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Water accounting of Kurukshetra district and assessing effects of sustainable interventions on water saving

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ABSTRACT

Appraisal of water resources at tempo-spatial scales enables proper planning for water resource utilization and efficient management for sustainable development. Water availability in the Kurukshetra district is declining due to the indiscriminate withdrawal of the groundwater aquifers. Therefore, this investigation aimed to carry out a water accounting exercise in Kurukshetra district, Haryana, to estimate water resources availability and present water use in the irrigation sector. Water accounting methodology is based on the water balance concept estimation of various water balance components *viz.,* surface water, groundwater, and water use by various sectors were done for the year 2015 employing standard methods. Results revealed that district's net available water was 646 million cubic meters (MCM). Also, total crop water demand and other sector's demand are estimated to be (domestic, hydropower, industrial and power generation) 1399.8 MCM and 48.6 MCM, respectively. The gross water demand in the year 2015 was 1448.2 MCM. This depicts that the demand is not full filled by the available water and there was a gap of 802.2 MCM between the water demand and water available. This demand gap was met by the withdrawal of groundwater. To improve water availability, the adoption of water management interventions was exercised. It was found that delayed rice transplanting from 21st May to 15th June saves crop water demand by 10.89%. Similarly, transplanting rice on 15th June reduces crop water demand by 9.03, 6.23, 4.31 and 2.46% compared to transplanting on 26th May, 31st May, 5th June, and 10th June, respectively. Additionally, a 1.92% reduction in rice crop demand may be achieved by transplanting on 20th June instead of 15th June. Replacement of rice by maize crop reduces crop demand by 54.66% ha^{-1}. Other water conservation techniques *viz.,* laser land levelling (LLL) and zero-till sowing offers great advantage and could be of great importance to improve the water availability in the district. Results of the present investigation may aid in the development of water management strategies at the district level to improve water sustainability.

1. INTRODUCTION

Irrigation sector's water use is anticipated to drop by 8-10% as rivalry from the urban and industrial sectors intensifies (Toung and Bhuiyan, 1994). The spread of irrigated agriculture into semiarid regions with low rainfall and surface water has significantly boosted irrigated crops' dependency on groundwater removal (Siebert *et al.,* 2010; Wada *et al.*, 2012a), a process dubbed the 'silent revolution of excessive groundwater usage (Lamas and Martínez-Santos, 2005). When groundwater extraction outweighs recharge over an extended period and across a large area, the resulting fall in the groundwater level disrupts groundwater discharge naturally, which may have a detrimental effect on groundwater dependent waterways, wetlands, and environments (Wada *et al.,* 2012a). Additionally, decreased groundwater levels can result in lowered well yields and increased pumping expenses and land subsidence on big scale (Konikow and Kendy, 2005).

Indian agriculture sector consumes approximately 83% of total freshwater resources available in the country

(Sonekar, 2017). However, due to the expansion of urban areas and population increase, other sectors' demand has been increased, limiting the available water for agricultural use. Also, Indian states have been suffering from water scarcity in varying degrees, resulting in crop failures frequently. Indiscriminate withdrawal of groundwater has several consequences on humans and the environment. This withdrawal of aquifers jeopardises rice crops sustainability, prompting cultivators and scientists to look for solutions to decrease rice cultivation's freshwater use (Ambast *et al.,* 2006; Hira, 2009). Conservation and management of water resources require integrated planning approaches for better utilization. In Haryana, the necessity for assured irrigation water supply has risen year after year, and groundwater pumping dependency for irrigation has also increased. However, due to continuous groundwater extraction via tube wells, the groundwater aquifers have been drained. The state owns 8 lakh 44 thousand tube wells that draw water from aquifers. In Haryana, the groundwater abstraction rate was approximately 35 cm yr^{-1} (Chatterjee and Purohit, 2009). With such scarce water resources, it is critical to maximising the use of existing water to support agriculture progress and other sectors' development.

As per the Central Ground Water Board (CGWB) report, the stage of groundwater development in all the blocks of the Kurukshetra district has exceeded the available recharge, thus all the blocks have been categorized as over-exploited. The stage of groundwater development ranges from -187% (block-Pehowa) to 331% (block-Ladwa) with district stage of ground water development reaching to 217%. Also, net annual replenishable groundwater availability in the district has been estimated to be 343.23 MCM whereas the total groundwater draft for all uses is about 746. 41 MCM, thus leaving shot-fall (over draft) of 403.18 MCM. In addition, a long-term net change of water levels during the period 2000-2011 indicated a general decline (negative change) trend in the entire district which ranged between 1.14 to 1.71 m yr^{-1} (CGWB, 2013). These water availability and water use scenario expresses concern to achieve sustainability of water resources for future generations. Under such a situation, the use of water management measures are pertinent to conserving depleting water availability in the district.

Adoption of effective water management techniques yields in water-saving increased production and improvement of overall water use in a given area as per suitability of interventions (Anantha *et al.,* 2021). Some of the water management interventions are modifying the rice transplanting schedule to match the onset of monsoon season, laser land leveling, and zero-till drill-direct seeded rice technique in the rice-wheat dominating cropping pattern. Rice is often irrigated continuously during crop season in various regions of the Indo-Gangetic Plains (IGP) using groundwater (Surendran *et al.,* 2021; Sarkar *et al.,* 2009). Owing to labour shortage, delays in transplanting beyond the optimal time result in a decline in crop yields. In Punjab, a yield reduction of 7-16% was found when transplanting extended from 15^{th} June to 5^{th} July (Mahajan *et al.,* 2009). The potential agronomic benefits of laser land leveling includes uniform distribution of irrigation water, fertilizer and other chemicals, increased irrigatable coverage due to increased application and distribution efficiency, soil and water conservation, and improved uniformity of crop growth and yield, have been recognized for more than half a century (Whitney *et al.,* 1950; Brye *et al.,* 2005). This technology is widely regarded as producing more outstanding standards of uniformity in land levelling and has tremendous opportunities for water conservation and increased crop yields (Jat *et al.,* 2006). Laser land levelling (LLL) has led to water savings up to 15-30% for different crops under different cropping patterns (conserveagri.org, 2009). Effective land levelling is supposed to enhance water use efficiency, improve crop establishment, reduce irrigation time needed to complete the harvest. Research undertaken at PAU, Ludhiana has shown that proper field levelling boosted crop output by 24% and decreased weed problems up to 40% (Rickman, 2002). Laser levelling farmers may save irrigation water and energy by 24% and gained 4.25% higher yields. The irrigation cost lowered by 44% over the typical technique, and water productivity enhanced by 39% (Kaur *et al.,* 2012). Zero tillage technology is reported to conserve irrigation water in 20-35% for the wheat crop (Karnal district; Nagarjan *et al.,* 2002). The water-logging and yellowing of the wheat crops after the first watering is consequently decreased (RWC-CIMMYT, 2003:95). Zero tillage reduces one irrigation (Laxmi *et al.,* 2003; Malik *et al.,* 2002b; Mehla *et al.*, 2000). This reduces cost of irrigation and can offer environmental benefits where water is lifted using diesel operated pumps systems.

Taking motivation from the previous studies and to critically understand the water resources use, the present investigation aimed at carrying out water accounting of the Kurukshetra district and to determine the potential of the well-known water management interventions on the water availability within the district. The results of the present study would aid to develop efficient policies for water use in the district by adoption of sustainable water saving techniques.

2. MATERIALS AND METHODS

Study Area

Kurukshetra district is located in Haryana state and having coordinates as latitudes of 29°53'00"N to 30°15'02"N and longitudes of 76°26'27"E to 77°07'57"E with average elevation of 241 m to 274 m above sea level. The area is drained primarily by the Markanda river. The region is irrigated with both surface and groundwater. The district's climate is distinctive, with scorching summers and bitterly

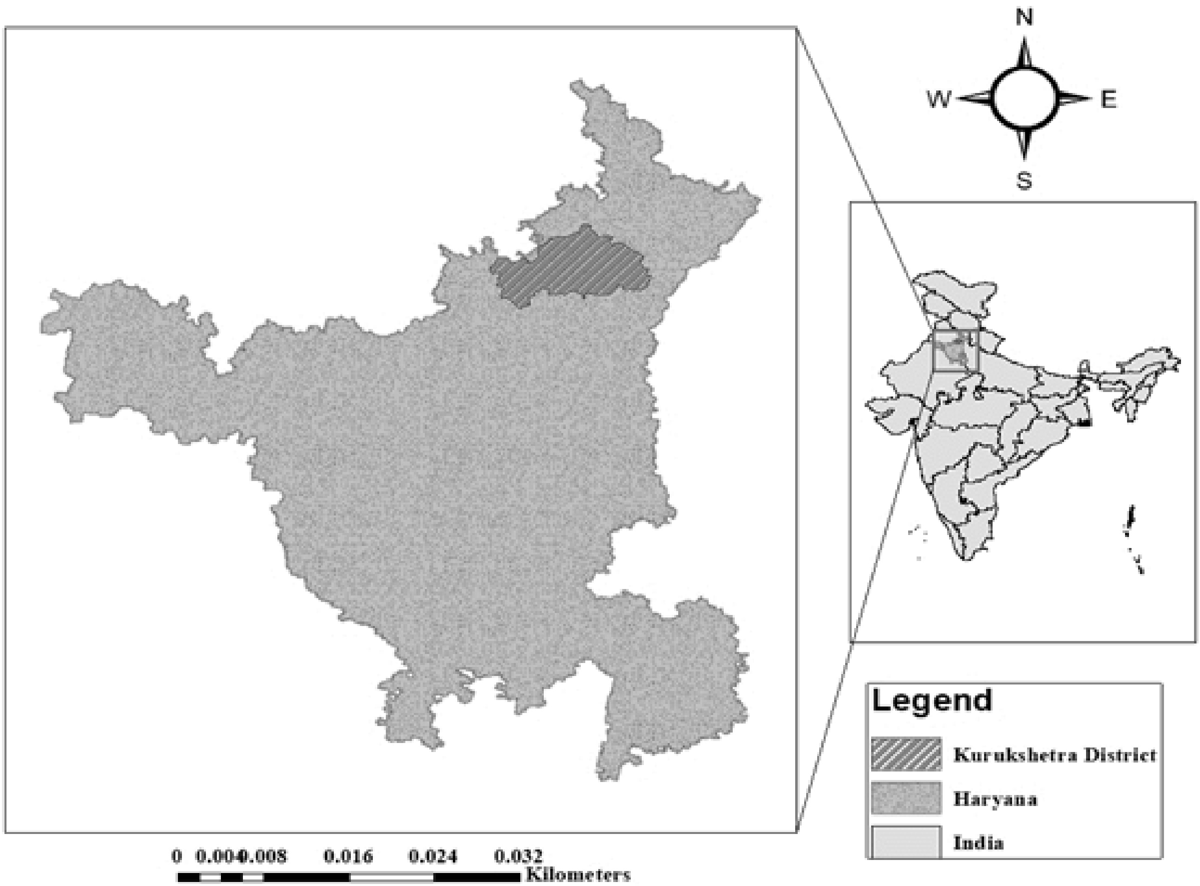

Fig. 1. Location map of Kurukshetra district, Haryana

frigid winters. It reaches temperatures upto 45°C in the summer and as low as 10°C in the winter. The south-west monsoon season runs from July to around mid-September, followed by a one-month transition phase. Fig. 1 depicts a map of the study area district.

Data Collection

This item includes basic information of the district, demographic, meteorological data, crop data (crop type, cropping pattern, crop area, crop calendar, and crop coefficient), land use, the status of irrigation resources, water resource availability data (surface water as well as groundwater), water demand data (crop, livestock, industrial, power generation etc.) and any other if needed. Long-term average values of climatological parameters (1981-2020) are given in Table 1 (GAMO, 2015).

Table: 1
Average values of climatological parameters (1981-2020)

Month	T_{max} (^{0}C)	T_{min} (^{0}C)	Relative humidity (%)	Wind speed (ms)
Jan	25.83	3.48	44.25	1.85
Feb	29.98	5.43	42.22	2.03
Mar	36.76	9.67	35.4	2.19
Apr	42.72	15.04	25.89	2.33
May	46.31	21.57	22.71	2.45
Jun	46.28	25.07	33.98	2.37
Jul	42.48	25.26	60.07	1.96
Aug	37.5	23.66	72.48	1.58
Sep	36.31	19.22	67	1.44
Oct	35.04	13.91	47.86	1.43
Nov	31.1	8.86	39.83	1.6
Dec	27.15	4.73	40.14	1.77

Water Accounting

Water accounting is the procedure of disseminating information about water resources and the services created by their consumption to users such as policymakers, water authorities, and managers within a geographical area, such as a river basin, a country, or a land-use class. More precisely, it is defined as a comprehensive examination of the current state and trends in a given domain's water supply, demand, accessibility, and use (FAO, 2012).

Estimation of Water Accounting Components

The unit of investigation in this study is the Kurukshetra district administrative area. The gross volume of inflow to the system includes rainfall volume, the surface flow coming from outside the study area and sub-surface flow (groundwater) entering into the study region. Information about inflows and outflows of surface and groundwater components into the domain are difficult to quantify. Therefore, these components are not considered at this stage of the investigation. The changes in the storage components of water balance are considered zero on an annual basis. Surface water available in the district includes the water available in the surface water reservoirs (dams, ponds etc.). Data on groundwater availability in this district was taken from CGWB, 2013 reports which estimate annual ground-water recharge using the water table fluctuation method and were extrapolated for the year 2015 based on previous years data.

The gross inflow to the system includes the total precipitation volume and total transfer inflow (surface water and groundwater flow into the domain). The full areal average rainfall depth was calculated using the Thiessen polygon method and was multiplied with the total district area to obtain the total rainfall volume for the district. For this, the gridded rainfall data procured from IMD was used. As the surface water inflow and groundwater inflow components are difficult to calculate at a preliminary stage for the district boundary case and these values at a district level are not available, their values have not been included in this analysis. The net inflow component of water accounting consists of the gross inflow to the district and any changes in storage. Any change in storage (both surface and subsurface) was assumed to be zero at the annual scale as considered in many past studies (Debolskiy *et al.,* 2021). Hence, net inflow is supposed to be equal to the gross inflow in this analysis. Excluding the amount of water allotted for some committed use, the rest water volume is available for use.

The available water constitutes blue water and green water available (here, green water storage). Bluewater available in the surface water and groundwater available in the district. Total available surface water is taken as the water available from canals for the district or any other surface water reservoirs, while the available groundwater resource of the district is the groundwater recharged from rainfall for the district. The annual groundwater recharge or the 'dynamic groundwater component' is generally calculated using the method outlined in GWREC, 1997, which is also followed by CGWB. These available surface and ground-water resource values were taken from the district irrigation plan (DIP) report of Kurukshetra district. Green water storage is taken as the 'effective rainfall' (water amount indicating a part of rainfall getting stored in the root zone for crop use). The 'effective rainfall' was calculated using the 'USDA-SCS' (USDA, 1970) method as this method takes multiple factors like runoff, soil storage factor, evapo-transpiration (ET), and rainfall into account unlike other empirical methods, which consider only rainfall for calculating effective rainfall. This method uses an empirical eq. 1 developed by scientists of Soil Conservation Service, USDA by analyzing 50 years of rainfall record at 22 locations throughout the United States.

$$P_e = 25.4 \times SF \times \left(0.70917 \times \left(\frac{P_{inf}}{25.4}\right)^{0.82416} - 0.11556\right) \times \left(10^{0.02426\times\left(\frac{ET_c}{25.4}\right)}\right) \quad ...(1)$$

Where P_e = monthly effective precipitation in mm; P_{inf} = monthly mean precipitation after runoff, mm; ET_c = monthly crop evapotranspiration, mm; SF = soil storage factor.

Here, the runoff was calculated using the SCS-CN method (SCS, 1985). As P_e is meant for the crop area, the runoff was calculated for the agricultural area here. The soil storage factor in eq. 2 was calculated as follows:

$$SF = (0.531747 + 0.295164 \times D - 0.057697 \times D^2 + 0.003804 \times D^3) \quad ...(2)$$

Where, D = the usable soil water storage, in; D is taken as the difference between field capacity and wilting point of soil.

The net inflow gets either depleted or flows out of the system (Molden, 1997). The depleted water is taken as the water used in different sectors (*i.e.* domestic, industrial, livestock and agricultural sectors). The agricultural water use is the amount of ET. The ET was calculated using the Hargreaves-Samani method (Hargreaves and Samani, 1985) as other weather parameters like relative humidity are not available for the area (eq. 3).

$$ET_0 = 0.408 \times 0.0023 \times R_a \times \sqrt{(T_{max} - T_{min})}\,(T + 17.8) \quad ...(3)$$

Where, ET_0 = daily reference evapotranspiration in mm day^{-1}; R_a = daily extraterrestrial radiation in MJ m^{-2} day^{-1}, calculated as a function of latitude; T = mean air temperature in ^{0}C estimated as the average of minimum (T_{min}) and maximum (T_{max}) daily air temperatures.

The ET_0 values obtained was multiplied with the corresponding crop coefficient values obtained from FAO 56 (Allen *et al.,* 1998) to get the crop ET values. Fig. 2. Shows the water accounting methodology flowchart followed in the present investigation. Table 2 shows the principal crops grown in the district.

Monthly ET_0 data revealed that highest ET_0 rate occurred in May (8.20 mm day^{-1}) while lowest in Jan (1.78 mm day^{-1}). These results indicates that there is a large variability in the ET_0 rate. Also, the highest value of effective rainfall for crop was obtained in July with value of 50.73 mm against rainfall amount of 149 mm followed by August month with effective rainfall amount of 47.39 mm. Usually, it was observed that there was less significant amount of

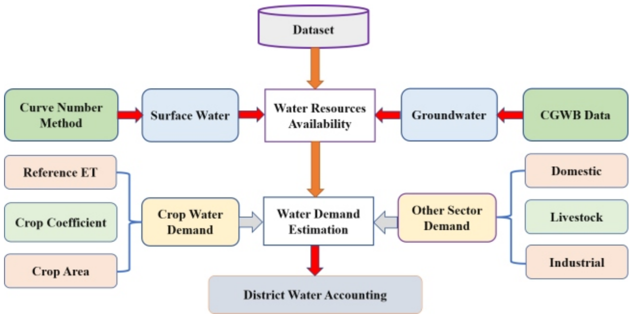

Fig. 2. Water accounting methodology flowchart

Table: 2
Principal crops are in the year 2015-16

District	Area (ha)			
	Wheat	Rice	Sugarcane	Sunflower
Kurukshetra	81300	121700	17000	8650

Source: District Irrigation Plan, Pradhan Mantri Krishi Sinchai Yojana

effective rainfall received during the winter months except March which had recorded effective rainfall amount of 9.46 mm. This result analysis helps in the understanding the onset of the monsoon and may assist in the selection of optimum sowing/planting dates for better crop production. Table 3 shows the monthly average values of ET_0 rainfall and effective rainfall.

Table: 3
Monthly values of climatological parameters in year 2015

Month	ET_0, mm	Rainfall, mm	Effective rainfall, mm
Jan	1.78	0	0
Feb	2.75	4.4	0.94
Mar	3.77	22.3	9.46
Apr	5.74	0	0
May	8.2	61.3	23.5
Jun	6.15	34.3	13.85
Jul	5.08	149	50.73
Aug	4.71	112.3	47.39
Sep	4.2	2	0
Oct	3.75	0.6	0
Nov	2.82	0	0
Dec	2.1	0	0

Water Saving Interventions

Improving water use is an important subject in agriculture in semi-arid regions, because of the increasing areas under irrigation and the high-water requirements of crops. The scarcity of water resources is leading to increasing controversy about the use of water resources by agriculture and industry, for direct human consumption, and for other purposes. Such controversy could be alleviated by increasing the crop water-use efficiency, so that improving water-use efficiency of crops is becoming a main agriculture and food security goal. The water issue is crucial for environmental sustainability of agriculture, because 60% of agriculture is located in semiarid areas and regular water applications are necessary to complete the growth cycle of crops. Crops in semi-arid regions grow and mature during the driest months, making irrigation scheduling and timing critical. Water saving interventions are discussed here to promote water saving in the Kurukshetra district of Haryana state.

A. Delayed transplanting of rice to avoid high ET summer months and synchronize crop growth with the onset of monsoons

Rice is the principal crop in the district cultivated in *kharif* season and consumes ample quantity of fresh water resources which has caused decline of groundwater tables. It is most water-intensive crops in the country, according to a water productivity report by National Bank for Agriculture and Rural Development released in 2018. The irrigation requirement of Rice as a unit and in total is the most compared to other crops grown in the country. Irrigation water productivity that is production of rice per unit of irrigation applied in Haryana is the lowest in the country, which is the primary reason for the state's groundwater depletion, according to the report. Altering the transplanting duration of rice crop to synchronize with the onset of monsoon season can be a water management strategy to reduce ET_c losses by avoiding transplanting during summer months.

Government of Haryana has enacted Haryana Prevention of Subsoil Water Act, 2009 an Act to provide for the prohibition of sowing of nursery of rice and transplanting of rice before the dates notified thereof and for the matters connected there with or incidental there to. According to this act, no farmer shall sow nursery of rice before the 15th may of the year and no farmer shall transplant rice before 15th June of the year or such date, as may be notified by the Government of Haryana state. However, this is practically not happening at field level and thus it is essential to evaluate the rice crop demand under different transplanting dates.

Under present study, 07 (seven) transplanting dates scenarios were considered to evaluate the impacts of changing transplanting dates on the crop water requirements of rice crop. These transplanting dates scenarios included 21st May, 26th May, 31st May, 5th June, 10th June, 15th June and 20th June. As 15th June is the recommendation of Haryana State Government, other dates of transplanting of rice crop are chosen to estimate the variation of crop water requirement of rice due to variation of ET. Also, the date notified by the government is such that that there would be no yield penalty. Therefore, in our study, we had restricted to the notified dates to maintain crop yield.

B. Promotion of alternate crops to rice and wheat cropping for saving water and other resources through "*Mera Pani Meri Virasat*" (My Water - My Inheritance) scheme of the State Government

The rice-wheat cropping system has led to an alarming situation and some parts of Haryana have been declared as dark zones; under such circumstances, it becomes essential to go in for alternative cropping systems, which may help in saving of water along with sustaining the income of the farmer. To save water for our future generations, Department of Agricultural and Farmers Welfare, Haryana launched a new pilot scheme. The scheme is for replacement of rice by maize and other crops in 7 dark zone brocks with a target to diversify around 50,000 ha area from this season. Due to continuous rice growing in the state about 1 m. water table is depleting per year. Crop diversification through the above scheme is intended to promote technological innovation with sustainable agriculture and enable farmers to choose crop alternatives for increasing productivity and income. Maize was a major crop in the present rice belt of Haryana state. Moreover, maize used to be food crop but at present ninety percent of its production is used in feed and starch industry in the country and thus it has turned into an industrial crop in India.

Haryana Government considered implementation of pilot project for change in cropping pattern by a voluntary scheme and support through provision for quality seed, MSP support and other incentives in an area of 50,000 ha spread in eight blocks in as many districts. Also, state government of Haryana is giving incentives to the farmers to the tune of ₹ 7000 acre^{-1} for switching from rice cultivation to other less water requirement crops.

Therefore, under this water saving strategy, rice was replaced by maize crop in different scenarios to understand the impacts of crop diversification on water saving potential. Four scenarios considered were 10%, 20%, 30% and 40% which means instead of cultivating rice crop maize might be taken in the aforesaid proportions. The basis of choosing these proportions is based on the fact that non-basmati varieties of rice are being cultivated in significant percentage of total area under rice cultivation in the district. This non-basmati rice grown area may be replaced by the maize crop to achieve water availability sustainability.

C. Adoption of laser land levelling (LLL) in rice-wheat cropping system to promote water saving

Laser levelling technology offers great potential for water saving, increasing water productivity, better environmental quality, and higher grain yields (Hung *et al.,* 2022; Kaghazchi *et al.,* 2020; Ahmed *et al.,* 2001). Studies reported from India and Pakistan showed that irrigation water savings in rice and wheat ranged from 10 cm to 25 cm in rice and 3.5 to 14 cm in wheat. The percent increase in irrigation water savings ranged from 14.7% to 25.1% in rice and 13.3% to 30.7% in wheat. This data shows that while the absolute amount of irrigation water saved under precision land levelling (PLL) is higher in rice than in wheat, the percent savings in water is nearly similar under the two crops. Similarly, irrigation water-saving in sugarcane under PLL is 42 cm or 20.5% compared with TLL (Jat *et al*., 2009a and 2009b). Average water saving in maize, wheat, cotton, rice is 27%, 26%, 27% and 26%, respectively (Aggarwal, 2010). The significant advantages are the saving of 22-33% of water in irrigation and a 9-12% increase in crop productivity (Kumar, 2017). Based on the previous studies conducted in the Indo-Gangetic states *viz.,* Punjab and Haryana state, this research investigation has assessed the water saving potentionanl of PLL technques. Therefore, water saving scenarios considered under laster land levelling technques were 19.9% in rice and 22% in wheat crop as average values based on the previous studies.

D. Adoption of zero till drill wheat and direct seeded rice over conventional methods

Zero-tillage planting of wheat after rice has been the most successful resource-conserving technology to date in the IGP, particularly in north-west India (Bhatt *et al*., 2021). In the conventional puddled transplanting system (PTR), large quantity of irrigation water is used for puddling which breaks capillary pores, destroys soil aggregates and results in formation of hard pan, creating problems for the establishment and growth of succeeding crops (Bhatt *et al.,* 2021). Since the water resources (both surface and underground) are shrinking day by day and the profit margins are decreasing in PTR mainly because of high labour cost and water requirement (Kumar *et al*., 2021). so, switching over from PTR to DSR cultivation took place. PTR has higher labour demand as compared to DSR as labour is required for uprooting seedlings from the nursery, field puddling and transplanting of the seedlings. Adoption of modern sowing / transplanting machines such as direct seeded rice and zero till drill for rice and wheat crop are promising to save precious irrigation water along with saving of other energy inputs (Mandal *et al*., 2014). Crop water demand under puddle transplanted rice-conventional till wheat (PTR-CTW) system is more compared to zero till direct seeded rice- zero till wheat (ZTDSR-ZTW) under rice-wheat cropping system. Therefore, water saving criteria considered for ZTDSR-ZTW over conventional methods were 5.5% and 30% for wheat and rice crop, respectively as per the previous studies.

3. RESULTS AND DISCUSSION

Water accounting of Kurukshetra district illustrated by water accounting diagram in figure 5. Net available water in the district was 646.0 MCM in the year 2015. Net available water consists of three components *viz.,* surface water (AWS), groundwater (AWgw) and green water (Pe). Rice (CDP), wheat (CDw), sunflower (CDs) and sugarcane (CDs) are the principal crops in the district. Other sector demands (Dos) consist of domestic need, livestock, industrial and hydropower generation were estimated for the year 2015 and found as 48.6 MCM. So, total demand in the district consists of crop demand and other sectors demand which found as 1448.4 MCM. The gap between the water demand in the district for various uses and the renewable water available in the district is 802.2 MCM. This unmet demand is fulfilled by the excessive withdrawal of groundwater which has caused the lowering of the water table in the district. Fig. 3(a) and (b) shows water resource availability and crop water demand of principal crops, respectively.

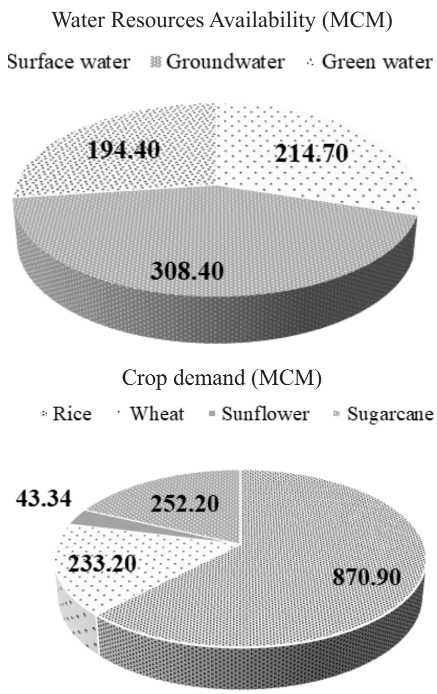

Fig. 3. (a) Water resource availability (b) Crop demand of main crops

From water accounting block diagram of Kurukshetra shown in Fig. 4, it is can be inferred that a considerable part of water demand is not fulfilled annual replenishable green and blue water resources available in the district. Total geographical area (TGA) of the district is 2,83,701 hectares. Kurukshetra received rainfall of 386.20 mm in year 2015. Water demand of 802.2 MCM was met excessive pumping of groundwater. Therefore, there is an excessive abstraction of non-replenishable groundwater, causing a declining water table in the district. Under such a situation of depleting groundwater tables, proper water management interventions are crucial to prevent depletion of water tables. The acronyms used in the Fig. 4 are stands for; P: Total runoff volume generated in the district considering TGA of the district and rainfall received in the year 2015, ABW: Available surface and groundwater resources, Pe: Effective rainfall for crop production, AW_{sw}: Available surface water, AW_{gw}: Available groundwater, GW_{abs}: Actual groundwater withdrawal in the year 2015, $CGRW_{use}$: Crop demand met from green water use (effective rainfall), CBW_{use}: Crop water demand met utilizing surface water sources, D_{os}: Other sectors demand (domestic, power generation, industrial, and recreation purposes needs etc.) and (NRW: is the non-renewable water which is drawn from the groundwater aquifers).

Water Management Interventions to Improve Water Availability in Kurukshetra District

I. **Effect of delayed transplanting of rice on ET_c and crop demand:** Crop water demand of rice in other months the district under the influence of different

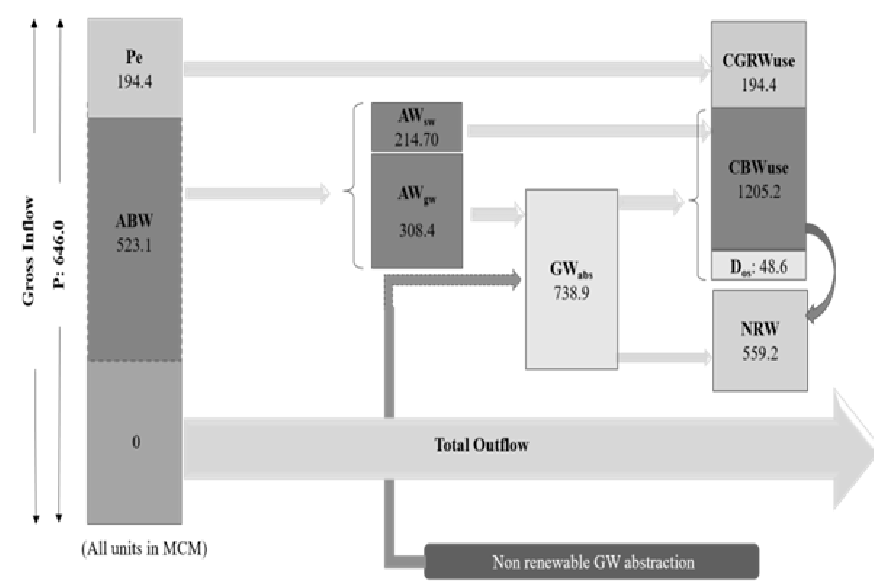

Fig. 4. Water accounting finger diagram for Kurukshetra district

transplanting dates was obtained as shown below in Table 4. It can be seen from Table 4 that when transplanting is done on 21st may, seasonal crop water requirement is 760.94 mm while transplanting is done as per the state government's recommendation seasonal ET_c is 706.09 mm. So, there is the possibility of reducing crop water demand of rice by 10.89% by transplanting on 15th June. Similarly, by transplanting of rice on 15th June reduces ET_c by 9.03, 6.23, 4.31 and 2.46% compared to when transplanting is done on 26th May, 31st May, 5th June and 10th June, respectively. Further, 1.92% reduction in rice ET_c can be achieved when transplanting is done on 20th June as compared to 15th June. Rice crop demand under different transplanting scenarios reduces in similar proportion when transplanting date is compared with 15th June. So, this way rice water demand can be decreased and thus decreases groundwater withdrawal and can help in meeting the sustainable crop production without dewatering deep groundwater aquifers. Influence of transplanting date on ET_c of rice is shown in Fig. 5. Fig. 6 shows rice water demand under different transplanting dates.

II. Effect of rice replacement by maize on crop demand: Maize crop can be substituted to replace rice crop (non-basmati) in certain percentage to tackle the groundwater tables decline issue. It requires far less water in the growing season when compared to rice. By replacing rice with maize crop helps in reducing crop demand by 54.66%. So, replacing rice crop in non-basmati grown area (40%) can save 126.21 MCM of crop demand water, which can be used in subsequent season. This helps in reducing groundwater withdrawal and CO_2 emission due to groundwater pumping. This intervention can help in reducing pressure on aquifers. Stubble burning events will be less and thus less environmental pollution. Fig. 7 shows effect of rice replacement by maize on water saving.

III. Effect of LLL on crop water demand: Rice-wheat cropping pattern is dominant in the IGP area and maximum area is occupied these two principal crops

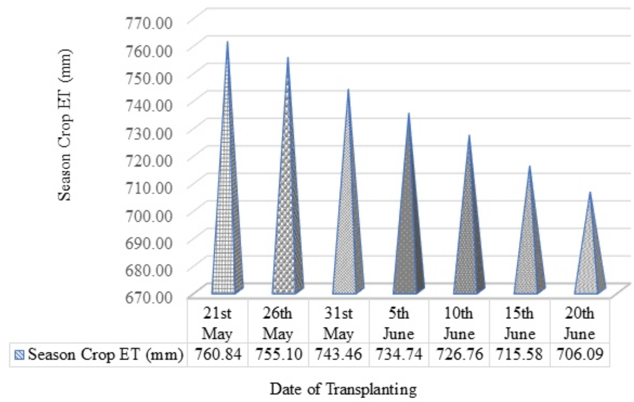

Fig. 5. Effect of transplanting date on rice evapotranspiration

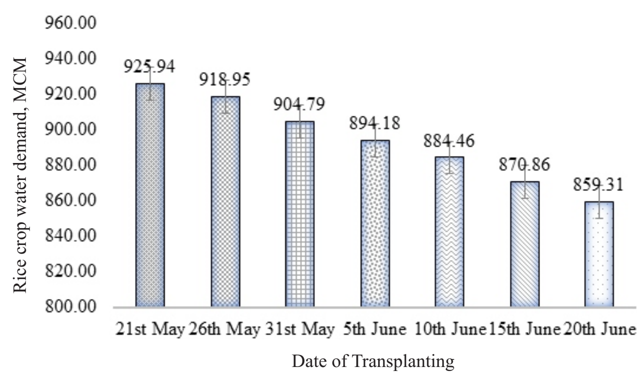

Fig. 6. Rice crop water demand under different transplanting dates

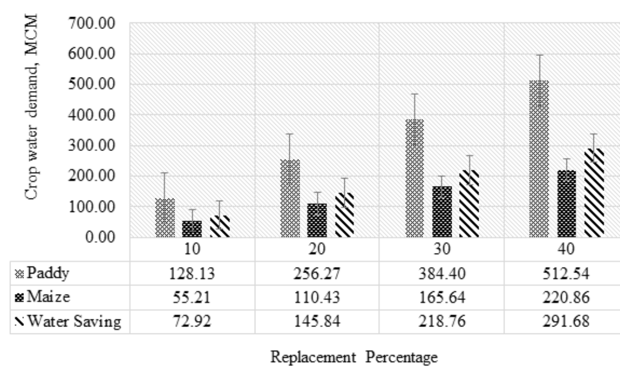

Fig. 7. Effect of replacement of rice by maize crop on water saving

Table: 4
Effect of rice transplanting date on crop evapotranspiration (mm)

Date of transplanting	May	Jun	Jul	Aug	Sept	Oct	Nov
21st May	93.92	215.53	196.68	186.84	136.62	29.49	0.00
26th May	51.23	214.72	201.53	186.84	141.09	50.55	0.00
31st May	8.54	214.41	199.40	186.84	145.56	71.61	0.00
5th June	0.00	185.64	197.26	186.84	150.04	92.68	0.00
10th June	0.00	149.76	195.13	186.84	154.51	113.74	0.00
15th June	0.00	106.70	192.57	186.84	157.19	133.19	6.96
20th June	0.00	78.25	190.65	186.84	157.19	136.66	20.87

cultivated in India. However, rice crop is water-guzzling crop and require ample quantity of water to cultivate. LLL offers several advantages such enhance input use efficiency, crop production, drainage effect and uniform distribution inputs. In order to quantify the LLL conservation technique effects on gross water demand in Kurukshetra district, average water saving scenarios of 19.9% for rice and 22% for wheat crop was considered. Several researchers reported varied scenarios of water-saving under LLL technique. Adoption of LLL over traditional land levelling (TLL) saves irrigation water significantly. Considering overall irrigation efficiency for rice and wheat crop as 60% and 50% to work out gross water demand by these crops under traditional land cultivation practices. Adoption of LLL in wheat crop can reduce crop water demand to the tune of 85.51 MCM overutilization of traditional levelling technique in Kurukshetra district. Considering irrigation efficiency for rice and wheat crop as 60 and 50%. While in rice crop, gross crop water demand can be decreased by magnitude of 346.62 MCM through adoption of LLL. The gross crop water demand for rice and wheat estimated as 1741.80 MCM and 388.67 MCM under TLL compared to 1395.18 MCM and 303.16 MCM under LLL, respectively. Influence of LLL technique on rice-wheat cropping system's crop demand of Kurukshetra district is shown in Fig. 8.

IV. **Effect of zero till drill of wheat and zero-till direct-seeded rice technologies on crop demand in rice-wheat cropping pattern:** Zero till drill of wheat (ZTW) and zero-till direct-seeded rice (ZTDSR) technologies are promising to conserve water and thus water availability retaining *in-situ* water conservation. Water-saving of 21.38 MCM in wheat and 522.54 MCM in rice crop can be achieved over conventional tillage system. Fig. 6 shows the effects of ZTDSR-ZTW system and puddled transplanted rice (PTR) and conventional tillage for wheat (CTW) on crop demand of rice and wheat cropping system in Kurukshetra district, Haryana. Fig. 9 shows effects of ZTDSR-ZTW over PTR-CTW on water saving.

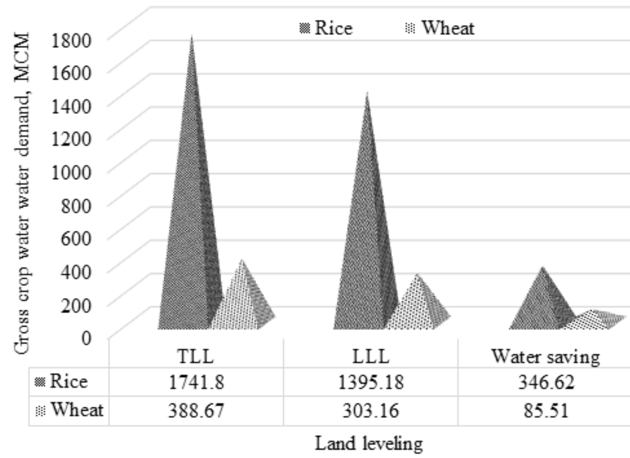

Fig. 8. Effect of laser land levelling technique on rice-wheat crop demand

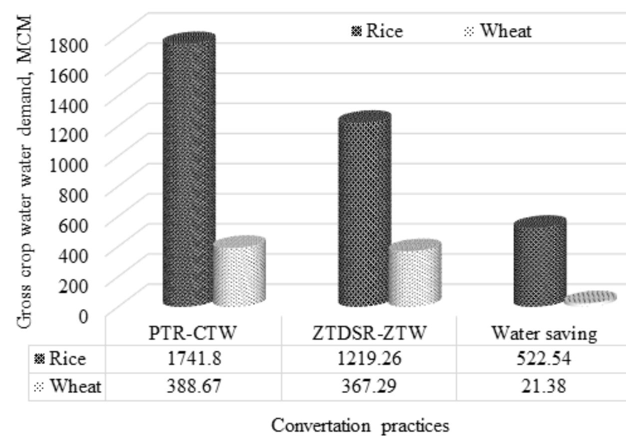

Fig. 9. Effects of ZTDSR-ZTW over PTR-CTW on water saving

4. CONCLUSIONS

Water accounting of Kurukshetra district showed that there are opportunities to improve water availability in the district adopting appropriate smart water management techniques. Delaying transplanting of rice to match with the onset of the rainy season reduces ET_c which can save a significant quantity of water and thus less withdrawal of groundwater. Delaying rice transplanting from 21st May to 15th June saves crop water demand by 10.89%. Similarly, by transplanting rice on 15th June reduces crop water demand by 9.03, 6.23, 4.31 and 2.46% compared to transplanting on 26th May, 31st May, 5th June and 10th June, respectively. Additionally, 1.92% reduction in rice crop demand can be achieved when transplanting is done on 20th June as compared to 15th June. Changing cropping system from rice-wheat to maize-wheat can reduce crop water demand significantly. Replacing rice crop by maize reduces crop demand by 54.66% ha^{-1} of crop. Adoption of LLL, zero till drill in wheat and direct-seeded rice techniques improves crop yield, saves water and fertilizers. Field level water management structures should be adopted to conserve water to improve crop production.

REFERENCES

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. 1998. Crop evapotranspiration: guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper no. 56, Rome, Italy.

Ambast, S.K., Tyagi, N.K. and Raul, S.K. 2006. Management of declining groundwater in the Trans Indo-Gangetic Plain (India): some options. *Agric. Water Manage.,* 82: 279-296.

Anantha, K.H., Garg, K.K., Barron, J., Dixit, S., Venkataradha, A., Singh, R. and Whitbread, A.M. 2021. Impact of best management practices on sustainable crop production and climate resilience in smallholder farming systems of South Asia. *Agric. Syst.,* 194: 103276.

Balingbing, C., Sandro, J., Khandai, S., Chea, H., Songmethakrit, T., Meas, P., Hitzler, G., Zwick, W., Viriyangkura, L., Bautista, E. and Gummert, M., 2022. Precision land leveling for sustainable rice production: case studies in Cambodia, Thailand, Philippines, Vietnam, and India. *Precis. Agric.*, 1-20.

Bhatt, R., Singh, P., Hossain, A. and Timsina, J. 2021. Rice-wheat system in the northwest Indo-Gangetic plains of South Asia: Issues and technological interventions for increasing productivity and sustainability. *Paddy Water Environ.*, 19(3): 345-365.

Brye, K.R., Slaton, N.A. and Norman, R.J. 2005. Penetration resistance as affected by shallow-cut land leveling and cropping. *Soil Till. Res.,* 81:1-13.

Chatterjee, R. and Purohit, R.R. 2009. Estimation of replenishable groundwater resource of India and their status of utilization. *Curr. Sci.,* 96: 1581-1591.

Conservation agriculture: Resource productivity and efficiency. 2009. *IVth World Congress on Conservation Agriculture, New Delhi,* PACA, 1st Floor, NASC Complex, DPS Marg, Pusa, New Delhi - 110 012.

Debolskiy, M.V., Alexeev, V.A., Hock, R., Lammers, R.B., Shiklomanov, A., Schulla, J., Nicolsky, D., Romanovsky, V.E. and Prusevich, A. 2021. Water balance response of permafrost-affected watersheds to changes in air temperatures. *Environ. Res. Lett.*, 16(8): 084054.

F.A.O. 2012. *Coping with water scarcity: An action framework for agriculture and food security.* FAO Water Reports 38.

Gill, M. 1998. Water for life. Proceeding of seminar on world Food Day. Directorate of Agriculture Information. Department of Agricultural, Government of Punjab, pp 9-13.

Global Modeling and Assimilation Office (GMAO). 2015. *inst3_3d_asm_Cp: MERRA-2 3D IAU State, Meteorology Instantaneous 3-hourly (p-coord, 0.625x0.5L42), version 5.12.4*, Greenbelt, MD, USA: Goddard Space Flight Center Distributed Active Archive Center (GSFC DAAC), doi: 10.5067/VJAFPLI1CSIV.

Hargreaves, G.H. and Samani, Z.A. 1985. Reference crop evapotranspiration from temperature. *Appl. Eng. Agric.*, 1(2): 96-99.

Hira, G.S. 2009. Water management in northern states and the food security of India. *J. Crop Improv.*, 23:136-157.

Jat, M.L., Chandna, P., Gupta, R.K., Sharma, S.K. and Gill, M.A. 2006. Laser land leveling: A precursor technology for resource conservation, rice-wheat consortium technical bulletin series 7, rice-wheat consortium for the Indo-Gangetic Plains, New Delhi, 48p.

Kaur, B., Singh, S., Garg, B.R., Singh, J.M. and Singh, J. 2012. Enhancing water productivity through on-farm resource conservation technology in Punjab agriculture. *Agric. Econ. Res. Rev.,* 25(1): 79-85.

Konikow, L.F. and Kendy, E. 2005. Groundwater depletion: A global problem. *J. Hydrogeo.,*, 13: 317-320.

Kumar, N., Chhokar, R.S., Meena, R.P., Kharub, A.S., Gill, S.C., Tripathi, S.C., Gupta, O.P., Mangrauthia, S.K., Sundaram, R.M., Sawant, C.P. and Gupta, A. 2021. Challenges and opportunities in productivity and sustainability of rice cultivation system: A critical review in Indian perspective. *Cereal Res. Commun.*, 1-29.

Lamas, M.R. and Martínez-Santos, P. 2005. Intensive groundwater use: silent revolution and potential source of social conflicts. *J. Water Resour. Manage.,* 131 337-341.

Laxmi, V., Gupta, R.K., Swarnalatha, A. and Perwaz, S. 2003. *Environmental impact of improved technology - farm level survey and farmers' perception on zero tillage (case study).* Presented at Roles of Agriculture Workshop 20-22 October, 2003 - Rome, Italy. Indira Gandhi Institute of Development Research, Mumbai.

Mahajan, G., Bharaj, T.S. and Timsina, J. 2009. Yield and water productivity of rice as affected by time of transplanting in Punjab, India. *Agric. Water Manage.*, 96: 525-532.

Malik, R.K., Mehla, R.S. and Singh, B.K. 2002b. Conservation tillage technologies and farmers participatory research, extension approaches in Haryana - A case study. In: RWC (ed.), *Proc. International Workshop on Developing an Action Program for Farm-level Impact in Rice Wheat Systems of the Indo-Gangetic Plains,* 25-27 September 2000, New Delhi, India. Rice-Wheat Consortium Paper Series 14. New Delhi, India, pp 31-45.

Mandal, B., Ray, D.P. and Hansda, A.K. 2014. Application of resource conserving technology (RCT) in wheat: A promising better option particularly during winter season in West Bengal. *Int. J. Bioresour. Sci.,* 1(1): 7-17.

Mehla, R.S., Verma, J.K., Gupta, R.K. and Hobbs, P.R. 2000. Stagnation in the productivity of wheat in the Indo-Gangetic plains : Zero-till-seed-cum-fertilizer drill as an integrated solution. Rice-Wheat Consortium Paper Series 8. New Delhi, India.

Molden, D. 1997. *Accounting for water use and productivity. SWIM Paper 1.* Colombo, Sri Lanka: International Irrigation Management Institute.

Nagarajan, S., Singh, A., Singh, R. and Singh, S. 2002. *Impact evaluation of zero-tillage in wheat through farmers' participatory mode.* In: R.K. Malik, R.S. Balyan, A. Yadav, and S.K. Pahwa (eds.), Herbicide resistance management and zero tillage in rice-wheat cropping system. Hisar, India: CCSHAU, pp 150-154.

Rickman, J.F. 2002. *Manual for laser land leveling. Rice-Wheat Consortium Technical Bulletin Series 5.* New Delhi-110 012, India: Rice-Wheat Consortium for the Indo-Gangetic plains, 24p.

RWC (Rice-Wheat Consortium of the Indo-Gangetic Plains). 2004. Highlights 2003-2004. New Delhi, India: Rice-Wheat Consortium for the Indo Gangetic Plains.

Sarkar, A., Sen, S. and Kumar, A. 2009. Rice-wheat cropping cycle in Punjab: a comparative analysis of sustainability status in different irrigation systems. *Environ. Dev. Sustain.,* 11: 751-763.

SCS. 1985. National Engineering Handbook, Section 4, Hydrology. Soil Conservation Service (SCS). US Department of Agriculture (USDA), Washington DC, USA.

Siebert, S., Burke, J., Faures, J.M., Frenken, K., Hoogeveen, J., Döll, P. and Portmann, F.T. 2010. Groundwater use for irrigation-a global inventory. *Hydrol. Earth Syst. Sci.,* 14: 1863-1880.

Sonekar, L. 2017. Problem of water stress in Indian agriculture. *J. Rural Dev. Rev.,* 1(1): 1-8.

Surendran, U., Raja, P., Jayakumar, M. and Subramoniam, S.R. 2021. Use of efficient water saving techniques for production of rice in India under climate change scenario: A critical review. *J. Cleaner Produc.,* 309: 127272, doi.org/10.1016/j.jclepro.2021.127272.

Toung, T.P. and Bhuiyan, S.I. 1994. Innovations towards improving water use efficiency in rice. Paper presented at the World's Bank's 1994 Water resource seminar, 13 -15 Dec. 1994, Virginia, USA.

Wada, Y., Van, B.L.P.H. and Bierkens, M.F.P. 2012a. Non sustainable groundwater sustaining irrigation: a global assessment. *Water Resour. Res.,* 48: W00L06.

Whitney, R.S., Gardner, R. and Robertson, D.W. 1950. The effectiveness of manure and commercial fertilizer in restoring the productivity of subsoils exposed by leveling. *Agron. J.,* 42: 239-245.