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The water use of Indian diets and socio-demographic factors related to dietary blue water footprint

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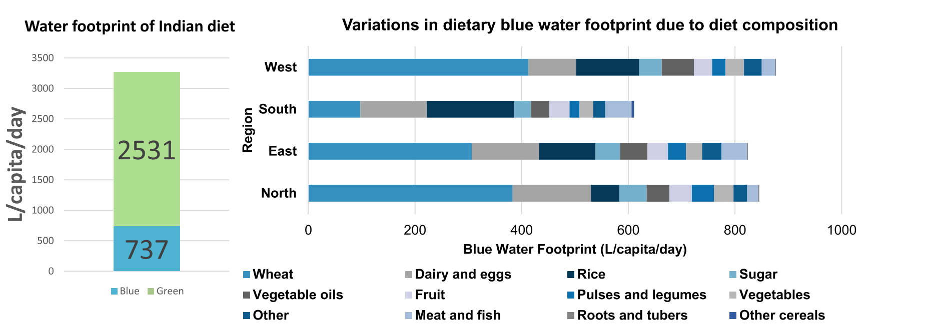
HIGHLIGHTS

- First analysis of the water used in the production of diets in India using individual-level food consumption data.
- The dietary blue (irrigation) water footprint in India is greater than estimates from high-income countries.
- Geographic region and socio-demographic factors are strongly associated with dietary blue water footprint.

GRAPHICAL ABSTRACT



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ABSTRACT

Agriculture accounts for ~90% of India's fresh water use, and there are concerns that future food production will be threatened by insufficient water supply of adequate quality. This study aimed to quantify the water required in the production of diets in India using the water footprint (WF) assessment method. The socio-demographic associations of dietary WFs were explored using mixed effects regression models with a particular focus on blue (irrigation) WF given the importance for Indian agriculture. Dietary data from ~7000 adults living in India were matched to India-specific WF data for food groups to quantify the blue and green (rainfall) WF of typical diets. The mean blue and green WF of diets was 737 l/capita/day and 2531 l/capita/day, respectively. Vegetables had the lowest WFs per unit mass of product, while roots/tubers had the lowest WFs per unit dietary energy. Poultry products had the greatest blue WFs. Wheat and rice contributed 31% and 19% of the dietary blue WF respectively. Vegetable oils were the highest contributor to dietary green WF. Regional variation in dietary choices meant large differences in dietary blue WFs, whereby northern diets had nearly 1.5 times greater blue WFs than southern diets. Urban diets had a higher blue WF than rural diets, and a higher standard of living was associated with larger dietary blue WFs. This study provides a novel perspective on the WF of diets in India using individual-level dietary data, and demonstrates important variability in WFs due to different food consumption patterns and socio-demographic characteristics. Future dietary shifts towards patterns currently consumed by individuals in

Abbreviations: WF, water footprint; IMS, Indian Migration Study; FFQ, food frequency questionnaire; SLI, standard of living index; NSSO, National Sample Survey Organisation; WHO, World Health Organization; CI, confidence interval; SD, standard deviation.

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higher income groups, would likely increase irrigation requirements putting substantial pressure on India's water resources.

1. Introduction

Growing populations and changing food consumption patterns are placing increased pressure on natural and agricultural systems. To ensure sustainable and healthy food systems, a combination of consumption- and production-side changes will be required (FAO, 2010; Smith et al., 2008). Many studies assessing environmental impacts of diets have focused on greenhouse gas emissions, largely in high income settings (Berners-Lee et al., 2012; Jones et al., 2016; Macdiarmid et al., 2012; Pathak et al., 2010). However, much less evidence is available on the water use associated with the production of diets which remains a major sustainability issue as agriculture accounts for ~70% of global water withdrawals (FAO, 2016). Dietary water use can be quantified using the water footprint (WF) concept (Cazcarro et al., 2012; Renault and Wallender, 2000; Vanham, 2013; Vanham et al., 2013). The WF Network has estimated the WF of crops and crop-derived products through a globally-gridded, multi-layer dataset (Mekonnen and Hoekstra, 2011), and used this to calculate the WFs of national food supplies (Hoekstra and Mekonnen, 2012). The WF is divided into three parts: green, blue and grey. For crops, the green WF represents the volume of precipitation expended during production, calculated from total rainwater evapotranspiration plus the water incorporated into the harvested crop. The blue WF represents the volume of ground and surface water delivered to crops through irrigation (Hess et al., 2015). The grey WF represents the volume of freshwater that would be required to dilute agricultural pollution to meet water quality standards (Aldaya et al., 2012). For livestock, WFs are derived from feed crop WFs and drinking and service water.

Analysing the water use associated with diets is particularly important for India, where ~90% of water withdrawal (ground and surface water use) is used for irrigated agriculture, making India the largest user of groundwater in the world (FAO, 2016). However groundwater resources are depleting in many areas (Rodell et al., 2009), particularly in the Indo-Gangetic Basin where the rice-wheat double cropping system is widely practiced (Hoekstra et al., 2012; Tiwari et al., 2009). Additionally, future environmental change could have implications for Indian agriculture. Predicted increases in temperature (Dash et al., 2007; Salvi and Ghosh, 2013) could reduce crop yields and water-use efficiency of rice and wheat (Jalota et al., 2013), although evidence remains conflicting (Deryng et al., 2016). Changes to melt water may reduce flow to key river basins for India's groundwater (Immerzeel et al., 2010), so water scarcity could worsen (Gerten et al., 2011). Furthermore, uncertainty in future rainfall patterns (Salvi and Ghosh, 2013) means ground and surface water resources may become an even more important irrigation reserve.

Quantifying the WF of diets and assessing socio-demographic drivers provides a valuable consumption-side perspective on water resource use and can inform strategies to improve the sustainability of the food system. For example, the approach may help to forecast the potential implications of dietary change on water resource use. The aims of this study were two-fold: first, to quantify the green and blue WFs of typical Indian diets by matching dietary data from a large cross-sectional study of Indian adults to green and blue WFs of food items. Grey WFs are not considered in this study. Due to the importance of the local climate and environment on crop water use, spatial variations in WFs were explored for the two major cereals, rice and wheat. Secondly, to explore the socio-demographic factors associated with dietary blue WF. Blue WFs, although typically much smaller than green WFs, are a particular concern given India's agricultural production is highly dependent on irrigation and availability of groundwater is a significant current issue.

2. Methods

2.1. Socio-demographic characteristics and dietary data

Dietary and population data were derived from the Indian Migration Study (IMS) as it provides in-depth data for >7000 Indian adults. The IMS was conducted during 2005–2007 as part of a pre-existing screening study of cardiovascular disease risk factors among Indian adults. The study used a cross-sectional sib-pair design to study factory workers who had migrated to one of the four following Indian cities – Bangalore, Hyderabad, Lucknow and Nagpur, and their rural-dwelling siblings and co-resident spouses. A 25% sample of urban non-migrants was also recruited. A total of 7067 individuals were included in the final sample with 90% of rural participants and 98% of urban participants living in four states (Karnataka, Andhra Pradesh, Maharashtra and Uttar Pradesh). Full details of the sampling methodology and study design have been reported elsewhere (Ebrahim et al., 2010; Lyngdoh et al., 2006).

Dietary intake was measured through an interviewer-administered semi-quantitative food frequency questionnaire (FFQ), assessing consumption of 199 common food items. For the current analysis, the 199 items were aggregated into 36 food groups based on similarity in nutritional content (Appendix Table A.1; Joy et al., accepted for publication). Reliability of the FFQ was assessed by selecting a subsample to repeat the questionnaire 1–2 months ($n = 185$), and 12 months ($n = 305$) after completion during the original period of data collection. A further 530 participants carried out three 24 h recalls as a reference method used to validate the FFQ. Most food items yielded acceptable validity (Ebrahim et al., 2010). However, to reduce the sensitivity of WF estimates to dietary intake reporting error, participants with extreme values for dietary energy intakes (mean $\pm$ 2 $*$ SD) were excluded ($n = 292$).

Information on socio-demographic characteristics was obtained through an interviewer-administered questionnaire. A Standard of Living Index (SLI) was calculated using an asset-based survey on 14 items, including quality of house, toilet facilities, land ownership, and source of lighting.

2.2. Water footprints of food items

The WF Network has quantified the WF of crops using a grid-based dynamic water balance model that considers local climate, soil factors, and rates of nitrogen fertiliser use (Mekonnen and Hoekstra, 2011). At the time of study, the majority of food consumed in India was produced domestically with little contribution from imports (FAOSTAT, 2016), so India-specific WF data were used. Due to the large size and varied environment of India, WFs of typical food items are reported at state-level, with green and blue WFs (l/g of food) available for the years 1996–2005 (www.waterfootprint.org; Mekonnen and Hoekstra, 2011). For animal products, WFs are reported by production system (i.e. industrial, grazing or mixed) at a national level, based on the volume and composition of feed, drinking and service water use, and conversion to edible product (Mekonnen and Hoekstra, 2012).

For the present study, state-level WFs of animal products were quantified based on methods from Mekonnen and Hoekstra (2012). Briefly, seven farm categories were considered: beef cattle, dairy cattle,