1 General comments

The work touches on a very interesting and relevant topic. I am not familiar with hydrological datasets such as the ones derived from GRACE but it appears that the presentation of groundwater storage from this information is a novel and valuable contribution.

We sincerely thank the anonymous reviewer 3 for reviewing our manuscript, appreciating our analysis, and providing valuable suggestions for its further improvement.

The shift to irrigated crops and the link with monsoon rainfall and groundwater depletion is also interesting. If the story regarding the nexus is simple and linear (population growth leads to increased food demand as well as more farmers, needing to irrigate more and using more electricity for that), then it is presented in too complicated a way. The language needs to be improved and there are many technical errors which need to be corrected.

We thank the reviewer for the above mentioned comment. We agree that nexus is not so simple, as there are multiple factors that affect the system. However, here we specifically focus on irrigation driven agriculture, associated ground water pumping demanding more energy with the resulting severe depletion of groundwater. We use the satellite, on site and government data to prove our hypothesis. We tried to present the complexity of the system and hence the presentation may appear complicated. We will modify the manuscript by properly linking different paragraphs and sections to make it more easily readable. We will also correct the errors as per the reviewers' suggestions.

2 Specific comments

• The focus on agriculture is not apparent from the title and could be included.

We will change the title to "Water Food Energy Nexus with Changing Agricultural Scenarios in India during recent Decades". We will also add following discussion to keep the focus on agriculture.

Indian agricultural production is divided into food crops and non-food crops. The essential food crops comprise of cereals (rice, wheat, bajra, maize, millets) and pulses (tur/arhar, gram). These are considered as the staple food for nearly the entire country. The non-food crops refer to oil seeds, cotton, tobacco to name a few, these are important from the perspective of the economy to generate revenue. Hence, it is important to maintain a balance between the two, with priority given to food crops. Following table R1 shows a decadal variation of the area under cultivation, production, and percentage area under irrigation for food grains and cash crops.

Table R1: Decadal variation of food grains and major cash crops of India.

	Food Grains			Major Cash Crops								
				Oilseeds			Cotton			Sugarcane		
Year	A	P	Area Under Irrigation (%)	A	P	Area Under Irrigation (%)	A	P	Area Under Irrigation (%)	A	P	Area Under Irrigation (%)
1950-51	97.32	50.82	18.1	10.73	5.16	NA	5.88	3.04	8.2	1.71	57.05	67.3
1960-61	115.58	82.02	19.1	13.77	6.98	3.3	7.61	5.6	12.7	2.42	110	69.3
1970-71	124.32	108.42	24.1	16.64	9.63	7.4	7.61	4.76	17.3	2.62	126.37	72.4
1980-81	126.67	129.59	29.6	17.6	9.37	14.5	7.82	7.01	27.3	2.67	154.25	81.2
1990-91	127.84	176.39	35.1	24.15	18.61	22.9	7.44	9.84	32.9	3.69	241.05	86.9
2000-01	121.05	196.81	43.3	22.77	18.44	23	8.53	9.52	34.3	4.32	295.96	92.1
2010-11	126.67	244.49	47.8	27.22	32.48	25.1	11.24	33	33.8	4.88	342.38	92.5

Source: Directorate of Economics and Statistics, Department of Agriculture and Cooperation, 2013-14

A=Area under cultivation (in million hectares)

P = Production (in million tonnes)

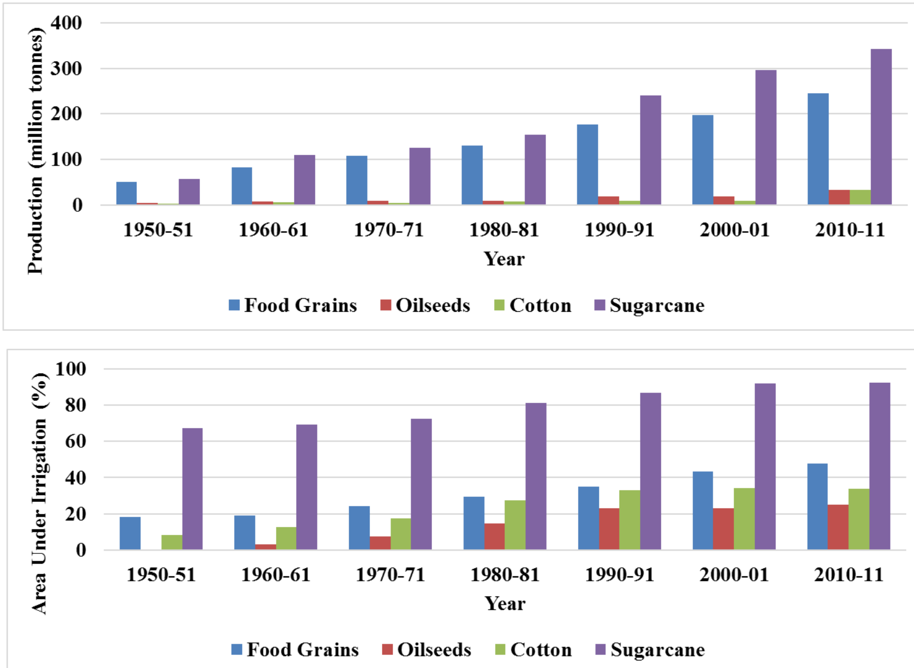

Fig.R1. Varying production (top) and percentage of area under irrigation (bottom) for food grain and cash crops.

The above Fig R1 brings out the disparity in production and percentage area of irrigation for food grains and cash crops (specifically, sugarcane) very clearly. However, the area under cultivation is largest for food grains, despite that sugarcane has higher productivity.

• The link with electricity and food production is useful and yields insights with regard to the increased role of groundwater pumping in the absence of sufficient rainfall. Some assumptions are not explicitly stated however, e.g. no estimate is given of how much of agricultural electricity use is for pumping and how that changes over time. This makes the correlations less convincing as giving strong evidence of the relationships claimed in the manuscript.

We sincerely thank the reviewer for this very important point and we agree that this has not really come out well in the previous version of the manuscript. We also agree that we have not mentioned about how much of agricultural electricity is used for groundwater pumping. Hence, we shall revise section 4.3.3 as the following:

A similar analysis has been conducted for food production and groundwater storage change. As the food production has increased there has been a decline in the storage of groundwater (Fig. 6a) and they have a high negative correlation (R= -0.73) as seen in the scatter plot (Fig.6b). On the other hand, a positive correlation (R = 0.96) exists between the food production and electricity consumption (Fig. 6d). This implies the high dependency of food production and ground water irrigation.

Energy usage in agriculture has two major usages: pumping groundwater for irrigation (electricity) (Scott and Shah, 2004; Birner et al., 2007; Kumar et al.,2013) and mechanisation (diesel) due to the use of tractors (Jha et al., 2012). Several studies have stated that the electricity for agricultural purposes is mainly used for irrigation (Scott and Shah, 2004; Birner et al., 2007; Kumar et al.,2013) because the farm mechanisation is dependent upon diesel (Jha et al., 2012). Hence, an assumption that has been considered for this analysis is that, the data for 'consumption of electricity for agricultural purposes' represent the electricity used for pumping groundwater. This will be added in the manuscript.

In Figure 6c we observe that in the year 1957-58 the electricity consumption was 544.64 GWh along with a food production of 64.31 million tonnes. 20 years later the electricity consumption increased by nearly 20 times (10107.36 GWh) but the food production increased only by twice the previous (126.41 million tonnes). In year 1997-98 electricity consumption was 97195 GWh but still the food production lagged (203 million tonnes). In the recent year of 2011-12 food production increased to 259.32 million tonnes and electricity consumption was 140960 million tonnes. Hence, over the past 54 years (1957-58 to 2011-12) electricity consumption has increased by more than 250 folds whereas the food production has increased only by four folds. Thus, when actual observed values are considered we see that electricity consumption has increased in leaps and bounds but food production has failed to do so, which brings out the concern regarding food security. Thus, there exists a clear dis-balance between the three facets of the nexus. This indicates that the food security has been maintained at the cost of water and energy security.

• There is a positive feedback between groundwater depletion and electricity consumption for pumping which is hinted at but not conclusively illustrated. This implies a progressive relationship between the groundwater table depth and electricity consumption for pumping. If the data allow demonstrating this, it would be a valuable addition to this research.

We thank the reviewer for stating this important finding and we will include the following analysis in the revised manuscript.

We hypothesize the progressive relationship between the groundwater table depth and electricity consumption for pumping, i.e., there exist a correlation between the annual change in ground water level (year 2-year1) and the electricity used for pumping in year2. We plot the same for the three regions, Middle Ganga Basin (MGB, Fig. R2(a)), North-West India (NWI, Fig. R2(b)) and West Central India (WCI, Fig. R21(c)). The duration of the analysis is from 1999 to 2011.

We find statistically significant positive correlation between ground water level drop and electricity consumption for MGB. However, statistically significant correlation does not exist for NWI and WCI. For WCI, this is expected and it is consistent with overall increase in ground water level that possibly attributes to judicious use of groundwater. However, a careful investigation for NWI reveals that the correlation value is dominated by two outliers (marked in red in Fig.R2(b)) of changes in ground water table depth. After removing the outliers, we obtain a very high statistically significant correlation as presented in Fig. R3.

We would also like to mention here, that the well data available from CGWB are not continuous (available for only months of Jan, May, August and November) and the sample size is also low. Under such situation, with spatially and temporally discontinuous ground observations, a high correlation may not be expected.

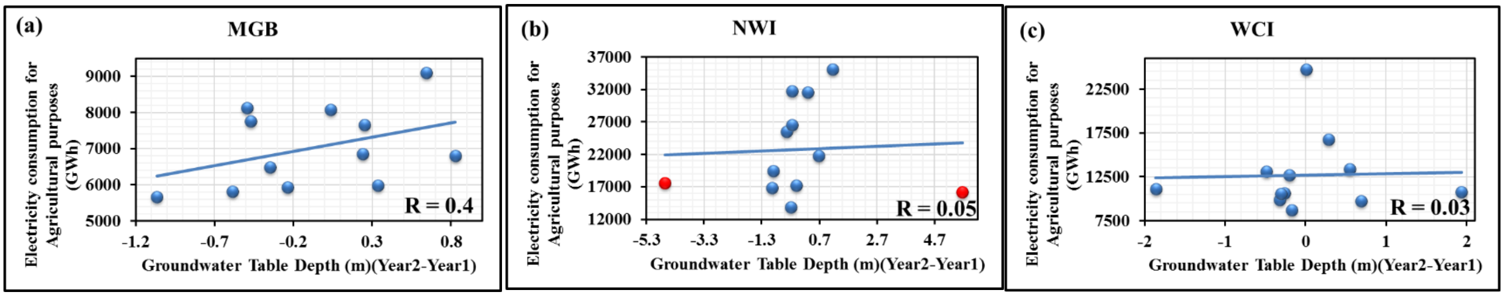

Fig. R2. Scatter plots showing the correlation between groundwater table depth and agricultural electricty consumption for the three sub region (a) MGB, (b)NWI and (c)WCI.

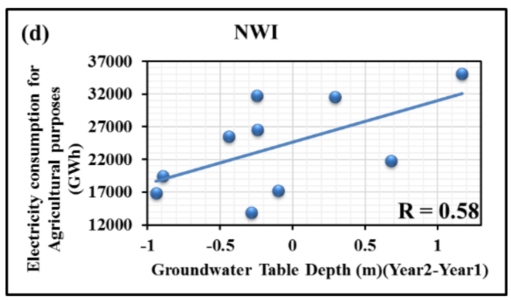

Fig. R3. Scatter plot of NWI after removing the outliers.

• The manuscript is not easy to read because of long composite sentences, poor language (omission of words, contaminations, singular/plural correspondence errors, split composite words, word placement), and unclear references. It would be correct and kind to the reader to correct all of these. I suggest having the final version proofread.

We thank the reviewer for mentioning the above discrepancy in the manuscript, we will revise the entire manuscript with reframed short sentences and better language. References will be added accordingly and the final version would be proof-read.

• URLs in the body should go into footnotes if allowed or in the references section.

We shall take care of this, reformat the references including the URLs.

• I suggest the use of vector graphics where possible.

All the figures will be plotted as vector graphics (.eps) in the revised manuscript.

• It would be good to define food security, water security and energy security.

The following definitions would be added in Sect.1 for a better understanding of their interlink

The United Nations has defined food security and water security as the following:

"Food Security is the condition in which all people, at all times, have physical, social and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life."

"Water security is defined as the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability."

The International Energy Agency (IEA) defines energy security as "the uninterrupted availability of energy sources at an affordable price".

• The summary and conclusions section must not contain new information but it does.

We will remove the new information from conclusions and add to results and discussions.

• The references are not formatted consistently, e.g. 'Pai D.S.', 'Panda, D . K.' and 'Pande S' are consecutive and all different.

These inconsistencies will be rectified as the following and all other references will be cross-checked.

Pai, D.S., Sridhar, L., Rajeevan, M., Sreejith, O.P., Satbhai, N.S. and Mukhopadhyay, B.: Development of a new high spatial resolution (0.25° X 0.25°) long period (1901-2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region, Mausam, 65(1), 1-18, 2014.

Panda, D. K. and Wahr, J.: Spatiotemporal evolution of water storage changes in India from the updated GRACE-derived gravity records. Water Resour. Res., 52(1), 135-149, doi:10.1002/2015WR017797, 2016.

Pande, S. and Savenije, H.H.: A sociohydrological model for smallholder farmers in Maharashtra, India, Water Resour. Res., 52(3), 1923-1947, doi:10.1002/2015WR017841, 2016.

• Line-by-line comments:

– 2/16: 'water used as hydro electricity to generate power' does not make sense. Rather say e.g. 'water used for hydropower to generate electricity'

This will be rectified too:

"Water is required for agricultural produce, energy is required to pump the water from various sources, and again water is used for hydropower to generate electricity."

– 4/9: 'depletion of ground water table' - 'falling groundwater table' or just 'depletion of groundwater'

This will be changed to 'depletion of groundwater'.

– 8/16: rate of population growth

This will be rectified:

"However, the net per capita availability of food shows a decline post 1996 as shown in Fig. 2b, which brings forth the clear picture of a decline in the per capita food production, but a steady increase in the rate of population growth."

– 9/1: something is wrong with figures 2g and 2h: the 50000-130000 scale corresponds to electricity consumption in 2g and to expenditure in 2h.

This will be rectified, we apologize for the inadvertent error in the axis values.

– 9/10-11: 'zero is the surface level denoting no change in the water table':this confused me - how does the surface level affect changes in the water table?

Here we meant that the groundwater level is at the surface (no fall in the level). We have modified the sentence for better understanding as:

"Figure 3b, d and f show the groundwater depths measured in meters below ground level (mbgl), where zero refers to the groundwater at the surface (opening of the observation well) denoting no change in the water table. A time series of the four months have been plotted from 1996 to 2014."

– 15/31-32: this claim is incorrect. The study involves but does not encompass all three sectors of water, food and energy. This study refers only to fractions of the energy and water sectors.

We agree with the reviewer but our claim is more concentrated with respect to the agricultural ground water use and agricultural energy use. We have modified the sentence accordingly as:

"This present study is the first of its kind for India, encompassing all the three major sectors of water, food and energy from the perspective of the agricultural sector."

3 Technical corrections

We thank reviewer 3 for taking time out to point out these intricate errors. Spelling and grammatical errors will be corrected to the best of our knowledge.

The various spelling and grammatical errors are not listed here.

The listed-out errors will be addressed in the revised manuscript as the following:

• 5/7-10: inconsistent formatting of numbers, and decimals completely superfluous.

This will be rectified in the revised manuscript as:

"The three sub-regions studied here are, North-West India (NWI) (the states of Rajasthan, Punjab, Haryana and Delhi) covering an area of 437,739.14 km^2; Middle-Ganga Basin (MGB) (the states of Uttar Pradesh and Bihar) covering an area of 339,488.09 km^2 and West-Central India (WCI) (the states of Maharashtra and Goa) encompassing an area of 311,249.34 km^2."

• general: 'well depth'

This will be rectified in the revised manuscript as suggested.

• 15/16: 'Validation of satellite derived groundwater' - add 'data' at the end of this

This will be rectified in the revised manuscript.

• Fig. 3a: coordinates right and bottom are duplicate and unnecessary.

The duplicate coordinates will be removed.

• Fig. 4a: ’Deficit/Excess’ first in legend but on secondary axis (on the right), this is counterintuitive.

This will be rectified by making deficit/excess as the second entry in the legend in Fig. 4a, also the same correction will be made in the supplementary material for Supplementary Fig. S2a, Fig. S5a and Fig. S8a.

References:

Agricultural statistics at a glance 2014, Ministry of Agriculture Department of Agriculture & Cooperation, Directorate of Economics & Statistics, Government of India, 2015 (http://eands.dacnet.nic.in/PDF/Agricultural-Statistics-At-Glance2014.pdf).

Birner, R., Gupta, S., Sharma, N., and Palaniswamy, N.: The political economy of agricultural policy reform in India: The case of fertilizer supply and electricity supply for groundwater irrigation, IFPRI, New Delhi, India, 2007.

Jha, G.K., Pal, S. and Singh, A.: Energy requirement for Indian Agriculture, ICAR, New Delhi, 2012.

Kumar, M.D., Scott, C.A. and Singh, O.P.: Can India raise agricultural productivity while reducing groundwater and energy use?, Int. J. of Water Resour. D.,29(4), 557-573, doi: 10.1080/07900627.2012.743957, 2013.

Scott, C. A., and Shah, T.: Groundwater overdraft reduction through agricultural energy policy: insights from India and Mexico, Int. J. of Water Resour. D., 20(2), 149-164, doi:10.1080/0790062042000206156, 2004.