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Impact of Water Management Options on Groundwater Draft, Energy Consumption and Carbon Emission in Different Districts of Bihar

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Abstract: The impact of different efficient water management options like sprinkler irrigation, drip irrigation, laser land levelling and raised bed planting for rice-wheat cropping system on ground water draft, energy consumption and carbon emission was studied for different districts of Bihar. The reduction in the total energy requirement under sprinkler irrigation system water management options in case-1(a), 1(b) and 1(c) (10 % , 20 % and 30 % of tube wellcomm and is converted from surface to sprinkler irrigation) were 5, 10 and 14%, respectively. The reduction in the total energy requirement under drip irrigation system water management options in case-2(a), 2(b) and 2(c) (10% 20 and 30 % of total tube well command is converted from surface to drip irrigation) were 8, 14.6 and 23.1% , respectively. The total carbon emission reduction under drip irrigation system water management options in case-2(a), 2(b) and 2(c) were 7.5, 15 and 22.5%, respectively. The reduction in the total energy requirement and carbon emission under laser land levelling water management options in case-3(a), 3(b) and 3(c) (If 10%, 20 % and 30 % of total irrigated area is levelled with laser land leveller) were 1.25, 2.5 and 3% respectively. The reduction in the total energy requirement under bed planting system water management options in case-4(a), 4(b) and 4(c) were 3.6, 8.5 and 12%, respectively. Among the different water management options, drip irrigation was most efficient for reduction in energy requirement and carbon emission for ground water pumping. The different water management options which included sprinkler, drip, laser land levelling and raised bed planting for rice-wheat cropping system can also be used as an alternative for a reduction in energy requirement and carbon emission for groundwater pumping.

Keywords: Carbon emission, Laser land levelling, Drip Irrigation, Sprinkler Irrigation

Groundwater is the country's most extracted resource with withdrawal rates currently in the estimated range of about 250 back per year, thereby putting India on the top of the World's biggest groundwater exploiting nations, being responsible for 25 % of total global abstraction (Sinha 2021). Groundwater irrigation plays an important role in increasing agricultural production and food security in India; however, declining groundwater results in an increase in energy consumption and carbon emission for groundwater lifting. About 88% of the total groundwater withdrawal in India is used for irrigation. Groundwater pumping for irrigation combined with the weakening of the Indian monsoon has resulted in widespread groundwater depletion in India in the last 20 years. The rate of abstraction in many regions is higher than groundwater recharge (Siebert et al 2010), causing recurrent water stress (Hanasaki et al 2008), persistent groundwater depletion (Gleeson et al 2010), and long-lasting impacts on stream flow, lakes, and wetlands (Wada et al 2010). The Indo-Gangetic plain and northwest India have experienced a severe decline in groundwater storage (Asoka et al 2017, Rodell et al 2009) and corresponds to one of the largest groundwater footprints in the world (Gleeson et al 2012).

Bihar state of eastern India has an area of 94163 km^2 with 60.5 per cent (5.696 m ha) area under crop cultivation at 144.7 per cent crop intensity. Irrigation potential through groundwater resources is a 3.48 million-hectare area. This may cover about 61 percent net sown area of state. Total availability of groundwater resources is 3.373-million-hectare meter with good quality for irrigation. Only 38 per cent of groundwater has been utilized. This shows high scope for further development. Sustainable groundwater management requires the practice of efficient water management options for reducing groundwater withdrawal. In state of Bihar most of the tube well commands are under surface irrigation. Water use efficiency in the case of surface irrigation is considerably low compared to pressurized irrigation systems such as sprinkler and drip irrigation (Chandra and Singh 2018, Koech and Langat 2018). Pressurized irrigation systems have the potential to avoid the water loss related to surface irrigation increasing the open irrigation application efficiency from 45-60% to pressurized irrigation with efficiency in the range of 75 -95%. Laser land levelling is an effective water saving tool in the new context of land use and ownership on smaller private plots. Abdulaev (2007) observed that laser land levelling can reduce the water application by 593m^3/ha, in 2005 by 1509m^3/ha in 2004 and in 2006 by 333m^3/ha in comparison with the unlevelled field, located in the similar agro-ecological conditions. The deep percolation was 8% lower and run off 24% less than in non-levelled field.

Irrigation is crucial for agricultural activities; however, if not managed well, it entails high water losses and can be inefficient in its application. The raised bed system is an improved surface irrigation strategy, which enhances water productivity and makes the application of water in irrigated systems more efficient (FAO 2016). Raised bed planting registered 40 to 50% saving in irrigation water (Chandra et al 2007). India is the world's largest groundwater user, withdraws about 230-billion-m³ groundwater annually for irrigation (Mishra et al 2018). Excessive groundwater pumping in India leads to rapid groundwater depletion and carbon emissions. The estimates show that groundwater irrigation emits 45.3–62.3 MMT of carbon annually, contributing 8–11% of India's total carbon emission (Rajan et al 2020). Food energy and water nexus is now a well-established fact and state like Bihar is energy deficient state. There are various viable water management technologies which can be useful in reducing the energy requirement and carbon emission. The objectives of this paper are to estimate (i) annual groundwater draft (ii) energy requirement associated with ground water pumping (iii) carbon emission associated with ground water pumping. The article also explains the impact of different efficient water management options on groundwater draft, energy requirement and carbon emission associated with groundwater pumping.

MATERIAL AND METHODS

General description of study area: Bihar is located in the eastern region of India between latitude 24°-20'-10" N ~ 27°-31'-15" N and longitude 83°-19'-50" E ~ 88°-17'-40" E. It is an entirely landlocked state, in a subtropical region of the temperate zone. Bihar lies between the humid West Bengal in the east and the sub humid Uttar Pradesh in the west, which provides it with a transitional position in respect of climate, economy and culture. It is bounded by Nepal in the north and by Jharkhand in the south. Bihar plain is divided into two unequal halves (North Bihar and South Bihar) by the river Ganges which flows through the middle from west to east.

GEC methodology: The method used for resource assessment is known as groundwater resource estimation methodology-1997(GEC-97). Fifth Minor Irrigation Census (reference year 2013–14) data were used for the calculation of energy consumption and carbon emission.

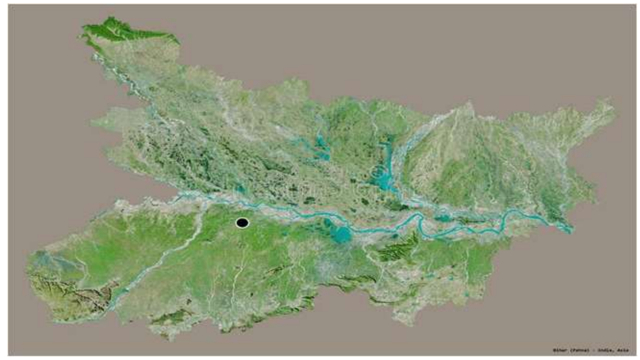

Fig. 1. Map of Bihar state

Estimation of annual draft (ha-m): The amount of ground water extracted from the tube well with the help of pumping unit is called ground water draft. The ground water draft was calculated by using the norms of GEC-1997 using unit draft as 0.6, 1.0, and 30.0 ha-m for dug wells, shallow tube wells and deep tube wells respectively. For medium tube wells, 4.0 ha m was considered as unit draft based upon the findings of sample tube well at RPCAU, Pusa. The annual draft was calculated by multiplying number of tube wells and unit draft.

Estimation of energy (kWh): The energy required for groundwater abstraction will be estimated as per the methodology provided by Rothausen and Conway(2011) which prescribes the energy required to lift 1 m^3 of water (with a density 1000 kg-m^{-3}) up 1m at 100% efficiency is 0.0027 kWh,

$$Energy(kWh) = \frac{9.8ms^{-2} \times lift(m) \times mass(kg)}{3.6 \times 10^6 \times efficiency(\%)} \quad (1)$$

In practice, the efficiency of this process is closer to 20 to 30 percent of theoretical maximum. Here 30 percent efficiency rate has been considered, the effective energy use in 9.080 kWh per thousand cubic meters of water lifted one meter vertically. All the district of Bihar selected for study and the standard lift for dug wells, shallow tube wells, medium and deep tube wells are 15, 30, 50 and 80 m respectively.

Estimation of carbon emission: The amount of carbon released to lift 1000 m^{3}of water one meter depends on source of energy. Diesel does not have a unique chemical formulation so the mass and carbon vary by mixture. A litre of standard diesel fuel contains approximately 0.85 kg carbon and energy content of approximately 10.01 kWh. Therefore, with diesel pump the amount of carbon released to lift 1000 m^3 of water one meter is 0.665 kg C (0.732*9.080/10.01). The ratio of carbon emission to energy content for diesel is 0.0732 kg C per kWh (Nelson and Robertson, 2008). The all India average value of 1.4894 kg of CO_2 per kWh at the station (0.4062 kg C per kWh) was used to estimate the release of CO_2 from electric pumps. With five percent transmission losses an effective carbon emission rate of 0.4265 kg C per kWh at the generating facility or 3.873 kg C to lift 1000 m^3upto one meter was used. The emission from coal based electricity is about 5.82 (3.873/0.665) times higher than the rate of emission with diesel pumps (Nelson et al 2009).

Efficient water management option for reduction in energy consumption and carbon emission: Different efficient water management options were considered for energy conservation and carbon emission reduction in Ground Water Pumping. The following water management scenarios were considered.

Case -1

If 10%, 20% and 30% of total tube well command area is converted from surface to sprinkler irrigation system and designated as 1a, 1b and1c

Case-2

If 10, 20 and 30% of total tube well command area is converted from surface to drip irrigation system and designated as 2a,2b and2c.

Case -3

If 10, 20 and 30% of total irrigated command area is leveled with laser land leveler and designated as 3a,3b and3c

Case-4

If 10, 20 and 30% of total irrigated command area is converted into bed planting system and designated as 4a,4b and5cImportant considerations

Important consideration:

- The total annual draft was reduced by 10, 20 and 30% respectively according to the case.
- The range of efficiency for the sprinkler irrigation system is 50-60%, but for this calculation, it was taken as 50%.
- The range of efficiency of drip irrigation system is 70-80%, but for this calculation, it was taken as 75%.
- Irrigation water savings under Precision Land Levelling versus traditional land leveling were 12–14% in rice and 10–13% in wheat (Jat et al 2006), but for this calculation, it was taken as 10%.
- 40 to 50% saving in irrigation water was recorded with Raised bed planting in comparison with flood irrigation of controlled plots (Ahmad and Mahmood 2005), but for this calculation, it was taken as 40%.

RESULTS AND DISCUSSION

Energy requirement and carbon emission due to pumping of groundwater from different irrigation structures: Estimated energy requirement in. The total energy requirement in ground water pumping was estimated to be 8256394 MWh for state of Bihar (Table 1). The lowest energy requirement for groundwater pumping was 44397 MWh for Banka district and highest energy requirement for

Table 1. Energy ('000' kWh) requirement and carbon emission (tonne) due to pumping of groundwater from different irrigation structures in different districts of Bihar

Districts	Energy ('000' kWh)	Carbon emission (Tonne)
Araria	93407	9145
Arwal	79286	7762
Aurangabad	190405	18641
Banka	44397	4346
Begusarai	266925	26132
Bhagalpur	74501	7294
Bhojpur	464755	45499
Buxar	52743	5164
Darbhanga	543512	53210
E.champaran	299943	29364
Gaya	303358	29699
Gopalganj	200461	19625
Jamui	58474	5725
Jehanabad	171842	16823
Kaimur	393017	38476
Katihar	196359	19224
Khagaria	332823	32583
Kishanganj	76124	7453
Lakhisarai	132086	12931
Madhepura	151960	14877
Madhubani	181101	17730
Munger	118017	11554
Muzaffarpur	399866	39147
Nalanda	845720	82796
Nawada	220079	21546
Patna	375224	36734
Purnia	79909	7823
Rohtas	86136	8433
Saharsa	51631	5055
Samastipur	541268	52990
Saran	314639	30803
Shekhpura	86729	8491
Sheohar	51609	5053
Sitamarhi	102705	10055
Siwan	106954	10471
Supaul	71141	6965
Vaishali	177612	17388
West Champaran	319676	31296
Total	8256394	808303

Table 2. Energy ('000' kWh) requirement for pumping of groundwater under efficient water management options of case 1a to case 1c (Sprinkler Irrigation)

Districts	Prevailing energy requirement	Case -1 (a)	Case -1 (b)	Case -1 (c)
Araria	93407	88736	84066	79396
Arwal	79286	75322	71358	67393
Aurangabad	190405	180884	171364	161844
Banka	44397	42177	39957	37737
Begusarai	266925	253579	240233	226887
Bhagalpur	74501	70776	67051	63326
Bhojpur	464755	441517	418279	395041
Buxar	52743	50106	47468	44831
Darbhanga	543512	516336	489160	461985
E.champaran	299943	284946	269949	254952
Gaya	303358	288190	273022	257854
Gopalganj	200461	190438	180415	170392
Jamui	58474	55550	52627	49703
Jehanabad	171842	163250	154658	146066
Kaimur	393017	373366	353715	334064
Katihar	196359	186541	176724	166906
Khagaria	332823	316182	299541	282900
Kishanganj	76124	72318	68511	64705
Lakhisarai	132086	125482	118877	112273
Madhepura	151960	144362	136764	129166
Madhubani	181101	172046	162991	153936
Munger	118017	112117	106216	100315
Muzaffarpur	399866	379873	359880	339887
Nalanda	845720	803434	761148	718862
Nawada	220079	209075	198071	187067
Patna	375224	356463	337702	318940
Purnia	79909	75914	71919	67923
Rohtas	86136	81829	77523	73216
Saharsa	51631	49049	46468	43886
Samastipur	541268	514205	487141	460078
Saran	314639	298907	283175	267443
Shekhpura	86729	82392	78056	73720
Sheohar	51609	49029	46448	43868
Sitamarhi	102705	97569	92434	87299
Siwan	106954	101606	96258	90910
Supaul	71141	67584	64027	60470
Vaishali	177612	168732	159851	150970
West Champaran	319676	303693	287709	271725
Total	8256394	7843575	7430756	7017936

Table 3. Energy ('000' kWh) requirement for pumping of groundwater under efficient water management options of Case- 2(a) to Case-2(c) (drip Irrigation)

Districts	Prevailing energy requirement	Case -1 (a)	Case -1 (b)	Case -1 (c)
Araria	93407	86401	79396	72390
Arwal	79286	73340	67393	61447
Aurangabad	190405	176124	161844	147563
Banka	44397	41067	37737	34408
Begusarai	266925	246906	226887	206867
Bhagalpur	74501	68914	63326	57739
Bhojpur	464755	429898	395041	360185
Buxar	52743	48787	44831	40876
Darbhanga	543512	502748	461985	421222
E.champaran	299943	277448	254952	232456
Gaya	303358	280606	257854	235102
Gopalganj	200461	185426	170392	155357
Jamui	58474	54088	49703	45317
Jehanabad	171842	158954	146066	133178
Kaimur	393017	363540	334064	304588
Katihar	196359	181632	166906	152179
Khagaria	332823	307861	282900	257938
Kishanganj	76124	70414	64705	58996
Lakhisarai	132086	122179	112273	102367
Madhepura	151960	140563	129166	117769
Madhubani	181101	167518	153936	140353
Munger	118017	109166	100315	91464
Muzaffarpur	399866	369877	339887	309897
Nalanda	845720	782291	718862	655433
Nawada	220079	203573	187067	170561
Patna	375224	347082	318940	290799
Purnia	79909	73916	67923	61930
Rohtas	86136	79676	73216	66756
Saharsa	51631	47758	43886	40014
Samastipur	541268	500673	460078	419483
Saran	314639	291041	267443	243845
Shekhpura	86729	80224	73720	67215
Sheohar	51609	47739	43868	39997
Sitamarhi	102705	95002	87299	79596
Siwan	106954	98932	90910	82889
Supaul	71141	65806	60470	55134
Vaishali	177612	164291	150970	137649
West Champaran	319676	295701	271725	247749
Total	8256394	7637162	7017936	6398708

Table 4. Energy ('000' kWh) requirement for pumping of groundwater under efficient water management options of Case- 3(a) to Case-3(c) (laser land levelling)

Districts	Prevailing energy requirement	Case -1 (a)	Case -1 (b)	Case -1 (c)
Araria	93407	92473	91539	90605
Arwal	79286	78494	77701	76908
Aurangabad	190405	188500	186596	184692
Banka	44397	43953	43509	43065
Begusarai	266925	264256	261587	258918
Bhagalpur	74501	73756	73011	72266
Bhojpur	464755	460107	455459	450812
Buxar	52743	52215	51688	51160
Darbhanga	543512	538077	532641	527206
E.champaran	299943	296944	293944	290945
Gaya	303358	300324	297290	294257
Gopalganj	200461	198456	196452	194447
Jamui	58474	57889	57304	56720
Jehanabad	171842	170124	168405	166687
Kaimur	393017	389086	385156	381226
Katihar	196359	194396	192432	190469
Khagaria	332823	329495	326167	322839
Kishanganj	76124	75362	74601	73840
Lakhisarai	132086	130765	129444	128123
Madhepura	151960	150440	148921	147401
Madhubani	181101	179290	177479	175668
Munger	118017	116837	115657	114477
Muzaffarpur	399866	395868	391869	387870
Nalanda	845720	837262	828805	820348
Nawada	220079	217878	215677	213476
Patna	375224	371472	367720	363967
Purnia	79909	79110	78311	77512
Rohtas	86136	85275	84414	83552
Saharsa	51631	51114	50598	50082
Samastipur	541268	535856	530443	525030
Saran	314639	311493	308346	305200
Shekhpura	86729	85862	84994	84127
Sheohar	51609	51093	50577	50061
Sitamarhi	102705	101678	100651	99624
Siwan	106954	105884	104814	103745
Supaul	71141	70430	69718	69007
Vaishali	177612	175836	174060	172284
West Champaran	319676	316480	313283	310086
Total	8256394	8173830	8091263	8008702

Table 5. Energy ('000' kWh) requirement for pumping of groundwater under efficient water management options of Case- 4(a) to Case-4(c) (Bed planting)

Districts	Prevailing energy requirement	Case -1 (a)	Case -1 (b)	Case -1 (c)
Araria	93407	89671	85934	82198
Arwal	79286	76115	72944	69772
Aurangabad	190405	182788	175172	167556
Banka	44397	42621	40845	39069
Begusarai	266925	256248	245571	234894
Bhagalpur	74501	71521	68541	65561
Bhojpur	464755	446164	427574	408984
Buxar	52743	50633	48523	46414
Darbhanga	543512	521771	500031	478290
E.champaran	299943	287946	275948	263950
Gaya	303358	291223	279089	266955
Gopalganj	200461	192442	184424	176405
Jamui	58474	56135	53796	51457
Jehanabad	171842	164969	158095	151221
Kaimur	393017	377296	361575	345855
Katihar	196359	188505	180651	172796
Khagaria	332823	319510	306197	292884
Kishanganj	76124	73079	70034	66989
Lakhisarai	132086	126803	121519	116236
Madhepura	151960	145881	139803	133725
Madhubani	181101	173857	166613	159369
Munger	118017	113297	108576	103855
Muzaffarpur	399866	383872	367877	351883
Nalanda	845720	811891	778062	744233
Nawada	220079	211276	202473	193669
Patna	375224	360215	345206	330197
Purnia	79909	76713	73517	70320
Rohtas	86136	82691	79245	75800
Saharsa	51631	49566	47500	45435
Samastipur	541268	519618	497967	476316
Saran	314639	302054	289468	276883
Shekhpura	86729	83260	79791	76321
Sheohar	51609	49545	47481	45416
Sitamarhi	102705	98597	94488	90380
Siwan	106954	102675	98397	94119
Supaul	71141	68296	65450	62604
Vaishali	177612	170508	163403	156299
West Champaran	319676	306889	294102	281315
Total	8256394	7926141	7595882	7265625

Table 6. Carbon emission (in tonnes) from pumping of groundwater under efficient water management options of Case- 1(a) to Case-2(c)

Districts	Prevailing carbon emission	Sprinkler irrigation			Drip irrigation		
		Case-1(a)	Case-1 (b)	Case-1 (c)	Case-2(a)	Case-2 (b)	Case-2 (c)
Araria	9145	17709	8230	7773	8459	7773	7087
Arwal	7762	7374	6986	6598	7180	6598	6016
Aurangabad	18641	17709	16777	15845	17243	15845	14446
Banka	4346	4129	3912	3694	4020	3694	3369
Begusarai	26132	24825	23519	22212	24172	22212	20252
Bhagalpur	7294	6929	6564	6200	6747	6200	5653
Bhojpur	45499	43224	40950	38675	42087	38675	35262
Buxar	5164	4905	4647	4389	4776	4389	4002
Darbhanga	53210	50549	47889	45228	49219	45228	41238
E.champaran	29364	27896	26428	24960	27162	24960	22757
Gaya	29699	28214	26729	25244	27471	25244	23017
Gopalganj	19625	18644	17663	16681	18153	16681	15209
Jamui	5725	5438	5152	4866	5295	4866	4437
Jehanabad	16823	15982	15141	14300	15562	14300	13038
Kaimur	38476	36553	34629	32705	35591	32705	29819
Katihar	19224	18262	17301	16340	17782	16340	14898
Khagaria	32583	30954	29325	27696	30140	27696	25252
Kishanganj	7453	7080	6707	6335	6894	6335	5776
Lakhisarai	12931	12285	11638	10992	11961	10992	10022
Madhepura	14877	14133	13389	12645	13761	12645	11530
Madhubani	17730	16843	15957	15070	16400	15070	13741
Munger	11554	10976	10399	9821	10687	9821	8954
Muzaffarpur	39147	37190	35232	33275	36211	33275	30339
Nalanda	82796	78656	74516	70377	76586	70377	64167
Nawada	21546	20468	19391	18314	19930	18314	16698
Patna	36734	34898	33061	31224	33979	31224	28469
Purnia	7823	7432	7041	6650	7236	6650	6063
Rohtas	8433	8011	7589	7168	7800	7168	6535
Saharsa	5055	4802	4549	4296	4676	4296	3917
Samastipur	52990	50341	47691	45042	49016	45042	41067
Saran	30803	29263	27723	26183	28493	26183	23872
Shekhpura	8491	8066	7642	7217	7854	7217	6580
Sheohar	5053	4800	4547	4295	4674	4295	3916
Sitamarhi	10055	9552	9049	8547	9301	8547	7792
Siwan	10471	9947	9424	8900	9685	8900	8115
Supaul	6965	6616	6268	5920	6442	5920	5398
Vaishali	17388	16519	15649	14780	16084	14780	13476
West Champaran	31296	29732	28167	26602	28949	26602	24255
Total	808303	776906	727471	687056	747678	687056	626433

Table 7. Carbon emission (in tonnes) from pumping of groundwater under efficient water management options of Case- 3(a) to Case-4(c)

Districts	Prevailing carbon emission	Sprinkler irrigation			Drip irrigation		
		Case-1(a)	Case-1 (b)	Case-1 (c)	Case-2(a)	Case-2 (b)	Case-2 (c)
Araria	9145	9053	8962	8870	8779	8413	8047
Arwal	7762	7685	7607	7529	7452	7141	6831
Aurangabad	18641	18454	18268	18081	17895	17149	16404
Banka	4346	4303	4260	4216	4173	3999	3825
Begusarai	26132	25871	25609	25348	25087	24041	22996
Bhagalpur	7294	7221	7148	7075	7002	6710	6418
Bhojpur	45499	45044	44589	44134	43680	41860	40040
Buxar	5164	5112	5060	5009	4957	4750	4544
Darbhanga	53210	52678	52146	51613	51081	48953	46825
E.champaran	29364	29071	28777	28484	28190	27015	25841
Gaya	29699	29402	29105	28808	28511	27323	26135
Gopalganj	19625	19429	19233	19036	18840	18055	17270
Jamui	5725	5667	5610	5553	5496	5267	5038
Jehanabad	16823	16655	16487	16319	16150	15477	14805
Kaimur	38476	38092	37707	37322	36937	35398	33859
Katihar	19224	19031	18839	18647	18455	17686	16917
Khagaria	32583	32258	31932	31606	31280	29977	28673
Kishanganj	7453	7378	7303	7229	7154	6856	6558
Lakhisarai	12931	12802	12673	12543	12414	11897	11379
Madhepura	14877	14728	14579	14431	14282	13687	13092
Madhubani	17730	17552	17375	17198	17021	16311	15602
Munger	11554	11438	11323	11207	11092	10630	10167
Muzaffarpur	39147	38755	38364	37973	37581	36015	34449
Nalanda	82796	81968	81140	80312	79484	76172	72860
Nawada	21546	21330	21115	20899	20684	19822	18960
Patna	36734	36367	36000	35632	35265	33796	32326
Purnia	7823	7745	7667	7588	7510	7197	6884
Rohtas	8433	8348	8264	8180	8095	7758	7421
Saharsa	5055	5004	4954	4903	4852	4650	4448
Samastipur	52990	52460	51930	51400	50871	48751	46631
Saran	30803	30495	30187	29879	29571	28339	27107
Shekhpura	8491	8406	8321	8236	8151	7811	7472
Sheohar	5053	5002	4952	4901	4850	4648	4446
Sitamarhi	10055	9954	9854	9753	9653	9250	8848
Siwan	10471	10366	10261	10157	10052	9633	9214
Supaul	6965	6895	6825	6756	6686	6408	6129
Vaishali	17388	17214	17040	16867	16693	15997	15302
West Champaran	31296	30983	30670	30357	30045	28793	27541
Total	808303	800218	792135	784052	775969	743637	711305

groundwater pumping was 845720 MWh for Nalanda district. The total carbon emission from pumping of groundwater for the whole state was 808301 tonne. Nalanda contributes highest to carbon emission followed by Darbhanga and Samastipur. The lowest carbon emission was for Banka district. The groundwater development in hard rock areas like Banka, Kishanganj and Jamui districts of Bihar are difficult and aquifer storage capacity is limited.

Impact of efficient water management options on energy requirement and carbon emission.

Case-1 If 10 , 20 and 30 % of tube well command area is converted from surface to sprinkler irrigation system: The reduction in the total energy requirement under sprinkler irrigation system water management options in case-1(a), case-1(b) and case-1(c) were 5, 10 and 14% respectively. The total carbon emission reduction under sprinkler irrigation system water management options in case-1(a), 1(b) and -1(c) were 4, 10 and 15%, respectively. Sprinkler Irrigation can be a useful irrigation method for crop like wheat, mustard, pulses. Sprinkler irrigation coupled with underground pipeline may further reduce energy requirement and carbon emission.

Case-2. If 10, 20 and 30 % of tube well command area is converted from surface to drip irrigation system: The reduction in the total energy requirement under drip irrigation system water management options in case 2(a), 2(b) and 2(c) were 8, 14.6 and 23.1%, respectively. The total carbon emission reduction under drip irrigation system water management options in case-2(a), 2(b) and (c) were 7.5, 15 and 22.5%, respectively. Drip irrigation can be useful irrigation method for vegetables, fruits, sugarcane, rabi maize etc. This study clearly indicates the% importance of micro irrigation in reducing ground water use, energy requirement and carbon emission.

Case-3. If 10, 20 and 30 % of tube well irrigated area is levelled with laser land leveller: This scenario includes three case 5% (3a), 20% (3b) and 30 % (3c) of tube well irrigated area is levelled with laser land leveller. The reduction in the total energy requirement under laser land levelling water management options in case 3(a), 3(b) and 3(c) were 1.25, 2.5 and 3%, respectively. The reduction in carbon emission under laser land levelling water management options in case 3(a), 3(b) and 3(c) were 1, 2and 2.5%, respectively.

Case-4. If 10, 20 and 30 % of tube well irrigated area is converted into bed planting cultivation system: In this system, the land is prepared conventionally and raised bed and furrows are prepared manually or using a raised bed planting machine. Crops are planted in rows on top of the raised beds and irrigation water is applied in the furrows between the beds.

If 10, 20 and 30 % of tubewell irrigated area is of converted into bed planting cultivation system reduction in the total energy requirement under bed planting system water management options in were 3.6. 8.5 and 12% , respectively. The total carbon emission reduction under bed planting system water management options in case 4(a), 4(b) and 4(c) were 3.7, 7.5 and 11%, respectively. Resource conservation technology are one of the important mechanism through which water use, energy use and carbon emission can be reduced for rice-wheat cropping system.

CONCLUSIONS

This study gives us insight for sustainable groundwater resource management along with energy management in agriculture. Among the different water management options, drip irrigation was most efficient for reduction in energy requirements and carbon emissions for groundwater pumping. The different water management options which included sprinkler, drip, laser land levelling and raised bed planting for rice-wheat cropping system can also be used as an alternative for a reduction in energy requirement and carbon emission for groundwater pumping. Climate resilient agriculture approach is required for efficient water, energy, and resource management. The combination of policies to optimize energy and water use in agriculture is required to respond to these hydro-climatic challenges.

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