, satellite data from BHUVAN by ISRO has been used to study cropping intensification over the years. Comparison with the administrative data revealed significant transition in the state of Madhya Pradesh in the period from 2005-18. A similar quasi-binomial logit regression was performed for 46 districts of Madhya Pradesh with additional explanatory variables.

Contents

Chapter 1

Introduction

Agriculture as the name indicates has been shaping cultures around the world for centuries. In a nation where more than 45% of the labor force is directly or indirectly involved in the sector, policy making over the decades has revolved around agriculture having a varied impact [1]. Every five-year plan since independence has paid much attention to the issue of food security. However, it is only after the mid 1960s that India embarked on a set of reforms today known as the Green Revolution which massively increased food grain production. It also set states like Punjab and Haryana (the Bread Basket of India) on a trajectory that is closely linked with contemporary issues like ground water scarcity and air pollution [2].

The sector remains a lifeline to millions of Indians despite industrialization and liberalization as seen in the wake of the pandemic when many migrant workers in urban areas returned back to the village and clocked a growth of 3.4 % (FY 2020-21) despite the recession throughout the economy [3]. Agriculture was an extensively debated topic the whole of last year as a result of the introduction of the "farm laws" that sought to modernize agriculture and relieve it from state regulation. Opponents of the laws brought up multiple concerns in its implementation that in their view would make them subordinate to big corporations. The laws were ultimately repealed in November last year.

Agriculture in India is marked by two seasons- Kharif (monsoon) and Rabi (Winter). Rice belongs to the former category while wheat belongs to the latter. As the primary food crops, these play an important role in food security. The government, while announcing a Minimum Support Price (MSP) for over 20 crops, procures only wheat and paddy through the Food Corporation of India.

Central to all these events and issues are decisions related to land use and crop intensification. Despite the increase in production since 1960, agricultural land as a share of total land has remained constant at around 60% [4]. This would indicate that the increased production is not driven by increased land but rather by better technology in all stages of production and increased crop frequency. Satellite data as shown by previous research indicates a profound land use transition from single to multiple cropping in years from 2005-14[5]. The purpose of this study is to extend the time period studied to 2018, study the impact of various factors such as rain, irrigation, soil nutrient deficiency on the intensification and understand the cropping pattern responsible for these changes.

Chapter 2

All-India district level regression analysis

2.1 Independent variables (Regressors)

In this model, I have limited my study to the following factors in Table 2.1.

Table 2.1- Explanatory variables and Description

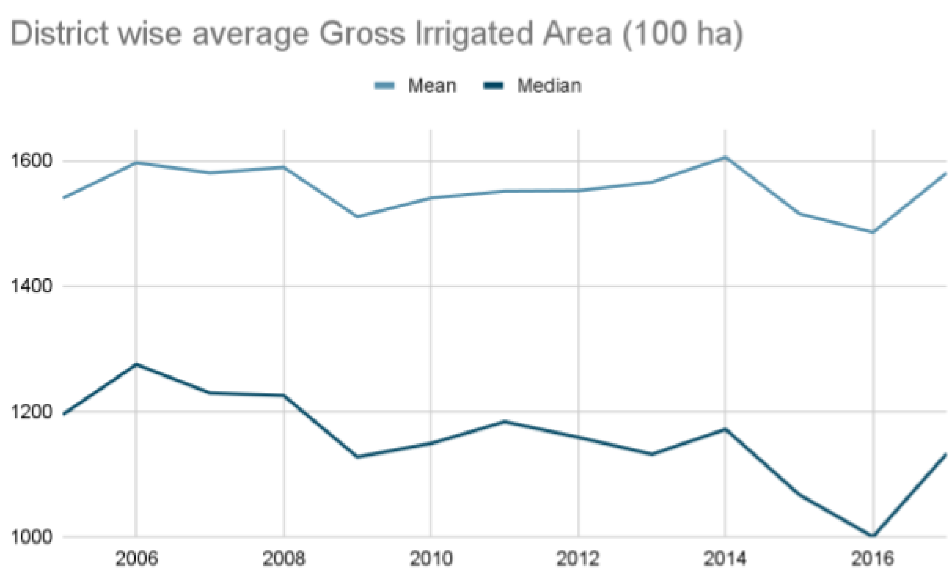
Variable Name	Notation	Description	Source
Irrigated Area	irrig	District wise gross irrigated area in 1000 hectares	Ministry of Agriculture and Farmers' Welfare (MoAFW) [6]
Rice Yield	Y_R	District wise rice yields in tonnes per hectare	MoAFW
Wheat Yield	Y_W	District wise wheat yields in tonnes per hectare	MoAFW
Rainfall	rf	District wise annual rainfall (cm)	India Meteorological Department (IMD) [7]
Nitrogen Deficiency	Ndef	District wise percentage of Nitrogen deficiency	MoAFW
Phosphorous Deficiency	Pdef	District wise percentage of Phosphorous deficiency	MoAFW
Potassium Deficiency	Kdef	District wise percentage of Potassium deficiency	MoAFW
Trend	Tr	Tr=1 (2005)....Tr=14 (2018)	-
Dummy 10	D_{10}	Variable to account for policy changes such as NREGS and loan waivers in 2009	-
Dummy 16	D_{16}	Variable to account for shock due to demonetisation. Value =1 for 2016	-

Data cleaning and collection was a long and tedious process because of district merging, splitting and renaming occurring between 2005 - 2018. The number of districts in India has grown from 593 (2001) to 773 (2021). Additionally even official sources don't have complete data for many districts in the studied period.

2.1.1 Gross Irrigated Area

Summary statistics- Gross irrigated area (hectares)

	Min	1Q	Median	Mean	3Q	Max	SD	n
2005	43	33966	119495	154003	214461	876843	148832.6	481
2006	44	41032	127476	159648	227188	870148	148845.8	470
2007	33	33294	122923	158040	223561	875004	151995.1	487
2008	32	30975	122519	158927	229683	891333	153792.6	491
2009	34	23878	112727	151041	224748	878545	150352.2	498
2010	32	21225	114878	154018	231048	884613	155593.2	511
2011	30	23226	118351	155119	242359	926890	152579.7	525
2012	24	24240	115855	155198	240288	983963	153669.0	489
2013	27	18266	113150	156561	231065	1053159	160372.6	504
2014	27	21364	117143	160530	247292	1087711	162040.0	536
2015	30	19253	106696	151525	224521	1150415	158761.7	580
2016	26	21725	100000	148550	219037	1052787	156554.1	600
2017	26	20090	113246	158045	240624	1097273	163062.0	550



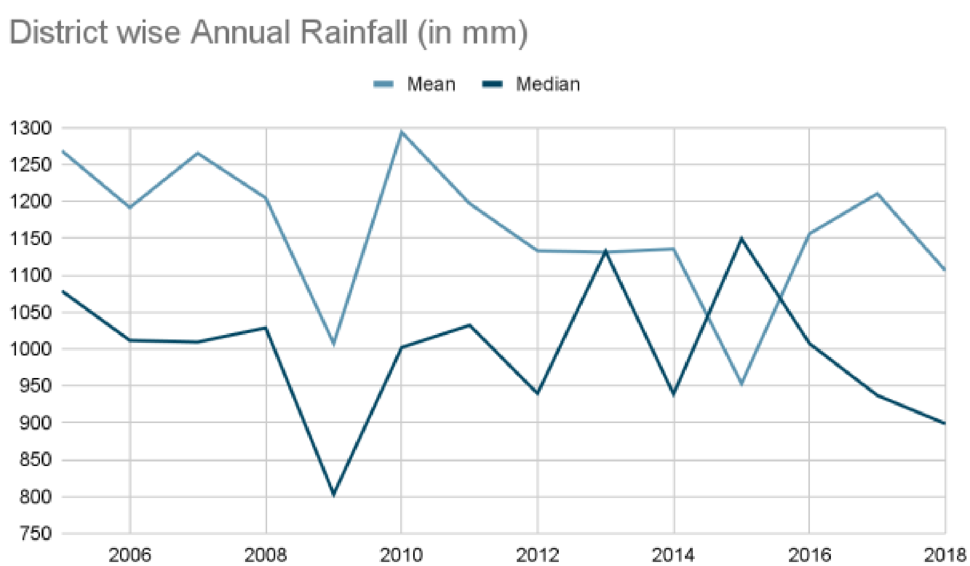
The mean and median district wise Gross irrigated area have shown a slight decline through the years excepting for a sharp dip in 2009 (a drought year) and 2016(southern states faced a drought from 2016-18). The decline in 2016 can also be attributed to demonetisation when farmers were unable to buy inputs with cash and reduced the irrigated area for winter crops[8].

Demonetisation also affected the construction industry that may have had a ripple effect in the irrigation sector as well. The average figures are greater than the median indicating a rightward skew.

2.1.2 Rainfall

Summary statistics- Annual rainfall (mm)

	Min	1Q	Median	Mean	3Q	Max	SD	n
2005	0.0	695.7	1078.6	1268.6	1489.0	6239.9	841.1668	514
2006	0.0	635.4	1011.5	1191.7	1520.7	4657.4	781.7276	514
2007	1.1	685.1	1009.3	1265.3	1578.8	8589.1	927.6373	515
2008	9.6	718.6	1028.5	1204.6	1488.4	6885.2	754.1395	519
2009	0.0	555.1	803.0	1007.4	1230.7	5386.3	744.9217	526
2010	0.0	750.5	1002.0	1293.8	1493.8	8291.4	921.4829	606
2011	0.0	706.0	1032.0	1197	1440.0	6161.0	795.5501	617
2012	0.0	594.9	939.6	1133.0	1389.5	6533.6	845.2249	625
2013	25.2	784.2	1132.2	1131.1	1577.0	5295.5	788.7366	612
2014	0.0	605.7	938.8	1135.6	1360.8	6293.1	812.2221	633
2015	0.0	631.6	1149.1	953.2	1391.0	7898.7	804.1695	619
2016	2.0	627.1	1007.2	1156.3	1392.5	6526.3	782.8184	642
2017	0.0	673.6	937.0	1210.5	1433.0	7679.7	902.6611	636
2018	1.0	617.1	898.7	1106.3	1321.4	5065.9	778.2549	667



There has been high variability in rainfall adding to the uncertainty of farmers. The worst years were 2009 and 2015(both drought years). The divergence of mean and median precipitation from 2015-18 can be explained by the 41 month long drought that affected districts primarily in South India and states like Maharashtra and Odisha). While the rest of India depends on Monsoon rain

(June to September), South India receives a significant portion of its precipitation from October to December through what is known as Northeastern or Winter monsoon. Deficit in northeastern rains caused successive droughts from 2016-18 in states like Tamil Nadu, Karanataka, Andhra Pradesh and Telangana [9].

2.1.3 Wheat and Rice Yield

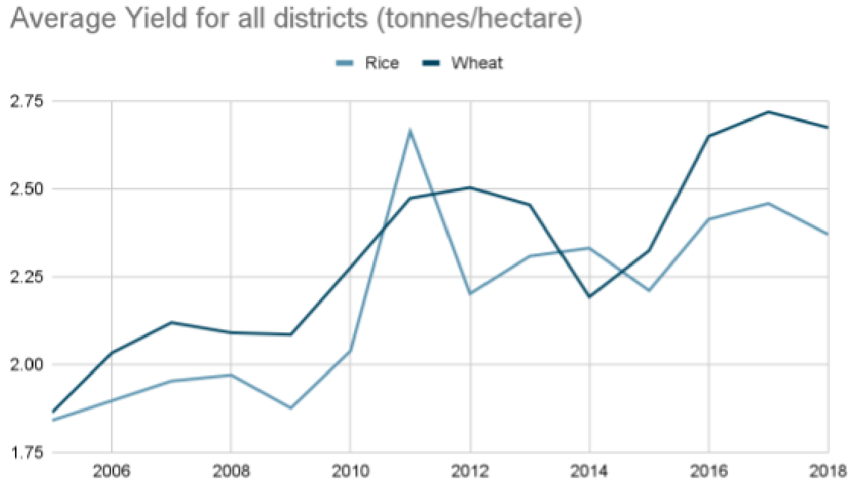
Summary Statistics- Rice Yield (tonnes/hectare)

	Min	**1Q**	**Median**	**Mean**	**3Q**	**Max**	**SD**	**n**
2005	0.080	1.155	1.720	1.841	2.470	5.000	0.9313761	563
2006	0.110	1.200	1.720	1.897	2.513	5.000	0.9742977	560
2007	0.000	1.230	1.850	1.953	2.562	5.000	0.9982688	552
2008	0.000	1.210	1.810	1.970	2.478	5.000	1.0939703	562
2009	0.000	1.210	1.760	1.876	2.612	6.130	1.0394608	563
2010	0.190	1.285	2.020	2.039	2.595	7.130	0.9780217	559
2011	0.000	1.470	2.160	2.663	2.663	5.420	0.9619660	597
2012	0.070	1.510	2.185	2.201	2.750	6.640	0.9233505	604
2013	0.000	1.610	2.210	2.308	2.800	6.080	1.0322464	589
2014	0.000	1.683	2.220	2.331	2.833	5.860	1.0080970	605
2015	0.000	1.485	2.105	2.210	2.786	7.18	1.0467285	610
2016	0.000	1.833	2.370	2.413	2.862	6.050	0.8531281	628
2017	0.120	1.833	2.352	2.458	2.940	5.500	0.9336327	639
2018	0.090	1.657	2.350	2.370	2.950	5.300	0.9489847	625

Summary statistics- Wheat Yield (tonnes/hectare)

	Min	**1Q**	**Median**	**Mean**	**3Q**	**Max**	**SD**	**n**
2005	0.12	1.077	1.635	1.864	2.460	4.780	0.9819087	472
2006	0.000	1.240	1.855	2.033	2.640	5.000	1.0207415	484
2007	0.130	1.370	1.900	2.119	2.750	5.050	1.0237099	490
2008	0.450	1.200	1.835	2.090	2.728	7.460	1.0980822	498
2009	0.280	1.210	1.900	2.085	2.730	4.930	1.0301848	500
2010	0.5000	1.355	2.010	2.276	5.130	5.130	1.1183046	500
2011	0.330	1.470	2.275	2.473	3.197	5.680	1.2099661	506
2012	0.000	1.580	2.460	2.503	3.277	5.180	1.1086770	502
2013	0.160	1.478	2.280	2.454	3.255	5.500	1.1780287	504
2014	0.230	1.430	2.040	2.192	2.840	4.860	0.9790240	498
2015	0.100	1.417	2.220	2.324	3.080	4.930	1.1245923	508
2016	0.130	1.635	2.500	2.649	3.505	5.560	1.1943171	514
2017	0.290	1.755	2.540	2.718	3.640	5.550	1.1956855	515
2018	0.190	1.755	2.540	2.674	3.575	5.800	1.1799080	491

Both rice and wheat yields have witnessed a secular increase from 2005-06 to 2018-19. Except for one or two sharp declines, there has been significant growth across the years. The sharp incline and decline (more pronounced in Rice than Wheat) is likely due to the availability (or



lack) of water through rainfall and irrigation (Rice is a monsoon crop while wheat is grown in winter).

2.1.4 Soil Health

Summary Statistics- Nitrogen, Organic Carbon, Phosphorous and Potassium Deficiency across districts (2015-16)

	Min	1Q	Mean	Median	3Q	Max	SD	n
N	0.00	0.4495	0.7057	0.8961	0.9982	1.00	0.3536073	652
P	0.00	0.1928	0.5133	0.5182	0.8448	1.00	0.3344097	652
K	0.00	0.07305	0.27987	0.20480	0.41352	1.00	0.2597379	652

Soils across districts suffer from greater Nitrogen deficiency than other macro nutrients. Since most fertilizers are either N or K based with P for balance, this is a likely indication of Indian farmers using K-based fertilizers [10]. The data also indicates that a majority of districts in India suffer from one or more types of soil nutrient deficiency. This is a cause for concern as it can adversely impact long term sustainability in agriculture.

2.1.5 Macroeconomic trends and shocks

The trend variable is introduced to understand the change in cropland use over the period of 14 years (2005-18) and study its interaction with other variables like irrig. The D_{10} variable is to quantify the changes post 2009 due to the implementation of Mahatma Gandhi National Rural Employment Guarantee Scheme at the national level and a spate of farm loan waivers at the state levels.

The D_{16} variable is to account for the effect of demonetisation.

2.2 Dependent variable (Regressand)

The dependent variable in the regression model is the multiplicative inverse of the crop intensification factor.

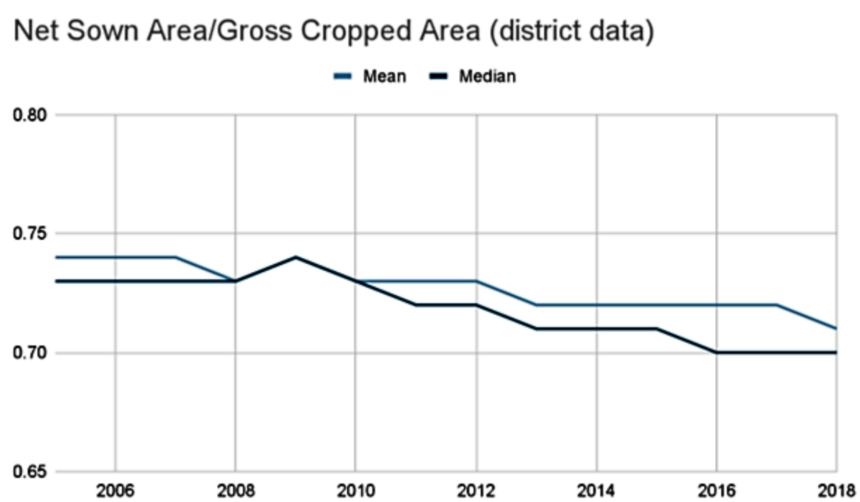
$$Crop\, intensity\, factor = Gross\, Cropped\, Area/Net\, cropped\, Area \tag{2.1}$$

where if an area is sown more than once in a year, it is counted in Gross Cropped Area but not in Net cropped area.

$$y = 1/Crop\, intensity\, factor = Net\, Cropped\, Area/Gross\, Cropped\, Area \tag{2.2}$$

This generally takes values from 0.33 (indicating triple cropping) to 1.00 (indicating single cropping). In 2015, the average value across districts was 0.74 which reduced to 0.71 by 2018. A further comparison of the average y between the periods 2005-11 and 2012-18 shows that the decrease in y is statistically significant indicating intensification of cropland use.

	Average y	Difference in Average y	P-Value
Years (2005-11)	0.735	0.015***	0.001
Years (2012-18)	0.720		



The Gross Cropped and Net Sown area data is taken from the annual “Source under Area” data from the Ministry of Agriculture and Farmers Welfare (MOAFW).

2.3 Result

$\ln(y_{i,t}/1-y_{i,t}) = \beta_0 + \beta_1 rf_{i,t} + \beta_2 rf2_{i,t} + \beta_3 irrig_{i,t} + \beta_4 Yw_{i,t} + \beta_5 Yr_{i,t} + \beta_6 Ndef_i + \beta_7 Pdef_i + \beta_8 Kdef_i + \beta_9 Tr_t + \beta_{10} Tr_t Irr_{i,t} + \beta_{11} Tr_t D_{10} + \beta_{12} D_{16} + \epsilon_{i,t}$ (2.3)

The above equation represents a fractional response (logit) regression model. The dependent variable is a fraction with values ranging from (0,1]. Hence we use the quasi-binomial likelihood estimator in this model.

Variable	**Estimate**	**Average Marginal Effect**
irrig	-7.3e-4 *** (1.3e-4)	-2.0e-4 *** (0.00)
Yr	-2.6e-2 * (1.2e-2)	-5.5e-3 * (2.5e-3)
Yw	-0.21 *** (0.01)	-0.04 *** (2.1e-3)
rf	-1.1e-3 ** (3.7e-4)	-2.0e-4 ** (1.0e-4)
rf^2	2.4e-6 (0.00)	0.00 (0.00)
Ndef	0.03 (0.03)	7.4e-3 (6.2e-3)
Pdef	-0.08 ** (0.03)	-1.6e-2 ** (5.8e-3)
Kdef	-0.08 * (0.04)	-1.7e-2 * (8.0e-3)
Tr	-7.7e-3 (9.2e-3)	-1.6e-3 (1.9e-3)
TrIrr	7.3e-9 (1.4e-8)	0.00 (0.00)
TrD10	6.9e-3 (6.7e-3)	1.4e-3 (1.4e-3)
D16	-0.04 (0.03)	-9.7e-3 (6.9e-3)

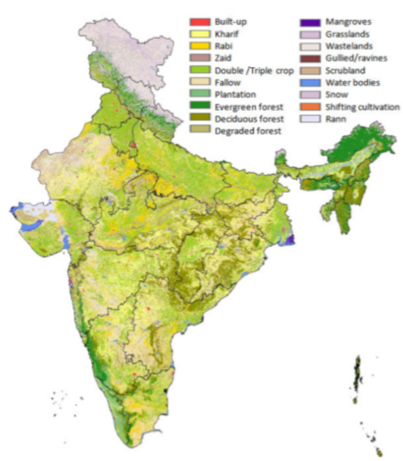
A negative value in the results indicate that the variable has a positive impact on crop intensification.
We can make the following inferences from the results:
1. Irrigation plays a small but significant role in crop intensification. However, over time the the marginal rate is decreasing (as indicated in TrxIrrig).
2. Both wheat and rice yield are significant positive drivers of crop intensification. The correlation between Yr and Yw is high and significant (r=0.52).The model when run to account each of these variables individually show the impact to be more significant. The greater significance

of Yw may be an indicator that farmers who are assured of increasing returns on cultivating wheat in the winter are ready to take the risk to cultivate rain fed crop in the monsoon as well.
3. Increase in rainfall has a positive influence on crop intensification which increases at a decreasing rate (as indicated in rf and rf^2).
4. Soil nutrient deficiency has a mixed effect on crop intensification.

Chapter 3

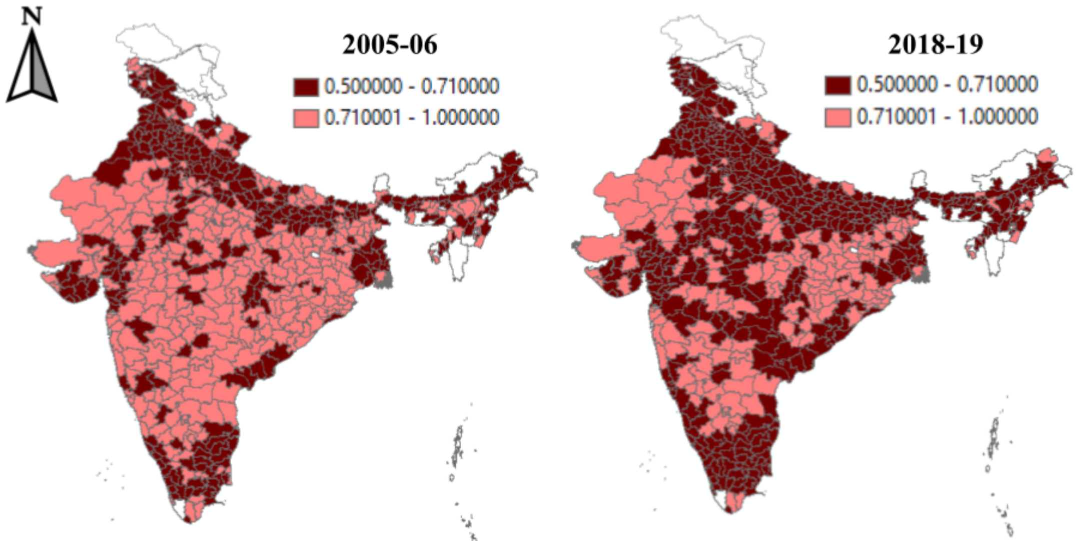
Spatial data Analysis

The data used in Model 1 are all administrative data recorded by various government agencies. Another useful data set to study land use and land change transitions is the BHUVAN LULC data from ISRO. This data is received from Advanced Wide Field Sensor (AWiFS) which operates in three spectral bands in VNIR and one band in SWIR with 56 metre spatial resolution and a combined swath of 730 km achieved through two AWiFS cameras. The scale for this data is 1:250K. The figure below gives information on the various categories of Land use for which satellite data is available.



We have taken pixel level data of Kharif, Rabi, Zaid and Double/Triple crop for 2005 & 2018 and aggregated them at a district level.Then we calculated crop intensities as follows: Crop intensity= (K+Z+R+2(DT)) / (K+Z+R+DT).
On the basis of existing data and research it was clear that triple cropping in India is a rare phenomenon (2-3% of total cropped area)[11]. Hence we decided on the value of the multiplier to be 2. We are using the inverse of crop intensity that ranges from 0.5 to 1. We have then visualized the data on ArcMap [12].

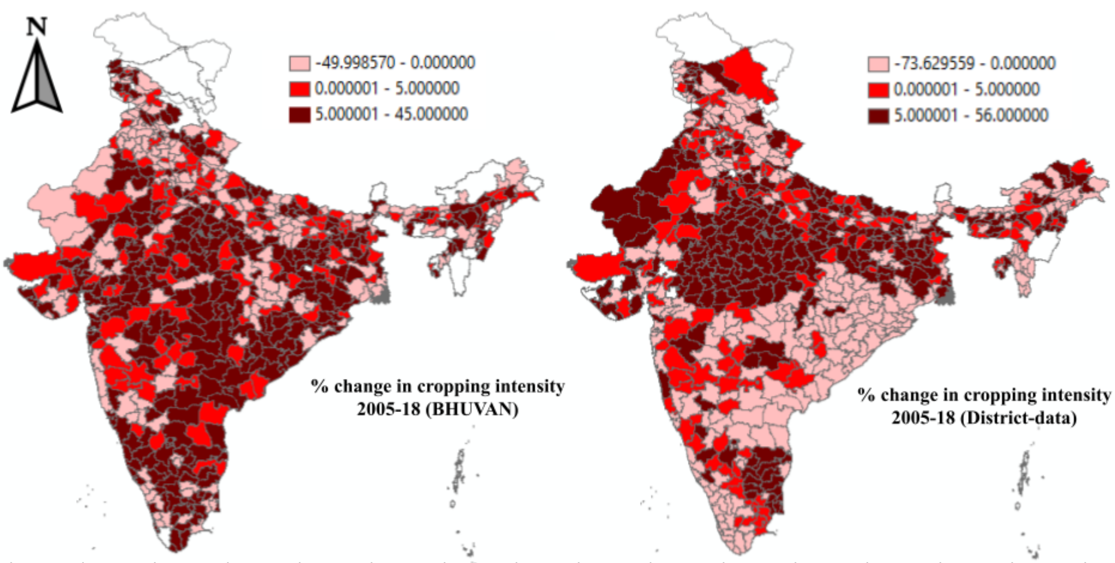
It is clear that in the period from 2005-18, the inverse of crop intensity factor for a large



min	1Q	median	mean	3Q	max	SD
0.5000	0.6004	0.7044	0.7122	0.8062	1.0000	0.14

min	1Q	median	mean	3Q	max	SD
0.5000	0.5999	0.6508	0.6642	0.7211	1.0000	0.09

number of districts has decreased indicating higher intensification. Spatially this transition is predominantly clustered in the Middle-Gangetic plain, Central, Eastern and Western Plateau and hills agro-climatic zones.

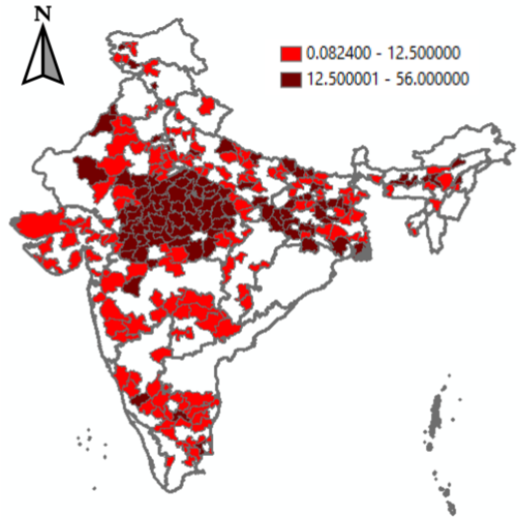


min	1Q	median	mean	3Q	max	SD
-49.9%	-1.0%	4.4%	5.2%	11.8%	42.8%	11.4

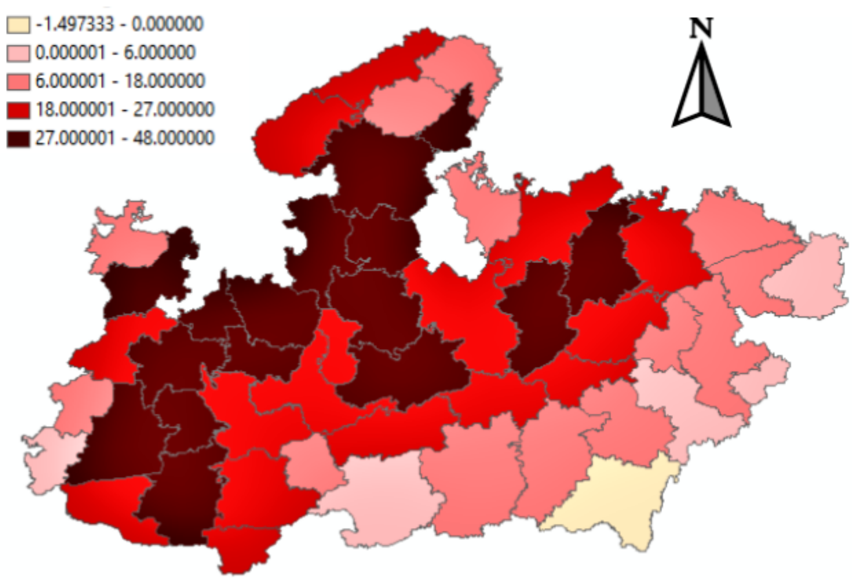
min	1Q	mean	median	3Q	max	SD
-73.6%	-3.6%	1.82%	2.5%	10.2%	55.8%	16.9

Using the inverse of cropping intensity ratio obtained from BHUVAN and district-level data, we can visualize the percentage change in these ratios for both these data sets. The calculation has been adjusted such that a negative sign indicates de-intensification and a positive sign for intensification. As seen in the above figure, there is significant divergence in the Western Dry region, Gujarat plains & hills and Eastern plateau & hills. This may be due to errors in the collection of administrative data or in the remote sensing process. This in-congruence certainly merits a deeper exploration.

For convenience, we have selected 256 districts where both the BHUVAN as well as district level administrative data indicate intensification. This is visualized below.



Both data sets appear to converge entirely in the state of Madhya Pradesh. This is our main state of interest. We have studied the changes in crop-wise area in these districts to identify which crop may be the likely driver of crop intensification.



% change in Cropping intensity ratio - Districts, MP

min	1Q	mean	median	3Q	max	SD
-1.49%	13.3%	21.08%	24.2%	27.7%	48%	11.4

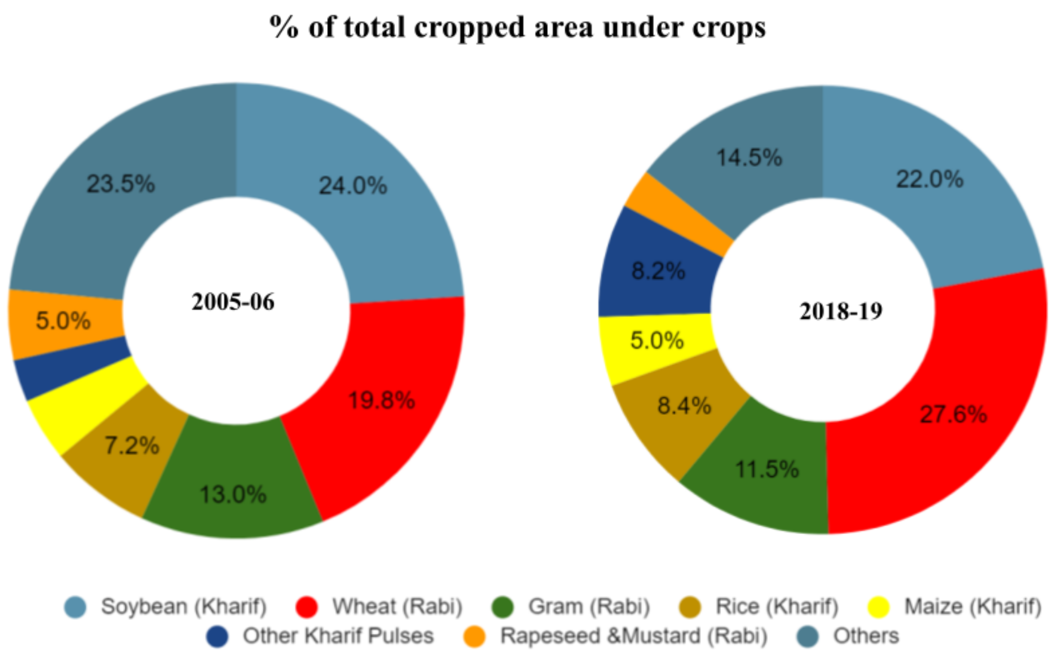
Chapter 4

Studying Crop-wise area changes

So far we have established the phenomenon of crop intensification in our study period and spatially located significant changes in Central India. The next step was to identify the cropping pattern and the specific crop (if any) driving it. To do this, district-level data on Crop-wise area for major crops (as a % of Gross cropped area) in 2005-06 and 2018-19 for the selected districts are compared. It yielded the following results:

Crop	% relative change in area 2005-18 (change in hectares)
Wheat	27.6% (3067324)
Rice	54% (710580)
Maize	47% (389550)
Gram	18% (428557)
Soyabean	21.8% (954303)
Other Kharif Pulses	253.5% (1421999)
Rapeseed and mustard	-16.11% (-132347)
Area sown more than once	134.3% (5876464)
Total cropped area	32% (5869526)

In the period from 2005-06 and 2018-19, the total cropped area in the selected districts increased by 32% while the area sown more than once increased by 134%.

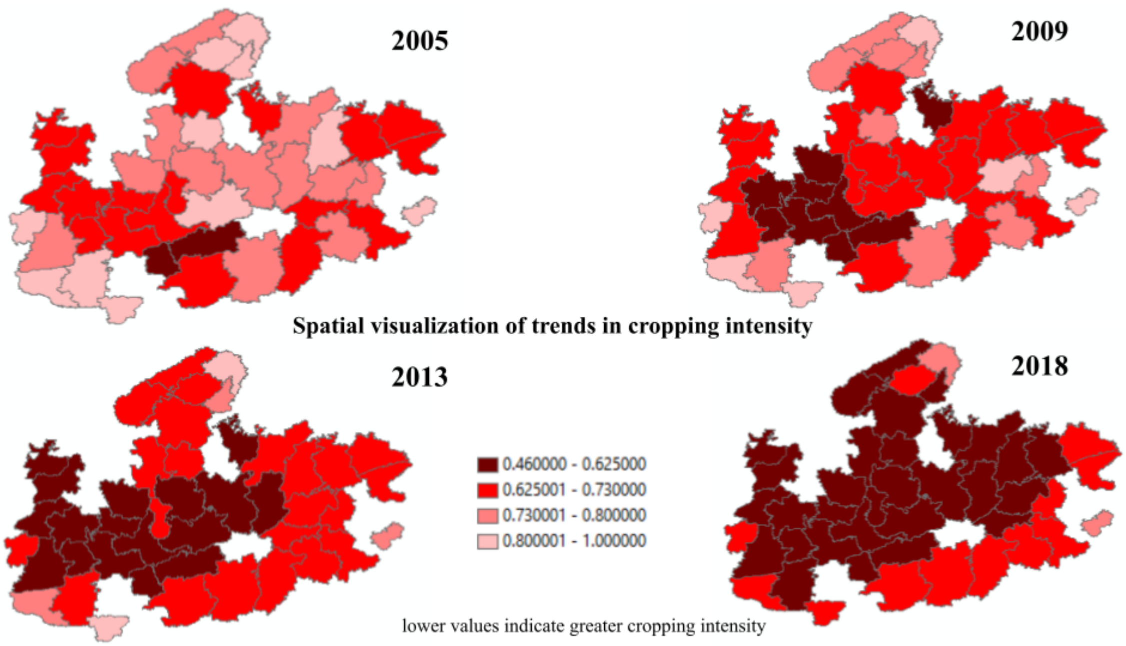


The crop wise dis-aggregation of acreage data for the major crops reveals that a significant portion of the change in cropped area comes from the cultivation of Other Kharif Pulses. The major Kharif pulses in India are Arhar, Urad and Moong. While the area under Arhar and Moong have reduced, Urad seems to have undergone a 330% increase in area and accounted for almost 8% of total cropped area in 2018-19.

Crop	% of total cropped area (2005-06)	% of total cropped area (2018-19)	% relative change 2005-18 (change in hectares)
Arhar (Tur)	1.49%	1.03	-8.70% (-23763)
Moong	0.5%	0.3%	-21% (-20410)
Urad	2.2%	7.9%	330% (1590854)

Secondary research seem to indicate a similar trend. Madhya Pradesh is the biggest producer of pulses in India contributing to about 35% of the total pulse production in the country. The Minimum Support Price for Urad was hiked 268% between 2005-18. The 12th five-year plan in 2013 laid special emphasis on pulses as part of the National Food Security Mission launched in 2007. The procurement of pulses by the National Agricultural Cooperative Market Federation of India (a Union government agency for the procurement for oil-seeds, pulses and cottons like FCI for wheat and paddy) increased from 7.02 lakh metric tonnes between 2008-13 to 91.098 Lakh metric tonnes between 2014-18 (a 1205% increase).

A plausible explanation from the crop-wise area data in the light of the aforementioned government policies is that farmers who were primarily either growing only Wheat in Rabi or Soybean in Kharif have begun to diversify to pulses in the Kharif season as well- particularly Urad. This is likely the result of increased policy focus and changed expectations of the farmer who is confident of supplying water to crops through irrigation and is expecting greater returns on Kharif crops. Additionally it appears as if the trend to grow pulses in Kharif is also impacted by increased returns on Rabi crops like Wheat (i.e.the farmer is willing to take the risk of cultivating pulses in Kharif season if the previous Rabi season was successful). To confirm this hypothesis and understand the causal impact of other factors such as bio-physical and anthropogenic drivers, the next step was to construct a regression model for the same.



Chapter 5

Madhya Pradesh- district level regression analysis

5.1 Explanatory Variables

In this model, I have expanded my study to the following factors in Table 5.1.

Table 5.1- Explanatory variables and Description

Variable Name	Notation	Description	Source
Irrigated Area	irrig	District wise gross irrigated area in 1000 hectares	Ministry of Agriculture and Farmers' Welfare (MoAFW)
Rice Yield	Y_R	District wise rice yields in tonnes per hectare	MoAFW
Wheat Yield	Y_W	District wise wheat yields in tonnes per hectare	MoAFW
Rainfall	rf	District wise annual rainfall (10 cm)	India Meteorological Department (IMD)
Depth to Groundwater	GW	District-wise depth to Groundwater	Water Information resources System (WRIS)
MSP Kharif ratio	MSP_{Rk}	Year-wise MSP ratio of Urad+Arhar and Rice+Maize	MoAFW
MSP Rabi ratio	MSP_{Rr}	Year-wise MSP ratio of Gram and wheat	MoAFW
%Loamy	Loamy	District wise percentage of Loamy soil	National Information system for Climate and Environment Studies (NICES)
%Clayey	Clayey	District wise percentage of Clayey soil	NICES
%water-erosion	waterero	District wise percentage of water-erosion in soill	NICES
% inorganic carbon	inorg	District wise percentage density of inorganic carbon in soil	NICES
Trend	Tr	Tr=1 (2006)....Tr=13 (2018)	-
Road Density	rd	District wise road density	GeoSadak

5.2 Summary Statistics

Rainfall (mm)- Summary Statistics

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Min	371.10	301.20	404.60	372.00	485.70	331.30	232.80	310.90	340.80	455.60	472.50	428.60	477.10
1Q	699.50	629.04	669.95	674.90	711.00	839.15	832.28	1,215.80	734.38	774.80	912.43	674.13	780.03
Median	1,057.05	872.25	773.40	789.50	817.70	1,093.85	974.25	1,352.10	840.90	936.05	1,138.05	807.00	891.75
Mean	1,047.32	828.24	842.79	815.63	847.95	1,091.72	1,004.02	1,397.43	860.11	976.35	1,160.43	773.88	886.33
3Q	1,281.45	1,008.65	992.03	919.80	928.96	1,300.53	1,111.83	1,615.80	960.63	1,197.28	1,427.05	885.98	970.10
Max	1,939.80	1,301.00	1,503.50	1,574.70	1,490.50	1,709.90	1,732.30	2,109.70	1,307.70	1,578.50	2,171.50	1,115.80	1,430.10
SD	413.70	257.65	252.08	233.31	208.54	300.17	280.50	330.16	202.84	280.03	374.69	156.31	172.97

Gross irrigated area (hectares)- Summary Statistics

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Min	1,515.00	1,682.00	1,552.00	1,527.00	1,573.00	1,377.00	1,992.00	2,938.00	3,631.00	3,648.00	3,624.00	4,082.00	4,215.00
1Q	85,296.00	94,621.25	76,722.75	89,297.25	94,413.25	99,498.75	119,136.00	132,868.00	136,891.50	142,696.75	136,814.00	162,390.50	151,703.25
Median	119,582.00	139,324.50	123,179.00	144,835.00	145,944.50	149,639.00	174,419.00	186,007.50	199,609.50	204,209.00	195,808.00	213,575.50	219,942.50
Mean	123,324.98	138,172.91	138,425.93	141,403.95	150,171.41	155,555.55	173,015.20	188,749.68	206,520.39	214,549.57	207,663.36	222,131.14	237,763.84
3Q	147,217.00	177,700.75	179,914.75	191,754.75	219,577.25	229,625.00	258,661.75	277,101.25	288,760.75	285,607.25	251,944.50	272,022.50	304,212.25
Max	261,022.00	281,918.00	326,508.00	279,111.00	286,184.00	313,383.00	311,441.00	344,320.00	408,869.00	447,690.00	450,460.00	464,250.00	498,699.00
SD	62,382.86	71,283.64	81,134.89	73,695.97	77,745.02	82,167.54	89,569.62	97,837.20	112,226.74	116,416.10	115,837.44	118,649.93	131,098.14

Rice Yield (tonnes/hectare)- Summary Statistics

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Min	0.39	0.00	0.35	0.38	0.45	0.71	0.37	0.35	0.40	0.11	0.36	0.35	0.30
1Q	0.54	0.54	0.65	0.53	0.76	0.92	0.86	0.73	0.87	0.88	1.27	1.21	0.80
Median	0.67	0.69	0.74	0.68	0.94	1.10	1.17	1.17	1.47	1.43	1.81	1.83	1.33
Mean	0.84	0.86	0.92	0.89	1.19	1.40	1.58	1.41	1.57	1.61	1.86	1.80	1.43
3Q	0.94	0.89	0.99	0.99	1.28	1.58	2.07	1.80	2.00	1.97	2.50	2.31	1.95
Max	2.35	3.74	2.64	2.57	2.99	3.50	6.64	4.33	3.45	4.56	3.31	5.16	3.91
SD	0.49	0.68	0.51	0.59	0.68	0.72	1.15	0.92	0.83	1.06	0.79	0.93	0.81

Wheat Yield (tonnes/hectare)- Summary Statistics

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Min	0.56	0.50	0.63	0.60	0.58	0.72	0.49	0.89	1.23	0.48	0.40	0.71	0.47
1Q	1.03	0.98	1.36	1.42	1.16	2.03	2.21	2.10	2.44	2.26	2.93	2.87	2.72
Median	1.78	1.50	1.87	1.87	1.78	2.62	2.84	2.37	3.07	2.99	3.33	3.49	3.22
Mean	1.69	1.50	1.75	1.85	1.83	2.66	2.85	2.56	2.94	2.91	3.28	3.34	3.19
3Q	2.18	1.90	2.12	2.30	2.32	3.08	3.32	3.01	3.41	3.67	3.75	3.83	3.80
Max	3.00	3.28	3.16	3.83	3.96	4.74	4.92	4.33	4.80	4.42	4.50	4.31	4.47
SD	0.69	0.65	0.60	0.74	0.81	0.94	0.87	0.74	0.78	0.91	0.74	0.71	0.85

Depth to Groundwater(m)- Summary Statistics

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Min	7.24	5.68	5.96	5.66	5.79	6.39	5.47	5.88	5.57	5.59	4.15	4.48	4.38
1Q	9.67	9.74	10.35	10.46	8.77	10.98	9.64	9.71	8.52	9.20	7.33	6.70	7.52
Median	11.37	11.56	12.25	12.09	10.86	12.41	11.62	11.34	9.68	10.16	7.86	7.68	8.39
Mean	55.99	55.86	56.79	56.53	55.92	56.72	56.02	55.84	54.65	55.39	53.09	52.98	53.60
3Q	13.73	13.20	14.14	14.05	14.57	13.79	12.95	12.77	11.64	12.22	9.12	9.26	10.68
Max	19.40	20.17	22.50	19.77	18.28	18.90	19.00	21.43	17.55	19.25	15.73	16.36	17.62
SD	2.64	2.66	3.26	2.77	3.17	2.77	2.83	2.93	2.59	2.95	2.22	2.50	2.71

Soil Data- Summary Statistics

	%Loamy	%Clayey	%inorgarnicCarbon	%watererosion
Min	0.00	1.79	1.13	6.77
1Q	9.10	43.07	2.85	12.73
Median	25.02	59.49	4.37	16.39
Mean	27.92	57.16	4.57	18.64
3Q	43.70	70.81	6.16	21.41
Max	91.25	94.76	8.21	43.35
SD	21.66	19.80	1.93	8.60

5.3 Result

A quasi-binomial logit regression model is constructed with the inverse of crop intensity as the dependent variable ($y_{i,t}$).

$\ln(y_{i,t}/1 - y_{i,t}) = \beta_0 + \beta_1 Tr_t + \beta_2 irrig_{i,t-1} + \beta_3 rf_{i,t-1} + \beta_4 Yw_{i,t-1} + \beta_5 Yr_{i,t-1} + \beta_6 GW_{i,t-1} + \beta_7 MSPkr_t + \beta_8 MSPrr_t + \beta_9 loamy_i + \beta_{10} clayey_i + \beta_{11} Tr_t Inorg_i + \beta_{12} Tr_t waterero_i + \beta_{13} rd_i + \epsilon_{i,t}$
(5.1)

	Model 1		**Model 2**	
Variable	**Estimate**	**AME**	**Estimate**	**AME**
Tr_t	-7.7e-3 (1.2e-2)	-0.0017 (2.0e-3)		
$irrig_{i,t-1}$	-1.5e-3 *** (1.7e-4)	-0.0003*** (0.00)	-1.5e-3 *** (1.6e-4)	-0.0003 *** (0.00)
$rf_{i,t-1}$	-1.7e-2 *** (4.5e-3)	-0.0037*** (1.0e-3)	-1.5e-2 *** (4.2e-3)	-0.0034 *** (9.0e-4)
$WY_{i,t-1}$	-8.3e-2 *** (1.8e-2)	-0.0179 *** (4.0e-3)	-7.7e-2 *** (1.7e-2)	-0.0166 *** (3.7e-3)
$RY_{i,t-1}$	3.9e-2 * (1.8e-2)	0.0084 * (4.0e-3)	4.3e-2 ** (1.8e-2)	0.0093 ** (3.9e-3)
$GW_{i,t-1}$	1.7e-2 ** (5.4e-3)	0.0037 ** (1.2e-3)	1.6e-2 *** (4.8e-3)	0.0036 *** (1.0e-3)
$MSPkr_t$	-3.8e-1** (1.4e-1)	-0.0815 ** (3.1e-2)	-2.0-1 ** (7.0e-2)	-0.0427 ** (1.5e-2)
$MSPrr_t$	1.8e-1 (1.4e-1)	0.0391 (3.0e-2)		
$\%Loamy_i$	5.4e-3 *** (1.6e-3)	0.0012 *** (3.0e-4)	4.9e-3 *** (8.9e-4)	0.0011 *** (2.0e-4)
$\%Clayey_i$	5.7e-4 (1.6e-3)	0.0001 (4.0e-4)		
$TrInorg_{i,t}$	-3.2e-3 *** (9.5e-4)	-0.0007 *** (2.0e-4)	-2.8e-3 *** (7.6e-4)	-0.0006 *** (2.0e-4)
$Trwaterero_{i,t}$	1.9e-4 (2.3e-4)	0.0000 (0.00)		
rd_i	-1.4e-2 . (8.5e-3)	-0.0032 . (1.8e-3)	-1.4e-2 . (8.3e-3)	-0.0030 . (1.8e-3)

Significance codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**

5.4 Discussion

A negative value in the results indicate that the variable has a positive impact on crop intensification.

We can make the following inferences from the results:

1. Irrigation and rainfall are significant driver of crop intensification. Similarly, districts with lower depth to ground water (lesser depletion) undergo greater intensification. These confirm our expectation that the intensification is driven by water-intensive cultivation of pulses in the Kharif season. If farmers expect (based on the rainfall, irrigation and ground water situation of the previous year) that they are capable of growing Kharif pulses, they go for it.

2. Wheat yield has a positive impact while rice yield has a negative impact. This may be an indicator that a good yield in Rabi drives cropping intensification in Kharif but not vice-versa which is expected because Rabi crops require higher external irrigation application while Kharif crops are rainfed.
3. The ratio of MSP of Urad+Arhar over Rice+Maize is a positive driver of crop intensification. An increase in MSP of Kharif pulses relative to the existing(major) Kharif crops such as Rice and Maize is reflective of pulse cultivation becoming relatively more profitable for farmers over time. This again confirms our hypothesis of the intensification phenomenon being largely a Kharif pulse driven one.
4. Greater inorganic carbon density in the soil is associated with greater crop intensification. However the results indicate that greater percentage of loamy soils leads to significant de-intensification. This is counter-intuitive since loamy soil is the best type for pulse cultivation. This may be explained by the fact that almost all existing loamy soil is already being utilized under double cropping.
5. Road density and by extension greater connectivity and access to infrastructure positively drive crop intensification.

5.5 Valuing the economic impact of crop intensification

While it may appear that the marginal effect of these factors are minimal, they translate into significant economic volume. Here I attempt to quantify such agricultural land use transition in monetary terms.

In 2017, the average of the inverse of cropping intensity was 0.61. Assume that a district had 1000 hectares of agricultural land. This meant that around 639 hectares was double cropped. A 0.001 decrease in the ratio between 2017-18 would imply that the multi-cropped area was 642 hectares (an increase of 3 hectares). If all this additional land was used to cultivate the Urad (as discussed earlier), the district would have generated an extra Rs. 99,000 (taking the average yield of last 4 years-577 kgs/hectare MSP 2018 = Rs.5600/quintal). On the other hand if all this were used to grow the Kharif crop with highest MSP- Moong, the district would have made an additional Rs. 1,54,008 (taking the average yield of last 4 years-736 kgs/hectare MSP 2018= Rs.6975/quintal). This is a reasonable interval to assume for the economic value added due to multi-cropping in three hectares. If all the area is used for cultivation of Urad, the figure comes to For a single hectare of land undergoing transition from single to double cropping we have Rs. 33,000 - Rs, 51,000 added in the economy.
In the state of Madhya Pradesh, area under double cropping increased by 58,76,464 hectares.

Note: These are back of the envelope calculations and not an exact valuation. However it may be used to gauge the significant value generation in the economy due to a small change in the inverse of cropping intensity ratio driven by factors like rainfall, yield and groundwater.

Chapter 6

Conclusion

Administrative data on crop intensification is consistent with the satellite data indicating greater cropland intensification. However there is a significant incongruence in the spatial extent of the same. This is an indication of serious flaws in the data collection process that merits an investigation.

However both data sets converge in Madhya Pradesh where a crop-wise dis-aggregation reveals a dramatic increase in cultivation of Other kharif pulses (particularly Urad). To confirm our hypothesis of farmers transitioning from only-Rabi cultivation to Kharif and Rabi cultivation and explore other drivers of cropland use change, the inverse of cropping intensity was modelled as a function of multiple bio-physical, policy and anthropogenic factors.

The results show that factors like irrigated area, rainfall, groundwater, yields of wheat and rice, road density, content of loamy and inorganic carbon in soil and policy decisions like the Minimum Support Price influence crop intensification.

A back of the envelope calculation shows that the gross valued added to the economy as a result of transition from single cropping to double cropping in one hectare of agricultural land is between the interval of Rs. 33,000 to Rs. 51,000.

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