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Water–food–energy nexus with changing agricultural scenarios in India during recent decades

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Table S1. 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

Table S2. Studies conducted using GRACE over the Indian region

Reference	**Case-study Region**	**Source**
Rodell, M., Velicogna, I., and Famiglietti, J. S.: Satellite-based estimates of groundwater depletion in India, Nature, 460, 999–1002, https://doi.org/10.1038/nature08238, 2009.	North-West India (Punjab, Haryana, Delhi, Rajasthan)	http://www.nature.com/nature/journal/v460/n7258/pdf/nature08238.pdf
Tiwari, V. M., Wahr, J., and Swenson, S.: Dwindling groundwater resources in northern India, from satellite gravity observations, Geophys. Res. Lett., 36, L18401, https://doi.org/10.1029/2009GL039401, 2009.	Indus-Ganga-Brahmaputra Basin.	http://onlinelibrary.wiley.com/doi/10.1029/2009GL039401/epdf

Chen, J., Li, J., Zhang, Z., and Ni, S.: Long-term groundwater variations in Northwest India from satellite gravity measurements, Global Planet. Change, 116, 130–138, https://doi.org/10.1016/j.gloplacha.2014.02.007, 2014.	North-West India	http://ac.els-cdn.com/S0921818114000526/1-s2.0-S0921818114000526-main.pdf?_tid=b0e17334-e9d5-11e6-9328-00000aab0f02&acdnat=1486101648_83a007a750a5b266c5a402b016f1bfa2
Dasgupta, S., Das, I. C., Subramanian, S. K., and Dadhwal, V. K.: Space-based gravity data analysis for groundwater storage estimation in the Gangetic plain, India, Curr. Sci., 107, 832–844, 2014.	Gangetic Plain (Uttar Pradesh, Bihar, West Bengal)	http://www.currentscience.ac.in/Volumes/107/05/0832.pdf
Prakash, S., Gairola, R. M., Papa, F., and Mitra, A. K.: An assessment of terrestrial water storage, rainfall and river discharge over Northern India from satellite data, Curr. Sci., 107, 1582–1586, 2014.	India	http://www.currentscience.ac.in/Volumes/107/09/1582.pdf
Khandu, K., Forootan, E., Schumacher, M., Awange, J. L., and Müller Schmied, H.: Exploring the influence of precipitation extremes and human water use on total water storage (TWS) changes in the Ganges-Brahmaputra-Meghna River Basin, Water Resour. Res., 52, 2240–2258, https://doi.org/10.1002/2015WR018113, 2016.	Ganga-Brahmaputra-Meghna Basin	http://onlinelibrary.wiley.com/doi/10.1002/2015WR018113/epdf
Yi, S., Sun,W., Feng,W., and Chen, J.: Anthropogenic and climate-driven water depletion in Asia, Geophys. Res. Lett., 43, 9061–9069, https://doi.org/10.1002/2016GL069985, 2016.	Asia	http://onlinelibrary.wiley.com/doi/10.1002/2016GL069985/epdf
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, 135–149, https://doi.org/10.1002/2015WR017797, 2016.	India	http://onlinelibrary.wiley.com/doi/10.1002/2015WR017797/epdf
Asoka, A., Gleeson, T., Wada, Y., and Mishra, V.: Relative contribution of monsoon precipitation and pumping to changes in groundwater storage in India, Nat. Geosci., 10, 109–117, https://doi.org/10.1038/ngeo2869, 2017.	India	http://palgrave.nature.com/ngeo/journal/v10/n2/pdf/ngeo2869.pdf

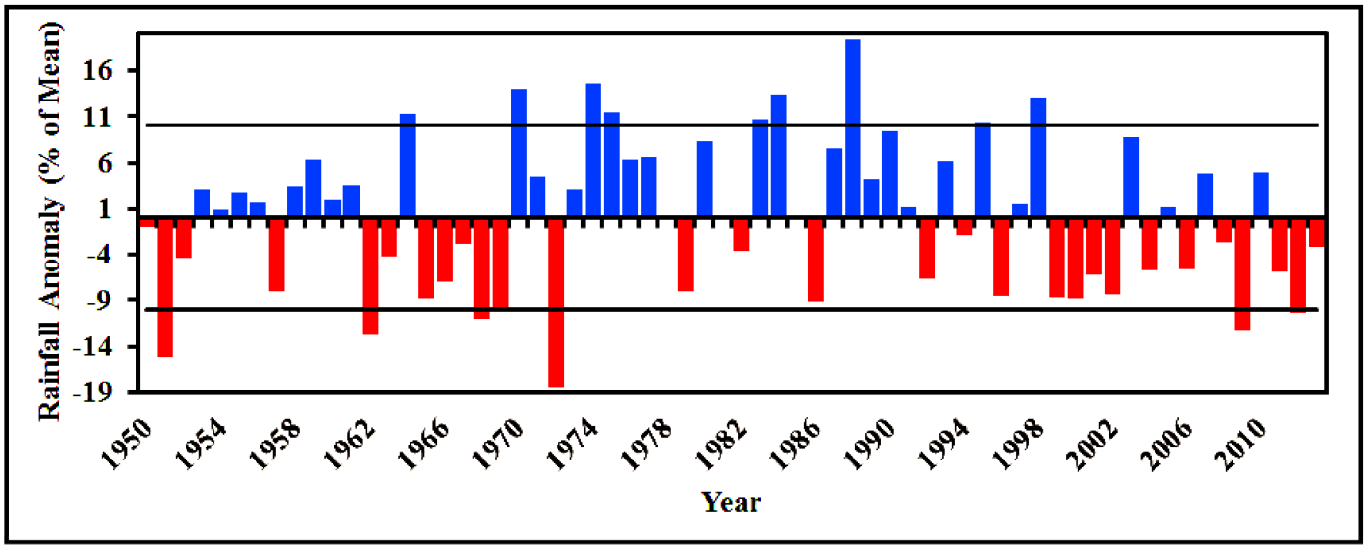

Fig.S1. Anomaly of AIMR computed with respect to its mean for the period from 1950 to 2013.

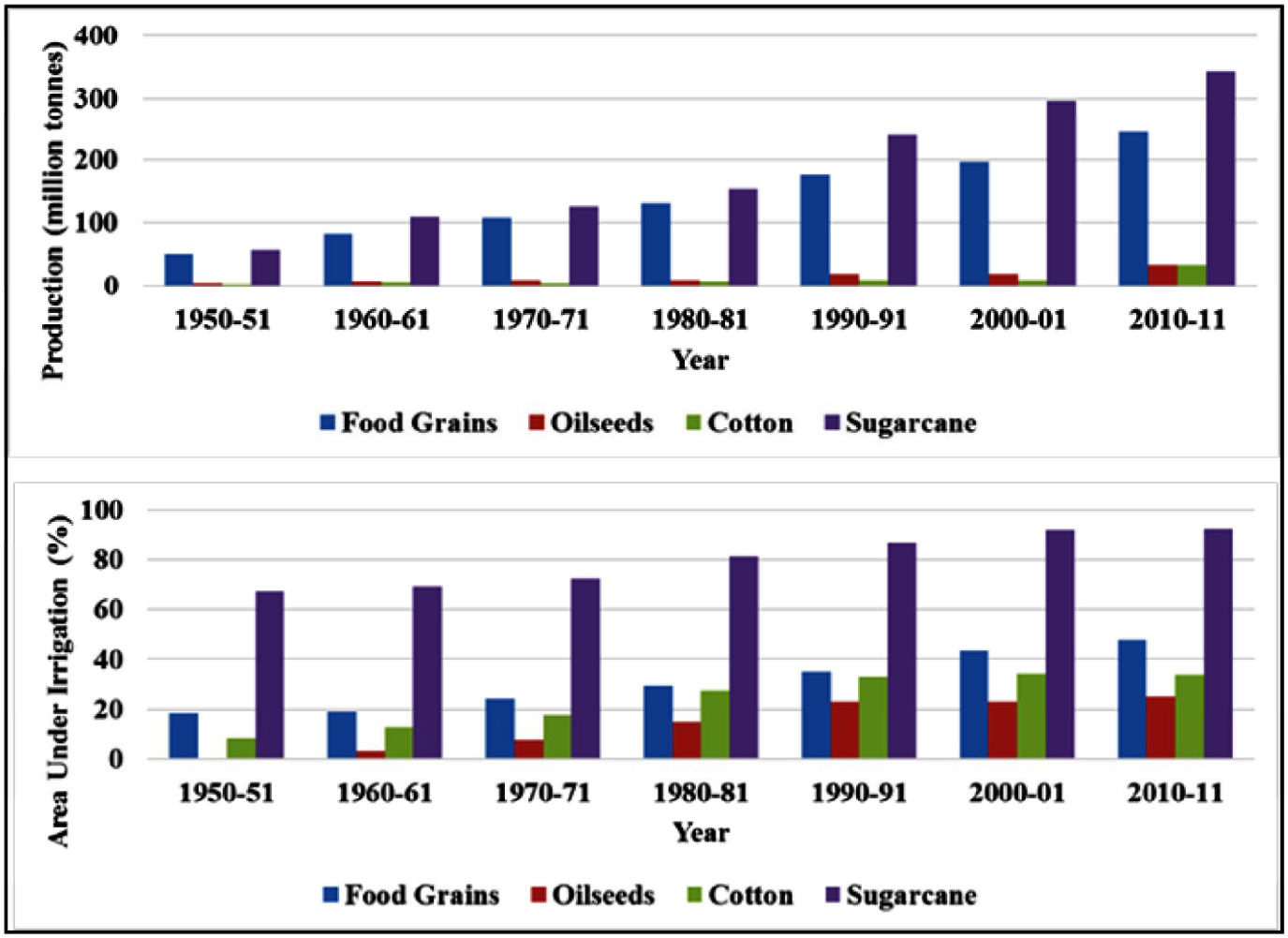

Fig.S2. Varying production **(top)** and percentage of area under irrigation **(bottom)** for food grain and cash crops.

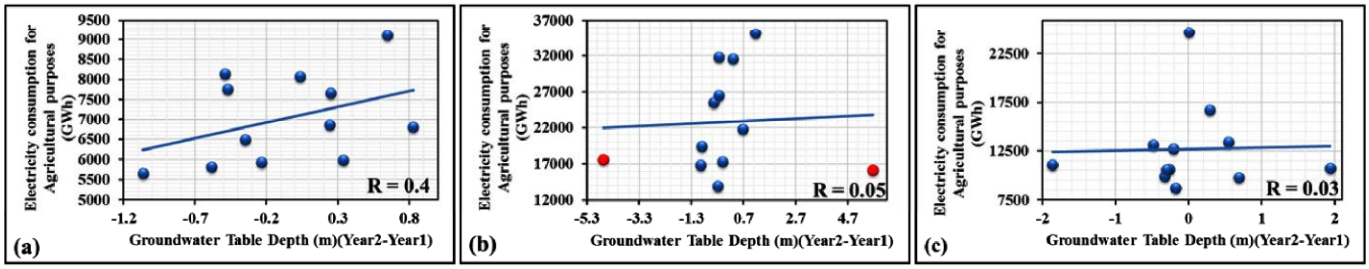

Fig.S3. Scatter plots showing the correlation between observed groundwater table depth and agricultural electricity consumption for the three sub-region **(a)** MGB, **(b)**NWI and **(c)**WCI.

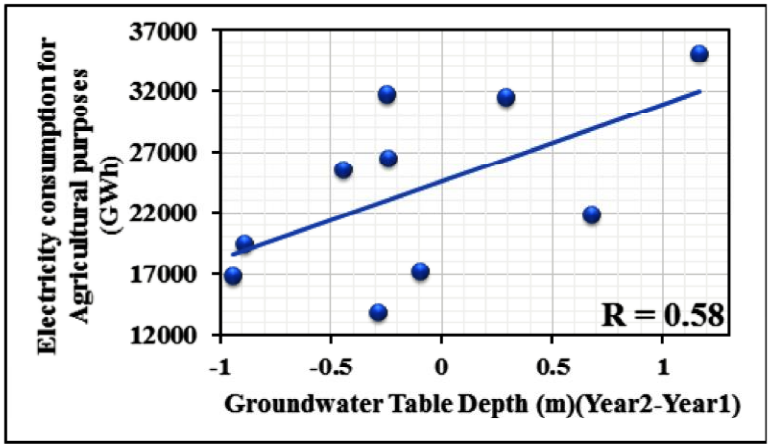

Fig.S4. Scatter plot of NWI after removing the outliers

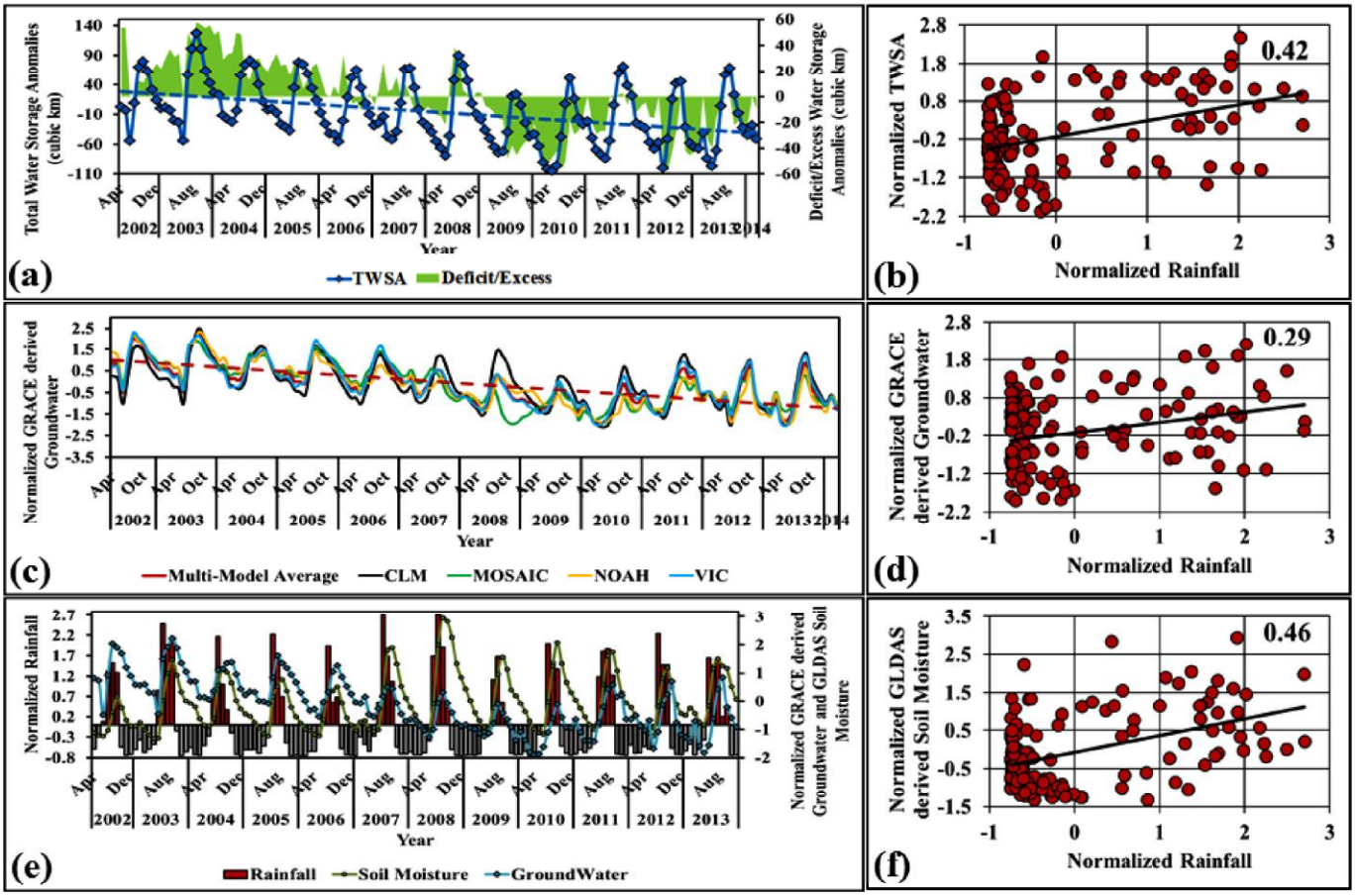

Fig.S5. Groundwater scenario of Middle Ganga Basin. (a) GRACE-derived total water storage anomaly. **(b)** Correlation between Rainfall and TWSA. **(c)** GRACE-GLDAS-derived groundwater storage anomaly. **(d)** Correlation between Rainfall and GRACE-derived groundwater storage anomaly. **(e)** Rainfall, GRACE-derived groundwater anomaly and GLDAS-derived soil moisture. **(f)** Correlation between Rainfall and GLDAS-derived soil moisture.

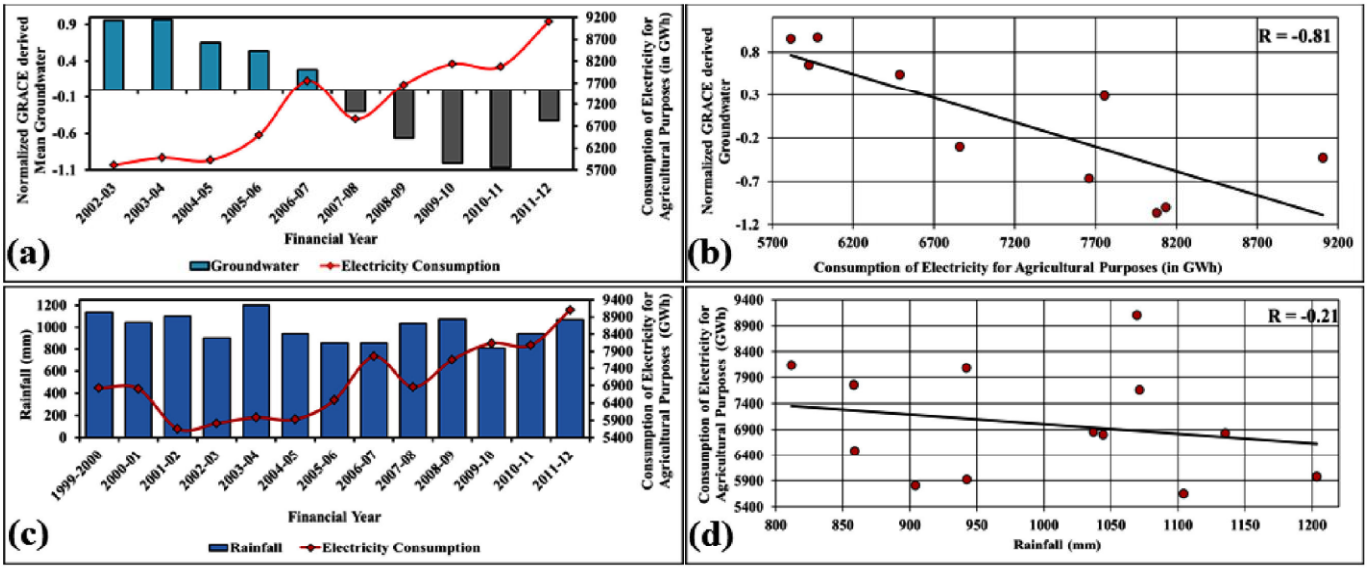

Fig.S6. Middle-Ganga Basin groundwater storage anomaly and energy consumption. (a) Electricity consumption for agricultural purpose and groundwater storage. **(b)** Scatter plot between electricity consumption for agricultural purpose and GRACE-derived groundwater storage anomaly. **(c)** Consumption of electricity for agricultural purposes and Rainfall. **(d)** Scatter plot between Rainfall and electricity consumption.

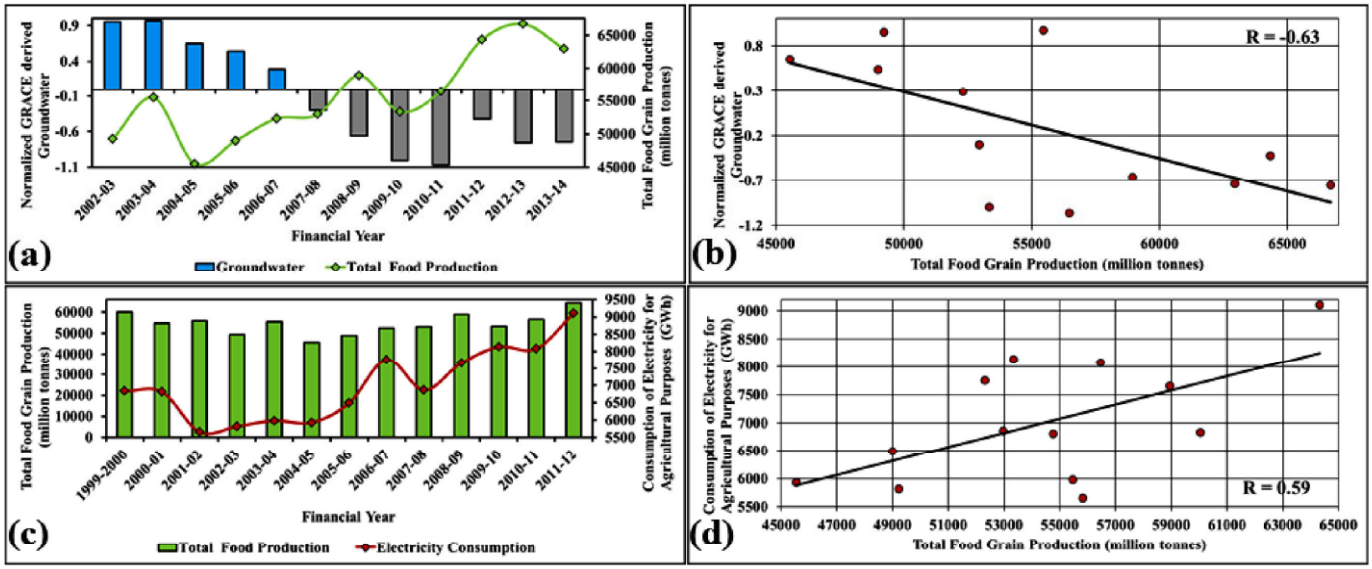

Fig.S7. Middle-Ganga Basin food-groundwater-energy nexus. (a) GRACE-derived groundwater storage anomaly and total food production. (**b)** Scatter plot between GRACE-derived groundwater storage anomaly and total food grain production. (**c)** Food grain production and electricity consumption for agricultural purposes. (**d)** Scatter plot between total food grain production and consumption of electricity for agricultural purposes.

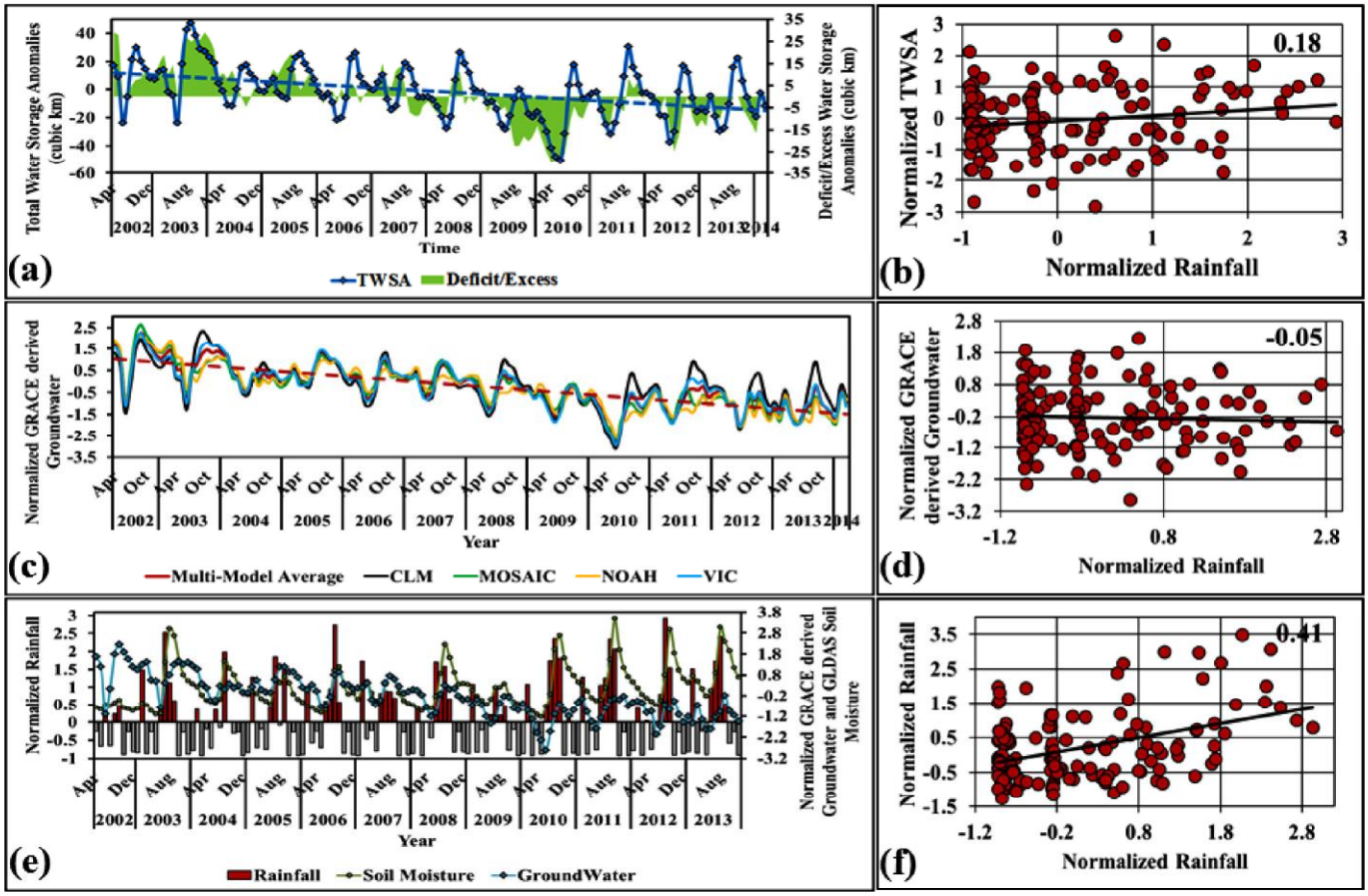

Fig.S8. Groundwater scenario of North-West India. (a) GRACE-derived total water storage anomaly. **(b)** Correlation between Rainfall and TWSA. **(c)** GRACE-GLDAS-derived groundwater storage anomaly. **(d)** Correlation between Rainfall and GRACE-derived groundwater storage anomaly. **(e)** Rainfall, GRACE-derived groundwater anomaly and GLDAS-derived soil moisture. **(f)** Correlation between Rainfall and GLDAS-derived soil moisture.

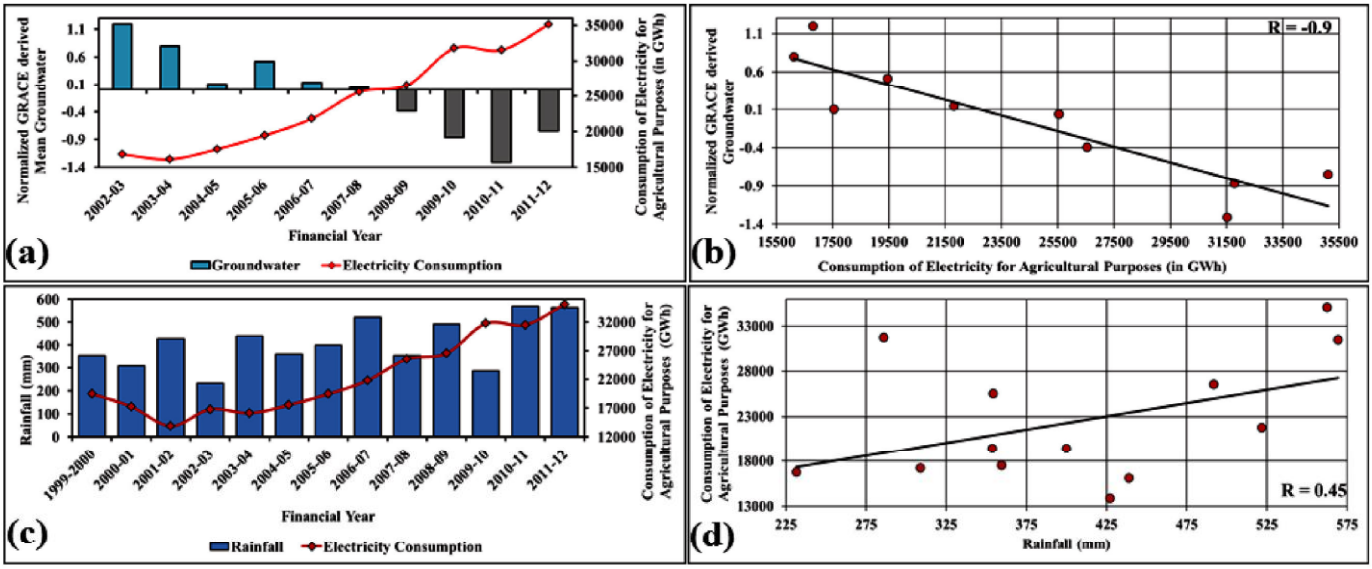

Fig.S9. North-Western India groundwater storage anomaly and energy consumption. (a) Electricity consumption for agricultural purpose and groundwater storage. **(b)** Scatter plot between electricity consumption for agricultural purpose and GRACE-derived groundwater storage anomaly. **(c)** Consumption of electricity for agricultural purposes and Rainfall. **(d)** Scatter plot between Rainfall and electricity consumption.

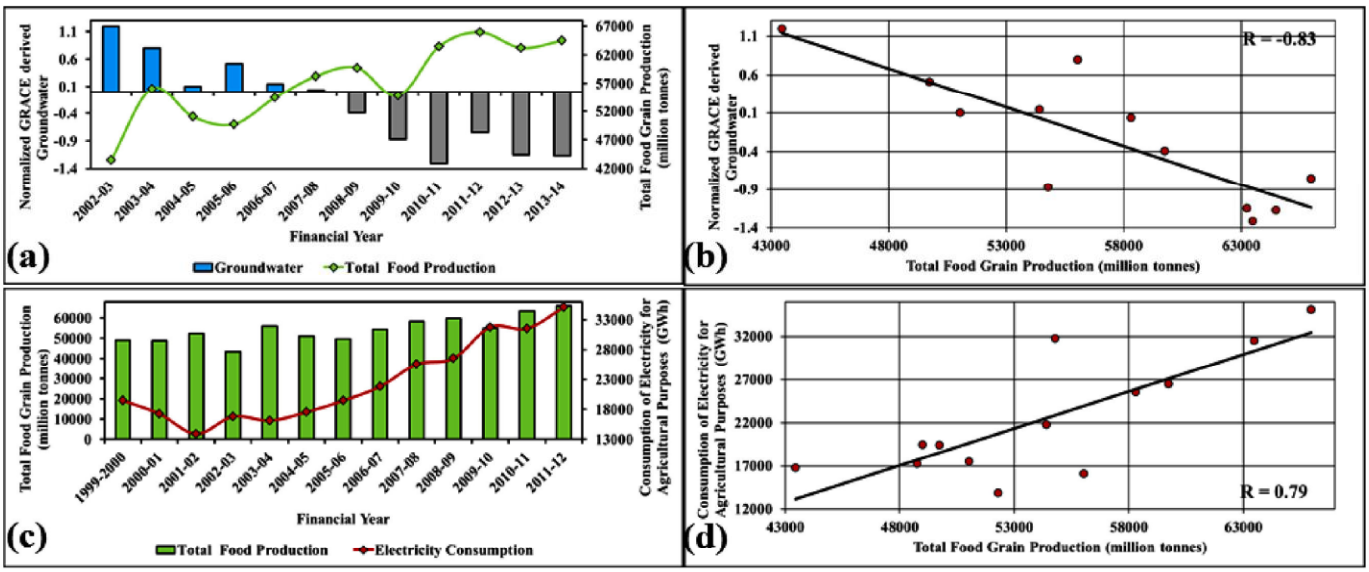

Fig.S10. North-Western India food-groundwater-energy nexus. (a) GRACE-derived groundwater storage anomaly and total food production. **(b)**Scatter plot between GRACE-derived groundwater storage anomaly and total food grain production. **(c)** Food grain production and electricity consumption for agricultural purposes. **(d)** Scatter plot between total food grain production and consumption of electricity for agricultural purposes.

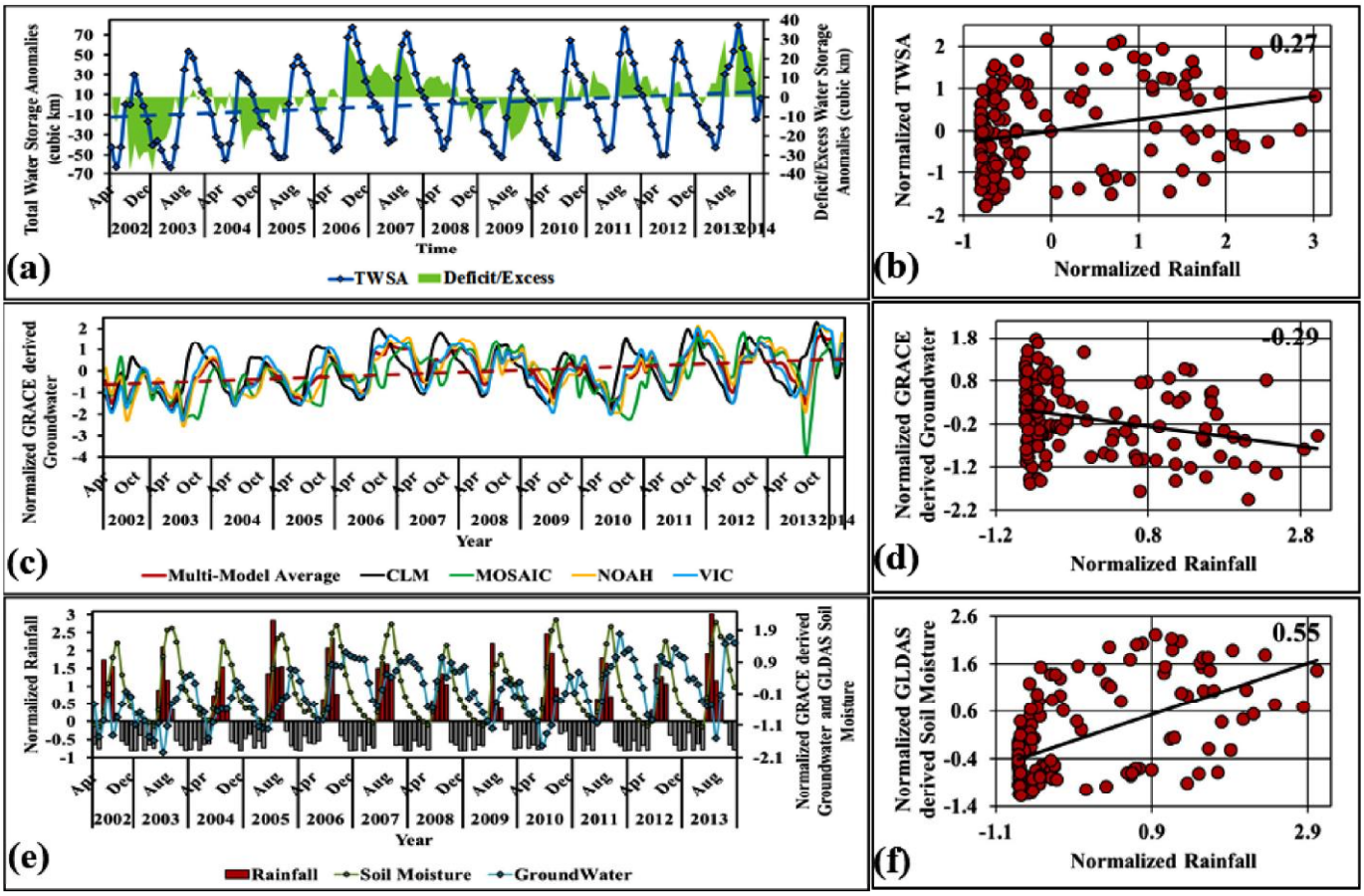

Fig.S11. Groundwater scenario of West-Central India. (a) GRACE-derived total water storage anomaly. **(b)** Correlation between Rainfall and TWSA. **(c)** GRACE-GLDAS-derived groundwater storage anomaly. **(d)** Correlation between Rainfall and GRACE-derived groundwater storage anomaly. **(e)** Rainfall, GRACE-derived groundwater anomaly and GLDAS-derived soil moisture. **(f)** Correlation between Rainfall and GLDAS-derived soil moisture.

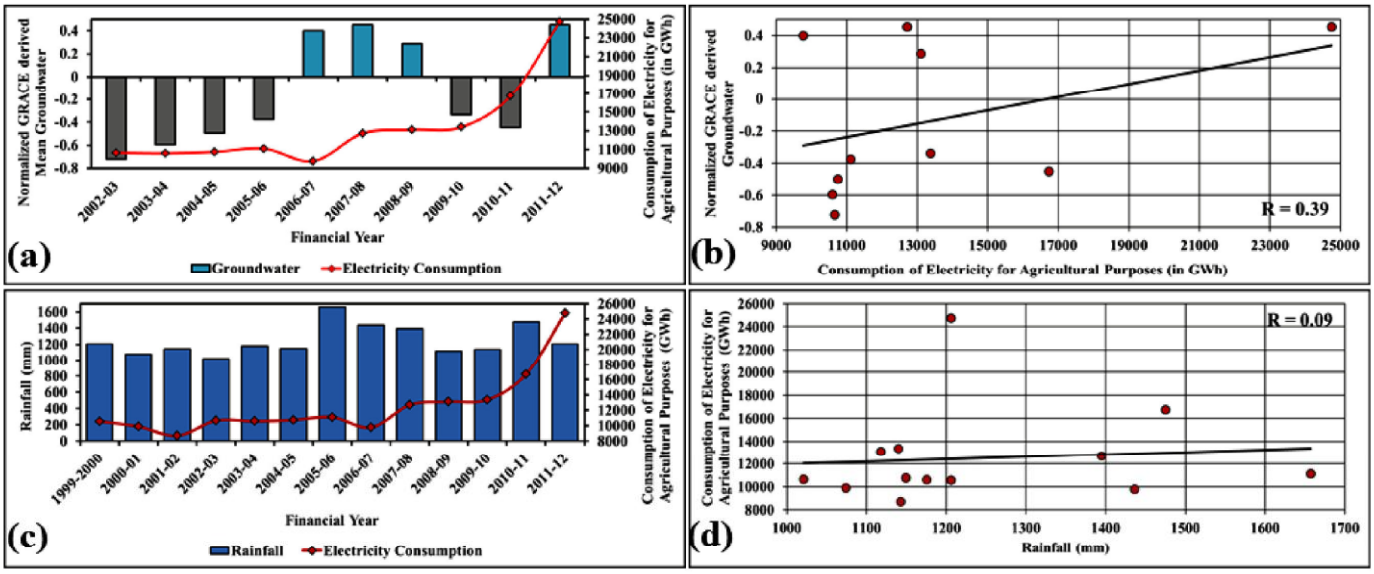

Fig.S12. West-Central India groundwater storage anomaly and energy consumption. (a) Electricity consumption for agricultural purpose and groundwater storage. **(b)** Scatter plot between electricity consumption for agricultural purpose and GRACE-derived groundwater storage anomaly. **(c)** Consumption of electricity for agricultural purposes and Rainfall. **(d)** Scatter plot between Rainfall and electricity consumption.

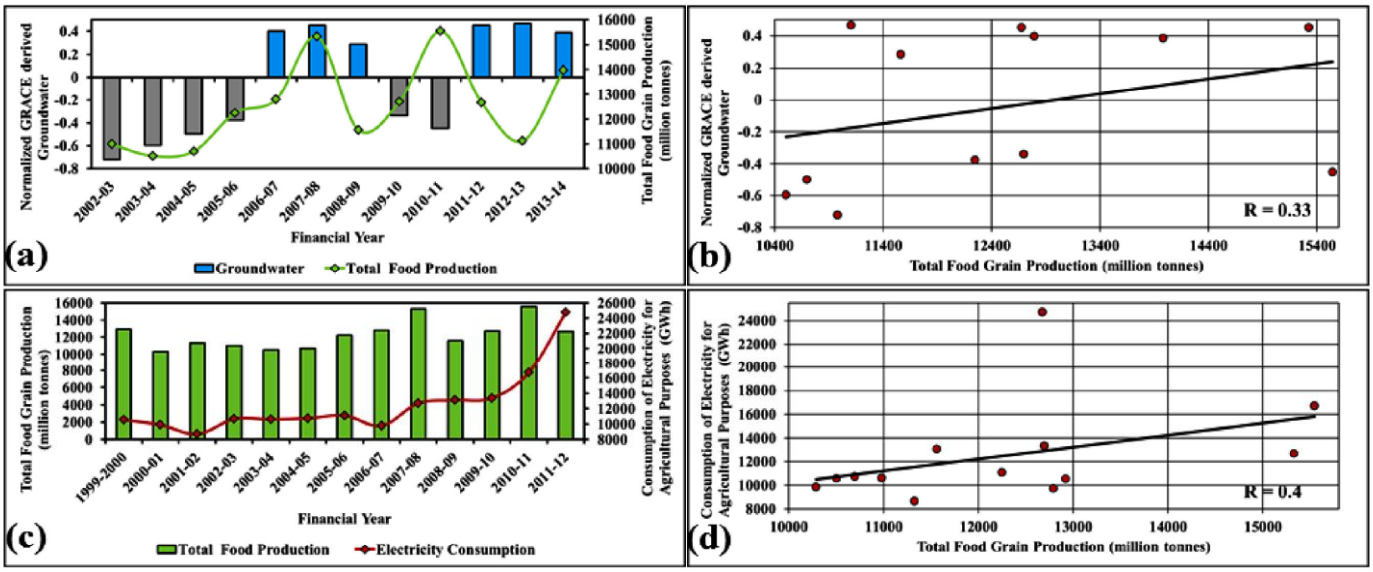

Fig.S13. West-Central India food-groundwater-energy nexus. (a) GRACE-derived groundwater storage anomaly and total food production. **(b)**Scatter plot between GRACE-derived groundwater storage anomaly and total food grain production. **(c)** Food grain production and electricity consumption for agricultural purposes. **(d)** Scatter plot between total food grain production and consumption of electricity for agricultural purposes.