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Continuing Groundwater Depletion Observed by GRACE Satellites over the North China Plain

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The North China Plain (NCP) is a highly irrigated region of expanding urbanisation in northeast China; around 70% of total water usage is supplied by local groundwater systems. During the past few decades, the on-going declines in water table (by up to 1m) due to unsustainable exploitation by agriculture, industry and domestic sectors prompted the government to carry out a series of water saving programs such as introducing water-efficiency irrigation techniques, water pricing and shutting down privately-own wells. However, the lack of volumetric measurements of pumping and the limitations of concurrent groundwater monitoring networks make regionally-scaled groundwater resources in the NCP not easily assessable. The launch of the Gravity Recovery and Climate Experiment (GRACE) satellites provide great potential for unprecedented accuracy in groundwater quantification. By mapping the mass redistribution on and below the surface of the Earth, the satellite measurements can be used to detect regional groundwater depletion and its corresponding magnitude. In this study, the GRACE observations were applied to examine the groundwater storage anomalies over the NCP during 2003-2011. The effectiveness of the groundwater mitigation strategies was evaluated as well. From GRACE observations, a decline in the deep subsurface water stores (deep unsaturated zone and shallow groundwater system) at a rate of -30. 7 to -16.1 mm/a (an approximate volumetric loss of 2.3 to 4.3 km3/a) between 2004 and 2006 was found; from 2007 to 2011, the depletion rate declined to a range between -7.9 and -0.4 mm/a (an approximate volumetric loss of 0.1 to 1.1 km3/a). These results are consistent with observations of in-situ groundwater data. Higher groundwater depletion rates occurred before 2006 which are intimately related to the rainfall trend: annual rainfall dropped from extremely wet year in 2004 to a dry year in 2006. After 2006, the depletion rate in groundwater storage was lowered, due to a recovery of annual rainfall levels and/or the success in the implementation of groundwater saving schemes taken by the government. A further comparison of GRACE-estimated inter-annual variations in groundwater storage during spring months (intensive irrigation season, from April to June) highlights the impacts of irrigation schemes during the periods 2004-2006 and 2006-2011. Data indicates that the changes due to irrigation do not correlate well with changes in the groundwater stores, therefore the decline in depletion rates observed for the deep subsurface water stores are more likely controlled by annual rainfall level changes rather than the effectiveness of the government irrigation-efficiency programs. The use of GRACE to quantify groundwater storage changes for a heavily irrigated district can essentially assist regional water resource management and determine the value of implementing the current water saving practices.