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Dynamics of well irrigation systems and CO_2 emissions in different agroecosystems of South Central India

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Water application systems under wells extracting groundwater are one of the major factors influencing climate change in the agricultural sector. In the context of growing demand for adaption of pressurized irrigation with electric pumps in South Central India, the present study was undertaken to assess the carbon dioxide emission (CO_2 e) for different irrigation systems. The crop water requirements and pumpsets prevailing in the area were considered for estimation of CO_2 e. The estimation includes operational energy consumption, well digging, installation and manufacturing of the irrigation system as well as the pumpsets. The irrigation systems used in major crops under wells include surface (rice, maize, groundnut, vegetables and sugarcane), raingun (maize, groundnut, vegetables and sugarcane), sprinkler (maize, groundnut and vegetables) and drip (vegetable and sugarcane). The analysis indicated that the energy used in pumping irrigation water made the highest contribution to total CO_2 e footprint, which ranged from 2.52 to 15.72 t/ha depending on the irrigation system. Sugarcane crop showed maximum energy requirement (17.27 MWh/ha) under surface irrigation system, contributing 15.72 t/ha CO_2 e. Maximum reduction in energy requirement and CO_2 e was recorded in the case of drip (11.52 MWh/ha; 10.48 t/ha) system followed by sprinkler (12.58 MWh/ha; 11.52 t/ha) and raingun (14.81 MWh/ha; 13.47 t/ha) under tube wells. It was observed that among all the irrigation systems, the drip system gave the lowest CO_2 e indicating the maximum climate change mitigation potential in the irrigation sector of selected region under wells.

Keywords: Carbon dioxide emission, climate change, groundwater, pressurized irrigation, tube and dug wells.

CURRENTLY, Indian agriculture is facing a challenge of irrigation water management strategies due to adverse impacts of climate change on groundwater. Globally, over 3800 km^3 groundwater is withdrawn annually, in which the share of agricultural sector is 70%. India is among the top abstractors of groundwater with 646 km^3 withdrawn annually followed by China (550 km^3) and the US (477 km^3)[1]. Climate change along with growing population in the country have caused a decline in the availability of surface water resources. Hence farmers have been pumping groundwater for successful crop production, which demands higher energy consumption. According to the Government of India estimates of 2005, the number of irrigation wells equipped with diesel or electric pumps in the country stands at more than 19 million, compared with just 0.15 million in 1950 (ref. 2). Currently, groundwater contributes to 80% of India's irrigation under minor irrigation projects. Besides, smallholder irrigation pumps in the country account for 4–6% of India's total carbon emissions[3]. It is due to the reason that electric pumps operate at 40% efficiency and result in transmission and distribution losses to the extent of 25% or more. In recent years, farmers are replacing the diesel pumps with electric pumps due to subsidized rate of electricity supplied by the Government. Since this is an economically cheaper option to the farmer, it plays a major role in groundwater exploration. The uncontrolled supply of power with higher rate of subsidy encourages excess irrigation. Thus, huge amount of excess water that is pumped is lost either through evaporation or deep percolation[4].

Water-use efficiency in the case of surface irrigation is substantially low compared to pressurized irrigation systems such as sprinkler and drip[5–7]. Pressurized irrigation systems using groundwater as source could reduce energy consumption by 12–44% (refs 8–11). Numerous field studies have shown that the use of drip irrigation reduces the quantity of groundwater pumped/ha by 30–70% over surface irrigation depending upon the crop and season. In India, between 1950 and 2000, due to rapid growth in deep wells[12], groundwater-based irrigation increased by almost fivefold from 6 to 33.6 m ha, while canal-based irrigation increased from 8.3 to 18 m ha (ref. 12). Well irrigation in India results in 14.38 million tonnes (Mt) of C by both electric pumps (11.09 Mt) as well as by diesel pumps (3.29 Mt)[2]. It was estimated that the lifting of 1000 m^3 of water to a height of 1 m consumes 2.73 kWh of energy in the case of no friction losses and at peak

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efficiency[13]. Carbon dioxide emission (CO_2 e) during pumping depends on type of energy source, carbon density and method of irrigation. It was estimated that the decline of groundwater level by 1 m would result in the increase in greenhouse gas (GHG) emissions by 4.37 and 6% in Haryana and Andhra Pradesh respectively[14].

Many researchers estimated CO_2 e in different parts of the world and reported that irrigation in China accounted for 36.72–54.16 Mt CO_2 e (ref. 15). Water pumping and conveyance account for 50–70% of total emissions from energy activities in the agricultural sector. Pumping through well is the biggest emission source, accounting for 61% of total emissions. A case study in Portland estimated 290 million tonnes (Mt) of CO_2 e under water-energy dynamics[16]. In Spain, estimated CO_2 e from well irrigation (0.24 Mt) was almost three times higher than Egypt (0.082 Mt). In Pakistan, 3.8 Mt C was reported to be emitted as a result of groundwater irrigation[17]. However, adoption of improved irrigation application methods like pressurized irrigation would increase the application efficiencies which in turn will reduce the groundwater withdrawals. This would lead to 40% decline in energy consumption and subsequent C emission of groundwater use[18]. Researchers have concluded that the water sector would face major challenges in the coming decade and would be a crucial part of policy[1].

South Central India suffers from an acute water crisis leading to groundwater depletion. The latest data compiled by the Ground Water Department Authority reveal that water level across all districts in Andhra Pradesh (AP) has fallen critically. The state of united AP, which is a part of the South Central Indian region has more than 2.9 million borewells, and on an average, 50,000 new borewells are being dug every year in the state[19]. The groundwater sources (wells and borewells) have registered a steep increase from a mere 0.28 million ha in 1955–56 to 3.67 million ha in 2010–11. There is scope to reduce C emission in groundwater irrigation by adopting low C technologies that lead to reduction in GHG emissions, which can alleviate the effects of climate variability on agricultural production system[18,20,21].

Materials and methods

Location and data

The 22 agriculturally dominated districts of united AP are distributed over 3 agroecosystems, namely Deccan Plateau (Telangana), South Deccan Plateau (Rayalaseema) and Eastern Coastal Plains (Coastal Andhra). According to NBSS&LUP classification, these regions are characterized as hot, moist, semi-arid; hot, dry, semi-arid, and hot, moist, sub-humid respectively. The major soil groups include Alfisol and Vertisol and are true to all the regions. However, available moisture content in these regions varies from low to medium (Rayalaseema and Telangana), and medium to high (Coastal Andhra). The socio-economic conditions of the farmers in these regions are highly varying. The small and marginal farmers constitute 78.5%, 90.0% and 85.9% practising cultivation on 46.7%, 60.4% and 55.5% of land respectively, in Rayalaseema, Coastal Andhra and Telangana regions[22]. The temporal distribution of tube and dug wells is presented in Table 1. Though the total number of wells is increasing in all the regions, consistent increase in the tube wells with decrease in dug wells is observed (Table 1). In all the regions, four different capacity pumpsets are popular among the farmers depending on the land holding capacity. Among these, the pumpset of 5 hp capacity is most popular, as 53% of pumpsets are under this category. However, less than 3 hp pumps (20%), relatively larger capacity pumps in the range of 10 hp (10%) and over 10 hp pumps (17%) are also popular in the regions. By taking weighted average of distribution of pumpsets of existing capacities, the average pump capacity was computed to 5 hp and considered for the purpose of all computations. The water depth in both tube as well as dug wells is varying, but for simplification in the estimation of various parameters, mean well depth of 91 and 12 m for tube and dug wells respectively, was considered.

Irrigated rice is the major crop in Telangana region occupying 71.5% of the area under wells. However, in Coastal Andhra and Rayalaseema, major rice acreage is under canal irrigation. Maize and sugarcane, and groundnut are other prominent crops under well irrigation in Coastal Andhra and Rayalaseema regions respectively. Vegetable cultivation is uniformly distributed over the regions (Table 1).

The present study was conducted with the objective of assessing the carbon emission for five different crops, namely rice, sugarcane, maize, groundnut and vegetables under four different irrigation systems, viz. surface, raingun, sprinkler and drip irrigation from tube and dug wells in 22 agriculturally dominant districts of united AP (Figure 1).

Based on the crop water requirement, the area under crop and pump discharge, the energy loads were calculated. Due consideration was given to the energy consumed in various components of groundwater pumping system while estimating CO_2 e. These components include energy consumption in (i) digging of tube/dug wells, (ii) pumpset manufacturing, (iii) installation of irrigation systems and (iv) pumping water for irrigation.

The energy consumption in water application component of the pumping system is more since it is recurring in nature. Thus reduction in CO_2 e footprint and energy use is possible here. In view of this, four different types of water application system were evaluated for CO_2 e footprint and energy reduction. These include conventional surface irrigation method, raingun method, sprinkler irrigation method and drip irrigation method. In

Table 1. Temporal distribution of irrigated area under different crops in different regions under wells

Crop	Tube well 1993–94	Tube well 2002–03	Tube well 2010–11	Dug well 1993–94	Dug well 2002–03	Dug well 2010–11
Telangana						
No. (lakhs)	0.74	4.06	6.77	8.11	5.69	5.52
Area under crops (lakhs ha)						
Rice	1.16	3.57	7.61	2.75	2.06	3.51
Maize	0.21	0.44	0.72	0.47	0.72	0.79
Sugarcane	0.39	0.83	0.69	0.23	0.15	0.06
Vegetables	0.06	0.23	0.47	0.15	0.14	0.17
Groundnut	0.18	0.49	1.22	1.12	0.49	0.3
Coastal Andhra						
No. (lakhs)	1.46	1.91	3.03	1.83	2.04	1.73
Area under crops (lakhs ha)						
Rice	1.11	1.5	2.14	0.09	0.22	0.1
Maize	0.07	0.27	1.16	0.01	0.06	0.1
Sugarcane	0.69	1.23	1.21	0.11	0.18	0.06
Vegetables	0.13	0.21	0.38	0.14	0.13	0.15
Groundnut	0.4	0.14	0.24	1.37	0.09	0.09
Rayalaseema						
No. (lakhs)	0.4	1.42	2.53	2.52	2.23	1.87
Area under crops (lakhs ha)						
Rice	0.37	0.86	1.18	0.75	0.28	0.16
Maize	0	0.04	0.19	0.01	0.01	0.04
Sugarcane	0.07	0.37	0.5	0.39	0.25	0.08
Vegetables	0.03	0.17	0.38	0.13	0.08	0.03
Groundnut	0.46	0.6	0.74	0.8	0.32	0.14

Source: Ref. 23.

surface irrigation method, the water is conveyed through unlined field channels spread over the field causing less overall water application efficiency. In rest of the water application method, water is conveyed through a pipeline from a water source and thus there is improvement in the overall irrigation efficiency compared to surface irrigation method. However, drip irrigation further improves the water application efficiency since it delivers the desired quantity of water in the root zone that minimizes both seepage/deep percolation and evaporation losses.

Estimation of CO_2 e in well digging

Details of average tube and dug well depths, average size of the dug wells and diesel consumption in digging are presented in Table 2.

The equations for calculating energy and the corresponding CO_2 e are given below

$$E = D_c \times E_{cd} \times T_i \times \left(\frac{K_e}{T_{lw}}\right), \tag{1}$$

where E is the energy (MWh); D_c the diesel consumption per well (l); E_{cd} the energy coefficient for diesel (MJ/l); T_i the irrigation time (h); K_e the conversion factor from MJ to MWh (0.000278); T_{lw} is the Useful life of a well (h).

The energy coefficient of 56.31 MJ/l for diesel was used for estimating CO_2 e for the construction of tube and dug wells[23]. Diesel consumption was estimated by taking the parameters from Table 2; it was 225 and 80 l for tube and dug wells respectively. The useful life of wells was considered as 20,000 h

$$CO_2 \text{ e} = E \times F_e, \tag{2}$$

where CO_2 e is the CO_2 emission rate (tCO_2 e/MWh), E the energy (MWh); F_e is the emission factor (taken as 0.264 tCO_2/MWh).

Estimation of CO_2 e from pumpset manufacturing

The energy coefficient of 64.80 MJ/kg as suggested by Sanjeeva Reddy *et al.*[24] was used for estimating CO_2 e. The average weight of a pumpset usually ranges from 80 to 90 kg with CI (cast iron) manufacturing. The total energy was calculated by taking 15,000 h of operation of pumpset under irrigation. The total energy was converted into CO_2 e by multiplying with the coefficient of 0.91 t CO_2/MWh (ref. 25).

The steps involved in the calculation of CO_2 e are given below

$$E = \frac{T_i \times P_{wt} \times E_c \times K_e}{T_{lp}}, \tag{3}$$

where E is the energy (MWh); T_i the irrigation time (h); P_{wt} the pumpset weight (kg); E_c the energy coefficient (MJ/kg, taken as 64.80); K_e the conversion factor from MJ to MWh (0.000278); T_{lp} is the useful life of a pumpset (h).

$$CO_2\ e = E \times C_{ef}, \tag{4}$$

where C_{ef} is the weighted average emission factor of the southern grid (0.91 tCO_2 e/MWh).

Estimation of CO_2 e for installation of irrigation systems

CO_2 e due to the installation of irrigation systems was computed as suggested by Lal[26]. Table 3 presents the values of C equivalent energy used in installation of irrigation systems.

Figure 1. Location map of Andhra Pradesh, India with different agroecosystems.

Estimation of CO_2 e for groundwater pumping into irrigation system

CO_2 e for pumping of groundwater through irrigation systems was estimated considering the energy consumed in the lifting of water in borewells and operating pressure required to function different components of irrigation system. Four different water application systems were considered according to the type of crop canopy. These included surface, sprinkler, raingun and drip irrigation systems. Table 4 provides details on the crop water requirement and corresponding irrigation system of major crops like rice, maize, sugarcane, vegetables and groundnut under wells in AP[27].

The average size of the pumpsets for CO_2 estimation is taken as 5 hp with discharges of 4 and 8 lps respectively, for submersible and centrifugal monoblock pumpsets with average efficiency of 50% based on field experience. This is important because the actual enhancement in irrigation efficiency depends on the behaviour and practice of farmers using the irrigation system. The farmer practice is not just determined by theoretical instruction of

Table 2. Theoretical data considered in the construction of wells (bore/dug wells)

Item description and units	Value
Tube/bore wells	
Average depth of well (m)	91
Fuel consumption per m of depth (l)	2.5
Dug wells	
Average depth of well (m)	12
Average diameter of well (m)	8
Volume of earth work (m^3)	603
Time required for earth work (h) with Tata Hitachi 200 model	5
Fuel consumption (l/h)	16

Table 3. Different carbon dioxide emission (CO_2 e) values for installation of irrigation systems

System	Installation energy (kg CE/ha/year)	CO_2 e (kg CO_2 e/ha)
Surface without IRRS	9.4	34.81
Surface with IRRS	24.6	91.11
Solid set sprinkler	121.3	449.26
Permanent sprinkler	35.5	131.48
Hand-moved sprinkler	16.3	62.59
Solid roll sprinkler	23.3	86.29
Centre pivot sprinkler	21.6	80
Traveller sprinkler	16.9	62.59
Trickle	84.9	314.44

IRRS, Irrigation run-off return system (source: ref. 26).

Table 4. Crop water requirement and duration of selected crops considered under different irrigation systems

Selected crop	Average water requirement (mm)*	Crop duration (months)	Surface irrigation	Raingun irrigation	Sprinkler irrigation	Drip irrigation
Rice	1200	6	Rice	Maize	Maize	Sugarcane
Maize	525	4	Maize	Sugarcane	Vegetables	Vegetables
Sugarcane	2000	12	Sugarcane	Vegetables	Groundnut	
Vegetables	550	3	Vegetables	Groundnut		
Groundnut	400	4	Groundnut			

*Source: Ref. 27.

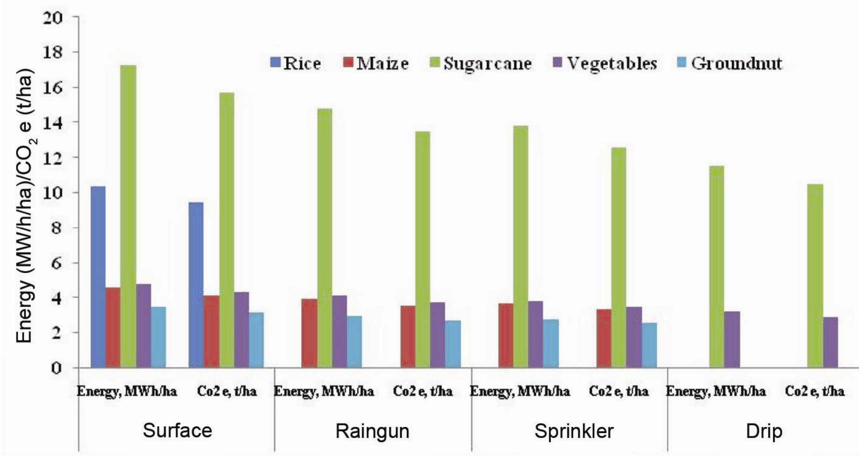

Figure 2. Energy consumption and carbon dioxide e (CO_2 e) under tube well irrigation for selected crops in Andhra Pradesh.

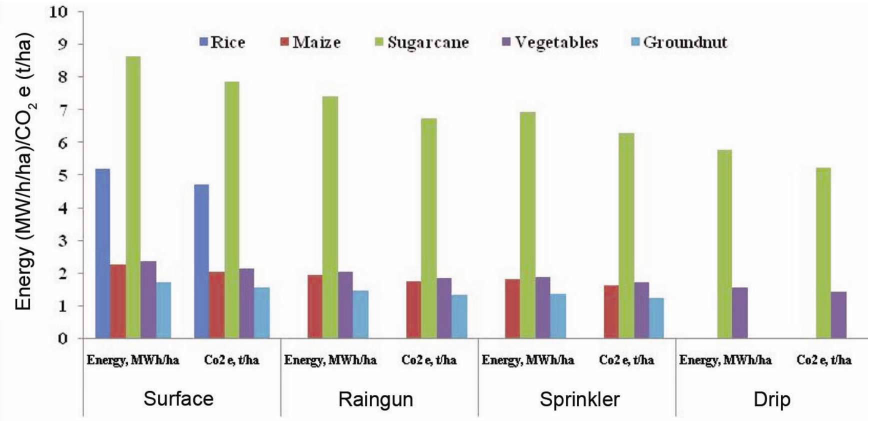

Figure 3. Energy consumption and CO_2 e under dug well irrigation for selected crops in Andhra Pradesh.

irrigation system, but broadly influenced by the broader objective of agricultural productivity. The overall efficiency of different irrigation systems, namely surface, sprinkler, raingun and drip is taken as 30%, 37.5%, 35% and 45% respectively[28].

The steps involved in estimating CO_2 e for lifting groundwater using agricultural pumpsets are given below

$$V_{\mathrm{w}} = 10 \times \mathrm{CWR} \times A_{\mathrm{c}}, \tag{5}$$

where V_{w} is the volume of water lifted by the pump (m^3); CWR the crop water requirement (mm); A_{c} is the cropped area covered (ha).

Total energy requirement

$$\mathrm{TE} = \frac{P_{\mathrm{r}}}{1340} \times \frac{V_{\mathrm{w}}}{Q_{\mathrm{p}}} \times 0.278 \times T_{\mathrm{i}}, \tag{6}$$

where P_{r} is the pump rated power (hp); V_{w} the volume of water lifted (m^3); Q_{p} the pump discharge (lps); T_{i} is the irrigation time (h/ha).

$$\mathrm{CO_2\ e} - \frac{\mathrm{TE} \times C_{\mathrm{ef}}}{E_0}, \tag{7}$$

where E_{o} is the overall system efficiency in well irrigation, expressed in fraction.

The CO_2 e values thus obtained were converted into per month basis after dividing by crop duration for comparison over crop and irrigation system.

Results and discussion

Energy and CO_2 e footprint in rice

Surface irrigation is mostly practised by the farmers in all the three regions. Thus irrigation in basin (a form of surface irrigation) from tube as well as dug wells was considered. CO_2 e for water application is a major component in total CO_2 e and was true to both the water sources. CO_2 e of 1.6 t/ha/month was estimated for tube well irrigation, whereas it was 0.8 t/ha/month in the case of dug well. The energy consumed to irrigate 1 ha of rice was 10.36 MWh/ha and it was half in case of dug well (Figures 2 and 3). Overall water application system efficiency of surface irrigation is limited to 30% due to excessive water loss due to seepage and evaporation from the rice field. In view of CO_2 e from irrigation acreage in rice may be kept minimum under wells and may be promoted under canal irrigation with lined field channel distribution and conveyance for minimizing the seepage losses.

Energy and CO_2 e footprint in maize

Maize is a prominent crop that is emerging in Telangana and Coastal Andhra regions in recent years replacing the traditional rainfed crops of castor and sorghum. In Coastal Andhra, substantial area of maize is under tube well irrigation, unlike Telangana and Rayalaseema. Three irrigation systems, namely traditional surface, raingun and sprinkler were evaluated for both tube as well as dug wells. In general, tube wells caused higher CO_2 e than dug wells. In surface irrigation system, CO_2 e was found to be 1.05 t/ha/month followed by raingun (0.91 t/ha/month) and sprinkler (0.80 t/ha/month) systems. Thus, 13.51% and 17.54% emission can be reduced by adopting raingun and sprinkler irrigation system over the traditional surface irrigation system (Figures 2 and 3), since the overall application efficiency is 35% and 37.5% respectively, compared to 30% for surface irrigation. Further reduction in CO_2 e can be achieved if the water source is dug well to an extent of 50% over different irrigation systems.

The energy consumption was computed as 4.53, 3.89 and 3.63 MWh/ha for the surface, raingun and sprinkler irrigation systems respectively, with tube well as water source. Almost 50% reduction in energy was observed for dug wells across the irrigations systems (Figures 2 and 3). There is an area of 0.79 and 0.72 lakh ha under maize in Telangana region with water resources from dug and tube wells respectively (Table 1). Therefore, in this region the raingun and sprinkler systems should be promoted under tube well for minimizing the energy use and CO_2 e. In Coastal Andhra, 1.16 lakh ha maize area is under tube well compared to 0.10 lakh ha under dug well. Therefore, in Coastal Andhra region, irrigation systems like raingun and sprinkler may be encouraged to reduce energy use and CO_2 e.

Energy and CO_2 e footprint in sugarcane

In all the three regions of Andhra Pradesh, sugarcane is mostly cultivated under tube well irrigation system. However, it can be irrigated through all the possible irrigation systems, with drip being the most efficient among them. The CO_2 e for different irrigation systems under two sources of water (tube and dug wells) for sugarcane and the respective energy requirements are presented in Figures 2 and 3 for both tube and dug wells. The traditional surface irrigation system results in more CO_2 e (1.30 t/ha/month) than the others like raingun, sprinkler and drip (1.15, 1.08 and 0.91 t/ha/month respectively). Significantly lower CO_2 e was computed in case of dug well, but cultivated in limited area across the three regions. Since major area of sugarcane is under tube well irrigation, the efficient irrigation system such as drip can be extensively promoted to minimize the energy consumption and CO_2 e.

Energy and CO_2 e footprint in vegetables

Like sugarcane, vegetables are mostly cultivated under tube well water source in all the three regions. Vegetable cultivation also provides the scope for adopting various irrigation systems like surface, raingun, sprinkler and drip. The CO_2 e footprint and energy consumption under different irrigation systems for vegetables are presented in Figures 2 and 3 respectively, for tube and dug wells. Maximum CO_2 e was observed in case of surface irrigation (1.47 t/ha/month) followed by 1.27, 1.21 and 1.08 in raingun, sprinkler and drip respectively. Adoption of drip irrigation in vegetables can lead to the reduction in CO_2 e to the tune of 26.3% over surface irrigation. Therefore,

Table 5. Total CO_2 e from different irrigation systems under well irrigation with few selected crops in Andhra Pradesh as on 2010–11

	Total CO_2 e (million tonnes)			
Crop	Surface	Raingun	Sprinkler	Drip
Rice	12.28	–	–	–
Maize	1.07	0.93	0.89	–
Sugarcane	4.00	3.44	3.24	2.76
Vegetables	0.62	0.54	0.51	4.61
Groundnut	0.79	0.69	0.67	0.00
Grand total	18.76	5.60	5.31	7.37

Table 6. Region-wise recommendations of different irrigation systems and crops

Crop	Telangana	Coastal Andhra	Rayalaseema	CO_2 mitigation potential (%)
Rice	Surface	Surface	Surface	–
Maize	Sprinkler/raingun	Sprinkler/raingun	–	17.5
Sugarcane	Drip	Drip	Drip	31.1
Vegetables	Drip	Drip	Drip	26.3
Groundnut	Sprinkler/raingun	–	Sprinkler/raingun	16.2

drip system may be adopted across the region under tube wells.

Energy and CO_2 e footprint in groundnut

Groundnut is the prominent crop of Telangana and Rayalaseema. Presently, substantial area of groundnut is under tube wells. However, during the 1990s, groundnut was cultivated with dug well water source, which has been reduced significantly and replaced by tube wells. In the case of groundnut, water is usually applied through surface, raingun and sprinkler irrigation. Since the water requirement is low, CO_2 e is also less compared to other crops. CO_2 e and corresponding energy use for groundnut are presented in Figures 2 and 3 respectively. Though the surface irrigation under tube wells causes highest CO_2 e of 0.8 t/ha/month, it is comparable to other crops with efficient irrigation system. CO_2 e can be further reduced by 13.08% and 16.2% by adopting raingun and sprinkler respectively, under tube wells. Since CO_2 e is significantly low for groundnut, it can be considered as a climate-resilient oilseed crop and may be promoted in Telangana and Rayalaseema with adoption of sprinkler system.

Total CO_2 e in different agroecosystems

The total CO_2 e for Telangana, Coastal Andhra and Rayalaseema in different irrigation systems under wells (tube as well as dug) considering total area under selected crops for 2010–11, is presented in Table 5. The maximum CO_2 e of 11.30 MT was estimated for surface irrigation in Telangana followed by Coastal Andhra (4.89 MT) and Rayalaseema (2.59 MT), combining all the crops. In raingun irrigation system, maximum total CO_2 e of 2.40 MT was observed in Coastal Andhra followed by Telangana (1.99 MT) and Rayalaseema (1.20 MT), excluding rice crop. Similarly, in the case of sprinkler irrigation system, maximum CO_2 e (2.28 MT) was observed in Coastal Andhra followed by Telangana (1.89 MT) and Rayalaseema (0.72 MT). Under drip irrigation, maximum CO_2 e of 1.52 MT was observed in Coastal Andhra followed by Telangana (0.98 MT) and Rayalaseema (0.72 MT), excluding rice, maize and groundnut. From Table 5, it can be observed that rice is the predominant crop under tube wells in Telanagana region having maximum CO_2 e of 8.98 MT compared to Coastal Andhra and Rayalaseema. This is because in these two regions, rice is grown under canal irrigation having no energy use. Therefore, it is suggested to reduce rice cultivation by replacing it with maize, vegetables and groundnut for lower energy use and CO_2 e by promoting sprinkler, riangun and drip systems under tube wells in the context of climate change. Similarly, this practice can be adopted in both Coastal Andhra and Rayalaseema regions for reducing CO_2. The total CO_2 e for the entire Andhra Pradesh was estimated as 18.76, 5.6, 5.3 and 3.22 MT respectively, for surface, raingun, sprinkler and drip systems (Table 6). Analysis showed that tube well irrigation causes higher CO_2 e and energy use than dug wells. However, dug wells are being replaced by tube wells across the regions by the farmers and thus, the recommendations on crop and corresponding irrigation system are made considering tube well as the water source (Table 6). Across the three regions, rice is irrigated using surface method, which could be replaced by new water-saving methods of SRI cultivation, and alternate wetting and drying methods. In the case of maize, sprinkler/raingun method of irrigation is recommended in the three regions under tube wells. For growing sugarcane and vegetables under tube wells, drip irrigation is the best option in reducing the CO_2 e and energy use in all three regions. In the case of groundnut which is grown under light texture soils of Telangana and Rayalaseema under tube wells, sprinkler irrigation system is recommended to mitigate climate change.

Conclusion

In the context of climate change, it is necessary to understand the dynamics of groundwater pumping and CO_2 e. The census of agricultural pumping systems in the region indicates manyfold increase of the tube wells annually. The analysis suggested that CO_2 e in irrigation water use component was maximum in all the selected crops (2.52–15.72 t/ha). Sugarcane crop requires maximum energy under surface irrigation and maximum reduction could be obtained by adopting drip irrigation. Among all the irrigation systems, the drip system results in the lowest CO_2 e, indicating maximum climate change mitigation potential in the minor irrigation sector of the region. Among the agroecosystems, it was found that the rainfed ecosystem of Telangana produces higher CO_2 e due to increased well density and pumping. Rice cultivation under tube well irrigation, particularly in Telangana may be discouraged in order to reduce CO_2 e and energy. Alternaively maize and suitable oilseeds, including groundnut may be encouraged wherever possible. The crops with lower water requirement and surface water resource development such as farm pond technologies should be promoted in the region to further reduce CO_2 e. The modern irrigation system and alternate cropping system may be popularized among the farmers by providing incentives for both water credits and carbon credits as per reduced CO_2 e so that the environment as well as the available water resources are protected.

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1. Rothausen, S. G. S. A. and Conway, D., Greenhouse-gas emissions from energy use in the water sector. *Nature Climate Change*, advance online publication, 2011, pp. 1–10; doi: 10.1038/Nclimate1147.
2. MoWR, Report on third census of minor irrigation schemes (2000–2001), Minor Irrigation Division, Ministry of Water Resources, Government of India, 2005.
3. Shah, T., Climate change and groundwater: India's opportunities for mitigation and adaptation. *Environ. Res. Lett.*, 2009, **4**, 035005 (1–13).
4. Jackson, T. M., Khan, S. and Hafeez, M., A comparative analysis of water application and energy consumption at the irrigated field level. *Agric. Water Manage.*, 2010, **97**(10), pp. 1477–1485; doi: 10.1016/j.agwat.2010.04.013.
5. Kumar, M., Kumar, N., Singh, K. P., Kumar, P., Srinivas, K. and Srivastva, A. K., Integrating water harvesting and gravity-fed microirrigation system for efficient water management in terraced land for growing vegetables. *Biosyst. Eng.*, 2009, **102**, 106–113.
6. Anbumozhi, V., Matsumoto, K. and Yamaji, E., Towards improved performance of irrigation tanks in semi-arid regions of India: modernization opportunities and challenges. *Irrig. Drain. Syst.*, 2001, **15**(4), 239–309.
7. Patil, R. K., Experiences of farmer participation in irrigation management: Mula command Maharashtra State, India. *Irrig. Drain. Syst.*, 1988, **2**(1), 21–41.
8. Srivastava, R. C., Verma, H. C., Mohanty, S. and Pattnaik, S. K., Investment decision model for drip irrigation. *Irrig. Sci.*, 2003, **22**, 79–85.
9. Zibaei, M. and Bakhshoodeh, M., Investigating determinants of sprinkler irrigation technology discontinuance in Iran: comparison of logistic regression and discriminant analysis. *Am-Eur. J. Agric. Environ. Sci. 2 (Suppl 1)*, 2008, **2**(1), 46–50.
10. Singh, A. K., Rahman, A., Sharma, S. P., Upadhyaya, A. and Sikka, A. K., Small holders' irrigation – problems and options. *Water Resour. Manage.*, 2009, **23**, 289–302.
11. Singh, A. K., Sharma, S. P., Rahman, A., Upadhyaya, A. and Sikka, A. K., Performance of low energy water application device. *Water. Resour. Manage.*, 2010, **24**, 1353–1362.
12. Nelson, G. C., Robertson, R., Msangi, S., Zhu, T., Liao, X. and Jawajar, P., Greenhouse gas mitigation: issues for Indian agriculture. In International Food Policy research paper, Environment and Production Technology Division, New Delhi, 2009.
13. Nelson, G. C. and Robertson, R., Estimating the contribution of groundwater irrigation pumping to CO_2 emissions in India. Technical report, International Food Policy Research Institute, 2008.
14. Shukla, P. R., Nair, R., Kapshe, M., Garg, A., Balasubramaniam, S., Menon, D. and Sharma, K. K., Development and climate: an assessment for India. A report submitted to UCCEE, Denmark by the Indian Institute of Management, Ahmedabad, 2003.
15. Zou, X., Li, Y., Li, K., Cremades, R., Gao, Q., Wan, Y. and Qin, X., Greenhouse gas emissions from agricultural irrigation in China. *Mitig. Adapt. Strat. Glob. Change*, 2013; doi: 10.1007/s11027-013-9492-9.
16. Sattenspiel, B. G. and Wilson, W., The carbon foot print of water, Technical report, River Network, May 2009.
17. Qureshi, A. S., Reducing carbon emissions through improved irrigation management: a case study from Pakistan. *Irrig. Drain*, 2014, **63**(1), 132–138.
18. Karimi, P., Qureshi, A. S. and Bahramloo, R., Reducing carbon emissions through improved irrigation and groundwater management: a case study from Iran. *Agric. Water Manage.*, 2012, **108**, 52–60.
19. Venu Gopal, K., Annual Report of State Groundwater Development Board, Hyderabad, 2012, p. 20.
20. Zou, X., Li, Y. E., Cremades, R., Gao, Q., Wan, Y. and Qin, X., Cost-effectiveness analysis of water-saving irrigation technologies based on climate change response: a case study of China. *Agric. Water Manage.*, 2013, **129**, 9–20.
21. Zou, X., Li, Y. E. and Gao, Q. Z., How water saving irrigation contributes to climate change resilience – a case study of practices in China. *Mitig. Adapt. Strategies – Global Change*, 2012, **17**, 111–132.
22. http://www.apsdps.ap.gov.in/apgmis_agri.html
23. Directorate of Economics and Statistics, 2012, Season and crop report, Government of Andhra Pradesh, Hyderabad.
24. Sanjeeva Reddy, B., Adake, R. V., Thyagarajan, C. R. and Srinivas Reddy, K., Utilization pattern of power sources on productivity of groundnut and cotton in dryland production systems. *J. Agric. Eng.*, 2009, **46**(4), 17–23.
25. CEA, Carbon emission baseline database for the Indian power sector. User Guide ver. 8.0, Ministry of Power, Government of India, New Delhi, 2013.
26. Lal, R., Carbon emission from farm operations. *Environ. Int.*, 2004, **30**, 981–990.
27. Veerendranath, G., *Vyavasaya Panchangam* (in Telugu language), Acharya N. G. Ranga Agricultural University, Hyderabad, 2012.
28. James, L. G., *Principles of Farm Irrigation System Design*, John Wiley, New York, USA, 1988.

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