

INDIAN SOCIETY OF WATER MANAGEMENT

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- ii) To promote basic and applied research and training in water management
- iii) To disseminate the information on scientific and technological aspects of water management
- iv) To arrange Symposia/Workshops/Seminars on specific aspects of water management
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Studies on Soil Nutrient Movement and Chemical Properties of soil as Influenced by Fertigation to Bt. Cotton

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ABSTRACT

The experiment was laid out with eight treatments replicated three times in randomized block design including surface irrigation along with two sources of fertilizers (water soluble fertilizers and conventional fertilizers), three levels of fertilizers (75, 100 and 125 per cent RD of WSF) as per schedule B and two other schedules i.e. schedule A and schedule C used for apportioning of fertilizers. The soil VerticInceptisol, clayey in texture with pH 8.03, EC 0.24 dSm⁻¹, organic carbon 0.45 per cent, low in available N, moderate in available P and high in available K content with 90 cm depth. The plant height, leaf area, number of bolls per plant, monopodial and sympodial branches were higher in the paired row planting with 125 per cent recommended dose of water soluble fertilizers with schedule B. The nutrient mobility was higher due to WSF as compared to CF and all the other treatments. The available N and K moved in soil 30 cm laterally and vertically while available P moved upto 15 cm both laterally and vertically from the emitter. The availability of N, P and K was significantly influenced by the treatments, indicating increase in availability of these nutrients due to water soluble fertilizer applied through schedule B with 125 per cent recommended dose of fertilizer than CF. Fertigation with water soluble fertilizers resulted into 61.66 and 55.18 per cent more seed cotton and cotton seed yield, respectively than the conventional method of irrigation and fertilizer application. Similarly, the yield of seed cotton and cotton seed 17.77 and 16.53 per cent, respectively was more in WSF than CF. Application of 75 per cent RD of fertilizer through water soluble fertilizer could produce more yield than surface irrigation with 100 per cent RD through conventional fertilizers. Paired row planting of Bt. cotton (0.75 – 1.5 x 0.75 m) with application of water soluble fertilizer through apportioning as per schedule B through drip irrigation can help in increasing the yields, saving of fertilizers upto 25 per cent, maintain soil fertility and have maximum movement of nutrients in soil under Inceptisol.

Key words: Fertigation, Bt.cotton, drip irrigation, paired row, water soluble fertilizers

The area under cotton in India is estimated to be 9.58 million ha with the production and productivity of cotton being 10.65 mt ha⁻¹ and 568.00 kg ha⁻¹ during 2009-10, while Maharashtra occupies the first position in India in respect of cotton during 2009-10 with an area of 35.03 lakh ha and second in cotton production 61.00 lakh bales of 170 kg after Gujrat. The average productivity of cotton in the state was 296 kg ha⁻¹ during 2009-10 (Anonymous, 2009). The scarcity of irrigation water and moisture stress leads to low productivity of crops. Next to water, plant nutrients like N, P and K are the most critical factors which seriously limit the growth, quality and yield of crop. Hence, judicious use of both water and fertilizer are the key factors for boosting up production and productivity of crop. In fertigation water and fertilizer

are applied in the vicinity of root zone of crop to achieve maximum productivity. Nutrient availability has direct bearing on yield, so it can be managed in a better way by fertigation through drip. Thus, it is today's prime need to apply water and fertilizers directly to crop root zone through drip irrigation which is an answer to judicious productivity management programme. A great deal of work has been carried out on fertigation on various horticultural crops, but while, reviewing the literature it is noticed that very meager work has been done on Bt. cotton with respect to fertigation as well as on nutrient mobility and use efficiency of the applied fertilizers. In view of the above it was felt appropriate to undertake study on fertigation to monitor their effects on soil nutrient movement and balance and yield of Bt. Cotton.

MATERIALS AND METHODS

A field experiment was conducted at the farm of Interfaculty Department of Irrigation Water Management, Mahatma PhuleKrishiVidyapeeth, Rahuri (Maharashtra) during summer. The experiment on Bt. Cotton (var. Rashi-2) was laid out in randomized block design with eight treatments replicated three times including surface irrigation with normal and paired row planting alongwith two sources of fertilizers (water soluble fertilizers and conventional fertilizers), three levels of fertilizers (75, 100 and 125 per cent RD of WSF) as per schedule B and two other schedules i.e. schedule A and schedule C used for apportioning of fertilizers (**Table 1**). The soil VerticInceptisol, clayey in texture with pH 8.03, EC 0.24 dSm⁻¹, organic carbon 0.45 per cent, low in

Table 1. Fertilizer schedules of water soluble fertilizers (nutrients in kg/ha) in equal weekly splits during specified duration.

Schedule A			
DAP	N (kg/ha)	P (kg/ha)	K (kg/ha)
1-10	–	–	–
11-30	46	00	00
31-65	59	36	36
66-80	35	12	12
81-100	07	00	23
Total	147	48	71
Schedule B			
1-10	-	-	-
11-30	24	12	06
31-60	48	30	24
61-100	48	18	30
100-150	-	-	-
Total	120	60	60
Schedule C			
1-10	-	-	-
11-30	75	00	00
31-65	24	24	24
66-80	07	23	07
81-100	04	00	13
Total	110	47	44

available N, moderate in available P and high in available K content with 90 cm depth. The soil had Hydraulic conductivity 0.15 cm hr⁻¹ , Bulk density 1.27Mg m⁻³, Infiltration rate 7.0 (Cm hr⁻¹), Field capacity 42.89%, Permanent wilting point 21.13%, Available soil moisture 21.76%. The soil and plant samples were analysed for different parameters before and after the harvest of the crops by using standard methods of analysis as mentioned by Jackson (1973).

The required quantity of irrigation water through drip was computed on the basis of CPE, pan factor and crop coefficient. The plots were irrigated on alternate days through drip for both sources of fertilizers and 75 mm CPE in the surface method treatments. The conventional fertilizers like urea and the different grades of water soluble fertilizers like 19:19:10, 0:52:34, 13:0:45 and 0:0:50 were used for fertigation. For conventional fertilizer application of N was done through urea while P and K were added through single super phosphate and muirate of potash, respectively. The biometric and yield observations viz., plant height, leaf area, number of bolls per plant, monopodial and sympodial branches , cotton yield, seed cotton yield and ginning percentage were recorded.

RESULTS AND DISCUSSION

The plant height, number of sympodia, monopodia and bolls per plant and the leaf area were more in the paired row planting (0.75 – 1.50 x 0.75 m) than normal planting (SI 0.9 x 0.9 m). As far as, levels and sources of fertilizers are concerned, application of 125 per cent recommended dose of WSF level with schedule B resulted in more plant height, number of monopodium, sympodium and bolls and leaf area (**Table 2**). Application of 75 per cent RD through water soluble fertilizers was superior to the treatment with surface irrigation and 100 per cent RD through conventional fertilizers. Similar results were also obtained by Kadam (1997) after application of liquid fertilizer to cotton crop.

The maximum seed cotton and cotton seed yield was obtained (52.33 and 32.65 q ha⁻¹) in 125 per cent RD of WSF with plant spacing 0.75-1.50 x 0.75 m and were 61.66 and 55.18 per cent, respectively more than the conventional method of application of fertilizers and irrigation (**Table 2**). Similarly, the yield

Table 2. Effect of fertigation on growth and yield parameters of Bt. Cotton

Treatments	Plant height (cm) at 120 DAP	Monopodium branches	Sympodium branches	No. of bolls per plant	Leaf area (dm ²)	Seed cotton yield (q ha ⁻¹)	Seed yield (q ha ⁻¹)	Ginning (%)
SI (NP-0.9 x 0.9 m) with CF	153.47	11.57	20.40	73.03	43.02	32.37	21.04	35.00
DI (PRP- 0.75 – 1.5 x 0.75 m) with CF	168.26	14.30	24.30	94.67	47.56	41.18	26.91	34.65
DI (N through drip P and K through soil at 0.75 – 1.5 x 0.75 m)	167.10	13.93	23.40	91.36	47.68	43.43	28.97	33.29
DI (PRP 0.75 – 1.5 x 0.75 m) with WSF as per schedule A	162.17	13.67	22.00	84.23	43.64	36.13	23.25	35.64
DI (PRP 0.75 – 1.5 x 0.75 m) with 75 % of RD of WSF as per schedule B	186.60	15.13	26.13	89.10	47.08	44.17	28.41	36.37
DI (PRP 0.75 – 1.5 x 0.75 m) with 100 % of RD of WSF as per schedule B	193.13	15.57	26.90	102.20	53.75	48.50	31.36	35.34
DI (PRP 0.75 – 1.5 x 0.75 m) with 125 % of RD of WSF as per Schedule B	204.23	17.43	30.27	120.10	56.66	52.33	32.65	37.60
DI (PRP 0.75 – 1.5 x 0.75 m) with WSF as per schedule C	183.10	16.23	29.67	95.07	51.59	47.06	29.99	36.27
S.E.±	2.21	0.15	0.27	0.17	0.76	0.15	0.81	0.41
C.D. at 5 %	6.62	0.45	0.81	0.51	2.28	0.46	2.42	0.87

RDF – Recommended dose of fertilizer; CF- Conventional fertilizer; WSF- Water Soluble Fertilizer; SI-Surface irrigation; DI-Drip irrigation.

Table 3. Nutrient movement as influenced by irrigation and fertigation.

Treatments	N movement (cm)		P movement (cm)		K movement (cm)	
	Lateral	vertical	Lateral	vertical	Lateral	vertical
SI (NP-0.9 x 0.9 m) with CF	0-15	0-15	15-30	0-15	30	30
DI (PRP- 0.75 – 1.5 x 0.75 m) with CF	15-30	15-30	15-30	0-15	30	30
DI (N through drip P and K through soil at 0.75 – 1.5 x 0.75 m)	30	30	30	30	30	30
DI (PRP 0.75 – 1.5 x 0.75 m) with WSF as per schedule A	30	30	30	30	30	30
DI (PRP 0.75 – 1.5 x 0.75 m) with 75 % of RD of WSF as per schedule B	30	30	30	30	30	30
DI (PRP 0.75 – 1.5 x 0.75 m) with 100 % of RD of WSF as per schedule B	30	30	30	30	30	30
DI (PRP 0.75 – 1.5 x 0.75 m) with 125 % of RD of WSF as per Schedule B	30	30	30	30	30	30
DI (PRP 0.75 – 1.5 x 0.75 m) with WSF as per schedule C	30	15-30	30	30	30	30

of seed cotton and cotton seed was more in WSF (17.77 and 16.53 %) than CF. Application of 75 per cent of RD of fertilizer through water soluble fertilizers produced more yield of cotton and cotton seed as compared to surface irrigation with 100 per cent RD through conventional fertilizers. Paired row planting of cotton (0.75 – 1.5 x 0.75 m) with application of water soluble fertilizer by apportioning of fertilizers as per schedule B through drip irrigation can help in increasing the yields, saving of fertilizers upto 25 per cent, maintain soil fertility and have maximum movement of nutrients in soil than surface irrigation with conventional fertilizers under planting of cotton crop in Inceptisol. Similar results were also reported by Bhakare and Fatkal (2008).

The overwhelming performance of drip irrigation and WSF over surface irrigation and CF was due to the application of adequate quantity of water and fertilizers at right time at right place, which has resulted in sufficient moisture content and distribution of nutrients in root zone. The soil remains moist and soft because of alternate day irrigation. The optimum moisture and fertilizers has promoted effect on physiological process like cell division and expansion of cell component, turgidity and nutrient uptake that resulted in higher plant growth. Through drip irrigation,

splitting of fertilizers was done due to this nutrient losses through leaching and volatilization were less and easily available to plant root zone. This ultimately increased plant growth rate and yield of cotton as compared to conventional fertilizer, which was also pointed out by Dhonde and Bangar (1998) and Mahajan and Singh (2006).

Nutrient movement (**Table 3**) influenced to greater extent due to water and fertilizer application methods. Lateral and vertical movement was found to be upto 15 cm when water was applied through ridges and furrows. In drip methods, the N movement was upto 15-30 cm, whereas it was upto 30 cm when fertilizers were applied through drip in the form of water soluble fertilizers. The lateral and vertical movement of P was less than 15 cm under conventional method of irrigation and fertigation. The lateral movement was improving to 15-30 cm under drip irrigation with conventional fertilization, but vertical movement under drip treatment remained at 15 cm. In drip irrigation coupled with fertigation treatment (T5 to T8) the lateral and vertical movement of P fertilizer was found to be improved to 30 cm. The lateral and vertical movement of K was found to upto 30cm.

Table 4. Balance sheet (kg ha⁻¹) of nutrients after harvest of crop as influenced by different treatments

Treatment	Nutrient applied during season (kg/ha)			Nutrient uptake (kg/ha) by crop during season			Soil available nutrient after harvest of crop			Net soil nutrient balance		
	N	P	K	N	P	K	N	P	K	N	P	K
T1 SI (NP-0.9 x 0.9 m) with conventional fertilizers	120	60	60	166.17	31.33	50.32	147	19.16	462	43.17	-28.11	126.32
T2 DI (PRP- 0.75 – 1.5 x 0.75 m) with conventional fertilizers	120	60	60	229.39	42.06	79.02	154	20.50	472	113.39	-16.04	165.02
T3 DI (N through drip P and K through soil at 0.75 – 1.5 x 0.75 m)	120	60	60	277.38	45.09	81.53	160	20.70	474	167.38	-12.81	169.53
T4 DI (PRP 0.75 – 1.5 x 0.75 m) with water soluble fertilizers as per schedule A	147	48	71	200.10	37.79	67.79	162	24.17	480	65.10	-4.64	150.79
T5 DI (PRP 0.75 – 1.5 x 0.75 m) with 75 % of RD of WSF as per schedule B	90	45	45	256.17	50.73	83.77	160	23.50	473	178.50	-10.63	185.77
T6 DI (PRP 0.75 – 1.5 x 0.75 m) with 100 % of RD of WSF as per schedule B	120	60	60	297.46	56.32	93.24	168	26.93	477	195.46	4.65	184.24
T7 DI (PRP 0.75 – 1.5 x 0.75 m) with 125 % of RD of WSF as per Schedule B	150	75	75	345.46	62.81	101.37	171	7.78	486	216.46	-3.01	186.37
T8 DI (PRP 0.75 – 1.5 x 0.75 m) with WSF as per schedule C	110	47	44	267.87	51.49	85.07	154	26.43	470	161.87	12.32	185.07

Initial status of soil- Av. N-150, Av.P-18.60, Av. K-326 Kg ha⁻¹; RDF – Recommended dose of fertilizer; CF- Conventional fertilizer; WSF- Water Soluble Fertilizer; SI-Surface irrigation; DI- Drip irrigation

The data in **Table 4** regarding nutrient balance at the harvest of crop has revealed that the results are variable due to different treatments of levels and sources of fertilizers. It was observed that the treatment with application of highest fertilizer with water soluble fertilizers had more residual N and K while it was negative for P. It was also observed that the water soluble fertilizer treatments had more nutrient balance than the treatments with surface irrigation and conventional fertilizers. The nutritional aspects are very clear from the treatments that the drip irrigation with water soluble fertilizers have got more nutrient availability as compared to conventional fertilizers, because of which at harvest the values of residual balance is also more due to easy dissolution in the soil complex. These results are in conformity to those obtained by Zhenan *et al.* (2007).

CONCLUSION

Paired row planting of cotton (0.75 – 1.5 x 0.75 m) with application of water soluble fertilizers and apportioning them as per schedule B through drip irrigation (fertigation) can help in increasing the yields, saving of fertilizers upto 25 per cent, maintain soil fertility and have maximum movement of nutrients in soil than surface irrigation with conventional fertilizers under planting of Bt. cotton crop in Inceptisol.

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Effect of Phosphorus on Soybean and Crop Residue Management, Irrigation Schedule and Nitrogen Level in Succeeding Wheat Crop in Soybean-Wheat Cropping System

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ABSTRACT

Experiments were conducted at Research Farm of Water Technology Centre, Indian Agricultural Research Institute, New Delhi during 2003-4 to 2006-07 on soybean- wheat cropping system. During rainy (*kharif*) season soybean (Var. DS7812) was grown under rainfed condition with four levels of phosphorus i.e. 0, 25, 50 and 75 kg P₂O₅/ha. The experiment was laid out in randomized block design with three replications. While in winter (*rabi*) season irrigated wheat (Var. HD2687) was sown and the treatments consisted of four levels of irrigation viz, 2 irrigations each at CRI and flowering, IW/CPE (0.9), soil moisture depletion using tensiometer and 5 irrigations each at CRI, late jointing, milk and grain filling stages and for levels of nitrogen i.e. 0, 50, 100 and 150 kg N/ha. These treatments were tested under both residue of *kharif* soybean soil incorporated and removed conditions. The experiment during *rabi* seasons were laid out in split plot design with three replications keeping residue management and irrigation schedule in main plots and N levels in sub-plots. Results revealed that the response of soybean for P application was up to 50kg and thereafter addition of P did not bring significant increase in seed yield and other yield attributes. Similarly, incorporation of soybean biomass produced significant effect on grain yield of successive wheat irrespective of the irrigation and phosphorus level than residue removed. However, response of residue incorporation was more with higher levels of P and irrigation than lower level. Moisture extraction pattern suggested that residue incorporation helped in retaining slightly more moisture in upper soil layers compared to residue removed. The water use efficiency was higher with 75kgP₂O₅/ha in case of soybean while in wheat it was higher with of—. The nutrient status of the soil after soybean harvest as well as wheat was slightly higher than the initial soil status due to the inclusion of soybean in crop rotation.

Key words: Crop residue, moisture extraction pattern, water use, water use efficiency

Diversification of rice-wheat system in Indo-Gangetic plains has led to the options of several pulse and oilseed crops as potential substitute for rice. Crop rotation increases the yield and profit, and allows for sustainable production especially with the inclusion of pulses. The substitution of rice with crops like soybean proves to be more promising owing to improved productivity of the succeeding crop. Soybean has occupied a prominent niche in oilseed production in India. Use of phosphatic fertilizers in soybean is known to increase the availability and improve the nodulation resulting in improved biomass. Wheat is the most important crop in a crop sequence occupying a very large area in India. Continuing rice-wheat system has resulted in almost stagnation of wheat productivity. Therefore, there is an urgent need to

include pulses in the crop rotation to sustain the productivity of the system to some extent. Both soybean and wheat crop responds to phosphorus application, however a major part of P remains unutilized by the first crop. Similarly, incorporation of green manure not only improves the soil health but also the yield of second crop. Therefore, an attempt was made to evaluate the effect of P on soybean under rain-fed and its residual effect, irrigation schedule and nitrogen level in wheat under both incorporation and removal of soybean residues.

MATERIALS AND METHODS

A field experiment was conducted at Research Farm of Water Technology Centre, Indian Agricultural Research Institute, New Delhi located at 28°48'N

latitude and 77012'E longitude at an altitude of 228.61 above mean sea level during the year 2003 to 2006 on soybean and wheat cropping system. The soil of the experimental field was sandy loam in texture with pH 7.4, low in organic carbon 0.35, available N (153kg/ha), medium in available P (15 kg/ha) and high in available K (372 kg/ha). During rainy (*kharif*) season soybean (Var. DS7812) was grown under rain-fed condition with four levels of phosphorus i.e. 0, 25, 50 and 75 kg P₂O₅/ha. Soybean 'DS7812' was sown in rows 30cm apart. The experiment was laid out in randomized block design with three replications. After harvest of soybean, the plots were harrowed down twice without much disturbing the previous layout and winter (*rabi*) wheat (Var. HD2687) was sown. The treatments consisted of four irrigation schedules viz. IW/CPE ratio of 0.9, as per soil moisture depletion using tensiometer, 2 irrigations each at CRI and flowering, and 5 irrigations each at CRI, late jointing, flowering, milk and grain filling stages and four levels of nitrogen i.e. 0, 50, 100 and 150 kg N/ha. These treatments were tested under both type of residue management i.e. incorporated and removed conditions. The experiment during rabi seasons was laid out in

split plot design with three replications keeping residue management and irrigation schedule in main plots and N levels in sub-plots. As per the treatment one third N and full P and K were applied basal and remaining N was applied in two equal splits. Total water use was worked out taking into the consideration of effective rainfall, irrigation water applied and soil profile contribution during the experimentation and the water use efficiency is expressed as the ratio of economic yield to water used during the crop period. Data for all the three years were averaged out, statistically analyzed and have been presented.

RESULTS AND DISCUSSIONS

Productivity of soybean

Phosphorus application significantly influenced the growth, nodulation, yield attributes and yield of soybean over control (**Table1**). Plant height, nodules/plant, number of branches/plant, LAI, nodules/plant and their dry weight showed increasing trend with the application of P than control. Successive increase in P levels up to 50kg/ha had significant effect on all the crop parameters. However, there was no significant

Table 1. Plant growth and nodulation of soybean as influence of phosphorus level (average of 3 years)

Treatment (P ₂ O ₅ kg/ha)	Plant height (cm)	No. of branches	LAI	Nodule/plant	Nodule dry weight, mg/plant
0	50.5	5.0	6.2	39	359
25	53.2	5.2	6.85	56	525
50	53.4	6.0	8.64	64	596
75	55.0	7.8	8.82	65	603
CD (P=0.05)	2.2	0.5	0.43	09	17

Table 2. Influence of phosphorus on yield and yield attributes of soybean (average of 3 years)

Treatment (P ₂ O ₅ kg/ha)	Pods/plant	Grains/plant	1000-seed weight, g	Grain yield, kg/ha	Biological yield, kg/ha
0	85	2.5	105.2	1124	3112
25	105	2.6	106.4	1565	4365
50	114	3.0	106.8	1915	4650
75	118	3.0	105.8	2032	5234
CD (P=0.05)	03	NS	0.43	127	204

Table 3. Available N, P and K in the soil after soybean harvest as influenced by P Level (average of 3 years)

Treatment (P ₂ O ₅ kg/ha)	N	P kg/ha	K
0	230	18.6	210
25	228	18.9	208
50	222	19.9	206
75	212	19.2	202
CD (P=0.05)	07	0.5	05

difference between 50 and 75kg P/ha. Application of P increased its availability resulting in better nodulation, plant growth, yield contributing characters and there by the seed yield of soybean than control (**Table 2**). Similar findings were also reported by Ghanshyam *et al.* (2004) and Sharma and Vyas (2001). Nutrient status of the soil after soybean harvest was significantly influenced by phosphorus application. Since the soybean is the leguminous crop and it responded to P application resulting in both root and shoots and in turn higher soil nutrient status (**Table 2**).

Residual and Direct effect on Productivity of wheat

Incorporation of crop residue had a significant effect on wheat yield irrespective of the irrigation scheduled followed compared to residue removed (**Table 4**). The nutrient sources due to slow and gradual decomposition showed residual effect and thus helped in improving the yield and yield attributes of succeeding wheat after soybean in case of crop residue incorporation. However, the response of residue management was more under assured irrigation water supply as compared to limited supply situation. Upadhyay (2003) also observed such residual effects of organic and inorganic sources of nutrients. Irrigation regimes had a significant effect on grain yield of wheat under both residue incorporation and residue removal of previous crop (**Table 3**). Nevertheless, it was found that 2 irrigations applied at CRI and flowering gave significantly less yield as compared to 5 irrigations applied either by critical stages of crop or by soil moisture depletion or IW/CPE ratio of 0.9 which is recommended for this region. Irrigation helped in producing more effective tillers and ear length which significantly contributed towards total grain yield and these yield attributes were significantly correlated with grain yield (**Fig. 1& 2**; R² 0.84 and 0.82

Table 4. Grain yield (kg/ha) of wheat as influenced by crop residue, irrigation schedule and N level

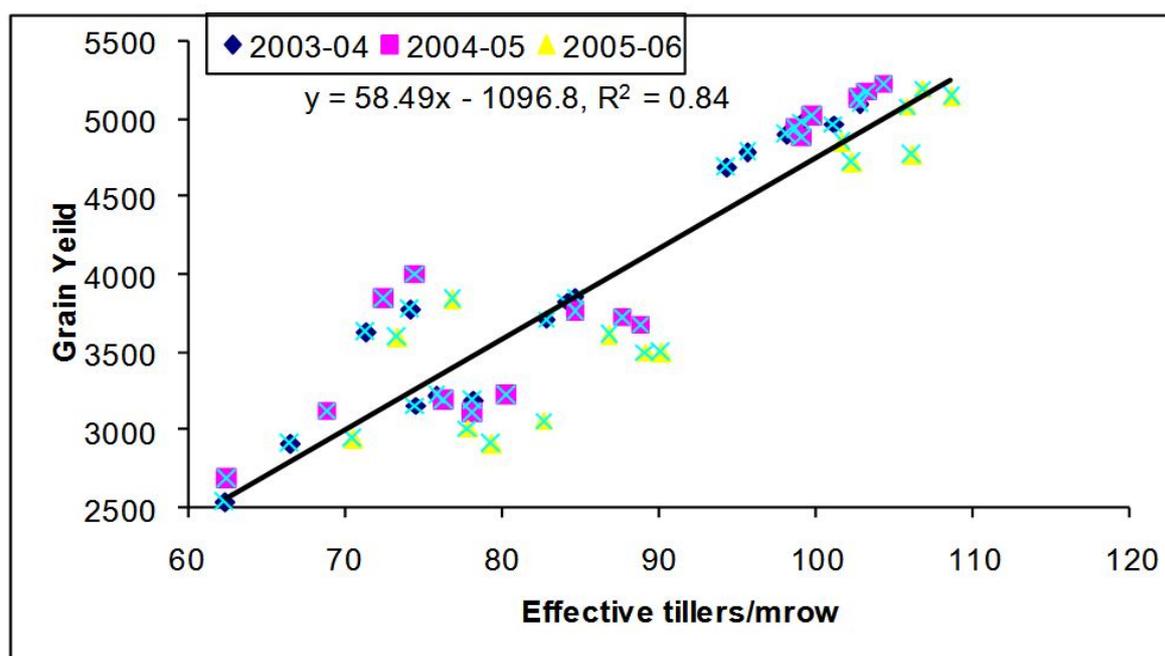
Irrigation	Nitrogen, kg/ha			
	0	50	100	150
Soybean crop residue removed				
l ₁	1665	1998	2415	2795
l ₂	2080	2532	3682	4185
l ₃	2110	2640	3715	4272
l ₄	2385	2765	3872	4410
Soybean crop residue incorporated				
l ₁	1982	2246	2790	3185
l ₂	2415	2812	4165	4550
l ₃	2605	3005	4240	4565
l ₄	2665	3122	4265	4765
CD (P=0.05)	CR-135 (I) Irrigation-216; (N) Nitrogen - 302; l×N - 192			

Table 5. Available N, P and K (kg/ha) in the soil after wheat harvest as influenced by irrigation regime (average of 3 years)

Irrigation	Residue removed			Residue incorporated		
	N	P	K	N	P	K
I ₁	232	17.6	212	235	18.2	219
I ₂	221	16.4	210	224	18.0	212
I ₃	220	15.8	206	222	17.9	209
I ₄	216	15.2	202	220	17.1	207
CD (P=0.05)	08	0.8	07	13	0.6	09

Table 6. Available N, P and k (kg/ha) in the soil after wheat harvest as influenced by nitrogen level (average of 3 years)

Nitrogen (kg/ha)	Residue removed			Residue incorporated		
	N	P	K	N	P	K
0	208	18.2	216	230	18.8	219
50	219	17.0	208	229	18.0	212
100	232	15.2	202	236	16.0	210
150	230	15.1	198	238	16.2	205
CD (P=0.05)	08	0.9	11	06	0.7	07

**Fig. 1.** Correlation between effective tillers and grain yield of wheat

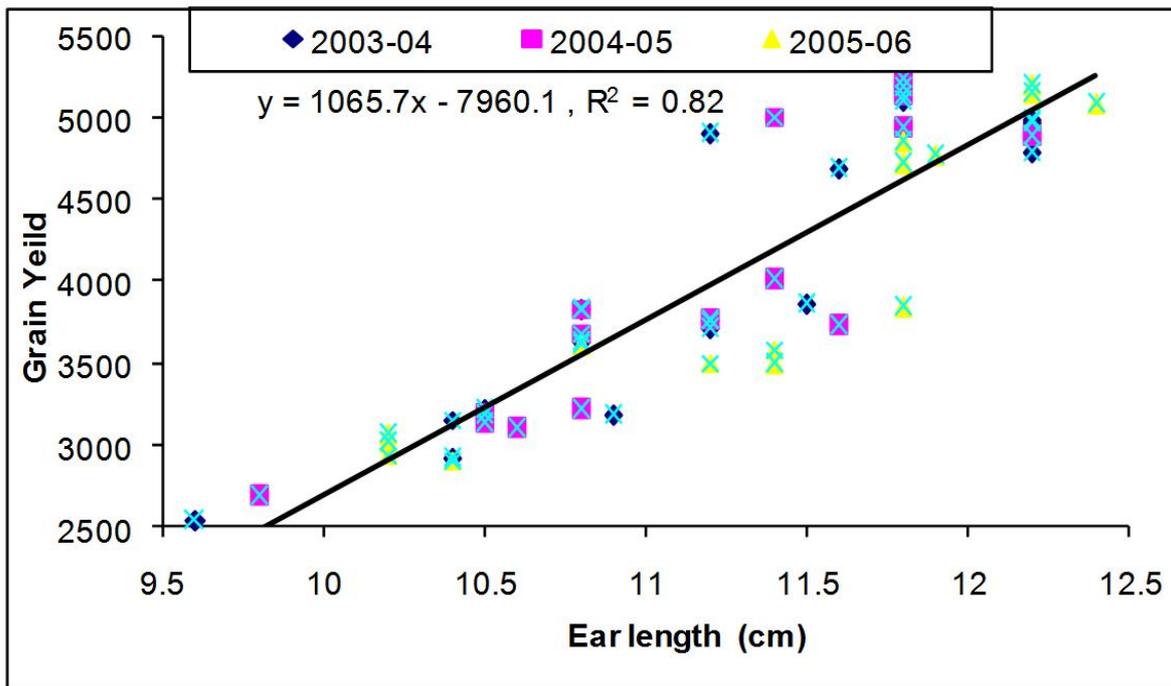


Fig. 2. Correlation between ear length and grain yield of wheat

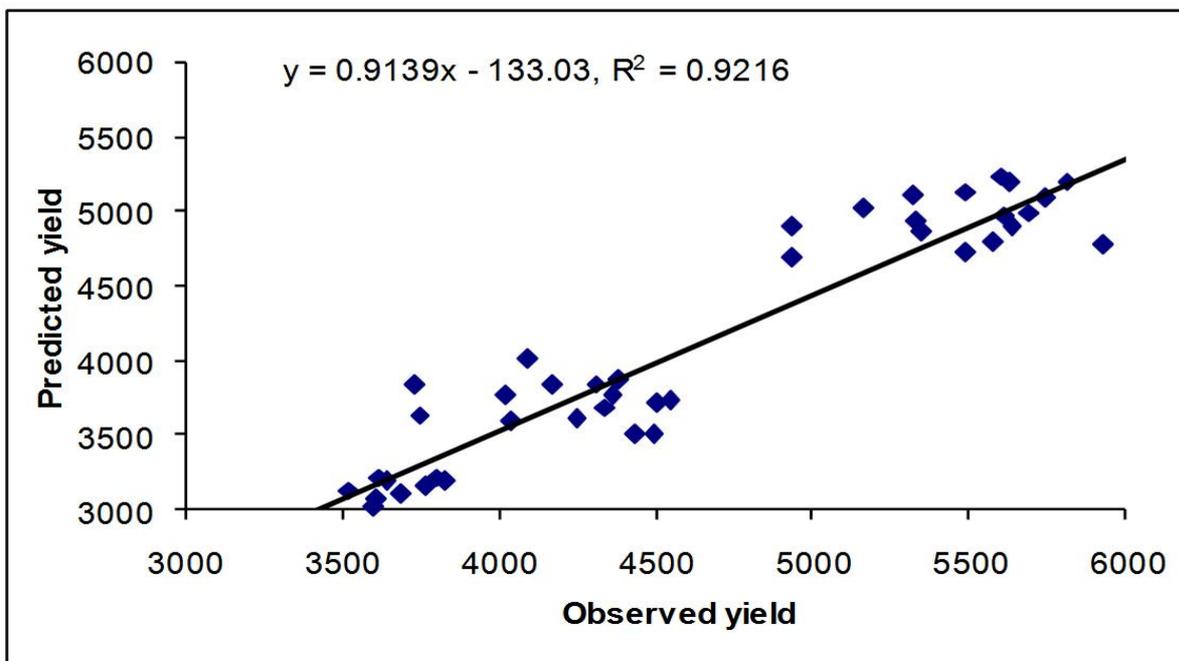


Fig. 3. Observed and predicted yield of wheat under different irrigation and nitrogen levels

respectively). However, it was observed that there was no significant difference in grain yield amongst irrigation schedules. Irrigations applied either by soil moisture depletion measured by tensiometer or by IW/CPE ratio of 0.9. There was a very positive correlation between observed and predicted (R^2 0.92) yield value of wheat (**Fig. 3**). Residues incorporation had significant effect on soil nutrient status after wheat harvest as compared to residues removed irrespective of the irrigation and fertilizer levels (**Table 1 & 2**). It suggests that load on fertilizer can be minimized if the residue of previous crop especially legumes are incorporated in the field.

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Assessment of the Water Resource Potential of Nuh Block of Mewat District, Haryana for Irrigation Planning

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ABSTRACT

The present study is an attempt to assess the total available water resources potential of the Nuh block (surface and Ground water both) for future exploitation especially for growing crops. The prime source of surface water resources available for irrigation; the canal water was estimated to be approximately 21,316.23 ha-m in the Nuh block; based on the supply minus losses on annual basis. The runoff contributes a small amount (20.5 per cent) of the total water resource available and 12.4 per cent of the total rainfall i.e. the total volume of water available from rainfall in the block. It was estimated to be nearly 5749.384 ha-m using an empirical assessment methodology as suggested by Khosla model of 1949 for India. It indicated that a large potential is waiting to be trapped. The ground water; although highly saline in nature, is another important source of irrigation water in the Nuh block. It was assessed by the water balance approach, as approximately 6436 ha-m. However, the net ground water available for irrigation was estimated to be only 965.40 ha-m because almost 85 per cent of available ground water was unusable for irrigation due to being highly saline in nature. Hence, the total water availability (potential) including canal water, surface runoff and part ground water was assessed to be approximately 28031.014 ha-m. The study suggested that although there are natural limitations in water availability the efforts should be made to conserve the moisture in-situ, its storage in reservoirs, checking the different types of losses and first and foremost the most efficient utilization by making a strategic selection of the methods of irrigation, crop rotation and varieties specially bred for salt and moisture stress tolerance for becoming self reliant and prosperous.

Key Words: Canal water, Ground water, Runoff, Water balance.

Water is the most vital input for successful and competitive agriculture. It has made significant contribution in providing stability in food grain production, food security and food self-sufficiency to the nation. This resource should be most optimally used and its supply can be made more sustained only by maintaining the quantity and quality. Assessment of water resources is highly desirable for planning and designing the water conservation techniques viz.; root zone soil moisture conservation, surface retention and over/under ground storage structures and on/off-farm water management for long term sustainability of this precious resource. Mewat district is one of the most backward (socio-economically) districts of the state of Haryana (NAIP, ICAR, 2009).

The district of Mewat is inhabited by Meo community (an ethnic minority) who are educationally

and socially less developed as compared to their counterparts in other districts of Haryana state. The district has a semi-arid climate, highly undulating topography and saline to highly saline ground water based on EC, pH and SAR. All these natural constraints with low to scanty rainfall have restricted the district to prosper and the farming community has been caught in a vicious circle of absolute poverty, illiteracy and backwardness. The district headquarters is Nuh which is nearly 80 km away from one of the most shining exemplary cities of India namely Gurgaon on Gurgaon-Alwar national highway.

Mewat bears its name from the word “Mewat” of the Persian language; the official and court language of the mighty Moghuls, which means “the barren or unproductive land”, which it is till today owing to its peculiar nature due to many adverse

edaphic and climatic factors. The Mewat district of Haryana has been a waste land since a long time mainly due to the reason that it was predominantly salt affected due to the high salinity of its ground waters. The underlain rocky structures have negligible hydraulic conductivity and thereby did not permit the runoff water to get percolated and join the ground water table substantially. Instead the water collected from the adjoining areas used to get accumulated on the ground in forms of lakes (there are three very famous lakes in the district namely Kotla, Ujjhina and Dundama Lakes) and while water got evaporated it left all the slats over ground making the land mass almost barren during the scorching heat of summers. It was quite late when human settlements started here with nomadic people especially the shepherds and growers of small ruminants. Highly saline ground water and low crop productivity is the main features of the water availability in Mewat district. Nuh block being the Headquarters; is also the representative block of Mewat district. Most parts of the Nuh block were suffering with water deficit and poor quality ground water problems (Kaur *et al.*, 2009). These scenarios represent water as the main limiting resource for agricultural production in the block. Therefore, keeping these facts in view; the efficient management of the water resources has emerged as one of the key issues to increase the agricultural production. Hence, to feed the increasing population by making the best use of available resources for producing maximum the present study was undertaken with the prime objectives of quantifying the water resources for possible future utilization for agricultural development.

The assessment of water resources is an important requirement for optimization of the crops production with available irrigation water (Yangchan *et al.*, 2006). The assessment of total water resources potentials of an area includes quantification of utilizable surface and ground water resources (Chowdary *et al.*, 2009). The assessment of water resources of a region requires adequate and reliable hydrological records (Aggrawal *et al.*, 2009). The water resources include both surface and ground water and in order to estimate the total potential one has to work out the surface as well as ground water potential and their temporal and spatial distribution as well. Surface water resources include the runoff water from the streams

and water being brought from other areas/ regions in form of canal water. While, surface runoff water contributes only small amount (20.5 per cent) of surface water resources potential of the block (Khan, 2007). The surface runoff water generated as a result of scanty rainfall in few main rain storms, can also be used for irrigation provided that it is conserved or stored properly. Thus it can also be considered as the alternative surface water resource.

Canal water is the prime source of surface water resources available for irrigation in the Nuh block. The canal water for irrigation is obtained from the Gurgaon branch of the Western Yamuna Canal (WYC). The Gurgaon branch canal is a branch of the WYC alternatively known as the Agra Canal (AC) from which a few distributaries carry water to the Nuh block and adjoining areas of Haryana and Western Uttar Pradesh (WUP). Nuh sub-branch (Indri, Nuh and Bhiraoti distributaries), Uleta distributery, Dubalu distributery, Ujina distributery, Kalanjar distributery and Pondiary distributery are the main distributaries for the canal water supply in Nuh block.

The ground water was another major source of irrigation water in the Nuh block that can be obtained directly by pumping of shallow and deep tube wells. However, the most parts of the block were suffering from highly saline ground water and salt affected soils and therefore, small percentage (15 per cent) of ground water is available for irrigation and remaining 85 per cent of ground water was un-usable for irrigation (Kaur *et al.*, 2009). Therefore, it can be concluded that the total water resources available for irrigation included the canal water (the water that is remaining in the canals at any given time after accounting the seepage and other losses), a fraction of the ground water available for irrigation up to safe draft (limit) and the surface runoff water (only if it could be conserved, harvested from the study area and stored properly for future utilization for irrigating crops). This study envisages in estimation of all the resources to quantify the total water potential for irrigation using standard tools and techniques.

MATERIAL AND METHODS

The Study Area

The place named as 'Nuh' is the most developed in the whole Mewat district and hence is the

headquarters for administrative purposes. Nuh block is also the representative block. It lies between 27° 59' 30.4" to 28° 13' 40.3" North latitude and 76° 57' 20.5" to 77° 10' 58.38" degree East longitude. The study area falls under the Survey of India (SOI) Topo-sheet no. 53 H/4 and 53 D/16. The location map of study area is presented in Figure 1. It covers a portion of the Indo-Gangetic plain and lies to the West of Yamuna River and South-West of Delhi, and form the Southern part of Haryana and North-Eastern part of Rajasthan. The district of Mewat was carved out from two erstwhile districts of the Haryana state namely Gurgaon and Faridabad by reorganizing the blocks of Tauru, Nuh, Punhana, Nagina, Hatin and Firozpur Jhirka. Later on the Hatin block has been transferred to the newly created district of Plawal. The total geographical area of the Nuh block is approximately 463.66 sq. km (46366 ha). The population of the Nuh block was 212855, including the male 112553 (52.88 per cent) and the female 100302 (47.12 per cent), during 2001 census. The rate of population growth in Mewat being high (3-5 per cent) it is expected that in the last 10 years the population might increase to approximately 319283 with 168837 males and 150446 females going by the trends. The people of the Nuh block are not highly educated despite the fact that the block is adjacent to one of the most developed and advance districts in the country; Gurgaon. The total literacy percentage was 33.63 per cent, including male 73.79 per cent and female 26.21 per cent (as per Census 2001). The total number of villages in the Block was 114. Representative villages from the whole block have been taken for conducting the household surveys.

Assessment of Canal Water Availability for Irrigation

As already mentioned the canal water is one of the major sources of water for irrigation in the Nuh block. The average water supply through the canal (i.e. the canal water available to the crops) was estimated for years (2008-09) using the data available from the office of Irrigation Engineer, Mewat Water Supply Services, Nuh Division, Haryana. The canal water availability to the crops can be estimated by following equations (Equation 1):

$$CIw = WSch - SLC \quad \dots\dots\dots (1)$$

where,

CIw = Canal water availability for irrigation;

WSch = Water supply at the canal head; and

SLC = Seepage losses during conveyance.

The water supply from the canal can be worked out by Equation. 2;

$$WSch = Q \times OT \quad \dots\dots\dots(2)$$

where,

Q = average discharge in the canal (m³/sec); and

OT = operating time of canal (sec).

Estimation of Seepage Losses from Unlined Canals

Estimation of seepage losses from canal network was done according to Tyagi *et al.* (1995) in case of Ghagger basin. For computing seepage, hydraulic data such as daily discharge, monthly discharge and number of running days for each major/ minor distributery were compiled from records of the office of Irrigation Engineer, Mewat Water Supply Services, Division Nuh, Haryana. Following calculation procedure was followed for estimation of seepage losses; the perimeter (P_w) was computed by using following formula (Yangchan *et al.*, 2006) (Equation 3):

$$P_w = 4.75 \times Q^{0.5} \quad \dots\dots\dots (3)$$

where,

P_w = wetted perimeter (m); and

Q = average discharge in the canal (m³/sec).

Wetted area (A_w) was calculated by formula given below (Equation 4):

$$A_w = P_w \times L \quad \dots\dots\dots (4)$$

where, A_w = wetted area of conveyance system ('10⁶ sq. meter); and

L = length of canal (m).

Seepage loss coefficient per million square meter of wetted area was calculated for lined and unlined channels separately by the Equation 5:

$$S_c = 0.35Q^m \quad \dots\dots\dots (5)$$

where, $m = 0.58669$ usually for lined channel and 1.8621 for unlined channel

Seepage losses (S_1) are calculated by the Equation 6 as given by Tyagi, 1989; and Yangchan *et al.*, 2006:

$$S_1 = T_r \times A_w \times S_c \quad \dots\dots\dots (6)$$

where, S_1 = Seepage loss (m^3);

S_c = Seepage losses factor in cumec per 10^6 sq. meter of wetted area; and

T_r = Operating time (sec).

The seepage losses from unlined main canal, branches, distributaries and watercourses were considered as deep percolation, which ultimately contributed to Ground water recharge in the study area. Tyagi, (1989) determined the wetted perimeter and wetted areas for different channels and estimated seepage loss coefficient for lined and unlined canal channels.

Assessment of Ground Water Resources Potential for Irrigation Purpose

Ground water was second major important source of irrigation to the crops in the Nuh block. The average ground water availability through the tube wells was estimated for year 2008-09 from data available from the Regional Office of Central Ground Water Board (CGWB), Chandigarh, Haryana. Monthly discharges of irrigation water through each distributery of canal network in Nuh block during 2008-09 was taken from the office of the Irrigation Engineer, Mewat Water Supply Service, Nuh for the estimation of irrigation water volume at head of canal, estimation of seepage losses and estimation of total canal water availability. There are eight observation wells in the study area. The pre and post monsoon ground water levels were recorded by the Regional Centre of Central Ground Water Board (CGWB) at Nuh. For the present study, ground water data have been obtained from the Regional Office of the Central Ground Water Board (CGWB), Chandigarh, Haryana. The ground water availability to the crops was estimated by water balance approach. The objective of the ground water balance study was to know the volume of ground water available for sustainable pumping. For the estimation of the ground water availability to the crops, total annual amount of ground water recharge, numbers of observation wells, pre-monsoon and post-

monsoon ground water levels were recorded. The ground water balance equation (Panda *et al.*, 1996) was used (Equation 7):

$$\Delta S = TGWR \pm TGWD \quad \dots\dots\dots (7)$$

where,

TGWR = total ground water recharge;

TGWD = total ground water draft; and

ΔS = change in ground water storage.

Ground Water Recharge Estimation using Water Balance Approach

The main sources of ground water recharge were inflows from the adjoining area, recharge from rainfall and seepage from major conveyance systems such as rivers, canals and drains. Equation 8 explains the above:

$$TGWR = GR_r + GR_c + GR_a \quad \dots\dots\dots (8)$$

where,

GR_r = Ground water recharge from rainfall;

GR_c = Ground water recharge from seepage of canal network; and

GR_a = Ground water recharge due water application losses.

Estimation of the Ground Water Draft/Withdrawal

Major portion of ground water withdrawal was used for irrigation in the Nuh block. Ignoring the other uses of ground water, amount of annual ground water withdrawal was estimated on the basis of area of different crops and their irrigation water requirements. It is assumed that the deficit in irrigation water supply was met from ground water pumping.

Assessment of Surface Runoff Potential and Water Availability for Irrigation

Assessment of runoff water from the study area is desirable because it is one of the alternative sources of water for irrigation use. The runoff water from the study area was estimated by using the empirical formula already prepared for the particular basin under which study area nearly belongs. The required data i.e.; the average annual rainfall for the year 2002 to

2009 were obtained from the Weather Station, Office of the CEO, at Nuh block of Mewat District. The annual runoff volume from the land mass of the Nuh block was calculated as below. Khosla (1949), developed a relationship for monthly runoff (Equation 9 & 10) :

$$R_m = P_m - L_m \quad \dots\dots(9)$$

$$L_m = 0.48 T_m \text{ for } T_m > 4.5^\circ\text{C} \quad \dots\dots(10)$$

where: R_m = Monthly runoff in cm and R_m 0, P_m = Monthly rainfall in centimeters (cm), L_m = Monthly losses in centimeters, T_m = Mean monthly temperature of the catchment in °C. This formula has been used for estimation of runoff in Nuh block (Mewat), Haryana.

RESULTS AND DISCUSSION

Assessment of Canal Water Resources Potential of Nuh Block, Mewat (Haryana)

The total water resource potential of the Nuh block constituted canal water, ground water and runoff water. Canal water was one of the major sources of

surface water for irrigation in the Nuh block. The canal water obtained in Nuh block for irrigation is from the WYC branch. The irrigation water volume at head of canal distributaries was estimated for six month basis i.e. monsoon and non-monsoon (**Table 1**). The seepage losses were estimated from each distributary separately which is presented in **Table 2**. Then, the total canal water availability was estimated for each distributary by deducting respective seepage losses from the water volume at the head of distributary (**Table 3**). Results show the Nuh sub-branch was the major channel including Nuh, Indri and Bhiraoti distributaries provided canal water in the Nuh block was 5271.35 ha-m during monsoon (*Kharif*) season and 11435.01 ha-m during non-monsoon (*Rabi*) season. The irrigation water volume at head of all canal networks for Nuh block was estimated to be 10288.29 ha-m during monsoon (*Kharif*) season and 17938.09 ha-m during non-monsoon (*Rabi*) season. The seepage losses were estimated from each distributary separately. The seepage loss was highest for Nuh sub-branch as this sub-branch was longest and having longest wetted area. Then, the total canal

Table 1. Estimation of irrigation water volume at head of canal (ha-m)

(A) Monsoon (<i>Kharif</i>) Season					
S. N.	Names of distributaries	Average discharge (m ³ /s)	Operating time (sec)	Volume at head ('000 m ³)	Volume at head (ha-m)
1.	Nuh sub-branch	13.26	3974400	52713.53	5271.35
2.	Uleta	5.27	5702400	30070.09	3007.01
3.	Dubalu	1.67	3628800	6076.12	607.61
4.	Ujina	2.66	2592000	6883.01	688.30
5.	Kalanjar	1.63	3196800	5201.99	520.20
6.	Pondiary	0.77	2505600	1938.17	193.82
Total				102882.91	10288.29
(B) Non-monsoon (<i>Rabi</i>) Season					
1.	Nuh sub-branch	14.39	7948800	114350.11	11435.01
2.	Uleta	2.68	3196800	8579.52	857.95
3.	Dubalu	2.67	5011200	13378.07	1337.81
4.	Ujina	4.83	5011200	24203.43	2420.34
5.	Kalanjar	1.46	11059200	16170.39	1617.04
6.	Pondiary	0.98	2764800	2699.41	269.94
Total				179380.93	17938.09
Annual				282263.84	28226.38

Table 2. Estimation of seepage losses during conveyance from various distributaries in Nuh block (Mewat), Haryana

(A) Monsoon (Kharif) Season									
S.N.	Name of distributaries	Length (km)	Average discharge (m ³ /s)	Operating time (sec)	Perimeter (m)	Wetted area X10 ⁶ m ²	Seepage loss coefficient (m ³ /s)	Seepage loss ('000 m ³)	Seepage loss (ha-m)
1.	Nuh sub-branch	28.55	13.26	3974400	17.30	0.49	1.59	3130.13	313.01
2.	Uleta	11.35	5.27	5702400	10.91	0.12	0.93	655.30	65.53
3.	Dubalu	11.17	1.67	3628800	6.15	0.07	0.47	117.96	11.80
4.	Ujina	14.08	2.66	2592000	7.74	0.11	0.62	175.35	17.54
5.	Kalanjar	5.90	1.63	3196800	6.06	0.04	0.47	53.22	5.32
6.	Pondiary	11.19	0.77	2505600	4.18	0.05	0.30	35.25	3.53
Total								4167.21	416.72
(B) Non-monsoon (Rabi) Season									
1.	Nuh sub-branch	28.55	14.39	7948800	18.02	0.51	1.67	6838.09	683.81
2.	Uleta	11.35	2.68	3196800	7.78	0.09	0.62	176.33	17.63
3.	Dubalu	11.17	2.67	5011200	7.76	0.09	0.62	270.43	27.04
4.	Ujina	14.08	4.83	5011200	10.44	0.15	0.88	649.43	64.94
5.	Kalanjar	5.90	1.46	11059200	5.74	0.03	0.44	163.92	16.39
6.	Pondiary	11.19	0.98	2764800	4.69	0.05	0.35	50.10	5.01
Total								8148.31	814.83
Annual								11315.52	1131.55

Table 3. Estimation of total canal water availability (ha-m)

(A) Monsoon (Kharif) Season					
S. N.	Names of distributaries	Input in canal/ volume at head (⁰⁰⁰ m ³)	Seepage loss (⁰⁰⁰ m ³)	Total canal water availability (⁰⁰⁰ m ³)	Total canal water availability (ha-m)
1.	Nuh sub-branch	52713.53	3130.13	49583.40	4958.34
2.	Uleta	30070.09	655.30	29414.79	2941.48
3.	Dubalu	6076.12	117.96	5958.17	595.82
4.	Ujina	6883.01	175.35	6707.66	670.77
5.	Kalanjar	5201.99	53.22	5148.77	514.88
6.	Pondiary	1938.17	35.25	1902.91	190.29
	Total	102882.91	4167.21	98715.70	9871.57
(B) Non-monsoon (Rabi) Season					
1.	Nuh sub-branch	114350.11	6838.09	107512.02	10751.20
2.	Uleta	8579.52	176.33	8403.18	840.32
3.	Dubalu	13378.07	270.43	13107.64	1310.76
4.	Ujina	24203.43	649.43	23554.00	2355.40
5.	Kalanjar	16170.39	163.92	16006.47	1600.65
6.	Pondiary	2699.41	50.10	2649.31	264.93
	Total	179380.93	8148.31	171232.63	17123.26
	Annual				26994.83

water availability was estimated for each distributary by deducting respective seepage losses from the water volume at the head of distributary. Nuh sub-branch provided highest canal water availability for Nuh block. **Figures 2 and 3** present the comparisons of volume discharge at the head, seepage losses and total water availability in respective distributaries. The total canal water availability was estimated to be 9871.57 ha-m during monsoon season and 17123.26 ha-m during non-monsoon season. The total annual canal water available for irrigation was estimated to be 26994.83 ha-m.

Assessment of Ground Water Resources Potential

Despite the water being of highly saline in nature in large part of the block, the Nuh block is dominantly irrigated by ground water, and in the recent past, irrigation by ground water has increased, especially in the area where crops are grown only in the non-

monsoon (*Rabi*) season. The ground water balance of Nuh block of Mewat is given in **Table 4**. The annual ground water recharge and annual ground water draft was estimated to be 8538.00 ha-m and 2102 ha-m respectively. Then, the total ground water balance was estimated to be 6436.00 ha-m. Nuh block was mainly irrigated by shallow tube wells. Ground water in Nuh block of Mewat district was mainly saline at all levels in almost 85 per cent of block including highly salt affected Ground water of 63.4 per cent and moderately saline Ground water with highly salt affected land of 22.6 per cent (Kaur *et al.*, 2009). Therefore, the actually available fresh ground water; usable for irrigation; was estimated to be only 965.40 ha-m.

Estimation of the Harnessable Runoff Water Resources Potential

Direct surface runoff is sometimes also channelized to cropped areas by the farmers for irrigation in Nuh

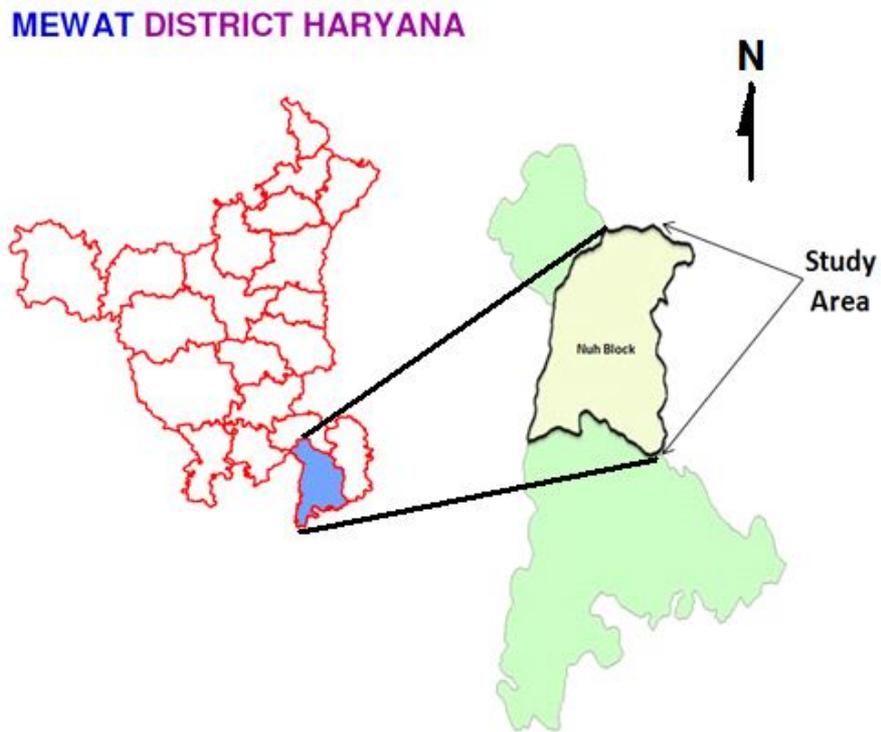


Fig. 1. Location of the study area (Nuh block of Mewat district, Haryana)

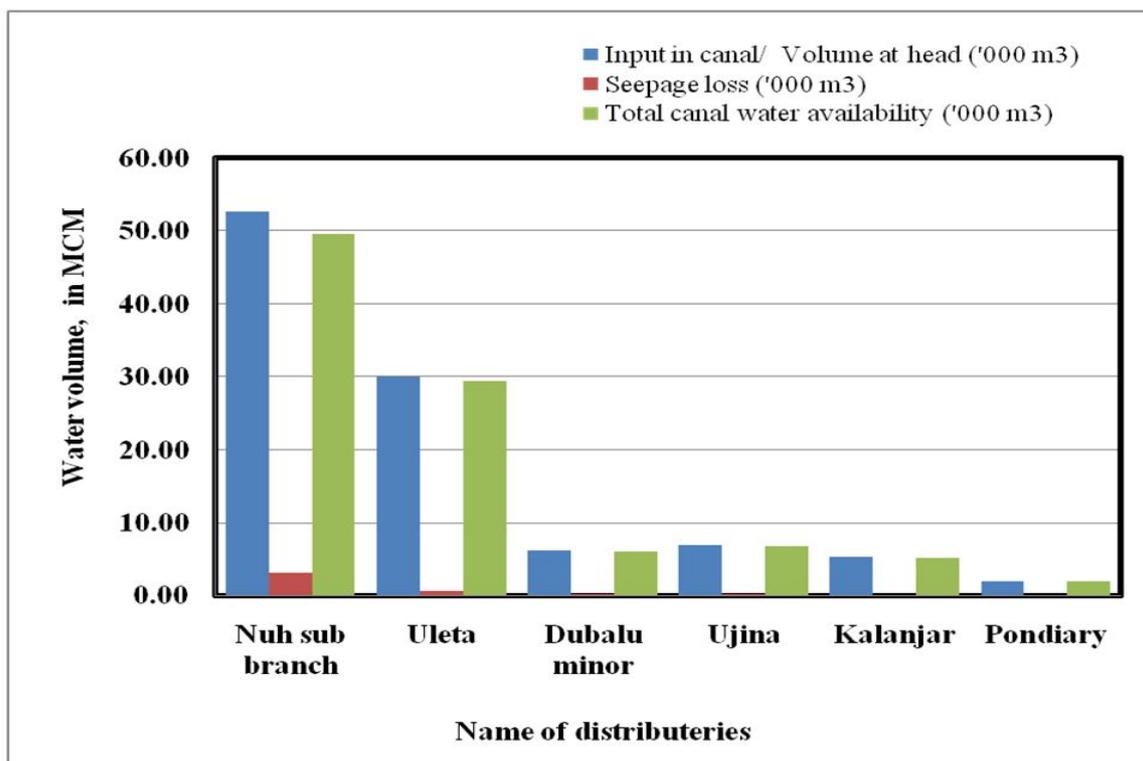


Fig. 2. Estimation of total canal water availability in Nuh block during *Kharif* season, 2008-09

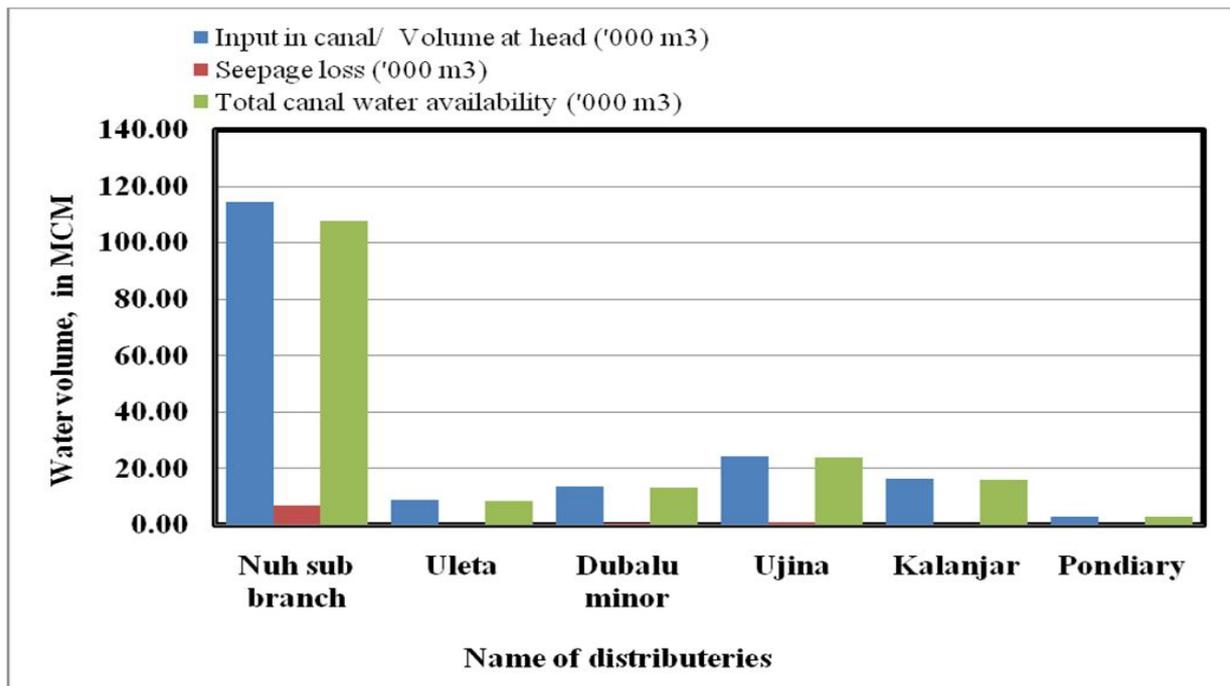


Fig. 3. Estimation of total canal water availability in Nuh block during *Rabi* season, 2008-09

Table 4. Annual Ground water balance of the study area

S.N.	Net recharge (MCM)	Net Draft (MCM)	GW Balance (MCM)	GW Balance (ha-m)
1.	85.38	21.02	64.36	6436

MCM- Million Cubic Meter

block wherever it is possible due to the slopy and undulating terrain conditions. The runoff volume from this region is estimated from the annual rainfall using an empirical formula given by Khosla for India, 1949; Jha *et al.*, 2005. The annual runoff volume from the land mass of the Nuh block was calculated as below. Khosla (1949) model; developed for monthly runoff (Equation 9 & 10) was used to estimate the surface runoff. Using this model the annual runoff can be estimated as a sum of monthly values. Khosla's formula is indirectly based on the water-balance concept and the mean monthly temperature is used to reflect the losses due to evapotranspiration. The formula has been used on a number of catchments in

India and is found to give fairly good results for the annual yield for use in preliminary studies. Considering the mean monthly values of the rainfall, mean temperatures and applying the Khosla, 1949 model the monthly runoff in Nuh has been estimated (Table 5). Leaving aside the negative values and taking the non negative values it was found that the total annual runoff in Nuh with the mean data of 1970-2002 is 12.7 cm. It was estimated to be 5749.384 ha-m using the Khosla, 1949; model. Thus the annual runoff volume for Nuh block was estimated to be 12.4 per cent of the annual volume of water received from the rainfall in the block and 20.51 per cent of the total available surface water resources. Direct runoff is also concentrated over ground in surface water harvesting structures of dugout cum embankment type structures. However, water is seldom channelized to cropped areas for irrigation in Nuh block from such structures because the block also faces the drinking water crisis. The rough estimation of runoff volume from the annual rainfall using an empirical formula given by Khosla, 1949 and quoted by Jha *et al.*, 2005 is possible but a process based distributed model can do this job in much better ways.

Table 5. Estimated monthly runoff (R_m) from monthly Rainfall (P_m) using Khosla, 1949 model in Nuh block (Mewat), Haryana

Month	Rainfall (R_m) cm	Mean Temperature (T_m) °C	$0.48 * T_m$	$R_m - L_m$	P_m
Jan	1.2	14.5	6.965946	-5.80838	0
Feb	1.1	17.0	8.149889	-7.02291	0
Mar	0.7	22.7	10.88504	-10.2311	0
Apr	0.9	28.8	13.81869	-12.97	0
May	1.8	32.8	15.71885	-13.8778	0
Jun	5.6	33.1	15.8956	-10.2721	0
Jul	20.0	30.2	14.51035	5.497388	5.5
Aug	20.7	28.8	13.82544	6.870773	6.9
Sep	8.7	28.	13.71628	-5.00119	0
Oct	0.9	26.1	12.52546	-11.6035	0
Nov	0.7	20.8	9.979959	-9.23703	0
Dec	0.5	15.9	7.633099	-7.13031	0
Total					12.4

After Khosla, 1949

Note: R_m = Monthly runoff in cm and $R_m 0$, P_m = Monthly rainfall in centimeters (cm), L_m = Monthly losses in centimeters, T_m = Mean monthly temperature of the catchment in °C.

Table 6. Total water resources potential for irrigation from all sources in Nuh block (Mewat), Haryana

Particulars	Water availability	Other losses	Actual water availability
Annual canal water availability (ha-m)	26645.30	5329.06 *	21316.23
Annual Ground water availability (ha-m)	6436.00	5470.60**	965.40
Surface runoff (ha-m)	—	—	5749.384
Total water availability (ha-m)	—	—	28031.014

*Other losses in canal irrigation including application losses, ET losses and special need, 20 per cent of water availability;

**85 per cent salt affected Ground water; unusable for irrigation

Assessment of the Gross Water Resources Potential from all Sources for Irrigation

The total water resource potential of Nuh block constituted the canal and ground water; and in addition, runoff water. Annual canal water was estimated to be 266645.30 ha-m and other losses

(water course losses and leaching requirement) excluding the seepage was taken as 20 per cent of total water availability. Hence, net water availability for irrigation from canal network was calculated to be 21316.23 ha-m. The annual ground water availability was estimated to be 6436 ha-m. The most of the part (85 per cent) of ground water in Nuh block

was highly saline (not usable for irrigation) and moderately saline (can be used only with high limitation for irrigation). Therefore, the net ground water available for irrigation was 965.40 ha-m. The surface runoff was also estimated as the alternative for irrigation. It was estimated to be 5749.384 ha-m when calculated using the Khosla, 1949; model. The total water resource potential of the Nuh block in different months is given in **Table 6**. Total water available for irrigation in existing conditions was 22281.63 ha-m against an area of 46366 ha. This amounts to 0.48055 m on the entire land mass (48.06 cm). From the above estimation it is evident that the Nuh block is not having a very high water availability but overall scarcity. Hence, all efforts should be made to collect the rainwater, soil moisture management for growing crops in rainfed conditions with life saving irrigation wherever it is possible. Alternatively, considering a huge sink of agricultural produce in the form of Gurgaon market (if the proper infrastructure could be created) the farmers can switch over to high tech irrigation for growing high value crops as there are ample opportunities for the same in the block.

CONCLUSIONS

The assessment of water resources is very important consideration for optimization of crop production with available irrigation water. The total water resources potential includes the surface water (canal water and runoff) and ground water (tube well water). The annual canal water run for irrigation in Nuh Block during 2008-09 was 28226.38 ha-m while the actual water available for irrigation after seepage losses, application losses and other losses was 21316.23 ha-m. The annual net ground water balance for irrigation was estimated to be 6436.00 ha-m but the actual fresh ground water usable for irrigation was estimated to be only 965.40 ha-m (15 per cent). This is because of high to excessive losses in conveyance. If these losses are checked the available water can be utilized either to increase the area or to provide more water to the existing cropping patterns. The annual runoff was estimated by the rainfall-runoff relationships. The average annual runoff water from Nuh Block was estimated to be 2.39849 ha-m. The total water availability for irrigation from canal and Ground water resources was estimated to be 22281.63 ha-m. The total water availability for irrigation including runoff stored water was estimated to be 24680.12 ha-m.

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Analyses of Long Term Monsoon Rainfall Pattern from Groundwater Recharge Perspective in Semi-arid Region

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ABSTRACT

Rainfall is the major source of groundwater recharge. Rainfall and its temporal distribution plays important role in groundwater recharge. Well distributed rainfall favours groundwater recharge. If the total rainfall of the month occurs only on few days, the groundwater recharge will be less as the infiltration opportunity time is reduced resulting in more surface runoff. Prolonged dry spells, erratic and uneven rainfall distribution and high evapotranspiration rate are major controlling factor for groundwater recharge in semi-arid region. Analysis of long term rainfall pattern is a pre-requisite for planning and design of groundwater recharge structures in semi-arid regions. In northern India the major portion of the rainfall and groundwater recharge occurs during monsoon season. Rainy and dry day's analysis, and rainfall distribution pattern at Indian Agricultural Research Institute (IARI) located in semi-arid region was done from groundwater recharge perspective using the 37 years daily rainfall data of monsoon season. Analysis revealed that average the average number of rainy days observed in the last 37 years was 26. The long term average of consecutive dry spells of 7 and 14 days were 7 and 3, respectively. The results also revealed that rainfall during monsoon season is erratic and dry spells of longer duration exhibit increasing trend.

Keywords: Groundwater recharge, Rainfall pattern, Rainy days, Consecutive dry days

Arid and semi-arid regions are characterized by a climate with no or insufficient rainfall to sustain agricultural production. These regions are mostly inhabited by developing countries with dense population. The Middle East, Pakistan, North-West and South India, Northern China, and Central Asia are among those regions dominated by harsh aridity. Groundwater recharge is the process by which replenishment of groundwater takes place. Main source of groundwater recharge is rainfall. Part of the rainfall infiltrates into the soil and after satisfying the soil moisture storage and evapotranspiration, reaches to water table. This is known as natural recharge if it is accomplished without artificial interventions. If natural recharge in an area is not sufficient enough to balance the groundwater pumping, level of groundwater goes down. This has become serious problem in arid and semi-arid regions where adequate canal water supply is not available. Artificial Recharge is the process by which the ground water recharge is accomplished at the rate faster than natural recharge

rate. Natural recharge measurements carried out in about 20 river basins across India suggest that about 15–20% of seasonal rainfall contributes to groundwater recharge in the Indo-Gangetic plains, and about 5–10% in the peninsular hardrock regions (Athavale *et al.*, 1992). Under Indian condition, the recharge in arid and semi-arid region varies from 4 to 20% (Rangarajan and Athavale, 2000). Massuelet *et al.* (2007) simulated the groundwater recharge for the Musi river sub-basin in Andhra Pradesh, which falls in semi-arid region and reported that the natural recharge from the rainfall constituted 9% of the total annual rainfall.

In arid and semi-arid region, the total duration of wet spells is invariably smaller than total dry spell. By definition, the duration of wet or dry spell is equal to the number of uninterrupted sequence of wet or dry days (Alyamani and Sen, 1997). Groundwater management plan requires information on consecutive wet and dry days and duration of dry spells since, during dry spells groundwater abstraction is expected

to increase. In arid semi-arid regions dry and wet spell durations estimated on the basis of daily rainfall records provide useful information for planning of agriculture, irrigation, and groundwater recharge (Alyamani and Sen, 1997). This study was undertaken to analyze the rainfall data which included determination of rainfall distribution in different monsoon months, number of rainy days and consecutive rainy and dry days. Daily rainfall data from 1972 to 2008 was collected from Division of Agricultural Physics and Water Technology Centre of IARI.

MATERIAL AND METHODS

Rainfall data of 37 years (1972-2008) was collected and analysed to determine the number of rainy days, average rainfall during monsoon season, and number of dry days. Rainfall data was analysed in two parts.

The total rainfall recorded during the monsoon months that is from June to September was used in the study. The monthly and seasonal rainfall was worked out by adding the daily and monthly rainfall. Monthly distribution of average rainfall for the monsoon months were also worked out for the last 37 years.

Distribution of rainy and dry days in a region determines the soil moisture supply and affects the groundwater recharge significantly. Long dry spells

results in more evapotranspiration and lesser groundwater recharge. Continuous rains results in more groundwater recharge. Well distributed rainy days reduce burden on groundwater pumping, maintain groundwater level and favours groundwater recharge. Rainy and dry day analysis was carried out to establish the trend and decide the pumping scenarios. Rainy and dry days analysis was done for the monsoon months of 1972 to 2008. A day was considered as rainy day if rainfall on that day was 2.5 mm or more (Arora and Jha, 2008). If rainfall on any day was less than 2.5 mm or no rain, it was defined as dry day. Analysis was done only for monsoon months because possibility of groundwater recharge during non-monsoon months under semi-arid climate is almost negligible. Number of consecutive dry days of 7 and 14 days was also determined as the consecutive dry spells of longer duration have greater impact on groundwater recharge.

RESULTS

Yearly distribution of monsoon rainfall during the period of 1972-2008 is shown in **Fig. 1**. Long term average monsoon rainfall is 611 mm and average annual rainfall is 711 mm.

Fig. 1 indicates that monsoon rainfall has decreasing trend. This is major concern as monsoon rainfall is the major source of groundwater recharge.

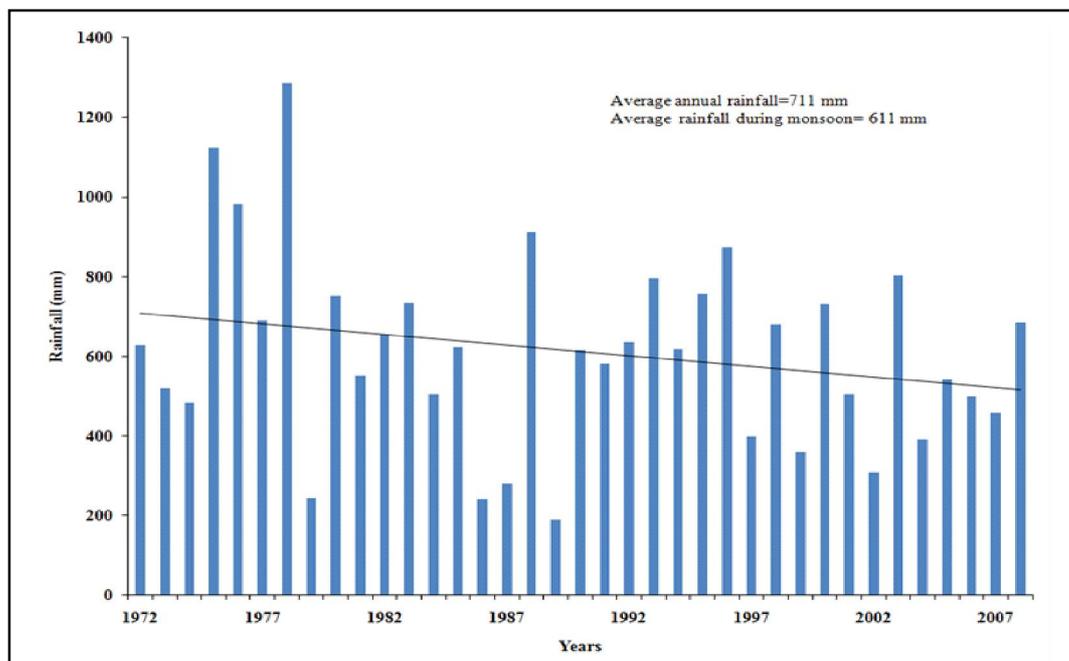


Fig. 1. Monsoon rainfall for IARI campus from 1972 to 2008

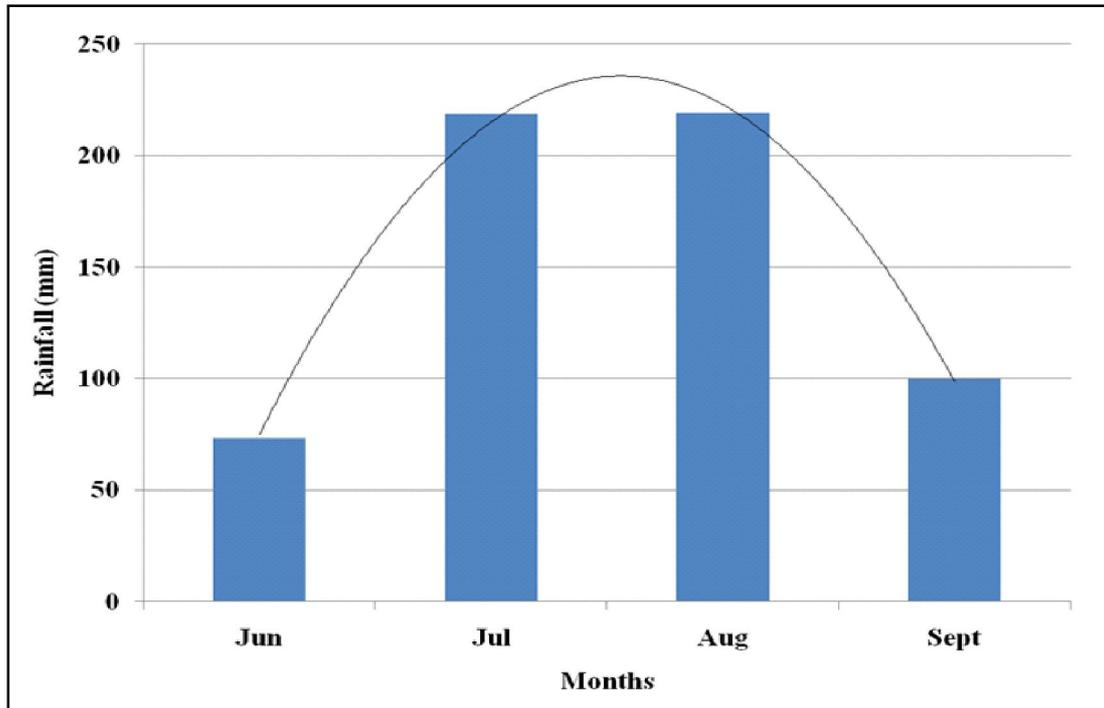


Fig. 2. Average rainfall in the monsoon months (1972 to 2008)

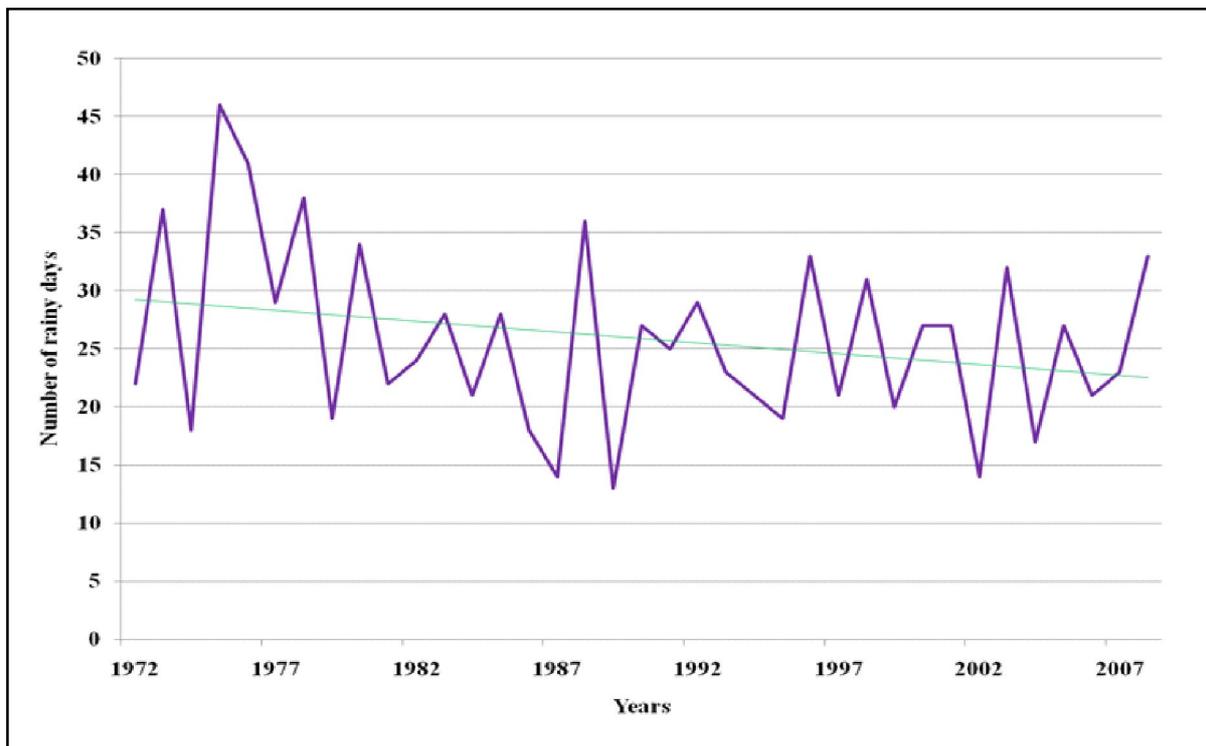


Fig. 3. Distribution of number of rainy days in monsoon months during the period of 1972 to 2008

During seventies rainfall in monsoon season were much higher than the eighties, nineties and beginning of 2000 (Babu Ram, 1978; Babu Ram and Singh, 2003). This would have affected the groundwater recharge as monsoon rainfall is the major source of groundwater recharge. Rainfall in the years 1979, 1986, 1987, and 1989 recorded rainfall less than 250 mm, indicating a complete drought. The long term average rainfall for the monsoon months (Fig. 2) showed that the rainfall in July and August month are almost same (218.7 and 219.15 mm respectively). The lowest rainfall is received in the June (73.4 mm) and September received rainfall of 100.1 mm.

The numbers of normal rainy day (average of number of rainy days during 1972-2008) were 26. The years 1975 and 1976 recorded the highest number of rainy days (46 and 41 days, respectively). It was also observed that the number of rainy days in monsoon months had decreasing trend (Fig. 3).

Consecutive dry days of 7 and 14 days were determined for monsoon months of each year from 1972 to 2008. This was done to establish the trend of consecutive dry days cover the years (Fig. 4). Number of consecutive dry days of 7 days varied from 3 to 7 during 1972 to 2008. Maximum number of consecutive 7 dry days were observed in 1985 and

2007 (each year has 7 events). Consecutive dry days of 14 days varied from 0 to 4. Years 1972, 2002 and 2004 recorded 4 spells. Fig. 4 revealed that number of 7 and 14 consecutive dry days had increasing trend.

The results revealed that rainfall during monsoon season is erratic and dry spells of longer duration exhibit increasing trend. This would decrease the natural groundwater recharge at IARI farm. Declining trend of total number of rainy days and increasing trend of consecutive dry days of longer interval in monsoon months are major concern from groundwater recharge point of view.

CONCLUSIONS

Analysis of rainfall is utmost important as it is the major source of recharge. Total rainfall for monsoon months, number of wet spells or rainy days and its magnitude and number of dry spells of different intervals play an important role in groundwater recharge. The yearly distribution of rainfall in IARI farm is erratic varying from less than 200 mm to more than 1200 mm. Number and interval of consecutive day's dry spell is major factor from groundwater recharge point of view as it determines the water available for groundwater recharge. Findings of the study indicates that number of rainy days in monsoon months had

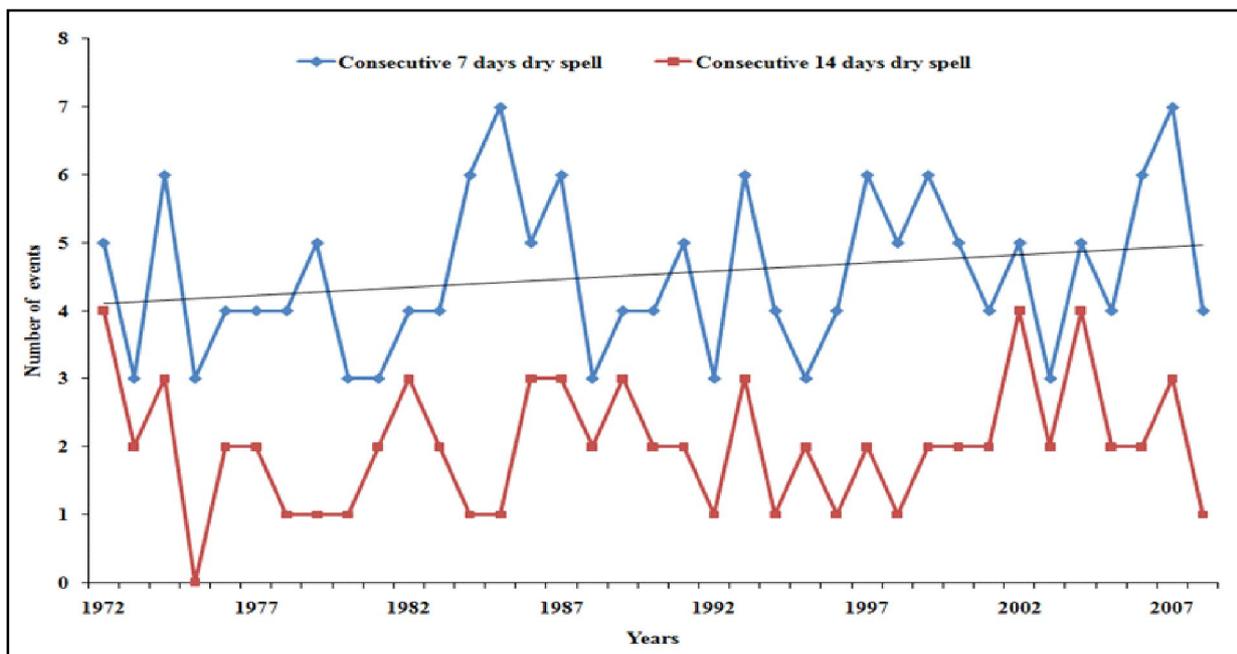


Fig. 4. Distribution of consecutive dry days of different interval during the period of 1972-2008

decreasing trend and number of 7 and 14 consecutive dry days had increasing trend. This suggests the groundwater recharge in the study area under natural condition had decreased. The dry spells of longer duration has a tremendous effect on the surface runoff generation. Hence this would reduce the the number surface runoff producing events which would result in lesser availability of available surface runoff for groundwater recharge.

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Groundwater Development and CO₂ Emission in Parts of Gangetic Alluvial Plains of India

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ABSTRACT

Irrigated agriculture is essential to increase crop production to meet the increased food requirement of increasing population of India. Immense pressure has been generated on water resources and water supply for irrigation, especially in the Ganga Alluvial Plain (GAP) of India. An attempt has been made to quantify the CO₂ emission of 5 districts viz; Patna, Gaya, Buxar, Bhojpur, Aurangabad of Bihar in GAP region. Farmers of Patna and Gaya districts depend more on groundwater whereas the other 3 districts farmers use groundwater in conjunction with canal water. Mostly diesel and electrical pumps are used for abstraction that emits CO₂ a major component of Green House Gas (GHG) which is of concern. The dugwells and shallow tube wells of this region use diesel pumps whereas deep tube wells relied on electric pumps. The CO₂ emission for existing groundwater draft has been estimated highest in Patna and lowest in Bhojpur. Dugwell driven by diesel was the most environment friendly option found for groundwater abstraction followed by shallow tubewell driven by diesel. Conjunctive use of groundwater along with surface or canal water is a better option found to meet the increased food demand.

Key words: Groundwater development, irrigation, CO₂ emission, Gangetic Alluvial Plain (GAP)

Rainwater is the main source of water for agriculture in India but its current use efficiency for crop production is quite low (30-45%). Irrigated agriculture is essential to increase crop production to meet the increased food requirement of increasing population of India. Reliance on groundwater resources that comprises of 38.5% of the available water sources of the country is the only suitable option found for sustainable crop production. Comprehensive policy for sustainable groundwater development and agriculture is highly required to combat the adverse of climate change. Groundwater meets nearly 55% irrigation, 85% of rural and 50% of urban and industrial needs (Government of India, 2007). Groundwater development in the country has expanded extensively. Surface and groundwater irrigation comprises of 26 and more than 60 per cent of the total irrigated area of the country to irrigate 63.19 M ha (44.5%) out of the 140.86 M ha of net sown area in the country. With increasing pressure on groundwater resources due to rising demand from agriculture and rapid growth in urbanization and industrialization over exploited blocks

are increasing in most parts of the country that has led to a rapid decline in the groundwater table. Uneven distribution of rainfall and prolonged dry periods during cropping period due to climate change has summed up to the stress on groundwater resources. This has threatened not only the food security and environment, but also the sustainable development and livelihood of small and marginal farmers. Access to groundwater is one of the important key to adapt and mitigate the drought and moisture stress condition leading towards food security, poverty alleviation and economic development in the rural areas.

The stage of groundwater development in the country is 61%. The status of groundwater development is very high in the hard rock area covering the states of Delhi, Haryana, Punjab and Rajasthan, where the Stage of Groundwater Development is more than 100% (CGWB 2012). Replenishable groundwater resource is significantly high in the Indus–Ganga–Brahmaputra alluvial belt in the North, East and North East India covering the states of Punjab, Haryana, Uttar Pradesh, Bihar, West

Bengal and valley areas of North Eastern States, where rainfall is plenty and thick piles of unconsolidated alluvial formations are conducive for recharge. Annual replenishable groundwater resource in these regions varies from 0.25 to more than 0.5 m (CGWB 2012). Immense pressure has been generated on water resources and water supply for irrigation, especially in the Ganga Alluvial Plain (GAP) of India. Groundwater is an important water resource in GAP for total foodgrain production of the country and constitutes 30% of the total annual replenishable groundwater resources of India. The Bihar state forms a part of mid-Ganga plain. The river Ganges flows in the state in west-east direction. In Bihar, about 1074301 ha area is canal water irrigated and about 3360032 ha area is well irrigated (Source: Bihar Agricultural Statistics at a Glance for year 2010-11). Increasing groundwater extraction from GAP has resulted in surfacing of aquifer stress symptoms like lowering of groundwater level and groundwater quality deterioration (World Banks, 1998).

About 54 percent area of the State is irrigated. Analysis of last 10 years (2001-2011) data showed that average gross irrigated area increased from 47 lakh hectares in 2001-06 to 47.98 lakh hectares in 2006-11 (Directorate of Economics and Statistics, Government of Bihar 2012). Tube well irrigated area constituted 62 percent of total irrigated area and canal irrigated area declined from 16.66 lakh hectares in 2008-09 to 12.02 lakh hectares in 2009-10. The annual replenishable groundwater resources of the state Bihar is 29.19 BCM. Net annual groundwater available is 27.42 BCM and annual groundwater draft estimated is 10.77 BCM. The stage of groundwater development is 39 %. About 31 percent of groundwater is still to be exploited for irrigation purposes under safe category. The groundwater development is expanding extensively. Though the area under food grain declined from about 68 lakh hectares during 2001-06 to 67 lakh hectares during 2006-11, there is increase in food grain productivity from 1176 kg ha⁻¹ during 2001-06 to 1743 kg ha⁻¹ during 2006-11. It has been observed that the food grain production (125 lakh tonnes) in drought (866 mm) year (2010-11) was even higher than food grain production (122 lakh ha) of the normal annual rainfall (1196 mm) year (2007-08). This has become possible due to increase in number of private tube wells installed by farmers.

Pumping groundwater for irrigation is the main energy consumption activity in agriculture in India. As small and marginal farmers dominate in agricultural sector, farm mechanisation is little restricted and groundwater abstraction became the highest energy consuming process. Mostly diesel and electrical pumps are used for abstraction that emits CO₂ a major component of Green House Gas (GHG) which is of concern. With increasing demand for groundwater increase in the emission of GHGs for further abstraction of groundwater from declined water tables are inevitable. A planned approach including assessment of available water resources (surface and groundwater), crop planning based on crop water requirement is therefore essential for sustainable development of this precious natural resource as dependence on groundwater is likely to increase in future. An attempt has been made to quantify and compare the GHG emission of 5 districts viz; Patna, Gaya, Buxar, Bhojpur, Aurangabad in Zone III B of Bihar in GAP region. Farmers of Patna and Gaya districts depend more on groundwater whereas the other three districts farmers use groundwater in conjunction with canal water using mostly diesel and electricity driven pumps.

Site Description

The state Bihar lies in the GAP covering an area of about 93.6 lakh hectares with a population of 82.9 millions and a density of 880 persons per sq km (Census 2001). The area falling in the north of the Ganga river is a monotonous flat land having regional slope towards south with altitude ranging from 887 m above msl to 34 m above msl. The area in the south of the Ganga river has the regional slope towards north. The southern border of the state is marked with presence of topographic highs made up of extensions the Chotanagpur plateau covering vast stretch in the Jharkhand state. The highest point observed in this part is 637 m above msl in Kaimur district. About 33% of the geographical area of the state in the south of the Ganga river is covered by alluvial deposits often referred to as marginal alluvial plain. Groundwater remains the life line of socio-economic development in the Ganga alluvial plain (GAP) since the dawn of civilization in the Indian subcontinent. The quaternary sequence forming top layer of the thick unconsolidated sediments of the GAP, holds nearly 30% of the total annual replenishable groundwater resources of India.

Table 1. Agroclimatic Zones of Bihar and cropping pattern

Agro climatic Zones	Districts	Texture	pH	Cropping Pattern/System
Zone-I (North west alluvial plane zone- Pusa)	13	Sandy loam, Loam	6.5-8.4	Rice – Wheat, Rice-Rai, Rice-Sweet Poatato, Rice-Maize, Maize-Wheat, Maize-Sweet Potato, Maize- Rai, Rice-lentil
Zone-II (North-East Alluvial Plane zone- Purnea)	9	Sandy loam, Clay Loam	6.5-7.8	Jute-Rice, Jute-Wheat, Jute-Potato, Jute-Kalai, Jute-Mustard, Rice-Wheat-Moong, Rice-Toria
Zone-III A (South Alluvial Plane Zone- Sabour)	6	Sandy loam, Clay loam, loam, Clay	6.8-8.0	Rice-Wheat, Rice-Gram, Rice-Lentil, Rice-Rai, Rice-Maize
Zone-III B (South Alluvial Plane Zone – Sabour)	10			

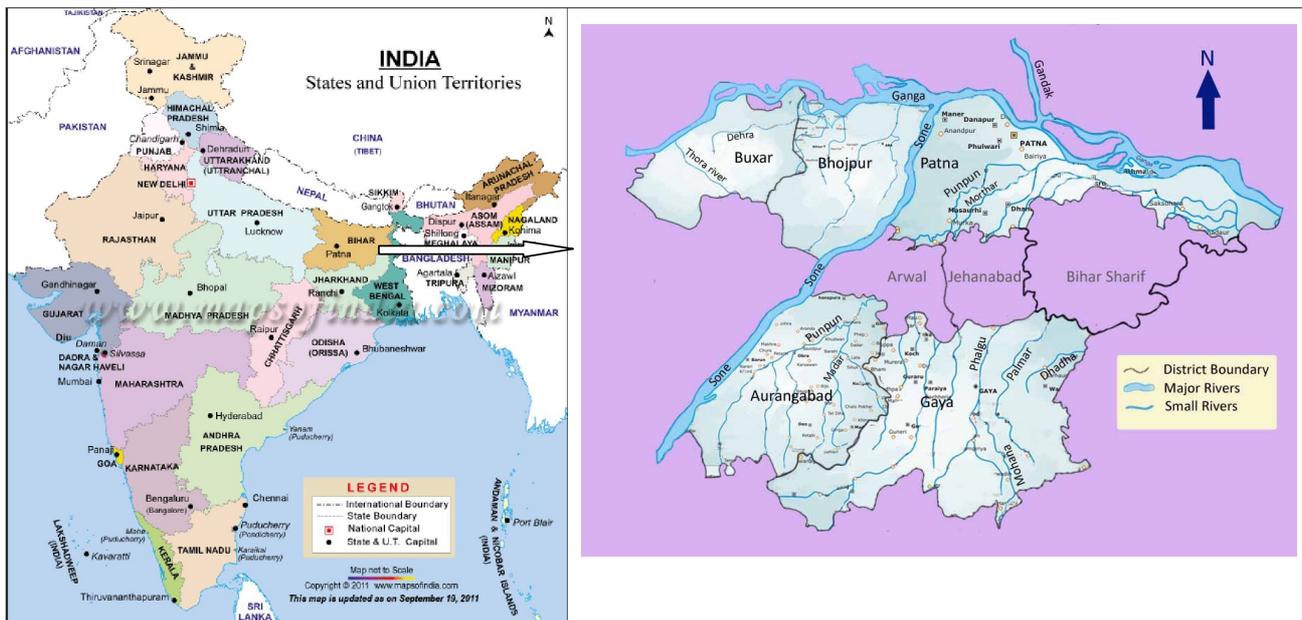


Fig 1. River map of the selected districts of Bihar state.

The gross and net sown area covers 79.46 and 56.03 lakh hectares respectively. About 82 % of the total land holdings (10.4 millions) belong to marginal farmers (0-1 ha) followed by 10 % of small farmers (1-2 ha). The State is divided into three agro-climatic zones and a brief description is presented in **Table 1**.

The selected five districts are in the Zone III B where 53% area is canal irrigated and 47 % area is groundwater irrigated. Patna district is surrounded by two important river systems namely Ganga and Sone, bordering the northern and western boundary of the district respectively. Punpun and Phalgu are the other two important rivers in the district. The Gaya district

comes under the fissured formation with Quaternary alluvial, Precambrian granite gneiss rock formation. The occurrence and movement of groundwater in this unit is controlled by the thickness and nature of weathered residuum besides presence of fractures in the rock. Phalgu is the main river of the district which dries during dry seasons. The river Sone and Ganges are the perennial source of surface water in Buxar and Bhojpur districts. Bhojpur district has rivers running almost along its three sides - North, East, and some part of Southern boundary. The agricultural prosperity of the district Buxar district depends on artificial irrigation. The three main sources of irrigation are artificial reservoirs, wells and Sone Canal, all of which helps to supplement the natural supply of water and to compensate for its inadequacy or untimely distribution. Sone Canal system is the most important source of irrigation in the district. *Sone, Punpun, Auranga, Batane, Morhar, Adari*, are the main rivers of Aurangabad district. *Batane, Adari and Madar* are the three big rivers of this district. Most part of Aurangabad district is irrigated by a number of canals. A view of the network of rivers flowing through the selected districts is shown in **Fig. 1**.

METHODOLOGY

The methodology used for resource assessment is known as groundwater resource estimation methodology-1997 (GEC-97). The groundwater 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. It has been estimated as 40,152.6, 37309.2, 19395.8, 13786.4 and 15190.8 ha m for Patna, Gaya, Bhojpur, Buxar and Aurangabad district, respectively. The number of groundwater structures were as per the last minor irrigation census (2000-01). With another approach annual groundwater draft was estimated using the numbers of irrigation structures, average discharge rates of 10, 20 and 40 lps and average hours as 160, 140 and 1800 hrs of pumping for dugwell, shallow tube well and deep tube wells, respectively that is being practised in this region.

Pumping groundwater for irrigation is the main energy consumption activity in agriculture in India. As small and marginal farmers dominate in agriculture sector, farm mechanisation is little restricted and groundwater abstraction became the highest energy

consuming process. Mostly diesel and electrical pumps are used for abstraction that emits Green House Gas (GHG) which is of concern. The energy required for abstraction has been estimated as per the methodology provided by Rothausen and Conway, 2011 which prescribes the energy required to lift 1 m³ of water (with a density 1000 kg m⁻³) up 1 m at 100% efficiency is 0.0027 kWh (1),

$$\text{Energy (kWh)} = \frac{9.8 \text{ m s}^{-2} \times \text{Lift (m)} \times \text{Mass (kg)}}{3.6 \times 10^6 \times \text{Efficiency (\%)}} \quad \dots(1)$$

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

The amount of CO₂ released to lift 1000 m³ of water one meter depends on the source of energy. Diesel does not have a unique chemical formulation so the mass and carbon content vary by mixture. A litre of standard diesel fuel contains approximately 0.732 kg carbon, a mass of approximately 0.85 kg and an energy content of approximately 10.01 kWh. So with diesel pumps the amount of carbon released to lift 1,000 m³ of water one meter is 0.665 kg C (0.732*9.08/10.01). The ratio of carbon emissions 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 CO₂ per kWh at the station (0.4062 kg C per kWh) was used to estimate the release of CO₂ from electric pumps. With 5 percent transmission losses an effective carbon emissions rate of 0.4265 kg C per kWh at the generating facility or 3.873 kg C to lift 1000 m³ 1 meter was used. The emissions from coal-based electricity are about 5.82 (3.873/0.665) times higher than the rate of emissions with diesel pumps (Nelson *et al.*, 2009). Total power generated in India constitute two-thirds of thermal power (54.8% coal based, 9.75% is gas based and 0.66% is oil based) 21% of hydel power, 2.63% is nuclear production and the rest

11.1% is collectively produced by renewable energy sources such as small hydro project, biomass gasifier, biomass power, urban and industrial waste power and wind energy (www.investindia.gov.in). Power system in Bihar is mostly thermal power and the contribution of hydro power is only 5%. The demand of power in the State is 2000MW and is mainly met from central sector allocation which is presently 1726 - 1722 MW (<http://energy.bih.nic.in/main.htm>).

Data on agricultural crops, landuses, rainfall and irrigation sources were collected from Bihar Agricultural Statistics at a Glance for year 2010-11.

RESULTS AND DISCUSSION

The study was carried out in Patna, Gaya, Bhojpur, Buxar and Aurangabad districts of Bihar state of India which falls in agro-climatic zone III B. It lies in the GAP consisting of Ganga, Sone, Dharmawati and Gangi. The average annual rainfall of Patna, Gaya, Bhojpur, Buxar and Aurangabad districts are 970.5, 961.8, 1048.6, 930.8 and 950.2 mm respectively. The major crops grown in this area are rice, wheat, maize, grams and vegetables. About 15 to 20 irrigations are provided using different irrigation structures in these districts.

Gaya and Patna districts of the state are mostly dependent on groundwater for irrigation while Bhojpur, Buxar and Aurangabad districts have a canal network of Sone command. The area irrigated through ground and surface water in different districts during the year 2008-09 is presented in **Table 2**.

The source of irrigation of the selected five districts other than Bhojpur are mostly dependent on

Table 2. Area irrigated (ha) using surface and groundwater sources in the selected districts.

District	Surface Water	Groundwater
Patna	24685 (14.9)	141352 (85.1)
Gaya	5217 (3.2)	157025 (96.8)
Bhojpur	131425 (69.4)	57954 (30.6)
Buxar	69584 (42.9)	92730 (57.1)
Aurangabad	95589 (41.7)	133587 (58.3)
Total	326500 (35.9)	582648 (64.1)

Source: Department of Agriculture, Govt. Of Bihar (<http://krishi.bih.nic.in/Irrigatedarea0809.pdf>)

groundwater especially in Patna and Gaya where surface irrigation contributes only 14.9 and 3.2 percent respectively **Table 2**. In Bhojpur surface irrigation has the major share compared to other four districts.

Distribution of Irrigation structures

The distribution of Irrigation structures of the selected districts are presented in **Table 3**. The numbers of dug well in Barachatty block (1720) are highest amongst 23 blocks of Gaya district. The numbers of shallow tube well are highest in Tekari block (2469) and lowest in Dobhi (360) block. The most numbers of deep tube well are in Belaganj block (45) of Gaya district.

The numbers of dug well in Masaruhi block (848) are highest amongst 23 blocks of Patna district. The numbers of shallow tube wells are highest in Masaruhi block (3327) and lowest in Khusarpur (118) block. The most numbers of deep tube well are in Bihta block (52) of Patna district.

The numbers of dug well in Piro block (512) are highest amongst 14 blocks of Bhojpur district. The numbers of shallow tube well are highest in Piro block (2232) and lowest in Sahar (300) block. The most numbers of deep tube well are in Koilwar block (13) of Bhojpur district.

A total of 11 block wise comparison in Buxar district revealed that Rajpur block is having highest numbers of dug well (181), highest numbers of shallow tube well (2388) and highest numbers of deep tube well (6). The lowest numbers of shallow tube well was found in Chakii block (196) of Buxar district.

The numbers of dug well are highest in Kutumba block (934) and lowest in Obra block (200), amongst 11 blocks of Aurangabad district. Similar comparison

Table 3. Distribution of Irrigation structures in selected districts of GAP.

Districts	Dug wells	Shallow Tube Wells	Deep tube wells
Patna	4971	27930	308
Gaya	17882	24810	59
Bhojpur	1638	17843	19
Buxar	349	12887	23
Aurangabad	6203	8589	96

for shallow tubewell reveals that the highest numbers of shallow tubewell is in Goh block (1952) and lowest in Deo block (75). The highest numbers of deep tubewell is in Kutumba block (41).

The distribution of dug wells according to horse power (hp) of lifting devices in the selected districts was analysed. Majority of dugwells, shallow tube wells and deep tube wells were in the range of 2 - 4, 5 - 7.5 and >10 hp respectively in all the selected districts. Accordingly the average discharge per dugwells, shallow tube wells and deep tube wells were estimated as 10, 20 and 40 lps. The small and marginal farmers own more than 71-77% of the total dugwells, medium farmers own 22-28% and big farmers own only 1-3% of the total dugwells. The marginal farmers own 40 % of the total shallow tubewell in both Patna and Gaya district. Similarly small farmers own 40% in Patna and 37% in Gaya district, medium farmers own 12 % to 29.3% and big farmers own 0.9% to 5.6% of the total shallow tubewell in the selected districts of Burhi Gandak basin. In Bhojpur, Buxar and Aurangabad districts of south Bihar the small farmers own more than 37-42 % of the total shallow tubewells, marginal farmers own 24-35%, medium farmers own 22-34% and big farmers own only 1-4 % of the total shallow tubewells.

Shallow tubewells are a source of livelihood for small and marginal farmers. Groundwater markets in the basin is prevalent, in which private tube-well owners sell surplus irrigation water after their own use to the farmers who don't have their own water extraction mechanism in the vicinity of their land. Though, such buying and selling of water is quite old practice, but the charges/ prices are not governed by any economic criteria but largely by informal agreement between buyers and sellers. The water markets are very crucial from distribution of irrigation water point of view, where state machinery for (groundwater/canal) irrigation are non-existing or has failed to deliver the promises to the resource poor farmers, as they cannot afford to invest themselves to construct water extraction structure for irrigating their small land holding.

There are 91.03 % diesel pumps, 7.1 % electric pumps and 1.83 % other pumps in Patna district. Mostly the dugwells and shallow tube wells are supported by diesel pumps and the deep tube wells

relied on electric pumps. It has been estimated that on an average 160 and 140 hrs pumping is done through dug wells and shallow tubewells to provide 15 to 20 irrigation to rice, wheat and summer crops in a year. The electric pumps are mostly owned by Government and water is provided to group of farmers on turn basis and covers larger area.

Groundwater draft

The annual groundwater draft of the selected districts of GAP is presented in **Table 4**. The data reveals that groundwater draft is more in Patna and Gaya district compared to other three districts. This may be attributed to the fact that Bhojpur, Buxar and Aurangabad farmers practice mostly canal irrigated agriculture where groundwater is used in conjunction. On the other hand Patna and Gaya farmers practice mostly groundwater irrigated farming. It is also observed that Patna has the highest groundwater draft compared to Gaya which may be attributed to the fact that intensive agriculture is being practiced with higher irrigation intensity. The energy use for the draft showed similar trend as that of the amount of draft.

As per the CGWB categorization based on the stage of groundwater development all the five districts fall in the safe category and there is scope of further development to meet the increased food requirement of the country.

CO₂ emission

The emission of CO₂ was estimated for all the five districts using different irrigation structures driven by diesel or electricity and presented in **Fig 2**. The data reveals that the Patna contributes highest followed by Gaya and Aurangabad. It is observed that more the number of deep tube wells more amount of C are emitted. Patna has the highest numbers of deep tube well followed by Aurangabad and Gaya (**Table 3**) and the C emission pattern showed similar trend. This is because Aurangabad has maximum irrigated area (**Table 3**) and intensively cultivated mostly with three crops for which higher amount of groundwater is drafted through deep tubewell using electric pump than other districts except Patna (**Table 4**).

Considering the Bihar power system and Central India Power system where 95 % and 54.8 % thermal power is utilized the CO₂ emission for all the five districts were estimated and presented in **Table 5**.

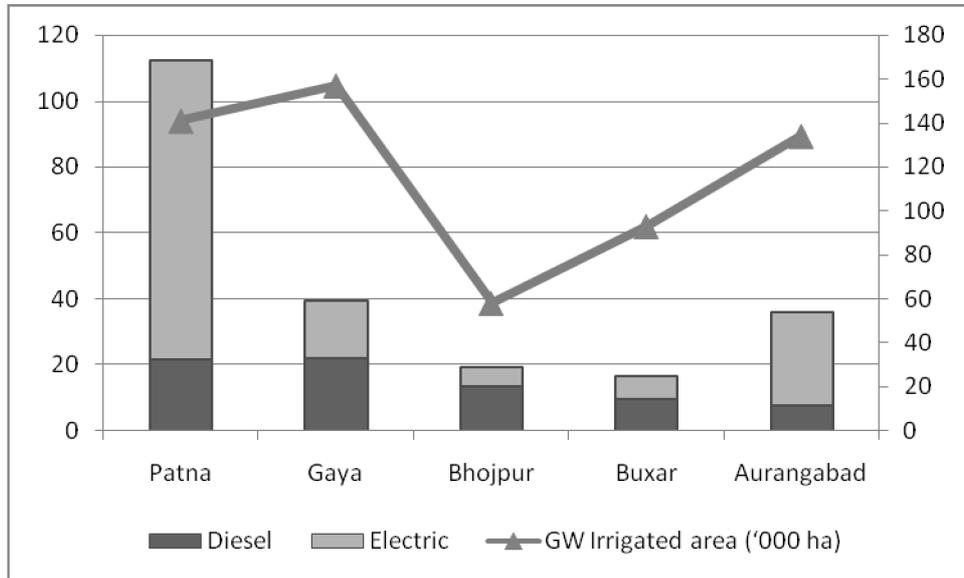


Fig 2. CO₂ emission in '000t CO₂ equivalent from groundwater pumping in selected districts

Table 4. Annual groundwater draft of selected districts

Districts	Irrigated area ('000 ha)	Annual Groundwater draft (ha m)				Total Energy Required (kWh)
		Dug wells	Shallow Tube Wells	Deep tube wells	Total	
Patna	187.0	2863.3	28153.4	7983.4	39000.1	138490464
Gaya	197.0	1030.0	25008.5	1529.3	27567.8	80582068
Bhojpur	159.0	201.0	12990.1	596.2	13787.3	39963224
Buxar	177.0	943.5	17985.7	492.5	19421.7	53820424
Aurangabad	194.0	3572.9	8657.7	2488.3	14719.0	46494728

Table 5. GHG emission from groundwater pumping using diesel and electric fuel

Districts	Stage of Groundwater Development (%)	GHG emission '000 t CO ₂ from pumping (diesel + electric) Thermal Power Contribution based on coal		
		100%	Bihar (95%)	India (54.80%)
Patna	57.2	112.3	107.8	71.3
Gaya	48.6	39.4	38.6	31.6
Bhojpur	35.23	19.1	18.8	16.6
Buxar	31.43	16.3	16.0	13.3
Aurangabad	23.12	35.9	34.5	23.1

Table 6. Proposed number of dugwells and shallow tubewells for future development of groundwater and projected emission of CO₂

Districts	Present stage of Groundwater development	Future groundwater available for irrigation (ha-m)	Number of dugwells proposed	Emission of t CO ₂	Number of shallow tubewell proposed	Emission of t CO ₂
Patna	57.2	35403	61464	12948.8	35122	25897.5
Gaya	48.6	45643	7924	1669.4	45281	33388.1
Bhojpur	35.23	36773	6384	1345.0	36481	26899.4
Buxar	31.43	30962	5375	1132.4	30716	22648.7
Aurangabad	23.12	56562	9820	2068.8	56113	41375.1

The carbon dioxide emission per well per year were estimated as 0.211, 0.737 and 294.5 t CO₂ for dugwell, shallow tube well (using diesel pumps) and deep tube wells (using electric pump considering 100 % coal based energy) respectively. Considering Bihar and Central India Power system a deep tube well emits 279.8 and 161.4 t CO₂ respectively in the Zone III B of Bihar which is about 1326 and 380 times more than dug well and shallow tube wells as per power distribution in Bihar and about 765 and 219 times more than dug well and shallow tube wells as per power distribution in Central India. The carbon dioxide emission from per hectare irrigated area per year were estimated as 0.421, 0.492 and 14.72 t CO₂ for dugwell, shallow tube well (using diesel pumps) and deep tube wells (using electric pump with 100 % coal based energy) respectively. Considering Bihar and Central India Power system a deep tube well emits 14.0 and 8.1 t CO₂ respectively in the Zone III B of Bihar which is about 33.2 and 28.4 times more than dug well and shallow tube wells as per power distribution in Bihar and about 19.2 and 16.5 times more than dug well and shallow tube wells as per power distribution in Central India.

The results suggest that conjunctive use of groundwater in association with canal water in three districts viz., Bhojpur, Buxar and Aurangabad emitted less amount of GHGs than Patna and Gaya districts those are dependent on groundwater irrigation. It has been also observed that in Gaya district groundwater contribute 96.8 percent towards irrigation but emits considerably less CO₂ than Patna where contribution of groundwater towards irrigation is 85.1 percent and

remained at par with Aurangabad district where contribution of groundwater towards irrigation is 58.3 percent only. This is because the number of dugwells are more in Gaya district than the other districts that uses diesel as fuel and emits less amount of CO₂. At present all the five districts are under safe category (CGWB 2010) (Table 5). The groundwater utilization is less in Aurangabad compared to other five districts. To meet the pressure of food production further exploitation of the groundwater resources with the development stage of 70% is acceptable for all the five districts selected. Dugwells and shallow tube wells using diesel pumps are proposed for further exploitation of groundwater in this zone. Based on the future groundwater availability the numbers of dugwell and shallow tubewell are proposed along with their possible CO₂ emission estimates (Table 6) for better planning and water management.

CONCLUSION

It may be concluded from the above study that the places where deep tube wells are used for irrigation using electric pumps contribute more towards Green House Gas emission. On the other hand use of dug wells and shallow tube wells using diesel pumps are more environment friendly. To meet the pressure of increased food requirement there is a scope of further development of groundwater in the GAP. Therefore, keeping in view of GHG emission in the atmosphere dug wells and shallow tube wells with diesel pumps are recommended. Renewable sources of energy like, solar, wind and biofuels may be encouraged to reduce carbon dioxide emissions.

It has been also observed that when groundwater was used in conjunction with canal water emission of CO₂ is less. Therefore, utilization of groundwater in conjunction with canal water or additional water resources that can be created by harvesting rainwater is more environment friendly and recommended.

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Study of Waterlogging and Drainage in Relation to Soil Characteristics in Coastal Areas of Odisha Using Remote Sensing and GIS

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ABSTRACT

In the coastal areas of Odisha waterlogging is a serious problem. The causes of waterlogging in the area are high rainfall coupled with poor water drainage, low land slope and inherent soil texture. In this study, an attempt has been made to make an assessment of the extent and severity of waterlogged areas and drainage of coastal Orissa using remotely sensed data and soil information. Indian remote sensing satellite (IRS-P6 LISS) data of 20th Oct., 2010 and soil series information were put into GIS mode to assess the extent and severity of waterlogging in coastal areas of Odisha. The near-infra-red: green ratio (R31), principal component analysis (PCA) and density slicing of IRS-P6 image were done to delineate waterlogging. The validation of IRS- derived waterlogged area was done using available field information and ground truth radiometry. An R31 value of 0.08-0.92 and pixel value of 108-120 in PCA image were assigned to waterlogged areas. A total of 11 soil series could be identified in the study area and the waterlogging areas mostly covered five soil series corresponding to where soil texture is fine (clay to fine loam) and hydraulic conductivity and organic carbon content of soil are low (0.1-3 cmh⁻¹ and 0.4-0.6%, respectively). R31 and PCA images along with land use map (ORSAC, 2002) showed that areas of some 45,833 ha in 2010 and 40736 ha in 2002 came under waterlogging. It was found that nearly 28.35 % area in 2010 and 25.2 % in 2002 were waterlogged. The 'severe' and 'slight' waterlogged areas were 29791 ha and 16042 ha respectively in 2010 and the severity (60-70% of waterlogged area) was more where groundwater depth was less than 5 m below ground level for obvious reasons. There are mainly five drain lines identified in the image which were mostly distributed over four different soil series and congested by silt deposits. The improvement can be done by excavation of new link drains through three different soil series where soil hydraulic conductivities are low (0.1-3 cm h⁻¹) and texture is fine to very fine (clayey) and renovating the silt congested drains and constructing ponds in relatively slight waterlogged areas for doing fish farming. Thus near infrared: green ratio, principal component analysis and density slicing coupled with GIS were useful techniques and tool in assessing extent and severity of waterlogging and drainage in different soils of coastal Odisha.

Key words: Waterlogging, Soil series, Principal component analysis, Green: infra-red ratio, Remote sensing, GIS.

Waterlogging is a serious problem in many parts of Odisha particularly in the coastal districts. The problem of waterlogging is due mainly to the flat terrain of the area, inadequacy and inefficiency of the drainage systems, heavy precipitation and poor outfall condition (Anonymous, 2010). The coastal area has been formed by sediments deposited under a variety of environments such as fluvial environment (sand dunes, channel deposits) etc. by natural agencies such as river water, sea wave tides, off shore currents and winds. In spite of fertile lands, suitable agro climatic

conditions and irrigation systems the crop yield of these areas is very low in comparison with others due to the drainage congestions, waterlogging and resulting salinity. The main prerequisites of improvement in agricultural practice lie in the improvement of adequate drainage system to overcome waterlogging of the coastal soils of Odisha.

The inherent stratification of soils causes poor drainage conditions. Sand layers are overlain or underlain by relatively impervious strata or slowly permeable strata which impede percolation and

causes poor drainage. The coastal area being a flat land with slope less than 0.02 percent, it does not permit easy drainage. Poor drainage conditions thus have developed waterlogging due to ponding on the surface and rising of groundwater table owing to excess inflow as compared to outflow (Anonymous, 2010). It is therefore required to study the soil characteristics like texture, organic component and conductivities of the area so that necessary measures can be taken to improve adequate drainage system to overcome waterlogging.

Satellite remote sensing coupled with geographical information system (GIS) has a powerful role in periodic mapping of surface waterlogged and drainage congested areas. Remote sensing data acquired in the visible, near infra-red and short wave infra-red regions have shown encouraging results in providing useful information on spatial pattern of waterlogging over the years (Choubey, 1997; Dwivedi *et al.*, 1999; Sudarsanam *et al.*, 2001; Ray *et al.*, 2002). Such studies have, however, enabled detection of waterlogged areas with either standing water or a thin film of water at the surface, using Landsat (MSS and TM) and Indian Remote Sensing Satellite (IRS-1A/1B/1C/1D/P6) Linear Imaging Self Scanning sensor (LISS) data (Goyal *et al.*, 2005). To make use of remotely sensed data, it is essential to understand the correspondence between scene radiance as recorded in multispectral images, geomorphological parameters and field parameters such as water table depth and vegetation cover, crop, species and their developmental stages, soil type etc. (Smith *et al.*, 1990). Many crops growing in soils affected by waterlogging exhibit marked visual symptoms of moisture stress (Yuan and Zhang, 2005; Salomonson, 1983). Black and white infra-red films as well as multiband images have been used in detecting waterlogging in different places (Choubey, 1994). The low reflection in near-infra-red wavelengths as compared to the visible bands for water body have been shown to exhibit the best tonal contrast for detecting waterlogging (Sidhu *et al.*, 1991).

Odisha Remote Sensing Application Centre (ORSAC) in collaboration with NRSA had developed wasteland atlas of Odisha (2003) in which district wise waterlogged areas of the State were delineated. It also used IRS -1B LISSIII data (1995) for delineation of flood affected areas of Rushikulya river basin

(ORSAC, 1995). But detailed investigations for study of extent and severity of waterlogging and drainage in relation to groundwater table, soil characteristics particularly at series level using remote sensing and GIS for coastal Odisha have not been taken up so far. This paper presents estimation of the extent and severity of waterlogged area with respect to soil characters, water table depth and drainage in different coastal areas of the State and possible drainage reclamation based on existing soil and drainage systems.

The study area mainly comprises of three coastal Blocks of Odisha namely, Ersama, Kujang and Marsaghai of coastal Orissa (lat. 20° -20°.44'N, long. 86° 15' -86° 56') and lies at the altitude between 5m and 45m above mean sea level (**Fig. 1**). The region mainly covers Luna Chitropala doab area of Mahanadi river systems and lies in the districts of Jagatsinghpur and Kendrapara of Orissa. Most of this area is having a land slope of less than 0.02 percent. The predominant soil type is fine loam to loam. The main rock type is granite gneiss. Agriculture is the main occupation of the people in the area. The shallow ground water table depth varies from 2-10 m below ground surface.

Physiography and Drainage

The area is a plain area and is drained by the Mahanadi (Ersama and Kujang Block of Jagatsinghpur) and Luna-Chitropala river (Marsaghai Block of Kendrapara) and range an altitude from 5-45 m above mean sea level. It is an extensive alluvial tract and the general slope is towards east and south-east. It enjoys a sub humid monsoon climate. The average annual rainfall in the region is 1500 mm, of which about 70% is received during the monsoon months i.e., from June-October. The distribution of rainfall at two important rainfall stations of the area namely, Ersama and Marsaghai, is shown in **Fig. 2**.

Hydrogeology and Geomorphology

The study area falls into semi-consolidated formations derived from granite gneisses. Adequate thickness of aquifers (12-60 m) are available for tapping in shallow and deep tube wells. Water table lies mostly 2-5 m below ground level (**Fig. 3**). The major portion of the excess water in the study area comes from the precipitation. Poor drainage conditions in addition to

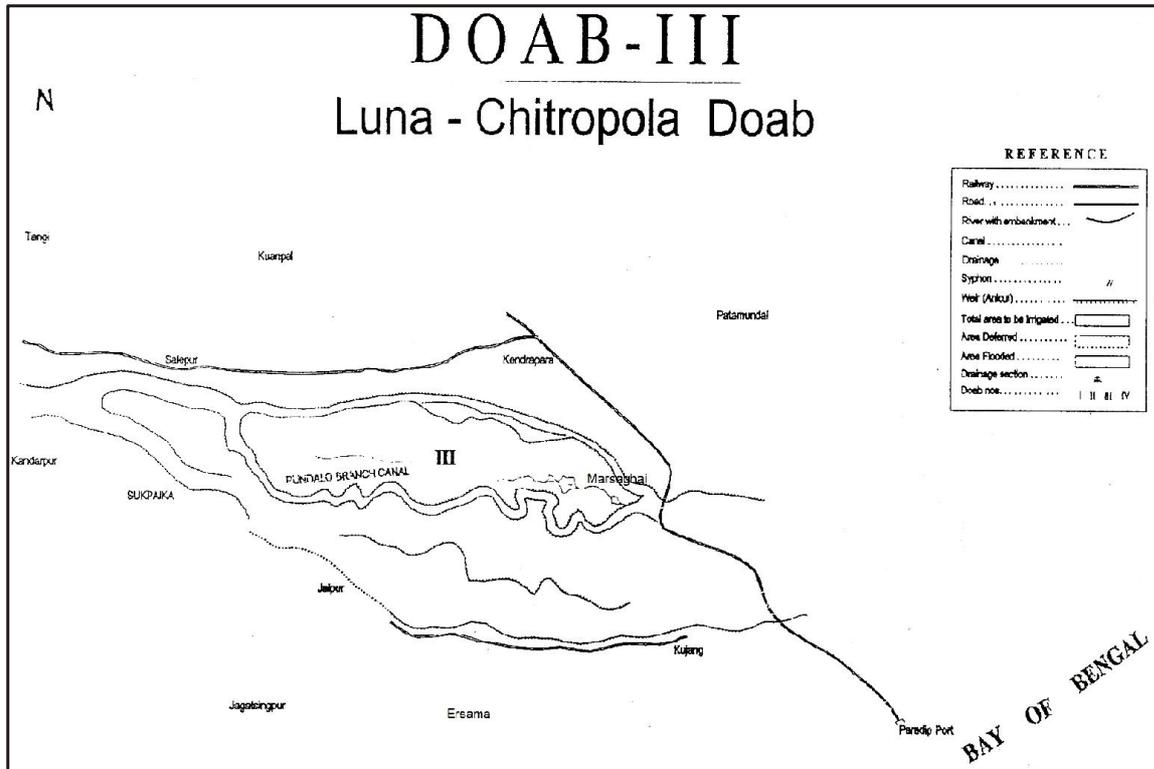


Fig.1. The study waterlogged area covering Ersama, Kujang and Marsaghai Blocks of Odisha

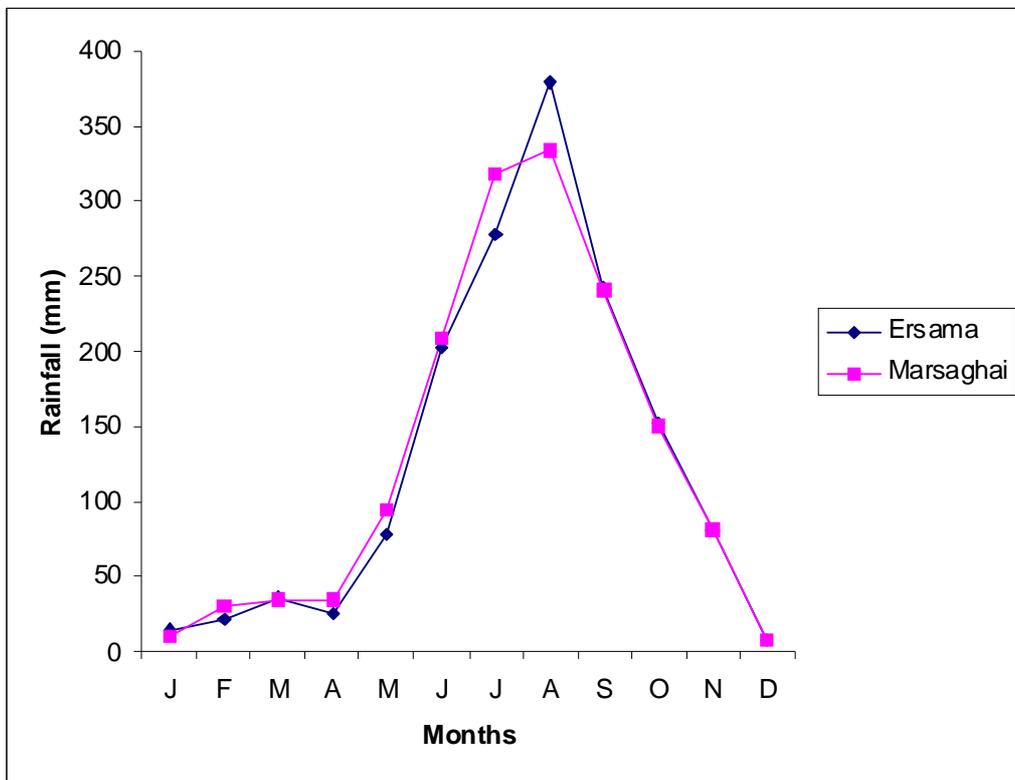


Fig. 2. Average monthly rainfall at Ersama and Marsaghai (2010)

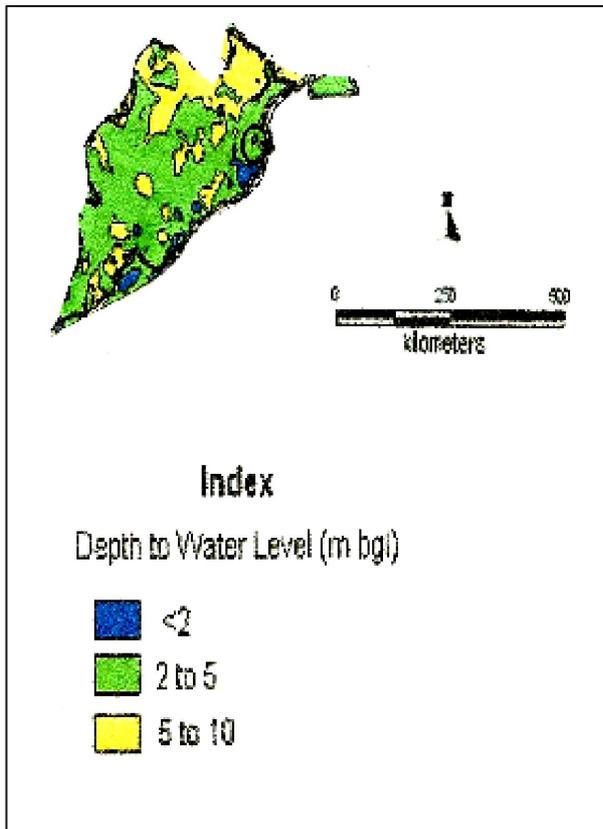


Fig.3. Groundwater table depth at different places of the study area of Odisha

low river capacity to regress the excess water lead to the development of waterlogging. The main landforms of the area are Young Coastal Plain, Old Coastal Plain, Alluvial Plain, Deltaic Plain and Flood Plain. The deltaic plain and flood plains are depressed areas which support waterlogging. The hydrogeomorphological map of one of the three study Blocks is shown in **Fig. 4**.

MATERIALS AND METHODS

The materials used and methodology adopted in the study are shown in **Fig. 5**.

Satellite data

- (i) Standard data of IRSP6 LISSIII date: 20th Oct., 2010; path-107 ; row-058.
- (ii) Land use map and geomorphology map (IRS 1C/ 1D, 2002-03) obtained from Odisha Remote Sensing Application Centre (ORSAC), Bhubaneswar.

Collateral data

SOI toposheet no.s F45U8, F45U11; cadastral village maps, groundwater table map, soil series map and data.

In the study, image processing of IRSP6 LISSIII data were carried out to map the waterlogged area. ERDAS IMAGINE 11 software was used for image processing. The standard satellite image was georeferenced with SOI (1:50,000) toposheets and linearly rectified using polyconic map projection. During rectification 20 GCPs (crossing of rivers, sharp turn in the river, canal- canal, road-canal intersection points) with latitude / longitude values selected from SOI toposheets (which were verified with a hand held GPS) were fed into the program. Thus a 1st order polynomial transformation was performed and resampling was done using the nearest neighbour interpolation method and an RMS error of ± 1.5 were ultimately kept for each points. The noises of images were then removed and histogram equalization was performed. The resulting image was then subsetted into three different blocks making area of interest layers for each Blocks with SOI toposheets.

R31 ratio

The MXL supervised classified image and NDVI image which are generally used to identify terrestrial features, did not produce very satisfactory results in identifying waterlogging when compared with field information/ existing reports. For this, the R31 index, an index similar to normalized difference water index (NDWI) (Mc Feeters, 1996; Goyal et al., 2005) was attempted. The selection of these wavelengths is important with a view to i) maximize the typical reflection of water features by using green light wavelengths, ii) minimize the low reflectance of NIR by water features and iii) take advantage of the high reflectance of NIR by terrestrial vegetation and soil features. When R31 was used to process a multispectral image that had reflected visible green band and NIR band, water features had fractional values (< 1.0) owing to their typical typically higher reflectance of NIR than green bands. The typical R31 values for severely waterlogged areas were found to be 0.08-0.45, whereas those of slightly waterlogged areas were 0.45-0.92. Deletion of the integer (> 1) values through the image processing software effectively eliminated the terrestrial vegetation and soil

information and retained the information on open water for analysis. In this software, an algorithm matches the signatures of a pixel with that of water to identify whether a pixel represents water or not. In addition, it also checks for the R31, which was created as a separate image. The algorithm then checks if the DN value of NIR band of a pixel is less than that of the green band, and if the R31 is < the threshold value (1.0), then it is classified as waterlogged, otherwise not. Masks were created to separate permanent water features (R31 0.0-0.08) from waterlogged areas (R31 0.08-0.92) and soil (1.0-1.10) from vegetations (1.0-1.7). The resulting images were calibrated with GTR reflectance spectra and field measurements of waterlogged and soil and vegetation features. Principal Component Analysis (PCA) was also carried out for the rectified image to map standing water and vegetation in the area. Density slicing of the PCA image were made to identify 'severe' and 'slight' waterlogged areas. While producing waterlogged area feature in R31 and PCA images we took the help of further ground tuthing, cadastral maps and GPS data to assign signatures for soil, waterlogged areas, crop etc.

The resulting R31 and PCA images were then separately imported in ARC-GIS 9.3.1 and projected with polyconic map projection. Soil series map (1:500000, NBSS & LUP) of the study area was enlarged to bring a scale of 1:50000 and was also projected (Tamilarasan *et al.*, 1992). The drainage maps were then made based on SOI toposheets and classified water features in the image. These maps were then superimposed to locate differently waterlogged areas based on severity and drainage features coming under different soil classes. Physico-chemical parameters like texture, organic carbon content, hydraulic conductivity, porosity of soils collected from selected 30 waterlogged sites were also determined. Based on the soil characters, depth of water table and present drainage lines reclamation plan map i.e., sites for construction of new drain lines and tanks was made.

During October, 2010 three field trips were made to carry out field checks, radiometric and ground water table measurements. Subsequently, field trips were made to identify drainage lines and collection of soil samples. Radiometric measurements of water, soil and vegetation were made from different

waterlogged sites using a Ground Truth Radiometer with a 15° field of view with four spectral bands similar to the IRS bands (i.e., 0.4-0.52, 0.52-0.60, 0.60-0.69 and 0.70-1.1 micro m). The average radiance values for water, soil and vegetation were thus used to obtain the corresponding IRS pixel values.

RESULTS AND DISCUSSION

The soils of the study area are mainly classified into 11 soil series namely, fine-loamy typic Tropaquepts (soil series 1), coarse loamy aeric tropic Fluvaquents in association with very fine vertic Tropaquepts (soil series 2), fine loamy vertic Fluvaquents in association with fine loamy aeric Tropaquepts (soil series 3), fine loamy aquic Ustifluvents in association with fine loamy aeric tropic Fluvaquents (soil series 4), sandy typic Ustipsammments (soil series 5), fine to fine loamy Tropaquepts (soil series 6), and fine loamy typic Ustoplepts in association with fine (calcareous) aquic Ustoplepts (soil series 7) (**Table 1**). These soils are mainly very fine to fine (clayey), fine loamy, and sandy in nature. The hydraulic conductivity varies from 0.2-20 cmh⁻¹ in soil series 1, 0.1-3 cmh⁻¹ in series 2, 0.1-0.2 cmh⁻¹ in 3, 2-33 cmh⁻¹ in 4, 0.1-3 cmh⁻¹ in 5 & 6 and 20-33 cmh⁻¹ in series 7. Organic carbon ranges from 0.39-0.62% (low) in most of the soils. In series no. 2 & 3 organic carbon is low to medium (0.7-1.1%). Saturation moisture content of soil series 1, 4, 5, 6 & 7 varies from 45-59% and that of soil series 2 & 3 varies from 50-62% (**Table 1**) (Sarkar *et al.*, 2005; Raut and Powar, 2011). The main landforms of the study area are Young Coastal Plain, Old Coastal Plain, Alluvial Plain and Flood Plain and Deltaic Plain. The lower deltaic plains (young and old coastal plains) of Ersama, Kujang and Marsaghai, where soils are poorly drained are mainly supporting waterlogging (**Fig. 4**). The waterlogged areas obtained in R31 and PCA images mostly cover soil series 1, 2, 3, 5 & 6 (**Fig. 6 & 7**) where soil texture is fine (clay to fine loam) and hydraulic conductivity is low (0.1-3 cmh⁻¹).

For the assessment of waterlogged land, radiance values were measured at different sites in the field representing water, soil, rice field, grass etc. with GTR for selecting the radiance value ranges in the image. It was observed that during 20th Oct. 2010 scenario, the radiance values for waterlogged area were in the

Table 1. Physico-chemical characteristics of different soil series studied in the waterlogged area

Sl no. Soil series	Characteristics
1. Fine loamy Typic Tropaquepts	Deep, poorly drained, fine-loamy soils with loamy surface, moderate flooding and moderate salinity (limited extent), hydraulic conductivity 0.2-20 cm/h, low organic carbon (0.6-0.7%), saturation moisture content 50-59%
2. -Coarse-loamy Aeric-Tropic Fluvaquents-Very fine, Vertic Tropaquepts	Deep, well drained, coarse-loamy soils on very gently sloping lower delta with sandy surface, moderate erosion and moderate flooding: associated with very deep, poorly drained, very fine cracking soils with clayey surface, slight erosion and moderate salinity (limited extent), low hydraulic conductivity (0.1-3 cm/h), low to medium organic carbon (0.7-1.1%), saturation moisture content 50-62%
3. Fine- loamy, Vertic Fluvaquents -Fine loamy Aeric Tropaquepts	Deep, moderately well drained, fine loamy soils on Nearly level lower delta with clayey surface, slight erosion and moderate flooding: associated with very deep, poorly drained, fine loamy soils with loamy surface, slight erosion, moderate flooding and strong salinity (limited extent), low hydraulic conductivity (0.1-3 cm/h), low to medium organic carbon (0.7-1.1%), Saturation moisture content 50-62%.
4. Fine-loamy Aquic Ustifluvents -Fine-liamy Aeric Tropic Fluvaquents	Deep, imperfectly drained, fine-loamy soils, on very gently sloping meander scars with loamy surface, slight erosion and slight flooding; associated with: very deep, imperfectly drained, fine-loamy soils, with loamy surface, slight erosion and moderate salinity (limited extent), hydraulic conductivity 2-33 cm/h, low organic carbon (0.6-0.7%), saturation moisture content 45-49%
5. Sandy, Typic Ustipsammments	Deep, excessively drained, sandy soils on very gently sloping and dunes with sandy surface, moderate erosion and strong salinity, low hydraulic conductivity (0.1-3.0 cm/h), low organic carbon (0.39-0.45%), saturation moisture content 49-57%
6. Fine (loamy) Tropaquents	Deep, poorly to very poorly drained, fine to fine- loamy soils on very gently sloping swamps with loamy surface, slight erosion and moderate to severe flooding (strong salinity), low hydraulic conductivity (0.1-3.0 cm/h), low organic carbon (0.39-0.45%), saturation moisture content 49-57%
7. Fine loamy Typic Ustropepts -Fine (calcareous) Aquic Ustropepts	Deep, imperfectly-moderately well drained, Fine loamy soils, slight erosion, slight salinity and slight to moderate flooding, hydraulic conductivity 20-33 cm/h, low organic carbon (0.6-0.7%), saturation moisture content 49-55%.

range of 0.24-1.2 mW/cm²- Sr- μ in infra red band 4 and 1.3 -2.9 mW/cm²- Sr- μ in band 2. Therefore, in R31 image, the ratio values 0.08-0.92 were used to delineate waterlogged areas. Similarly, the observed radiance ranges of 0.95-1.5 mW/cm²- Sr- μ were used for soil in band 4 and 1.0-1.4 mW/cm²- Sr- μ in

band 2. A radiance range of 1.1-2.0 mW/cm²- Sr- μ in band 4 and 1.1-1.2 mW/cm²- Sr- μ in band 2 were observed in rice crop. The corresponding R31 value ranges for soil and rice were 0.95-1.0 and 1.0-1.7 (**Table 2**).

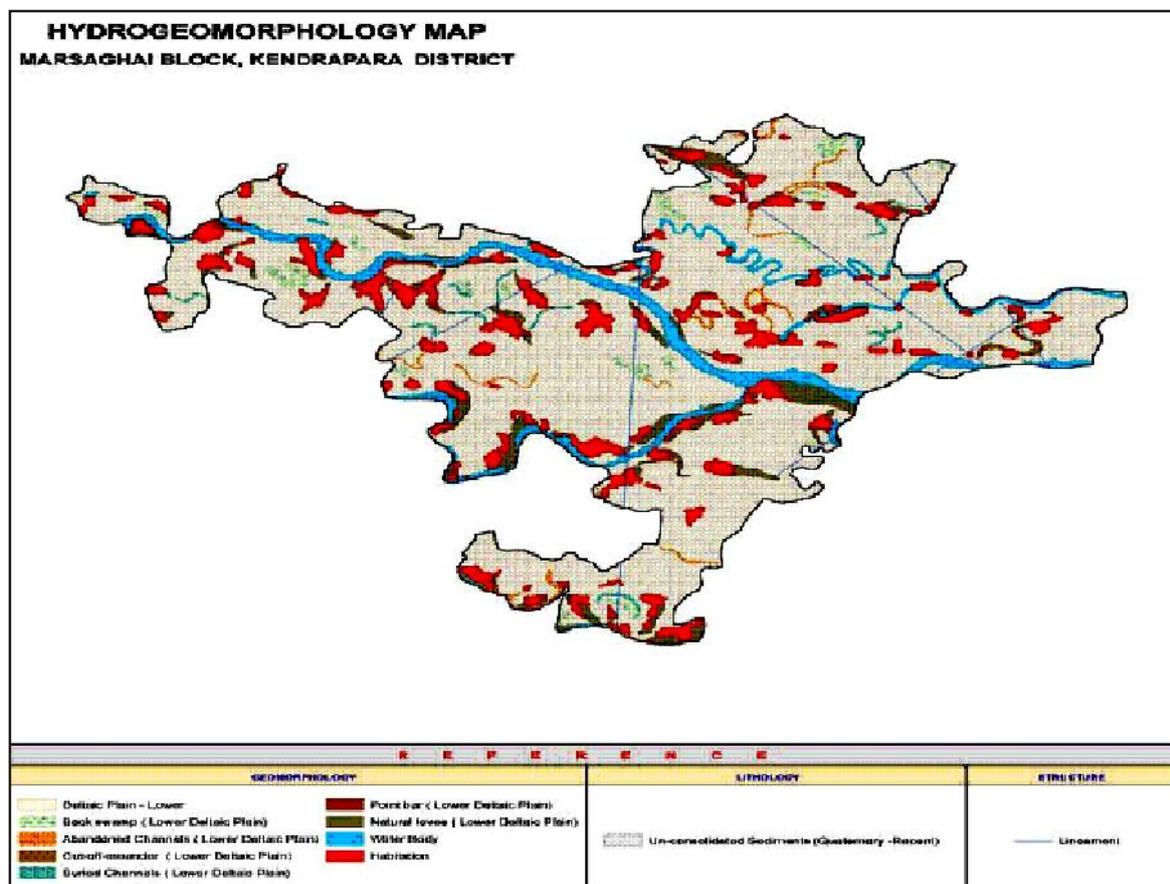


Fig. 4. Hydrogeomorphology map of Marsaghai Block of coastal Odisha (source: ORSAC, Bhubaneswar)

Table 2. R31 values of different features obtained with GTR

Features	R31
Rice	1.0-1.7
Grasses	1.0-1.15
Water logged area	0.08-0.92
i) Severe	i) 0.08-0.45
ii) Slight	ii) 0.45-0.92
Soil	1.0-1.10

The major areas affected by waterlogging fell near Ersama and Kujang (Fig. 6 & 7). Waterlogged areas were divided into i) severely waterlogged area and ii) slightly waterlogged area on the basis of differential R31 values on R31 image and density slicing (Choubey, 1998) of the PCA image. These data were verified with field ground truth radiometer

(GTR) observations ; where waterlogging was > 0.5 m, it was classified as ‘severe’ and where it was <0.5 m , it was classified as ‘slight’. In order to identify severe (0.5-1.0m) and slight (0-0.5m) waterlogged areas a radiance value of 0.24-0.58 mW/cm²- Sr- μ in band 4 and 1.3-2.6 mW/cm²- Sr- μ in band 2 were found for severe waterlogged areas whereas, 0.58-1.2 mW/cm²- Sr- μ in band 4 and 2.6-2.9 mW/cm²- Sr- μ in band 2 were found for ‘slight’ waterlogged areas. Therefore, an R31 value of 0.08-0.45 were assigned to ‘severe’ and 0.45-0.92 were assigned to ‘slight’ waterlogged areas (Table 2). Thus a combined map was generated in ARC-GIS showing the ‘severe’ and ‘slight’ waterlogged areas obtained through masked R31 image and PCA images which are shown in Fig. 8.

The total waterlogged areas mainly coming under Ersama, Kujang and Marsaghai Blocks, obtained from classified images are 45,833 ha. The waterlogged

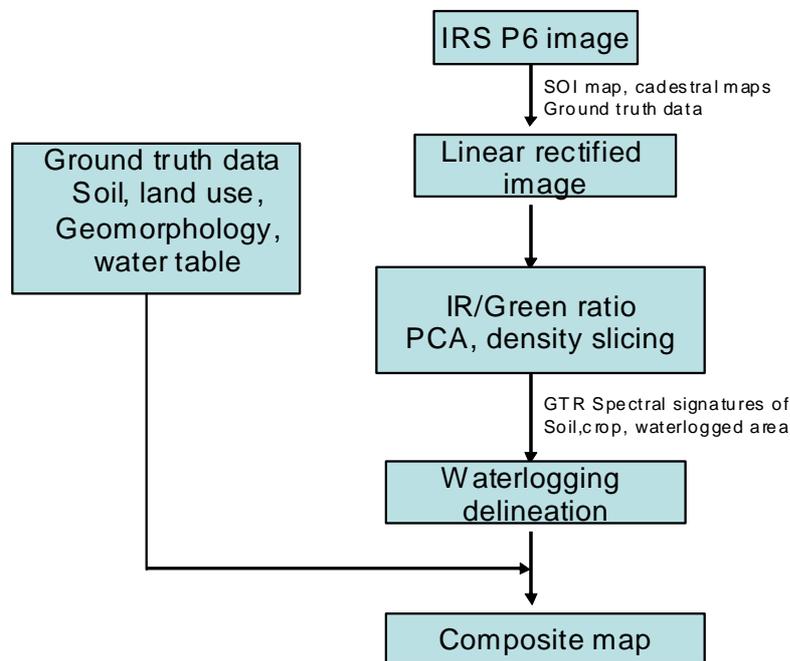


Fig. 5. Data used and methodology followed in the study

areas obtained by R31 and PCA images (the values were close for two images) for the coastal area are shown in **Fig 6 and 7** and the relative statistics are given in **Table 2**. It was found that nearly 28.35 % area in 2010 and 25.2 % in 2002 were waterlogged. The 2002 waterlogging area data were derived from land use map developed by ORSAC (**Fig. 9**). The ‘severe’ and ‘slight’ waterlogged areas were 29791 ha and 16042 ha respectively in 2010 (**Table 3**). The depth of water table during post monsoon period of 2010 varied from 2-10 m in the area.

The superimposed final R31 /PCA image showing waterlogging, hydrogeomorphological maps and groundwater table map showed that the lower deltaic plain and flood plains which are depressed areas of young and old coastal plains of Ersama, Kujang and Marsaghai Blocks, were mostly supporting waterlogging. The areas where depth of water table was 2-5 m below ground level, composed of fine textured soil and situated near the coast were mostly severely waterlogged ; whereas, those areas where water table was 5-10 m deep were slightly waterlogged (**Fig. 8**). The areas obtained in the image were relatively lower than obtained through groundwater table maps made by Central Ground

water Board, because the areas obtained through ground water table data included permanent water features like pond, pits etc. in addition to waterlogged areas (Anon, 1993; Choubey, 1998; Goyal and Gupta, 2003). There was an increase in waterlogged area in 2010 (5097 ha) when compared with the 2002 data (**Table 3; Fig. 9**). Thus the cause of permanent waterlogging was found to be topography, whereas for seasonally waterlogging it was due to the high rainfall and low river regress coupled with inherent soil textural properties.

The doab study area is bounded by river Luna and Chitropala in the right and there are very few numbers

Table 3. Waterlogged areas in the study coastal regions using R31, PCA images and density slicing

Features	Years	
	2010	2002
Total area (ha)	161652	161652
Waterlogged area (ha)	45833	40736
Severely waterlogged area (ha)	29791	-
Slightly waterlogged area (ha)	16042	-
- data not included		

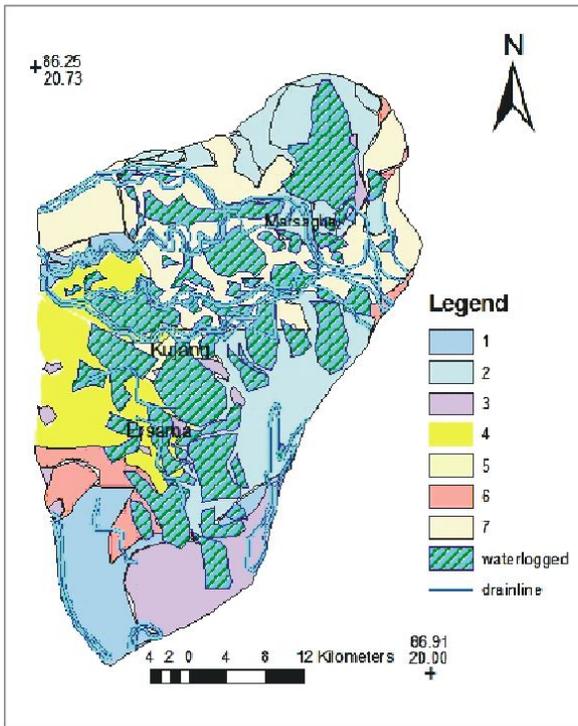


Fig. 6. Map showing waterlogged areas in the coastal Odisha on 20th October, 2010 (by near-infrared:green ratio)

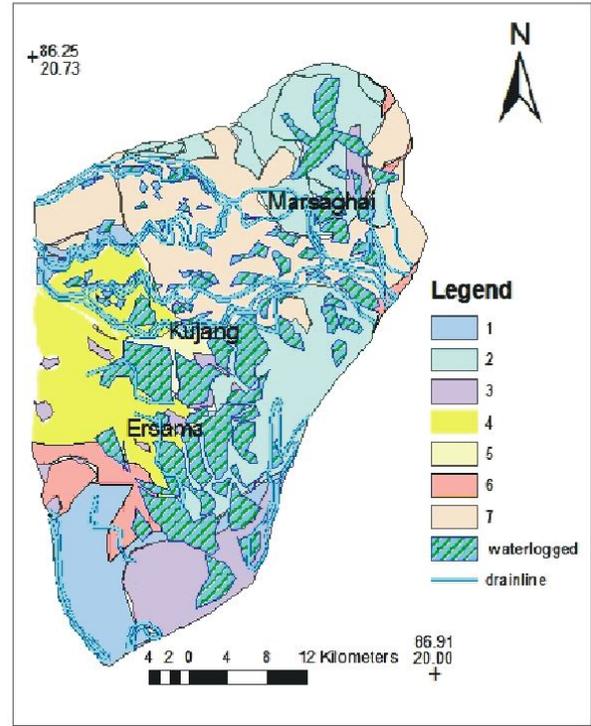


Fig. 7. Map showing waterlogged areas in the coastal Odisha on 20th October, 2010 (by principal component analysis)

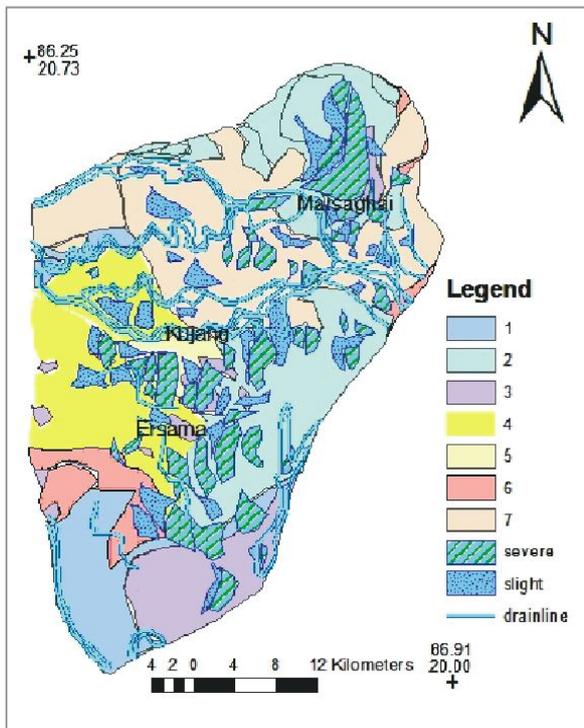


Fig. 8. Map showing severity of waterlogged areas in the coastal Odisha on 20th October, 2010 (by near-infrared:green ratio, principal component analysis and density slicing)

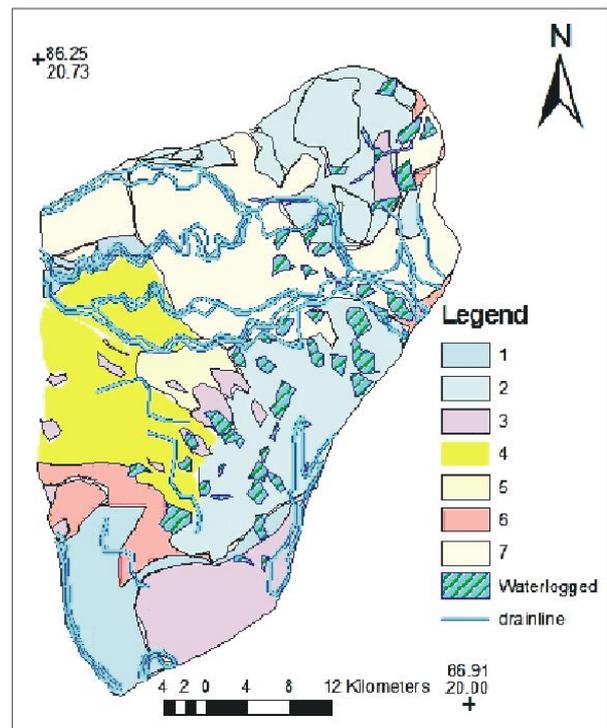


Fig. 9. Map showing waterlogged areas in the coastal Odisha during 2002 (by land use map-2002 and soil series map)

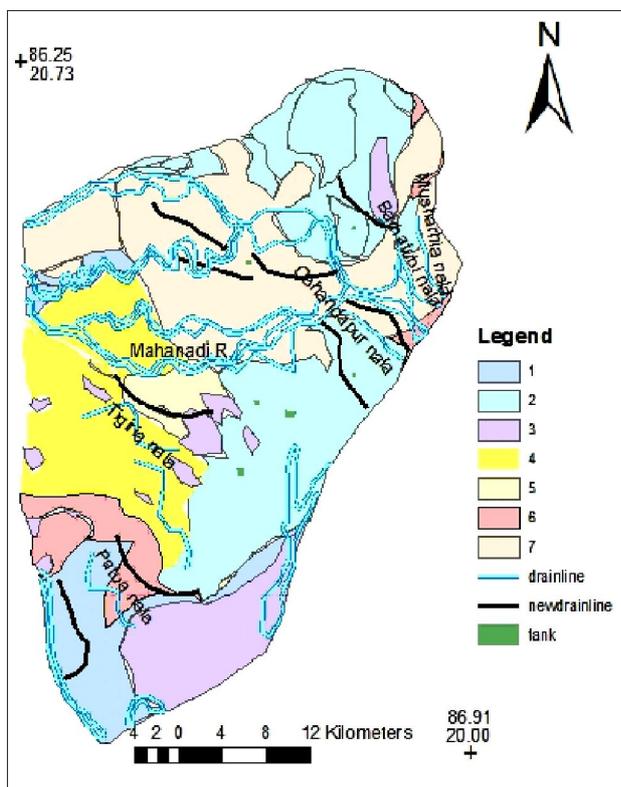


Fig.10. Composite map of the study area showing soil series, drain lines, suggested new drain lines and sites for tanks

(Legends: Fig. 6-10: 1: fine-loamy typic Trophaquepts 2: coarse loamy aeric tropic Fluvaquents in association with very fine vertic Trophaquepts 3: fine loamy vertic Fluvaquents in association with fine loamy aeric Trophaquepts 4: fine loamy aquic Ustifluvents in association with fine loamy aeric tropic Fluvaquents 5: sandy typic Ustipsamments 6: fine to fine loamy Trophaquepts 7: fine loamy typic Ustoprepts in association with fine and calcareous aquic Ustoprepts)

of drains present within the topographical scenario. Mainly 5 drainage lines namely, Musharhia nala, Barhatubi nala, Cahandapur nala, Tigiria and Patua nala located in the study image & were verified by SOI toposheets (**Fig. 10**). The present drains of the study area are shown in Fig. 10. These drains mainly pass through soil series 2, 3, 6 & 7 (**Fig. 10**). The general slope of the land is towards East and South-East.

Since about 28.35% of the total area (1,61652 ha) was waterlogged which has a major impact on crop

growth and survival, management of waterlogged soil should be given a major priority. The improvement can be done by excavation of new link drains in the soil series no. 2, 3, and 4 where soil hydraulic conductivities are low ($0.1-3 \text{ cm h}^{-1}$) and texture is fine to very fine (clayey) (**Fig. 10**). Improvement can also be made by dredging (removing silts) the congested main drains and their interlinked branches.

The areas where the land slope is very less ($<0.02\%$) and waterlogging is slight, bio-drainage through *Eucalyptus*, *Casuarina* plantation etc. can be adopted. Through the initiation of new drainage, farmers would be able to take two crops instead of one of rice in a year at present. In the slight waterlogged areas construction of fish ponds in soil series 2, 3, and 5 where soil texture is clayey and hydraulic conductivity is $0.1-3 \text{ cmh}^{-1}$, can be done for practising rice fish farming (**Fig. 10**).

CONCLUSION

Indian remote sensing satellite (IRSP6 LIH) data of 20th Oct., 2010 and geomorphology and land use maps of 2002-03 obtained from Orissa Remote Sensing Application Centre were analysed to assess the extent and severity of waterlogging in relation to soil and drainage in coastal areas of Orissa. The infra-red: green ratio (R31), principal component analysis (PCA) and density slicing of images were done to delineate waterlogging. Area masking was done to separate waterlogged areas from other terrestrial features. The resulting R31 and PCA images were imported in ARC-GIS and superimposed with soil series maps, ground water table map, drainage map, and geomorphological maps of the waterlogged areas. The spectral signatures of rice, water logged areas and soil features were recorded with a spectral radiometer which were used to calculate R31. These values along with spatial data and GPS data obtained during field visits were used to obtain the corresponding IRS pixel values in the R31 image during separation of waterlogged, soil and crop classes. In the PCA image first principal component (PC1) accounted for most of the variance in the data. Two pixel ranges 108-120 and 120-190 were chosen from the PC1 analysed images and waterlogged feature and terrestrial features were separated out. In R31 image, the ratio values 0.08-0.92 were used to delineate waterlogged areas. In case of severe waterlogging, a R31 value

of 0.08-0.45 and in case of slight waterlogging R31 value of 0.45-0.92 were assigned.

The total waterlogged areas mainly coming under Ersama, Kujang and Marsaghai Blocks, obtained from classified images are 45,833 ha. It was found that nearly 28.35 % area in 2010 and 25.2 % in 2002 were waterlogged. The 'severe' and 'slight' waterlogged areas were 29791 ha and 16042 ha respectively in 2010.

A total of 11 soil series could be identified in the study area. The waterlogged areas obtained in superimposed R31 / PCA images, SOI toposheets, soil series map and field verified soil data showed that the affected areas mostly cover five soil series where soil texture is fine (clay to fine loam) and hydraulic conductivity and organic carbon are low ($0.1-3 \text{ cm h}^{-1}$ and $0.4-0.6\%$, respectively).

The deltaic plain and flood plains of the study area which come under young and old coastal plains were mostly supporting waterlogging. There were mainly five drain channels identified in the image each of which were directed Eastward and were mostly distributed over four different soil series. These drains are mostly congested by silt deposit. The improvement can be done by excavation of new link drains through three different soil series (2,3 & 4) where soil hydraulic conductivities are low ($0.1-3 \text{ cm h}^{-1}$) and texture is fine to very fine (clayey). Improvement can also be made by dredging (removing silts) the congested main drain channels and their branches (2, 3 & 5). Thus IRSP6LIII data and GIS were effectively used to assess waterlogging and drainage of the study area with reference to soil characteristics.

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The Technological Constraints Relating to Canal Irrigation System and Appropriate Strategy for Effective Utilization of Canal Water for Increasing the Productivity of Different Crops

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ABSTRACT

The study on “Technological constraints of canal irrigation system of coastal command in Kendrapara district of Orissa” was undertaken to find out the technological constraints of canal irrigation system by water users. An attempt was made to secure their responses about judicious use of canal water and to identify the various technological constraints perceived by them about canal irrigation system in the area of investigation. Kendrapara Block and four villages in it, were selected purposively, whereas the respondents were selected by random sampling method. The major findings of the study were: (1) Ninety one percent of the farmers opined that excess and shortage of canal water to plots in close proximity and those at a distance from the irrigation channels (2) Lack of irrigation responsive varieties. (3) The requirement of water at critical stage of growth is inadequate. (4) Water management in nursery bed difficult due to scarcity as well as excess of water. (5) Alternate irrigation is not possible. (6) Soil reclamation is not possible. The most important suggestion given by the respondents was canal water should be released at the time of requirement.

Key words: Adoption, constraints, irrigation, recommendation, technological.

India, the leader of the developing countries is entirely situated in the northern hemisphere. It is a tropical country. The total land mass of India is 329 mha which is 2.4% of the land mass of the world. The population of India is 110 crore which is almost 16.8% of the world population and India supports 4.2% of the world water resources. It is obvious that there is a tremendous pressure on natural resources to meet the human requirement in India.

We know that there is a positive correlation between increasing utilization of water resources and increasing production. It is an established fact that water is the single most essential ingredient of crop production which can affect crop production up to 70% keeping other ingredients constant. The average yields of different crops in Orissa are well below nation's average. All India average irrigated land is 32% whereas it is 24% of the total cultivated land in Orissa. So the low yield in Orissa can be attributed to two factors-

1. Lower availability of irrigated land.
2. Improper utilization of water resources.

MATERIALS AND METHODS

As the study is intended to know the technological constraints of canal irrigation system of farmers of command area of Mahanadi Delta irrigation project. It was thought prudent to select Kendrapara district in Orissa purposively as this is progressive district of the state and it is situated on the bank of canal (Kendrapara canal) which is lower end of the main canal of Cuttack. A total four villages namely Ajadhya Nagar, Talabaranga, Saranga and Dey Pura were selected for the study. These four villages are irrigated villages and a total 100 respondents from 25 each village were selected as respondents.

The help of statistical methods such as frequency distribution and percentage of measure of different items were taken. To study the constraints yes and no taken as code one and zero. Agree and disagree taken as one and zero complicated and simple zero as one.

RESULTS AND DISCUSSION

In the study of different technological constraints relating to canal irrigation system were identified. The major constraints were found out by different methods. The constraints were categorized into five groups.

1. Distribution of respondents according to constraints of maintenance of canal.
2. Distribution of respondents on constraints pertaining to variety, nursery and transplanting.
3. Constraints perceived by the respondents in water management.
4. Constraints perceived by the respondents with respect to diseases, pests and weed control in irrigated command.
5. Constraints perceived by the respondents with respect to soil health.

From the above table the most important constraints was preparation of cement channels to reduce water losses in inadequate. Fifty three percent

of the respondents opined that, preparation of cement channels was not done adequately. The second rank was assigned to the supervision work by the officials in renovation and re-silting canal is unsatisfactory, 48% of the respondents said that, supervision work by the officials was unsatisfactory. The third rank was given to the inspection of canal bonds by the officials are improper and having 44% of respondents in favor of it. The statement “the maintenance of canal is improper” was not a problem with farmers. It was ranked fourth (37%).

It was revealed from the **Table 2** that the most important constraint was lack of irrigation responsive varieties. 82% of the respondents said that, there was lack of irrigation responsive varieties. The second rank was assigned to “the requirement of water at critical stages of growth is inadequate” (81%). Third rank was given to the Recommended amount of water is not available for transplanting” (78%). “Availability of canal water for adoption of recommended cropping pattern is inadequate” was ranked fourth in the rank order (74%). “Washing away of seedlings due to excess water “ and “Selection of crops according to

Table 1. Distribution of respondents according to constraints of maintenance of canal.

S. No.	Statements	Frequency N=100	Per-centage	Rank
1.	The maintenance of canal is improper	37	37	IV
2.	The inspections of canal bonds by the officials are not regularly done	44	44	III
3.	The supervision work by the officials in renovation and de-silting of canal is unsatisfactory	48	48	II
4.	Preparation of cement channels to reduce water losses is inadequate	53	53	I

Table 2. Distribution of respondents on constraints pertaining to variety, nursery and transplanting.

S. No.	Statements	Frequency N=100	Per-centage	Rank
1.	Selection of crops according to the water availability is not done	48	48	VI
2.	Availability of canal water for adoption of recommended cropping pattern is inadequate	74	74	IV
3.	Lack of irrigation-responsive variety	82	82	I
4.	Recommended amount of water is not available for transplanting	78	78	III
5.	The requirement of water at critical stage of growth is inadequate	81	81	II
6.	Washing away of seedlings due to excess water	50	50	V

Table 3. Constraints perceived by the respondents in water management.

S. No.	Statements	Frequency N=100	Per-centage	Rank
1.	The requirement of water during crop season is inadequate	68	68	IX
2.	Judicious supply of water in the field is inadequate	76	76	VI
3.	The requirement of water according to crop water management in inadequate	67	67	X
4.	Water logging is a problem in the field	55	55	XII
5.	Water management in nursery bed difficult due to scarcity as well as excess water	62	62	XI
6.	Washing away of seedlings due to excess water	83	83	III
7.	Excess and shortage of water supply to plots in close proximity and those at a distance from the irrigation channels	91	91	I
8.	Alternate irrigation is not possible in wet nursery	88	88	II
9.	Loss of fertilizer through leaching and run off due to over irrigation	77	77	V
10.	Dry nursery is not possible due to non-availability of water	81	81	IV
11.	Due to serious water logging there is low germination.	75	75	VII
12.	High seed rate in wet nursery.	69	69	VIII

the water availability” were ranked fifth and sixth respectively (50 % and 48 % respectively).

The constraints analysis was made with the questionnaire set for the respondents with respect to water management. The large number (91%) of respondents were of opinion, that Excess and shortage of water supply to plots in close proximity and those at a distance from the irrigation channels was the major constraints relating to water management. The statement “Alternate irrigation is not possible in wet nursery” stood second in the rank order. This was the opinion expressed by 88% of the respondents. The third rank was assigned to “Water management in nursery bed difficult due to scarcity as well as excess water”. This was opined by 83% of respondents. “The

Dry nursery is not possible due to non-availability of water”, was ranked fourth (81%). “Water logging is a problem in the field” scores low and it was ranked twelveth (55%).

The constraints analysis was made with a set of administered to respondents with respect to diseases, pest and weeds control. The important constraints were “Plant protection measures are difficult to adopt in wet nursery.” It was ranked first and 68% of the respondents opined in favor of it. The second rank was assigned to “Spraying is not effective in the nursery due to standing water” which was expressed by 66% of the respondents. “Control of weeds in the channels is not possible” was ranked third (63%).

Table 4. Constraints perceived by the respondents with respect to diseases, pests and weed control in irrigated command.

S. No.	Statements	Frequency N=100	Per-centage	Rank
1.	Control of weeds in the channels is not possible.	63	63	III
2.	Spraying is not effective in the nursery due to standing water.	66	66	II
3.	Plant protection measures are difficult to adopt in wet nursery.	68	68	I

Table 5. Constraints perceived by the respondents with respect to soil health.

S. No.	Statements	Frequency N=100	Per-centage	Rank
1.	Adverse effect of continuous application of irrigation on soil health.	64	64	III
2.	Physical status and microbiological activities of soil is hampered due to stagnations of water.	65	65	II
3.	Soil reclamation is inadequate.	82	82	I

Table 6. Constraints as perceived by the farmers in canal water use:

S. No.	Statements	Frequency N=100	Per-centage	Rank
1.	Availability of water all the year round is inadequate.	89	89	I
2.	Balance distribution of water is inadequate.	87	87	II
3.	Supervision work by the officials is improper.	83	83	III
4.	Preparation of bonds in the canals is improper.	67	67	IV
5.	Preparation of cement channels is not proper.	53	53	V
6.	Seeds, fertilizer, agricultural implements are not adequate.	49	49	VI

The constraints analysis was made with a set of questions for the respondents with respect to canal irrigation versus soil health. The largest number of respondents was of opinion that “soil reclamation was inadequate”. It was ranked first (82%). The statement “Physical status and microbiological activities of soil is hampered due to stagnations of water” stood second in the rank order (65%). “The Adverse effect of continuous application of irrigation on soil health” was ranked third. Sixty four percent of the respondents expressed this.

Suggestions of respondents about effective utilization of canal water for increasing the productivity of different crops

Study of constraints and suggestion are important for its successful implementation. The constraints were categorized into six. The frequency and percentage were calculated, after which they are ranked to find out their relative position.

The constraints study was made with the questionnaire set for the respondents with respect to canal water use. The largest number of respondents was in opinion of “Availability of water all the year round is inadequate”. It was ranked first (89%). The

statement “Balance distribution of water is inadequate”, stood second in rank (87%). The third rank stood “Supervision work by the officials is improper” (83%). The low score was assigned to seed, fertilizer and agricultural implements was not adequate. It was ranked sixth (49%). So the constraints with respect to canal water use have ranked the above table according to their magnitude.

In this study different technological constraints relating to canal irrigation system were identified. The constraints were categorized into five groups.

1. Distribution of respondents according to constraints of maintenance of canal.
2. Distribution of respondents on constraints pertaining to variety, nursery and transplanting.
3. Constraints perceived by the respondents in water management.
4. Constraints perceived by the respondents with respect to diseases, pests and weed control in irrigated command.
5. Constraints perceived by the respondents with respect to soil health.

Constraints pertaining to maintenance of canal

The most important constraints is “preparation of cement channels to reduce water losses is inadequate”. The supervision work by the officials in renovation and de-silting of canal is unsatisfactory. The officials do not regularly inspect the canal bonds, because of which water is lost. The farmers also opined that, the maintenance of canal is not done properly.

Constraints pertaining to variety, nursery and transplanting

Selection of crops according to the water availability is not done, which was the most important constraints among all. Water is not available at critical stage of crop growth. During transplanting, the recommended level of water is not available for transplanting. The canal water is not available for adoption of recommended cropping pattern. Farmers were not found to select crops on the basis of water availability.

Constraints pertaining to water management

By analyzing the constraints of water management it was found that, excess and shortage of water to plots in close proximity and those at a distance from the irrigation channels respectively are important constraints which affect yield. Alternate irrigation is not possible in wet nursery because, the canal water is not available in all the time. Water management in nursery becomes difficult due to scarcity as well as excess water. Dry nursery is not possible due to non-availability of water. Due to over irrigation, there is loss of fertilizer through leaching and runoff. The other important constraints are, low germination due to serious water logging, and high seed rate in wet nursery. Inadequate and inefficient fields' channels are also responsible for water loss.

Constraints pertaining to diseases, pests and weed control in irrigated command

Constraints in relating to diseases, pests and weed control were identified. The largest numbers of farmers were of opinion that, plant protection measures are difficult to adopt in wet nursery. The second constraints were “spraying is not effective in the nursery due to standing water”, because there are possibilities of loss of chemicals through flow of

water. Due to continuous irrigation of canal water, weed control in the channels are not possible, which affects the smooth flow irrigation water.

Constraints pertaining to soil health

Constraints analysis was made with respect to canal irrigation versus soil health. The largest numbers of farmers were of opinion that soil reclamation was not possible. The other constraints were, due to excess water supply, “physical and microbiological activities of soil are hampered”. Due to continuous application of water in the field, there is adverse effect on soil health.

Suggestions of respondents for better utilization of water use for increasing productivity of crops:

1. Canal water should be released at the time of requirement.
2. Immediate attention should be focused for immediate repair of canal embankments during off-time.
3. The canal water should be available at the tail end of the canal.
4. The farmers should be intimated prior to the release of water. So that they will be in a position for planning of the cropping pattern.
5. There should be adequate supervision and guidance of the field personnel of agriculture department for better and maximum utilization of canal water.
6. The canal authority should have a look for no loss of canal water by construction of cement channels and ‘V’ – shaped notches.
7. There should be a village irrigation society with the presence of personnel of irrigation/ revenue department for rational distribution of canal water.
8. There should be enforcement of law for any breach of misutilization of irrigation water. For such cases, the irrigation should be scrupulously be dealt with.
9. The Government should have a special facilities for farmers for commissioning of electricity as and when required for crop production.

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Methodology to Monitor Groundwater Quality for Potable Use based on Indian Standards

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ABSTRACT

In India groundwater is the main source of irrigation and potable use. Injudicious and excessive use of fertilizers, discharge of untreated urban and industrial effluent in rivers and land deteriorates the groundwater quality. Once the groundwater is contaminated, its quality cannot be restored by stopping the pollutants from the source. It therefore becomes imperative to regularly monitor the quality of groundwater and to devise ways and means to protect it. Water quality or suitability for use is judged on the potential severity of problems that can be expected to develop during long-term use. The process is slow and gradual so one must be very careful about the quality of water being used for domestic as well as for irrigation purpose. Evaluating the quality of water for domestic purpose especially for potable use, Water quality index (WQI) based on chemical characteristics is found to be one of the most effective tools. The elemental status of the water will address the mobile elements that contaminate the groundwater quality either by surface or subsurface flow. An attempt has been made to assess the groundwater quality for potable purpose through development of a WQI using chemical parameters based on Indian Standards. The WQI developed was validated through a case study along Daya River the drainage point of entire Bhubaneswar city, the capital city of Odisha State located in the eastern part of the country. Based on the WQI five classes were defined *viz.*, excellent, good, poor, very poor and unsuitable. None of the samples collected were found of good quality and were categorised as poor (57.14 %), very poor (14.28%) and unsuitable (28.57%). The results were in good agreement with the users' perception surveyed along the river using River Water in place of ground water for domestic purpose where the measured WQI based on chemical properties stand 'unsuitable'.

India receives 4000 billion cubic meter (BCM) of annual rainfall with an average runoff generated is only 1869 BCM. The annual replenishable groundwater resource of the country is 433 BCM and net groundwater available for utilization is 399 BCM. Annual groundwater draft is 231 BCM out of which 213 BCM is used for irrigation and 18 BCM for domestic and industrial use (CGWB, 2010). In many countries like India groundwater is the main source of irrigation as well as for drinking purpose too. Groundwater is extensively used for irrigation in India and the status of groundwater development in India varies from 0.04 percent in the state of Arunachal Pradesh to 170 percent in Chhattisgarh. Other than availability it is the quality of the water that restricts its use for agriculture as well as domestic purpose. Due to injudicious and excessive use of fertilizers, discharge of untreated urban and industrial effluent in rivers and land deteriorates the groundwater quality.

Once the groundwater is contaminated, its quality cannot be restored by stopping the pollutants from the source. It therefore becomes imperative to regularly monitor the quality of groundwater and to devise ways and means to protect it.

Conceptually, water quality refers to the characteristics of a water supply that will influence its suitability for a specific use, i.e. how well the quality meets the needs of the user. Quality is defined by certain physical, chemical and biological characteristics. Irrigation water quality is being evaluated based on the chemical and physical characteristics of the water and only rarely are any other factors considered important (FAO 1985). Irrigation and domestic uses have different quality needs and one water supply is considered more acceptable (of better quality) if it produces better results or causes fewer problems than an alternative water supply.

There have been a number of different water quality guidelines related to irrigated agriculture. Each has been useful but none has been entirely satisfactory because of the wide variability in field conditions. The modified guideline by Ayers and Westcott 1985 was found to be the most reliable to predict the water quality for irrigation. The suitability of water for irrigation is determined not only by the total amount of salt present but also by the kind of salt. Various soil and cropping problems develop as the total salt content increases, and special management practices may be required to maintain acceptable crop yields. Water quality or suitability for use is judged on the potential severity of problems that can be expected to develop during long-term use. The process is slow and gradual so one must be very careful about the quality of water being used for domestic as well as for irrigation purpose.

Evaluating the quality of water for domestic purpose especially for potable use Water quality index (WQI) based on chemical characteristics is found to be one of the most effective tools. Water Quality Index (WQI) were formulated in many countries based on their National standards. Horton, 1963 proposed the first WQI to be used as a tool for assessing the overall quality of water. Cude 2001, improves the understanding of water quality issues by integrating complex data and generating a score that assess the appropriateness of the quality of water for a variety of uses. Sargaonkar and Deshpande, 2003 defined quality in terms of its physical, chemical and biological parameters and developed an overall index of pollution for surface water based on a general classification scheme in Indian context. Hülya Boyacioglu 2007 developed the Universal Water Quality Index (UWQI) to provide a simpler method for describing the quality of the surface water used for drinking water supply. Most of the WQI proposed were based on the physical, chemical and biological parameters though the hydro geology and groundwater flow influences the quality of water directly or indirectly. The mobile elements contaminate the groundwater quality either by surface or subsurface flow.

India is a vast country with varied hydro-geological situations resulting from diversified geological, climatological and topographic settings. Water-bearing rock formations (aquifers), range in age from Archean

to Recent. The natural chemical composition of groundwater is influenced predominantly by type and depth of soils and subsurface geological formations through which groundwater passes. Its quality is also influenced by contribution from the atmosphere and surface water bodies. An attempt has been made to assess the groundwater quality for irrigation using FAO guidelines and for potable purpose through development of a WQI using chemical parameters based on Indian Standards.

MATERIALS AND METHODS

Sampling

Sampling is the first essential step in assessing the quality of water and waste water. A representative sample that highlights the exact condition existing in water and waste water system has been collected. After collection, the sample has been handled and preserved carefully to prevent any alteration in physical, chemical and biological state. Some parameters like temperature, pH, EC were determined in the field at the time of collection using portable meters. The analysis of physical parameters such as colour and odour was done by visual observation and personal smelling. The temperature was measured by the thermometer. For the chemical analysis of samples for electrical conductivity, total alkalinity, TDS hardness, cations, anions etc. were done by the standard methods established for the examination of water and waste water as described in APHA-AWWA-WEF, 1995.

The concentration of cations viz., Na⁺, and K⁺ were determined by flame emission spectroscopy using flame photometer while Ca⁺⁺, Mg⁺⁺ content and total hardness were estimated using EDTA (Versenate) method. The sodium adsorption ratio (SAR) was estimated by the following relationship

$$\text{SAR} = \text{Na} / (\text{Ca} + \text{Mg})/2$$

where Na, Ca and Mg are their respective contents in water in me/l.

Carbonates, bicarbonate and alkalinity were estimated by titrimetric method. Alkalinity was determined by volumetry using H₂SO₄ as titrant and phenolphthalein and methyl orange as indicators. Chloride was estimated by Mohr method as described in Gupta and Varshney 1997. Fluoride was estimated

Table 1. Chemical Characteristics of Ground Water along Daya River Water

Parameter	Min	Max	Range	Mean	SD
pH	6.47	7.3	0.83	6.97	0.268
EC $\mu\text{mohs/cm}$	0.33	2.6	2.27	0.949	0.6701
TDS mg/l	211.2	1664.0	1452.8	607.4	428.9
Total Alkalinity as CaCO_3 mg/l	132.35	487.2	354.2	262.2	105.4
Total hardness as CaCO_3	172.3	1707.2	1534.9	555.9	319.6
Bicarbonate mg/l	139.2	512.4	373.2	275.8	110.9
Chloride mg/l	149.1	435.4	286.3	237.5	70.4
Sulphate mg/l	3.92	235.2	231.3	54.06	50.74
Phosphate mg/l	0.02	0.667	0.547	0.168	0.204
Nitrate mg/l	59.7	169.6	109.9	108.2	29.01
Calcium mg/l	7.21	346.3	339.1	77.9	77.1
Magnesium mg/l	48.1	192.4	144.3	111.0	15.55
Sodium mg/l	13.4	232.5	219	68.65	67.41
Potassium mg/l	0.6	49.3	48.7	8.16	11.66
Iron mg/l	0.329	7.31	6.981	1.69	1.81
Manganese mg/l	0.089	1.356	1.267	0.415	0.345

SPANDS method as described in Tomar, M. 1999. Sulphate was estimated by turbidimetric method. $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ was assessed by Kjeldahl method using Auto Kjeldahl instrument. Phosphate – P was estimated using ascorbic acid method.

The suitability of groundwater quality for irrigation was assessed using guidelines as framed by Ayers and Westcot 1985. It is a management tool. The guidelines are practical and have been used successfully in general irrigated agriculture for evaluation of the common constituents in surface water, groundwater, drainage water, sewage effluent and wastewater. They are the first step in pointing out the quality limitations of the water supply, but this alone is not enough; methods to overcome or adapt to them are also needed.

Water Quality Index

The present study aimed at assessing the water quality index (WQI) for the groundwater along Daya River through a comprehensive physicochemical analysis. For calculating the WQI, the following 12 parameters have been considered: pH, total hardness,

calcium, magnesium, bicarbonate, chloride, nitrate, sulphate, total dissolved solids, iron, manganese and fluorides as per the standard procedures. The chemical analyses of the groundwater and the percent compliance with the Indian Standards were estimated. For computing WQI three steps are followed. In the first step, each of the parameters has been assigned a weight (w_i) according to its relative importance in the overall quality of water for drinking purposes as well as per cent deviation from the standards. A deviation of 0-20, 21-40, 41-60, 61-80 and 81-100 % has been assigned weight of 5, 4, 3, 2, 1 respectively. In the second step, the relative weight (W_i) is computed from the following equation:

$$W_i = \frac{w_i}{\sum_{i=1}^n w_i} \quad (1)$$

Where, W_i is the relative weight, w_i is the weight of each parameter and n is the number of parameters. In the third step, a quality rating scale (q_i) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the BIS and the result multiplied by 100:

Table 2. Groundwater quality as per FAO and BIS Standards

Parameters	Ground water	As per FAO	As per BIS	FAO Standards	BIS (1991)
pH	6.97	Suitable	Suitable	6.5-8.4	6.5-8.5
EC (dS/m)	0.949	Suitable	-	<3.0	-
Cations (mg/l)					
Na	68.65	-	-	-	-
K	8.15	-	-	-	-
Ca	77.9	-	Unsuitable	-	75
Mg	111.0	-	-	-	-
SAR	7.06	Suitable	-	3-9	-
TDS	610.4	-	Unsuitable	-	500
Alkalinity as CaCO ₃ (mg/l)	262.2	-	Unsuitable	-	200
Anions (mg/l)					
HCO ₃	275.8	-	-	-	-
SO ₄	54.06	-	-	-	-
Cl	237.5	Suitable	Suitable	140-350	250
PO ₄	0.168	-	-	-	-
NO ₃	108.2	Unsuitable	Unsuitable	45	45
Hardness	559.9	Unsuitable	Unsuitable	90-500	300
Heavy Metals (mg/l)					
Fe	1.63		Unsuitable		0.3
Mn	0.415		Unsuitable		0.1
Zn	0.320		Suitable		5

$$qi = (Ci / Si) \times 100 \quad (2)$$

where qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in mg/L, and Si is the Indian drinking water standard for each chemical parameter in mg/L according to the guidelines of the BIS 10500, 1991.

For computing the WQI, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation

$$SI_i = Wi \cdot qi \quad (3)$$

$$WQI = SI_i \quad (4)$$

SI_i is the subindex of ith parameter; qi is the rating based on concentration of ith parameter and n is the number of parameters.

The computed WQI values are classified into five types, excellent, good, poor, very poor and unsuitable with WQI ranging as <50, 50-100, 101-200, 201-300 and > 300 respectively.

Case Study

Odisha (formerly Orissa) lies in the eastern part of India under coastal and hilly agroclimatic zone. The largest river of Odisha, Mahanadi drains a basin area of 1, 43, 000 km² with a deltaic plain of 7000 km² built up by the main river and its six branches-Birupa, Chitrotala, Kathjuri-Devi, Kusabhadra, Bhargavi and Daya as shown in **Fig 2**. Two barrages exist - one 100 km upstream of the river and the other barrage 20 km downstream. Water from these two barrages is used for irrigation purpose covering an area of about 3000 km². The main drainage channel of Bhubaneswar city, the capital of Odisha is the

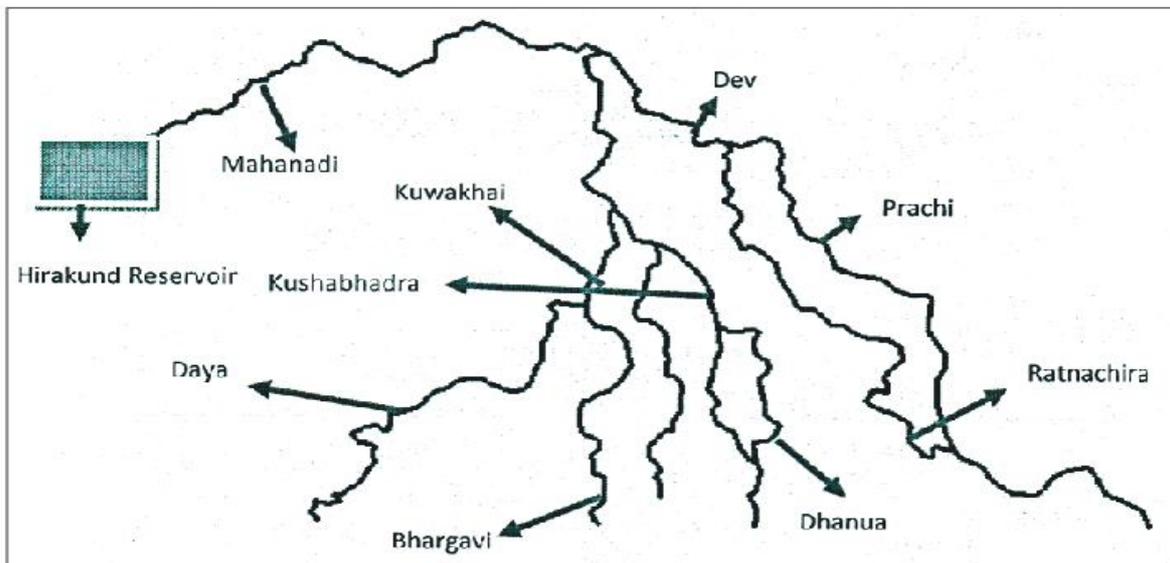


Fig 1. Mahanadi River System of Odisha and its tributaries

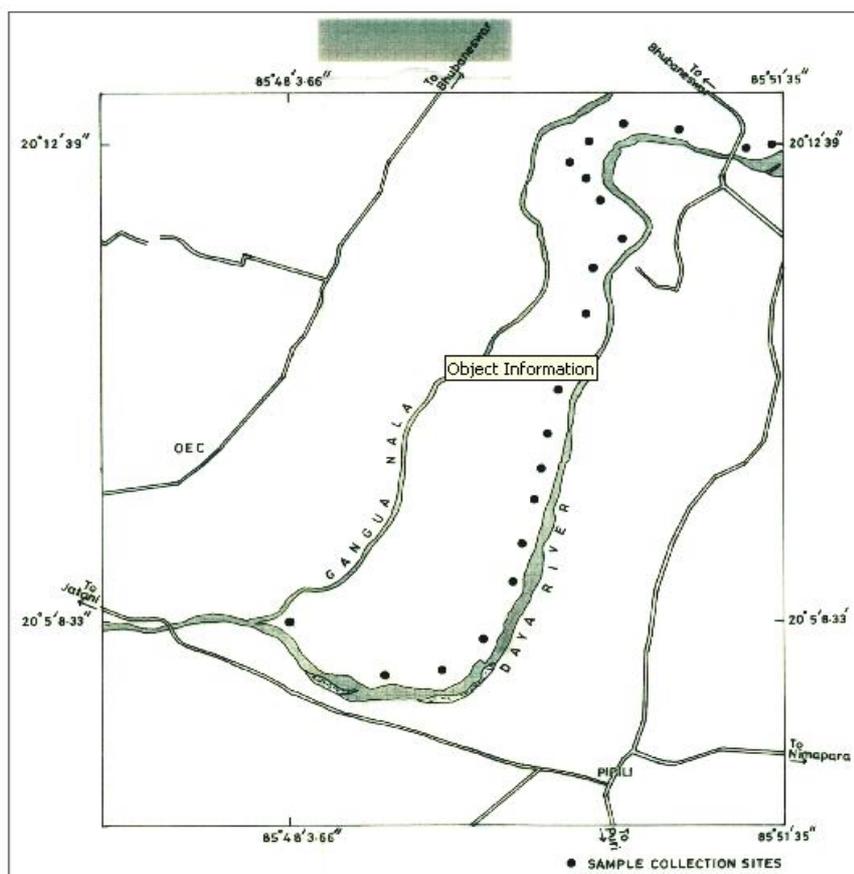


Fig 2. Sampling Site along Daya River

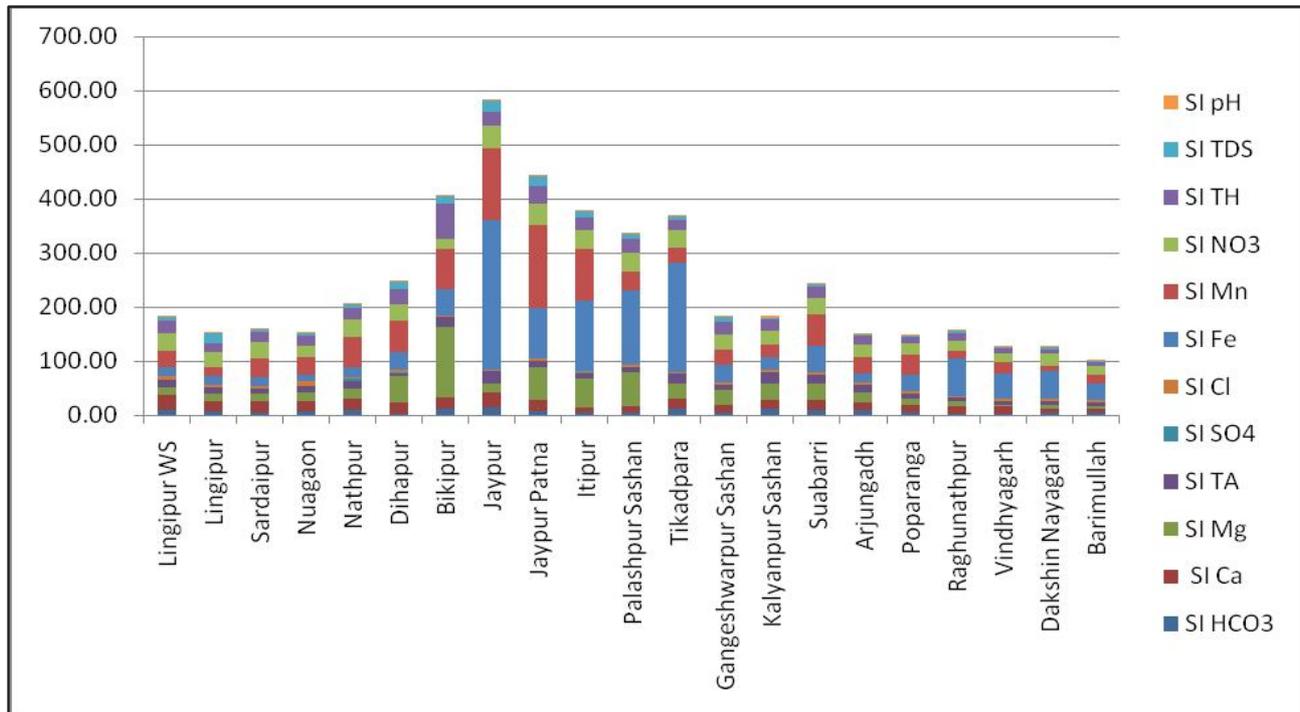


Fig 3. Water Quality Index of groundwater along Daya River

Kuakhai River, a distributary of the Mahanadi river, which flows along the eastern margin of the city. The Kuakhai river has been sub-divided into the Bhargavi and the Daya river in the extreme south eastern part of the city. The minor tributaries of the Kuakhai and Daya rivers flows through the city mostly in easterly and south easterly direction.

The study area is spread over in and around Daya River which lies between $20^{\circ} 12' 39''$ N to $20^{\circ} 5' 8.33''$ N latitude and $85^{\circ} 51' 35''$ E to $85^{\circ} 48' 3.66''$ E longitude (**Fig 3**). Studies conducted along the 20 km stretch of Daya river from its origin from the Kuakhai river (Lingipur water supply station from where water is being supplied to the entire city of Bhubaneswar) to the point where Ganguanala carrying load from nine drains meets Daya river at Barimullah village where the Daya River water is extensively used for irrigation.

The climate of the study area is subtropical with summer season from March to middle of June followed by the rainy season from June to September followed by the winter season from November till the end of February. Relative humidity is generally high throughout the year and varies from 62-85%. The mean monthly potential evapo-transpiration values

vary from 57mm. in January to 254 mm in May. The mean annual wind velocity is recorded as 14.8 km/hr. The rainfall in the study area is mostly governed by the southwest monsoon and the average annual rainfall of the Puri and Khurda district is 1449.1 mm and mm respectively. The rainfall is uneven with maximum rainfall (2146mm) recorded in 1991 and minimum (522mm) in 1974. June-September is the peak rainy season and floods are quite common in the site.

Physiographically the study area is in the upper part of the deltaic plains divided into three parts: lower, middle and upper with very gently slopes. This alluvial plain is characteristically flat. The altitude of the deltaic plain varies from 1 to 10 m above mean sea level. There are mainly three types of soils in the area, which are Alfisols, Aridisols and Entisols. However, Ultisols occur over a small patch. The study area is mostly dominated by Alfisols and are mostly acidic in nature generally deficient in P_2O_5 and N_2 and medium to high in K_2O content The soil pH ranges from 5.8 -6.4.

As per the Central Groundwater Development Report the geological formations are mostly the Tertiary and Quaternary formations consist of laterites

and alluvium while the major parts are covered by alluvium of varying thickness. The average thickness of laterite is around 8 to 10 m. The younger alluvium is dominating in the area covering nearly 90% of the area, occurring as flood plain deposits along the course of Daya river. These sediments consist of an admixture of silt, sand, gravel and pebble in varying proportions.

The aquifer system in the area is mostly shallow. The thickness of shallow aquifers (near surface aquifer) varies widely due to salinity problem. The geological setup governs the occurrence and movement of ground water. The unconsolidated sand and gravel layers of Tertiary and Quaternary age form the main repository of ground water. Groundwater occurs under water table conditions. The sand and gravel layers form the main repository of ground water in this area. The groundwater in near surface shallow aquifers occurs under phreatic conditions, even down to a depth of even 135 m below ground level. The laterites occurring as capping over the country rocks are vesicular, ferruginous and highly porous, which support large number of domestic wells. The depth to water level of the study area varies from 0.16 m bgl to 5.96 mbgl as recorded during pre monsoon, 2006 and varied from 0.08 mbgl to 5.13 m bgl as recorded during post-monsoon, 2006. The fluctuation of depth to water level in 2006 between pre-monsoon and post-monsoon varied from 0.1 m to 3.51 m (CGWB 2010).

As per the Ministry of Water Resources, Water Management wing, Odisha, the total area was under high and very high population density. Basically, agriculture is the main occupations of the large section of the society. Generally, agriculture is carried out in a primitive and traditional way in most part of this region. Business and trade is also a way of life for a minor section of the population. Water from various rivers flowing in this areas serve as a major source for irrigating the agricultural lands which help the farmer's in improving their living conditions with increased agricultural production. On the other hand, this area faces natural calamities like floods and cyclone every year, which worsen the socio-economic condition of the people living in these areas.

RESULTS AND DISCUSSION

Groundwater Quality

The important physico-chemical parameters tested for ascertaining the water quality of groundwater were pH, E.C. turbidity, DO (dissolved oxygen), TDS (Total dissolved solid), total hardness, chlorides, sulphates, phosphate, fluorides, carbonates, bicarbonates, nitrates, ammonium, calcium, sodium, potassium, magnesium and estimated parameters viz., SAR (sodium absorption ratio), RSC (Residual sodium carbonate), RSBC (Residual sodium bicarbonate).

The pH and EC of groundwater tested ranged from 6.47-7.30 and 0.33 to 2.60 dS/m respectively. The alkalinity as CaCO_3 and hardness of groundwater samples tested ranged from 132.4 to 487.2 mg/l and 172.3 to 1707.2 mg/l respectively. The $\text{NO}_3\text{-N}$ content ranged from 34.1 to 62.0 and 59.7 to 169.6 mg/l respectively.

The Fe, Mn and Zn content groundwater samples tested ranged from 0.329 to 7.31 mg/l 0.0892 to 1.356 mg/l and 0.0835 to 3.248 mg/l respectively.

The chemical characteristics of surrounding groundwater samples along Daya River varied widely along the 20 km stretch studied showing increasing or decreasing trend towards the confluence with Ganguanala. It has been observed that the groundwater quality declined wherever there is water table depth is high i.e. mostly between < 2 m from the origin of Daya River covering Dihapur, Bikipur, Jaypur Patna and Itipur village and sometimes upto Tikarpara village.

Assessment of Groundwater quality for irrigation

The average pH and EC values of groundwater were 6.97 and 0.949 dS m^{-1} . According to FAO and BIS standards the groundwater was found suitable for irrigation purpose. The total dissolved salts and the cations viz., Na, K, Ca and Mg present in the the groundwater as 68.65, 8.15, 77.9, 111.0, mg/l (**Table 3**). As per the BIS standards the groundwater was found unsuitable for irrigation on the basis of TDS. The anions viz., bicarbonates, sulphate, chloride, phosphate and nitrate content was as 275.8, 54.1, 237.5, 0.168 and 108.2 mg/l respectively (**Table 3**). The heavy metal content viz., Fe, Zn and Mn was as

Table 3. Interpretations of groundwater quality along Daya river for irrigation

Potential Irrigation Problem	Degree of Restriction on Use
Salinity (<i>affects crop water availability</i>)	Slight to moderate
Infiltration (<i>affects infiltration rate of water into the soil. Evaluate using EC_w and SAR (sodium adsorption ratio, RNa) together</i>)	Slight to moderate
Specific Ion Toxicity (<i>affects sensitive crops</i>)	
Sodium (Na)	
Surface irrigation	Slight to moderate
Sprinkler irrigation	Slight to moderate
Chloride (Cl)	
Surface irrigation	Slight to moderate
Sprinkler irrigation	Slight to moderate
Miscellaneous Effects (<i>affects susceptible crops</i>)	
Nitrogen (NO ₃ -N)	Severe
Bicarbonate (HCO ₃) (<i>overhead sprinkling only</i>)	Slight to moderate
pH	None

1.58, 0.32 and 0.415 ppm respectively. The Fe and Mn content in the groundwater exceeded the BIS standard concentration and found to be unsuitable for irrigation purpose.

Specific Ion toxicity hazards

The groundwater samples were found rich in cations and anions content. Calcium and magnesium are the most abundant cation found and Mg/Ca ratio varied from 1.1 to 12.2 with a mean of 2.21. This can be attributed to the fact that severe damages/erosion caused by flood and stagnant water has polluted the ground water with more leaching and runoff of bases. One of the most important criteria in determining quality of water for irrigation is the Mg : Ca+Mg ratio which is found to be varying from 0.52 to 0.92 with an average of 0.69 which is more than 0.5 predicting harmful effect on soil due to hardness. Suitable measures by enriching the soil with Ca should be taken to maintain the Ca and Mg ratio to eliminate adverse effect on soil.

As per the BIS and FAO standards the chloride content ground water was found within the permissible limit as prescribed for drinking and irrigation purpose.

The proportion of bicarbonate ions in the groundwater used for irrigation is higher than calcium ions is considered undesirable because after evaporation of irrigation water, bicarbonate ion tends to precipitate calcium ions. Gupta (1984) suggested that alkalinity hazards should be determined through the index called Residual Sodium bicarbonate (RSBC). The RSBC calculated was found to be 0.256 me/l. Absolute concentration of bicarbonate ions in amounts greater than 10.0meq/l, affect mineral nutrition, tends to reduce the availability of iron in many plants thereby causing chlorosis, and also create severe problems if used for irrigation through overhead sprinklers. High concentration of bicarbonates (12.5-14.0 meq/l) associated with low content of calcium were reported to cause iron chlorosis in sugarcane in Tamilnadu. The groundwater and river water was found absolutely free from carbonate.

Nitrates in excessive amounts >10 me/l cause specific ion toxicity on plant growth. Nitrates are more harmful than chlorides. Fertilisers help plants by giving them extra supplies of minerals they need to grow. But the plants cannot use all these due to high mobility the nitrates wash away in the rivers and leach down into the groundwater reserves which is the drinking water source of many villages. The nitrate content in

both the river water and the groundwater was found beyond the permissible limits of BIS 1991, 2003 making both the water unsuitable for drinking and irrigation purpose. High nitrate levels were reported in shallow groundwater beneath farming areas. Occurrence of nitrates in groundwater of different states of India has been also reported.

Sodium adsorption ratio

Apart from the total salinity the next important consideration is whether the use of irrigation water of given quality will cause sodicity in the soil. Water which might be considered suitable for irrigation on the basis of EC may not be suitable if sodium predominates. As irrigation water after entering the soil becomes more concentrated SAR is an important index for evaluating the quality of irrigation water where the concentration of the dominating ions were taken into consideration.

As per the guidelines given by Ayers and Westcot, 1985 for interpretations of water quality for irrigation the groundwater was classified and presented in **table 3**. The result depicts that slight to moderate restriction in use of the water for irrigation and with respect to nitrate severe restriction is recommended.

Assessment of groundwater quality for potable use based on Indian Standard

WQI was determined following three steps as described above. In the first step, weight was assigned to each parameter (w_i) according to its relative importance in the overall quality of water for drinking purposes as well as per cent deviation from the standards (**Table 4**). The maximum weight of 5 has been assigned to the parameter nitrate, calcium, magnesium, iron and manganese along with total hardness due to its importance in water quality assessment as well as 80 % or more than 80 % of the samples are beyond the permissible limit. The pH is given the minimum weight of 1 as all the samples have the pH within the permissible limit and of no harm for potable use. The second step was followed and relative weight was assigned accordingly (**Table 4**). The WQI computed as per the methodology ranges from 102.83 at Barimullah to 584.97 at Jaypur (**Fig 3**). It has been observed that none of the samples were found to be safe and all the samples are of poor quality to unsuitable. Majority of the samples (57.1 %) are of poor quality with WQI ranging from 102.83 to 184.5 (**Table 5**). The high value of WQI at these stations has been found to be mainly from the higher values of iron, manganese,

Table 4. Weightage assigned to individual parameters

Parameters	Indian Standards (BIS 1991)	% compliance	weight	Relative weight
pH	6.5-8.5	100	1	0.022727
TDS (mg/l)	500	57.1	3	0.068182
Total Hardness as CaCO ₃ mg/l	300	19.05	5	0.113636
Cl mg/l	250	66.7	2	0.045455
SO ₄ mg/l	200	100	1	0.022727
NO ₃ mg/l	45	0	5	0.113636
HCO ₃ mg/l	244	47.6	3	0.068182
Ca mg/l	75	14.29	5	0.113636
Mg mg/l	30	19.05	5	0.113636
Fe mg/l	0.3	0	5	0.113636
Mn mg/l	0.1	4.76	5	0.113636
TA as CaCO ₃ mg/l	200	33.33	4	0.090909
		Total	44	

Table 5. Classification of Groundwater quality based on Water Quality Index

WQI Value	Water quality	% of water samples
<50	Excellent	0
50-100	Good	0
101-200	Poor	57.14
201-300	Very Poor	14.28
>300	Unsuitable	28.57

magnesium, nitrate, hardness, calcium, alkalinity and bicarbonate in the groundwater. In this part, the groundwater quality may improve due to inflow of freshwater of good quality during rainy season. The analysis reveals that the groundwater of the area needs some degree of treatment before consumption, and it also needs to be protected from the perils of contamination. The results were quite agreeable and at par with the farmers perception surveyed along the river for validation of the results. Inhabitants residing in Itipur, Jaypur, Jaypur Patna and Bikipur villages preferred river water over ground water for domestic use.

It may be concluded from the study that WQI defined based on chemical characteristics have been acceptable and can predict the suitability for domestic purpose based on Indian standards. The methodology is quite simple and adaptable and programmable to develop a software leading towards decision support system. Water quality is of immense importance to maintain soil, crop and human health and any causality may lead to show poisoning of natural resources and human being.

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Development of Artificial Neural Network Models for Forecasting Reference Evapotranspiration

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ABSTRACT

The study has been undertaken for forecasting one month ahead ET_o using artificial neural networks (ANNs). Climatic parameters for 35 years (1977-2011) were collected for Akola station. The ET_o was estimated by using standard Penman-Monteith method which was further used for development and validation of the ANN models as the observed data on ET_o was not available. The training results were compared with each other and performance evaluations were done for untrained data. Based on results obtained, the ANN model with architecture of 4-12-1 (four, twelve and one neuron(s) in the input, hidden, and output layers, respectively) was found to be the best amongst all the models with mean square error (MSE) of 0.73 mm day⁻¹ and correlation coefficient of 0.9260. From the study it is concluded that ANN4 model has given better performance with mean absolute error of estimate (MAE) and root mean square error (RMSE) of 0.20 and 0.27 mm day⁻¹ respectively, mean absolute relative error (MARE) of 5.7 % and model efficiency of 0.9745.

Key Words: Reference evapotranspiration, ANN, Levenberg-Marquardt.

The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. Evapotranspiration is essential in negotiating water treaties and in the irrigation and adjudication of water rights in major river systems, in which the welfare of people in villages, cities, valleys, states and even nations is involved. The ability to predict events with reasonable accuracy enables one to plan in advance what course of action to take to get the best out of situations.

The ability to forecast reference evapotranspiration is of utmost importance for water resources development and utilization, project planning, design and management of irrigation systems effectively in agricultural areas where crop production is the principal user of water.

An ANN is capable of identifying nonlinear relationship between input and output data sets, which may be too difficult to represent by conventional mathematical equations. ANNs are universal approximators which can approximate a large class

of functions with a high degree of accuracy (Kumar *et al.*, 2002; Sudheer *et al.*, 2003; Trajkovic, 2005; Zenetti *et al.*, 2007; Landaras *et al.*, 2008). It seems necessary that nonlinear models such as artificial neural networks (ANNs), which are suited to complex nonlinear systems, be used for the analysis of real-world temporal data. Forecasting is mentioned as one of the most promising application areas of ANN. Hence in this study ANNs are developed to predict one month ahead ET_o (i.e. $ET_{o,t+1}$) for Akola station.

MATERIAL AND METHODS

In order to carry out study, mean monthly meteorological data, *viz.* maximum temperature (Tmax), minimum temperature (Tmin), maximum relative humidity (RHmax), minimum relative humidity (RHmin), bright sunshine hours (SH) and wind speed (WS) were collected from Agricultural Meteorological Observatory, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, for the duration of 35 years (1977-2011). Other parameters like geographic locations, *viz.* latitude and longitude of Akola station also were obtained.

Out of 35 years data first 34 years (1977-2010) data were used for model development and remaining one year (2011) data was used for model validation.

Estimation of reference evapotranspiration (ET_o)

In this study, the reference evapotranspiration was determined by using standard Penman Monteith (FAO - 56) equation.

Development of artificial neural network models

The different multilayer back propagation feed forward neural networks were trained to forecast ET_{o,t+1} based on different combinations of ET_{o,t-11}, ET_{o,t-23}, ET_{o,t-35}, ET_{o,t-47} and ET_{o,t-59}. Summary of the inputs used for the implementation of each ANN model strategy for prediction of ET_{o,t+1} is as given in **Table 1**.

Thus five feed forward neural networks were developed for selected station. To avoid overtraining and undertraining, the available data were split in three separate data sets: (1) training set, (2) cross validation set, (3) testing set in proportion of 60:20:20. The ANN model implementation was carried out using Neuro-Solution 5 version.

The most common architecture: composed of the input layer, hidden layer and output layer was used in this study, where the number of neurons in the input and output layer (corresponded to ET_{o,t+1}) were fixed in each strategy of input combinations and number of neurons in the hidden layer were varied up to three times of number of neurons in input layer in order to get the minimum mean square error (MSE) and high correlation coefficient. In order to train the

network the Levenberg-Marquardt (L-M) algorithm was used, because on function approximation problems it has the fastest convergence and obtain lower mean square errors (Kisi, 2007). Single hidden layer network with linear sigmoid transfer function in the hidden layer and linear transfer function in the output layer were used. The network was trained for maximum of 5000 epochs and with goal for MSE of 0.001. The number of iterations when training stopped and errors were noted down.

Performance evaluation of developed ANN Models

In the next step the network response was analyzed. The best model architecture was selected from each ANN strategy on the basis of minimum mean square error of the testing set. Then the trained networks were used for predicting the ET_{o,t+1} for the independent data set of year 2011 and predicted ET_{o,t+1} were compared with predetermined ETo of the same year. The variations of the ANN predicted and targets were presented graphically.

The model evaluation results were compared quantitatively using statistically measures and criteria viz. mean absolute error (MAE), mean absolute relative error (MARE), root mean square error (RMSE), coefficient of correlation (r), coefficient of determination (R²), model efficiency (E) used for evaluation and comparisons.

RESULTS AND DISCUSSION

Training of ANNs

It is observed from the **Table 2** and **Fig. 1** (ANN1) for ANN1 model strategy having only one input (i.e.

Table 1. Strategies of development of different ANNs using following input combinations.

ANN1	ANN2	ANN3	ANN4	ANN5
ET _{o,t-11}				
	ET _{o,t-23}	ET _{o,t-23}	ET _{o,t-23}	ET _{o,t-23}
		ET _{o,t-35}	ET _{o,t-35}	ET _{o,t-35}
			ET _{o,t-47}	ET _{o,t-47}
				ET _{o,t-59}

ET_{o,t+1} = One month ahead ETo

ET_{o,t-23} = Previous 2 year's ETo for respective month

ET_{o,t-47} = Previous 4 year's ETo for respective month

ET_{o,t-11} = Previous 1year's ETo for respective month

ET_{o,t-35} = Previous 3 year's ETo for respective month

ET_{o,t-59} = Previous 5 year's ETo for respective month

Table 2. Architectures of neural networks with their performance indices obtained during training phase of ANN1.

Sr. No.	Architectures	Number of epochs	Mean square error for test data set	Correlation coefficient for test set
1	1-1-1	83	0.7868	0.8857
2	1-2-1	83	0.8127	0.8857
3	1-3-1	19	0.7552	0.8894

Table 3. Architectures of neural networks with their performance Indices obtained during training phase of ANN2

Sr. No.	Architectures	Number of epochs	Mean square error for test data set	Correlation coefficient for test set
1	2-1-1	277	0.6073	0.9141
2	2-2-1	321	0.6186	0.9175
3	2-3-1	195	0.5772	0.9195
4	2-4-1	259	0.5849	0.9179
5	2-5-1	19	0.5791	0.9198
6	2-6-1	15	0.5726	0.9199

Table 4. Architectures of neural networks with their performance indices obtained during training phase of ANN3

Sr. No.	Architectures	Number of epochs	Mean square error for test data set	Correlation coefficient for test set
1	3-1-1	1091	0.6878	0.9241
2	3-2-1	94	0.5976	0.9222
3	3-3-1	195	0.7217	0.9151
4	3-4-1	275	0.5857	0.9211
5	3-5-1	183	0.7129	0.9203
6	3-6-1	275	0.6232	0.9201
7	3-7-1	358	0.5989	0.9215
8	3-8-1	1950	0.5850	0.9196
9	3-9-1	3837	0.5707	0.9222

$ET_{o,t-11}$), that 1-3-1 architecture (1, 3 and 1 nodes in input, hidden and output layer respectively) was enough for training the network as it resulted in lowest (0.7552) mean square error (MSE) and highest correlation coefficient (0.8894). Therefore in ANN1 model strategy, the model with 1-3-1 architecture was selected for validation.

It is observed from the **Table 3** and **Fig. 1** (ANN2) for ANN2 model strategy which was having two inputs (i.e. $ET_{o,t-11}$ and $ET_{o,t-23}$), that the minimum

MSE (0.5726) was found for 2-6-1 architecture with highest correlation coefficient (0.9199). Therefore scatter plot of test data set for this architecture was obtained. Hence in ANN2 model strategy, the model with 2-6-1 architecture was selected for validation.

In ANN3 model strategy, which was having three inputs, it is observed from **Table 4** and **Fig. 1** (ANN3) that the architecture 3-9-1 was enough for training the network as it has lowest MSE (0.5707) as well as second highest correlation coefficient (0.9222). Therefore in ANN3 model strategy, the

Table 5. Architectures of neural networks with their performance indices obtained during training phase of ANN4

Sr. No.	Architectures	Number of epochs	Mean square error for test data set	Correlation coefficient for test set
1	4-1-1	5000	0.6068	0.9259
2	4-2-1	1512	0.6286	0.9238
3	4-3-1	358	0.6399	0.9232
4	4-4-1	328	0.7206	0.9163
5	4-5-1	35	0.5988	0.9263
6	4-6-1	145	0.6690	0.9232
7	4-7-1	207	0.6303	0.9245
8	4-8-1	117	0.6399	0.9253
9	4-9-1	2017	0.6436	0.9257
10	4-10-1	1335	0.7750	0.9235
11	4-11-1	37	0.7503	0.9211
12	4-12-1	156	0.6561	0.9214

Table 6. Architectures of neural networks with their performance indices obtained during training phase of ANN5

Sr. No.	Architectures	Number of epochs	Mean square error for test data set	Correlation coefficient for test set
1	5-1-1	78	0.6548	0.9247
2	5-2-1	189	0.8957	0.9085
3	5-3-1	334	0.6502	0.9232
4	5-4-1	40	0.6669	0.9216
5	5-5-1	119	0.6368	0.9251
6	5-6-1	95	0.6378	0.9231
7	5-7-1	146	0.7300	0.9205
8	5-8-1	149	0.6550	0.9261
9	5-9-1	411	0.6285	0.9238
10	5-10-1	437	0.6584	0.9227
11	5-11-1	205	0.6741	0.9241
12	5-12-1	90	0.5941	0.9262
13	5-13-1	313	0.6487	0.9243
14	5-14-1	438	0.6519	0.9212
15	5-15-1	2335	0.6347	0.9261

model with 3-9-1 architecture was selected for further evaluation.

For ANN4 model strategy, in which four inputs were used for training, it is seen from **Table 5** and **Fig. 1** (ANN4) that MSE (0.5988) obtained during testing of different architectures was lowest with highest correlation coefficient (0.9263). Therefore in ANN4 model strategy, the model with 4-5-1 architecture was selected for further evaluation.

It is observed from **Table 6** and **Fig. 1** (ANN5) for ANN5 model strategy with five inputs, that MSE (0.5941) was lowest in respect of 5-12-1 architecture and highest correlation coefficient (0.9262). Therefore scatter plot of test data set for this architecture was obtained. Therefore for ANN5 model strategy, the model with 5-12-1 architecture was selected for further evaluation.

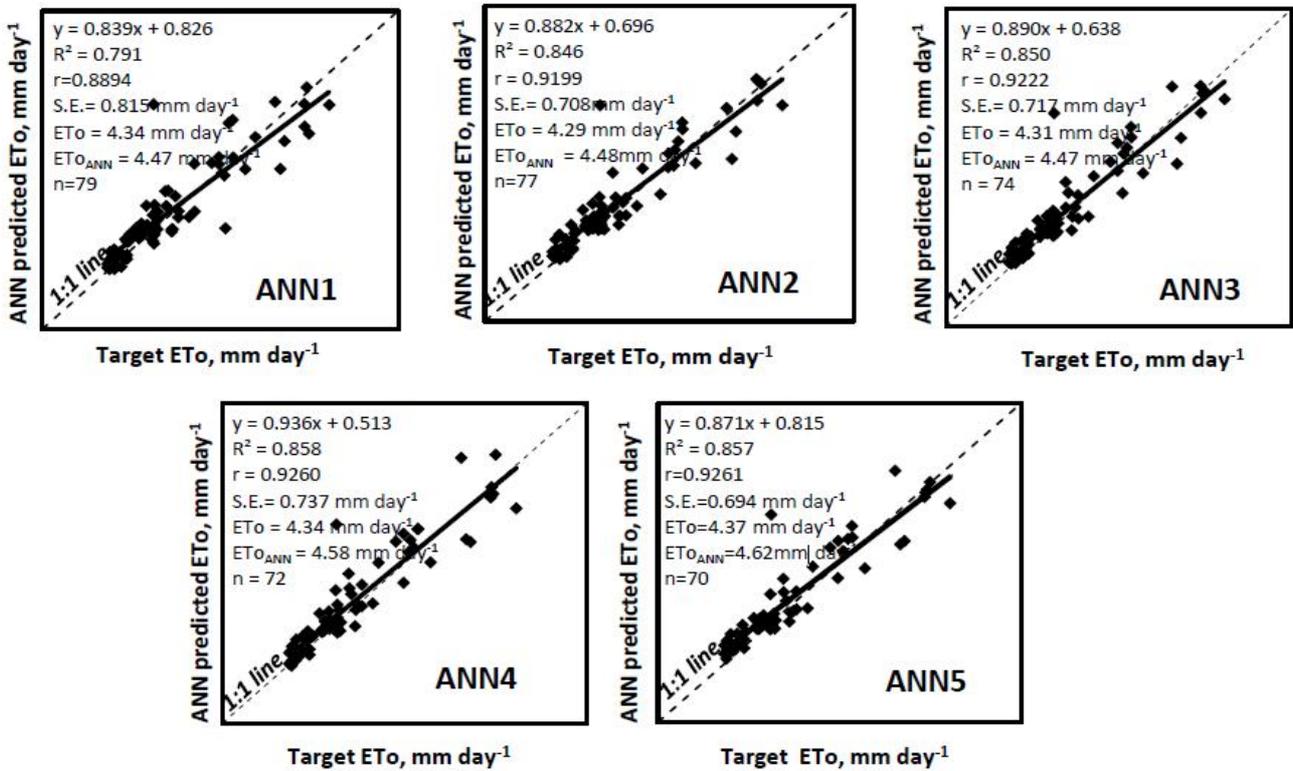


Fig. 1. Scatter plot between target and ANN predicted ETo values for test data set obtained during training phase of different ANNs

Model evaluation

Independent evaluation data set of 2011 was used for validation of the trained and selected networks. For this purpose the data regarding $ET_{0,t-11}$, $ET_{0,t-23}$, $ET_{0,t-35}$, $ET_{0,t-47}$ and $ET_{0,t-59}$ were given as inputs to the networks developed and $ET_{0,t+1}$ was predicted. For ANN1, only one input was used i.e. $ET_{0,t-11}$ which was one year previous data. Likewise each of ANN1, ANN2, ANN3, ANN4 and ANN5 models developed using only inputs from independent evaluation data set. Predicted rates of ETo were then compared with the target values of ETo.

The variation and scatter plot between target and predicted ETo using selected ANN models are presented in Fig. 2 and 3. It is seen from Fig. 2 and 3 (ANN1), that ANN1 model having only one input ($ET_{0,t-11}$), yields fairly accurate estimates of ETo for the most of periods of years. The correlation coefficient between target and predicted ETo was obtained significantly high with 0.46 mm day⁻¹ standard error (SE) of estimate. It is observed from Table 7 (ANN1) that low MAE, RMSE and MARE

were obtained with good coefficient of determination and model efficiency of 0.9366. Results of ANN1 model suggest that only previous one year data can approximate the model for forecasting of ETo and is suitable for fairly accurate prediction of ETo.

It is observed that ANN2 model having only two inputs, has accurately predicted ETo throughout the year. The correlation between target and predicted ETo was highly significant. The regression line is close to 1:1 line with low SE of estimate (0.36 mm day⁻¹). Table 7 shows that MAE, RMSE and MARE were found to be low with high coefficient of determination. The model efficiency was also high (0.9410). ANN2 model indicates that even with only two inputs, it is possible to predict ETo with good accuracy.

ANN3 model having three inputs has predicted ETo accurately. The significantly high correlation between target and predicted ETo was obtained with 0.26 mm day⁻¹ standard error of estimate. It is observed from Table 7 that low MAE, RMSE and MARE were obtained with good coefficient of

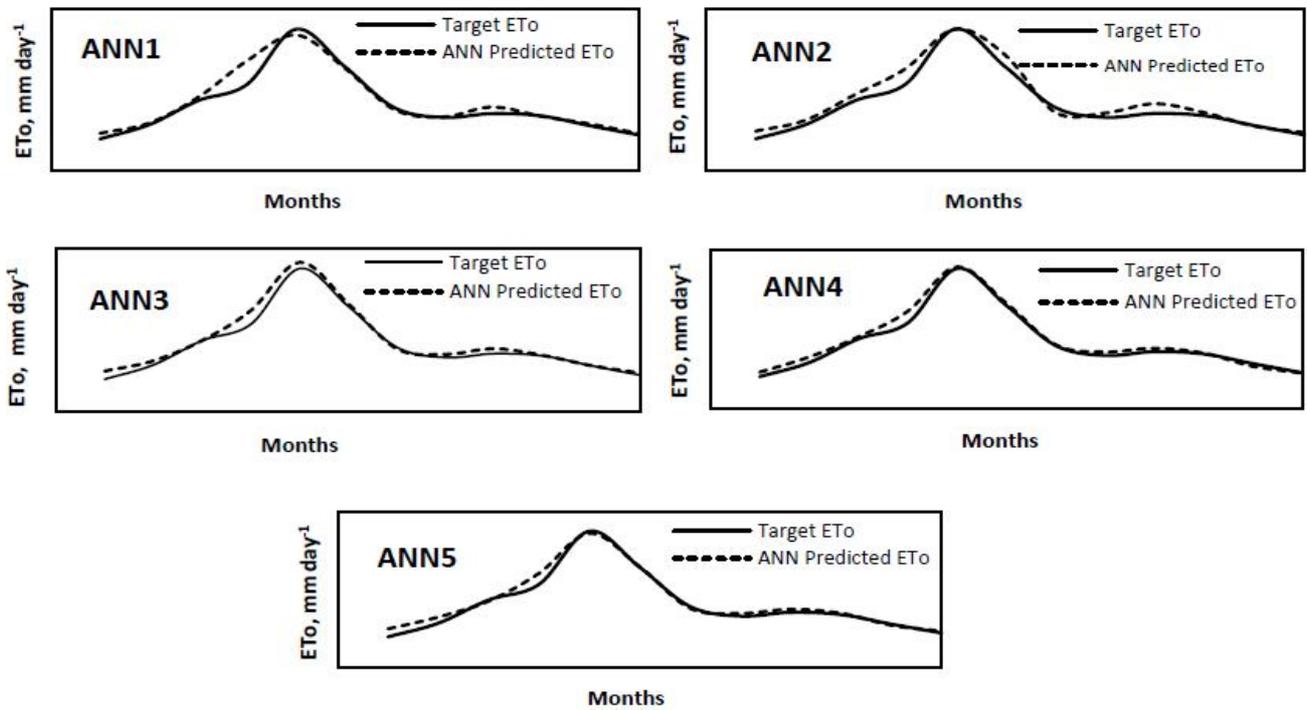


Fig. 2. Variation between target and ANN predicted ETo using ANNs model for the independent evaluation data set

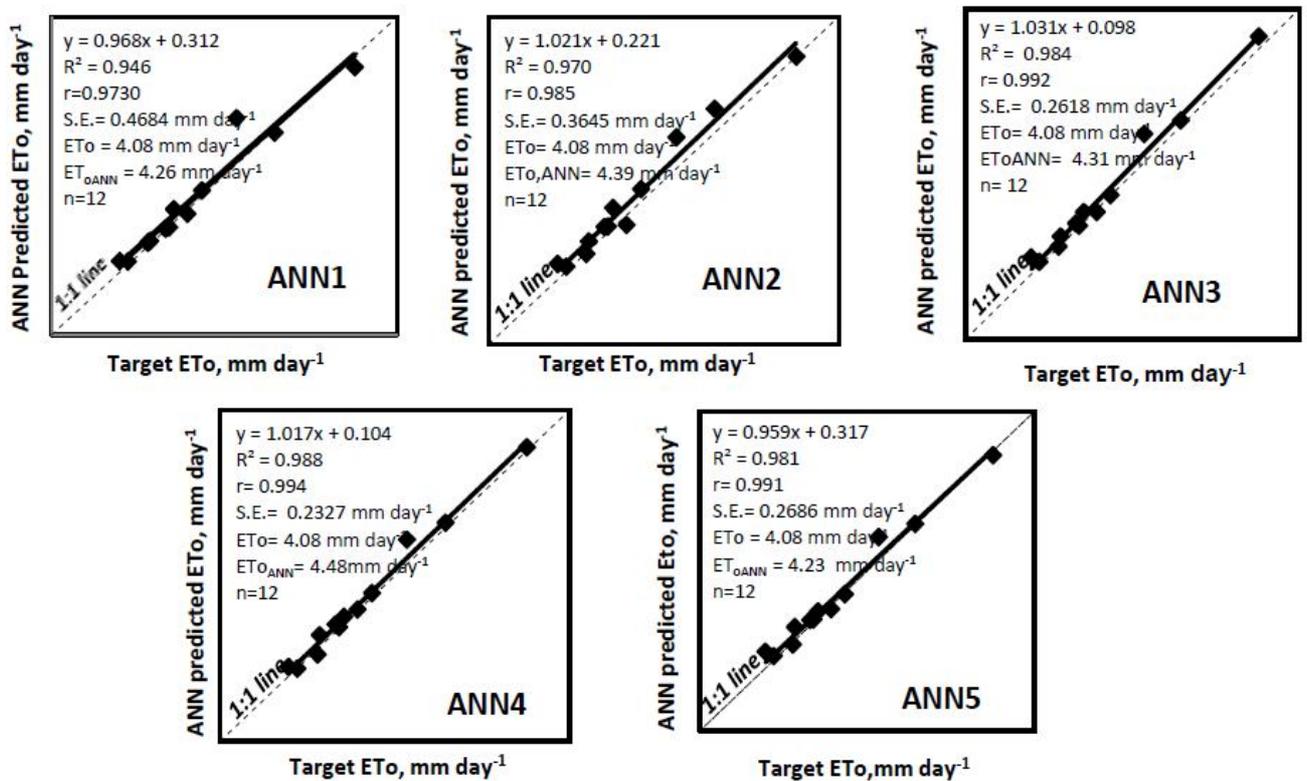


Fig. 3. Scatter plot between target and ANN predicted ETo values for the independent evaluation data set using ANN models

Table 7. Comparative performances of different ANN models developed

Sr. No.	Performance Index	ANN1	ANN2	ANN3	ANN4	ANN5
1	Mean absolute error, mm day ⁻¹	0.2773	0.3617	0.2410	0.2061	0.2211
2	Root mean square error, mm day ⁻¹	0.4703	0.4538	0.3351	0.2778	0.2983
3	Mean absolute relative error, %	6.8763	9.7664	6.7039	5.7772	6.8122
4	Correlation coefficient	0.9730	0.9850	0.9920	0.9940	0.9910
5	Coefficient of determination	0.9467	0.9700	0.9840	0.9880	0.9820
6	Model efficiency	0.9366	0.9410	0.9678	0.9779	0.9745

determination. The model efficiency was obtained high enough (0.9678). These results of ANN3 model indicate that ANN3 model is suitable for prediction of ETo.

It is observed that ANN4 model having four inputs, has accurately estimated ETo. The correlation between target and predicted ETo was highly significant. The regression line coincides the 1:1 line, with 0.23 mm day⁻¹ SE of estimate. **Table 7** reveals that MAE, RMSE and MARE were very low with high coefficient of determination. The model efficiency was also high (0.9779) enough. The results of ANN4 model indicate that it is possible to predict ETo with high accuracy.

ANN5 model having five inputs has predicted ETo accurately. The correlation between target and predicted ETo was highly significant. The regression line coincides with 1:1 line with SE of estimate of 0.27 mm day⁻¹. **Table 7** reveals that MAE, RMSE and MARE were low with high coefficient of determination and model efficiency was also high (0.9745). Results of ANN5 model indicate that it is possible to predict ETo using ANN5 network model with high degree of accuracy.

Comparative performances of different developed ANNs

Table 7 shows the comparative performances of different ANN models developed. From **Table 7**, results indicate that MAE, MARE, RMSE, r, R² and model efficiency (E) recorded in respect of all ANN models developed were found to be acceptable and reveal that all are suitable for forecasting the ETo with accuracy. Out of five ANN models, ANN4 forecasted ETo with highest accuracy among all, with lowest MAE, MARE, RMSE and highest r, R² and E.

CONCLUSION

Developed ANN models were found to be suitable for prediction of one month ahead ETo and can be used according to the availability of historical data. Whereas ANN4 is suggested to be best among ANN1 to ANN5 models for prediction of ETo.

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2. Manuscript should be typed on one side of good quality bond paper of quarter size (21.5 cm x 28 cm), with wide margins and double spacing throughout. Every page of the manuscript including tables, references should be numbered on the upper right hand corner. However, in the text, no reference should be made to page numbers. The length of the manuscript should be limited to 10 typed pages including figures, tables, etc. Short notes should not exceed 4 pages. Full length papers based on field experiments must include at least two years data.

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- v) Key words : Not more than five,
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- vii) Materials and Methods,
- viii) Results and Discussion,
- ix) Acknowledgements,
- x) References,
- xi) Tables and
- xii) Figures with captions.

- 3.2 The short research note will not have the above sections as in a research paper.

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A well written, condensed form of the paper up to 150 words giving objectives, methods used, main results and a conclusion of the investigation should appear just before introduction. For a short research note, the abstract is not necessary.

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Randhawa, N.S. and R.K. Rajput 1986. Irrigation water management research - National perspective. pp. 379-410. In J.S. Kanwar (ed.) *Water Management - The Key to Developing Agriculture*. Agricole Pub. Acad. New Delhi.

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