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Water Management Research in South Gujarat

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The South Gujarat comprises of seven districts *viz.*, Valsad, Dangs, Navsari, Surat, Tapi, Bharuch and Narmada with TGA of 23.81 lakh hectares. The Dangs, Navsari, Valsad and southern part of Surat district falls in South Gujarat heavy rainfall agro climatic zone-I. While northern part of Surat and whole of Tapi, Narmada and Bharuch comes under South Gujarat agro climatic zone-II. The climate, soil, cropping pattern, land use pattern, irrigation and production constraints of the region are discussed here.

Climate

At national level, though major portion of the South Gujarat is grouped under coastal ecosystem with sub humid climate yet, at taluka level tremendous variations in climatic parameters is observed (Fig. 1).With an exception of Nandod of Narmada, Nizer and Uchal of Surat district, whole of the eastern belt is subhumid (moist/dry) and the South eastern part comprising Dharmpur and Kaparada talukas of Valsad district along with Gandevi taluka of Navsari district are classified as humid. Most of the talukas of Bharuch district are classified into semiarid (dry/moist) whereas the talukaVagra and Hansot of Bharuch and Surat districts are semiarid, respectively. This diversity is also evident in precipitation received in South Gujarat as Dharampur and Kaparada talukas get 2384 mm and that of Jamusartaluka get only 773 mm of rainfall. In Valsad,Navsari and Dangs districts, rainfall is more than evaporation (Table 1). This implies that the these districts are water excess particularly during monsoon month.

Table 1: Annual rainfall and evaporation for different districts of South Gujarat

Districts	Rainfall (mm)	Evaporation (mm)
Bharuch	871	1700
Narmada	1144	1700
Surat	1321	1600
Tapi	1398	1636
Valsad	1807	1538
Navsari	1845	1625
The Dangs	1813	1636

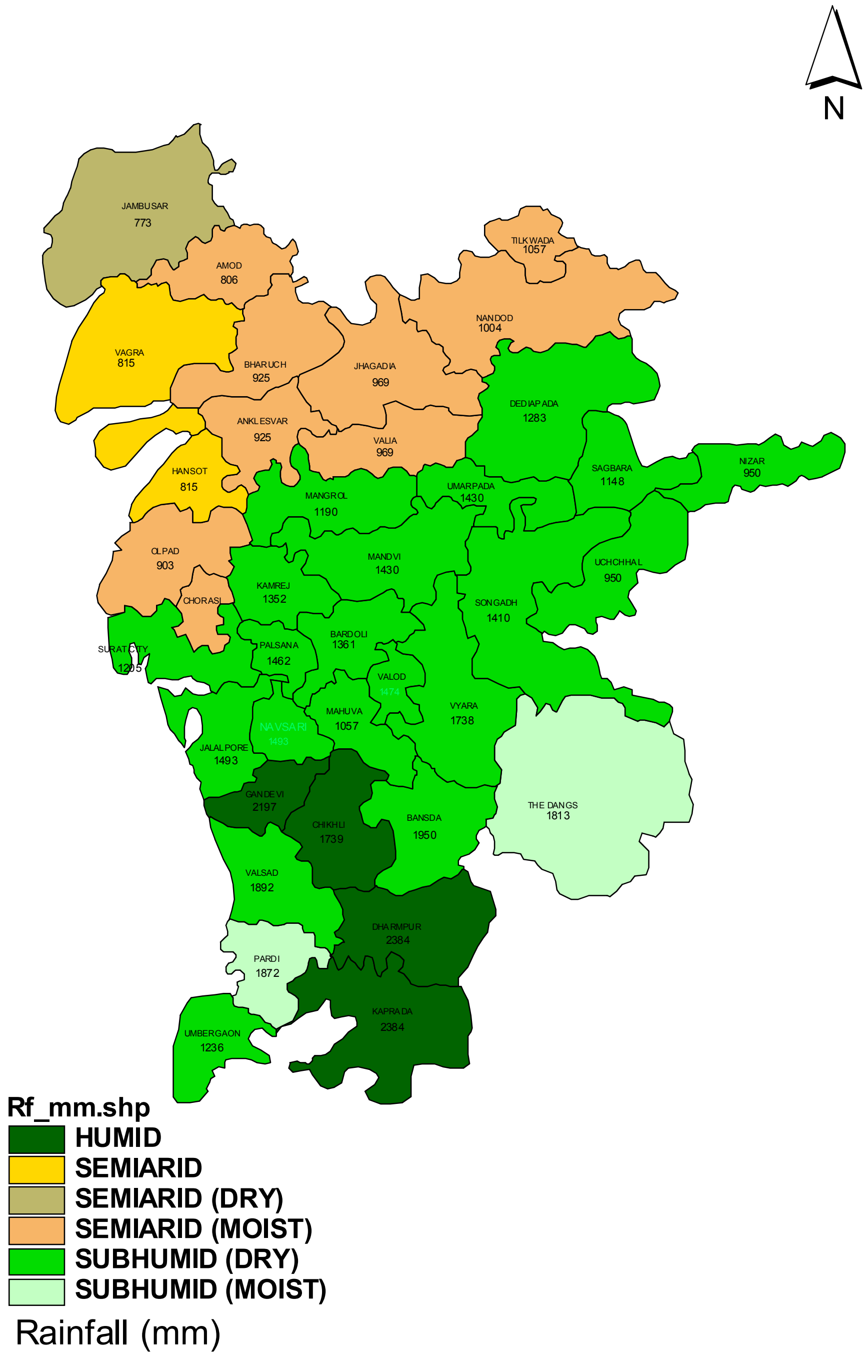

Fig.1: Climatic conditions of South Gujarat

Soils

The soils of this region differ widely in their characteristic. The district wise distribution of the soils of South Gujarat is given in table 2. In both the zones, a deep black cotton soil occupies more than 50 per cent area. Though, the soils as per crop based classification grouped under deep black cotton soils, yet, these soils are not true *Vertisols* except some pockets in Bharuch district. In rest of the South Gujarat, the soils belong to *Inceptisols* having *Vertic* as characteristics horizon with predominance of montmorillonite silicate clay mineral. Because of high clay content (> 40 %) that too with montmorillonitic silicate mineral, these soils exhibit cracking, gillgai formation *etc*. properties. The physiographic units and soil type wise, the water management related problems are listed in table 3. In general, the soil of eastern hilly belt of both the zones are shallow in depth and prone to erosion while the soils of mid plain are heavy in texture, cracking and poor in drainage which accentuate the water logging and secondary salinization problems particularly in canal command areas. In coastal belts of both the zones, the soils are salt affected, highly dispersive and poor in drainage. Under all the three physiographic units, separate water management technologies are required to be followed.

Table 2: Zone and district wise distribution of the soils

Zone (Influential districts)	Types of soils	Approximate area ('000 ha)	% of total area
South Gujarat heavy rainfall (Dangs, Navsari, Valsad and Surat	Deep black cotton soils	483.7	55
	Laterite soils	159.5	18
	Hilly and forest soils	109.6	12
	Coastal alluvial soils	136.7	15
	Saline/alkaline soils	015.4	00
South Gujarat (Tapi, Narmada and Bharuch)	Deep black cotton soils	542.0	53
	Coastal alluvial soils	290.6	28
	Saline/alkaline soils	079.2	08
	Hilly and forest soils	117.2	11

Table 3: Agro climatic zone wise soil related water management constraints

Agroclimatic zone	Physiographic locations	Predominent sub-order association	Constraints
South Gujarat heavy rainfall	• Piedmont slope and plain	Ochrepts	• Shallow depth, highly erosive, low to modrate MHC, high permeable
	• Mid alluvial plains	Ochrepts Usterts	• High MHC, severe cracking, low to very low permeability, poor internal drainage, secondary salinization, water logging in parts
	• Coastal alluvial plains	Aquepts Ochrepts	• Salt affected, highly dispersive, poor drainage low permeability, mild cracking
South Gujarat	• Piedmont slope and valley plains	Ochrepts	• Highly erosive, low to medium MCH, highly permeable
	• Alluvial plains	Usterts Ustochrepts	• Prone to erosive, moderate to poor drainage, medium to low permeability, secondary salinization and water logging in parts
	• Coastal alluvial plains	Aquepts Ochrepts	• Same as those of coastal alluvial plains of zone- I

Irrigation

In both the zones, rainfall is higher as compared to rest of the Gujarat. Similarly, two major rivers *viz.*, Tapi and Narmada are also flowing in South Gujarat. The major multipurpose project Ukai-Kakrapar is built on river Tapi with command area of 3.42 lakh ha area. Though, the mega project Sardar Sarovar built on river Narmada is in South Gujarat, yet, the major command area is in other parts of Gujarat. The command area of Sardar Sarovar covers only 121700 ha in Bharuch and Narmada districts of South Gujarat. In command area of South Gujarat, the menacing problems are water logging and secondary salinization due to high rainfall, heavy textured soils, aberration in suggested cropping pattern, adoption of faulty irrigation methods *etc*.

With respect to ground water, in all the seven districts its development is less than 50 per cent except Bharuch (Table 4). In other words, the net ground water balance is positive. This implies that there is good scope for conjunctive use of surface and ground waters. However, farmers are not in favour of conjunctive use due to availability of perennial canal irrigation facility in mid plain and extremely poor quality in tail end owing to coastal area.

Table 4: Ground water development (MCM/yr)

Districts	Utilizable recharge	Net draft	Balance	Development (%)
Bharuch	268	150	118	56
The Dangs	50	10	40	20
Narmada	204	64	140	31
Navsari	484	225	259	46
Surat	1290	467	823	36
Valsad	338	145	193	43

Irrespective water sources, water utilization pattern at state level are quite skewed. The data reported in table 5 suggest that in South and Central Gujarat, the water utilization is only 18 per cent as against 35 per cent utilization at state level. It is the maximum of 98 per cent in North Gujarat.

Table 5: Water utilization pattern in Gujarat (‘000MCM)

Region	Available	Utilization	% Utilization of total available
South and Central	38.0	7.0	18
North Gujarat	6.1	6.0	98
Saurastra	9.2	5.4	59
Kutch	1.2	0.7	58
Total	**54.5**	**19.1**	**35**

The district and source wise irrigated area depicted in Fig.2 suggest that in South Gujarat, the contribution of surface (54 %) and ground water (46 %) resources is almost equal. However, district wise there is considerable variation in terms of contribution of surface and ground water towards irrigated area. For instance, in the Dangs districts, ground water contribution is 100 per cent and that in Surat district it is only 33 per cent. The ground water utilization for irrigation in Narmada and Bharuch districts is more than 50 per cent. From gross irrigated area point of view, Navsari and Surat districts have higher irrigated area as compared to the remaining districts of South Gujarat.

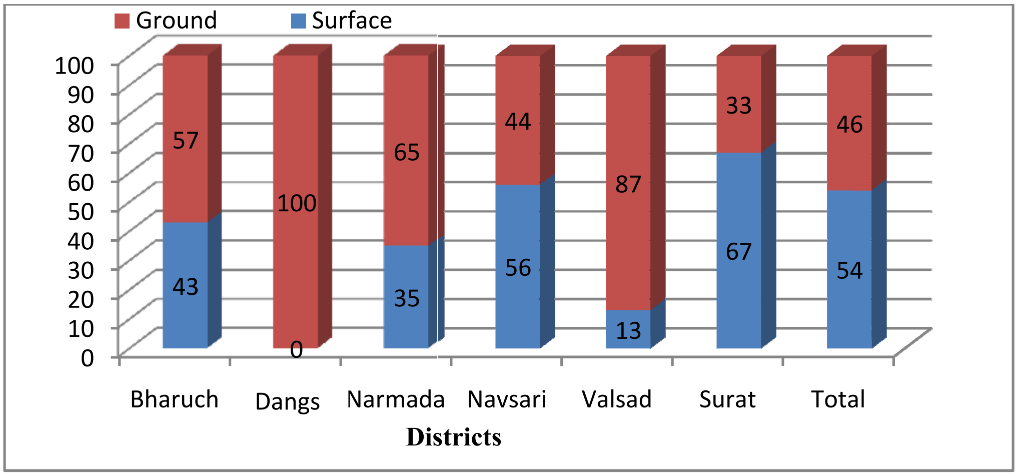

Fig 2: District and source wise irrigated areas (%) of South Gujarat

Crops and cropping pattern

In South Gujarat, due to perennial irrigation facility and heavy rainfall zone, paddy and sugarcane along with mango, sapota and banana are the major crops. The cereal crops which comprises mainly paddy are occupying 35 per cent of area in South Gujarat. It is followed by pulses and sugarcane. The 11 per cent area is under fruit crops predominantly consist of mongo, sapota and banana. With respect to cotton, it occupies 13 per cent area in South Gujarat, which is grown major in Bharuch and Narmada districts only.

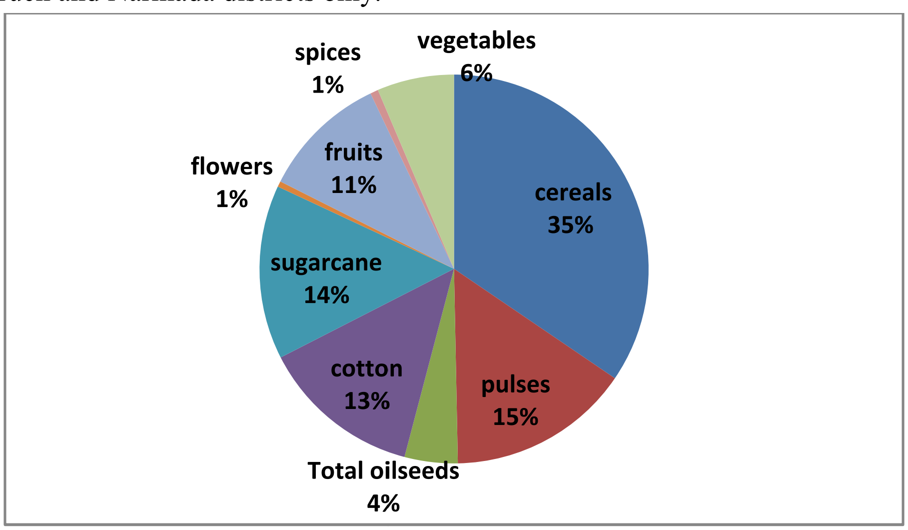

Fig. 3: Distribution of area under different crops in South Gujarat

Surface irrigation technologies

In earlier publication, the water management technologies developed prior to the year 2000 have already been included. Here, the technologies developed after the year 2000 are discussed. The schedules for the crops which are recently introduced in South Gujarat mentioned here (Table 6). Among the arable crops, the palmarosa being perennial crop, it requires highest number of irrigation (14). The next in order is garlic sown after *kharif* paddy which requires 11 irrigations. Apart from regular winter crops of wheat and gram, the schedule for castor (basically *kharif* crop) grown during *rabi* requires only 8 irrigations each of 60 mm depth and that nizer requires only 4 irrigations. It is our experience that both these crops are capable of replacing summer paddy which requires around 1200 mm water. These crops not only give net profit equal to summer paddy but also require much less water thereby minimizing the problems of water logging and secondary salinization in canal command. Another crop under which the area is increasing rapidly is spider lily for which the appropriate schedule has been developed. Otherwise farmers are irrigating spider lily just like paddy (ponding water). Even adoption of irrigation schedule based on 1.0 IW/CPE ratio, the water saving to the tune of 65 per cent could achieve as compared to farmers practice.

Table 6: Surface irrigation technologies

SN	Location	Crop/Variety	No. of irrigation (D:mm)	Schedule
1	Danti	Wheat (Lok-1)	8(60)	AS,15,30, 45,57,69,79,89 DAS
2	Navsari	Wheat (LOK-1)	5(60)	AS,21,42,63,80 DAS
3	Danti	Wheat (GW-173/GW-275)	4(60)	AS,CRI, Tillering, Boot leat
4	Navsari	Gram (Gujarat-2)	1(60)	Sowing or Branching (60 % more yield than conserved moisture)
5	Danti	Castor (GCH-4)	8(60)	First 4 at 20-25 DI Rest 4 at 16-18 DI
6	Navsari	Nizer (R) (RCR-317)	4(60)	AS, 2nd 18-20 DI, Rest 9-10 DI
7	Danti	Paddy (S) (Gurjari)		3-5 days after disappearance
8	Navsari	Garlic	11(60)	AS, 2nd 9-10 DI, Rest 9-15 DI
9	Navsari	Pamarosa (RC-1)	14(60)	25-27 DI Oct-Nov., 10-14 DI Mar.-April
10	Navsari	Spider lilly	20(60)	12-15 DI Winter 7-10 DI Summer

AS: After sowing, D: Depth of irrigation in mm, DAS: Days after sowing, DI: Days interval

Drip irrigation technologies

The drip irrigation technologies were developed for about 18 important crops of South Gujarat. In field crops, the drip system details have been worked out for crops like sugarcane, cotton, *rabi* castor *etc*. (Table 7). The extent of water saving with drip method over surface method of irrigation in sugarcane, cotton and castor (*rabi*) was 40, 20 and 39 per cent, respectively. In another experiment where castor crop was subjected to stress by stopping the drip system for about 20-30 days starting from 50 per cent of main spike initiation stage, 18 per cent of irrigation water could be saved over the drip irrigation system operated on alternate day throughout the crop growth period. Similarly, saving in fertilizer N and/or K up to 30-35 per cent also achieved without any reduction in crop yield.

On banana lot work with respect to drip, mulching and fertigation has been done. Of these, drip + mulching technology was demonstrated on farmers' fields continuously for 3 years. The data obtained from farmers' fields substantiated the results obtained at research farm *i.e.,* 40 per cent water saving as well as yield increase by 13-21 per cent. In papaya, though fruit yield was at par with surface control, yet the water saving of 40 per cent was achived with drip method of irrigation. This enable the farmers to bring more area under irrigation using same volume of water available with the farmer (Table 7).

Turmeric is another crop recently spreading in South Gujarat. This crop responded excellently to drip method of irrigation coupled with raised bed planting and fertigation. Here, the water and fertilizer (N and K) saving of 40 to 20 per cent was achieved along with increase in yield by 20-25 per cent. Irrespective of vegetable crops studied, the water saving was ranging from 5 in round melon to as high as 40 per cent in bitter gourd and brinjal. Similarly, the yield increase over control with drip method of irrigation was maximum with pointed gourd (47 %) and that of minimum was with bitter gourd (18 %). In addition, most of the vegetable crop, fertilizer (N and K) saving of about 20-40 per cent was recorded (Table 7).

Apart from field, fruit and vegetable crops, drip irrigation method was also recommended for flower crops like rose, gladiolus, spiderlilly *etc*. The drip irrigation schedule developed for flower crops, if adopted by the farmers than they can save about 17-40 per cent of irrigation water along with 20 per cent saving in N and K fertilizer. The yield advantage except rose (54 %) was not visible in the cases of spider lily and gladiolus.

Table 7: Drip irrigation technologies for different crops of South Gujarat

SN	Crop/Variety (Spacing:cm)	Location	WS (%)	YI (%)	Spacing		DD (Nos.)	Schedule
					Lateral	Dripper		
1	Sugarcane (60 x 120 pair)	Navsari	40	22	180	60	4	25 min Oct-Dec 37 min Jan-March 35 April-June
2	Maize/Sweet corn Var. sugar-75 (60 x 20)	Navsari	28	65	120	100	8	50 min. Dec-Jan 65 min. Feb-March (5 equal splits of NK at 10 DI, starting from 30 DAS)
3	Bt Cotton/RCH -2 BG-II (60 X45 X 180)	Surat	20	11	240	45	4	70-85 min (6 equal splits of 75 % RDN at 15 DI, staring from 15 DAS, 25 % N saving)
4	Castor/GCH -4 (60 x 60 x 120)	Navsari	39	-	180	120	8	40-60 min. Nov-Jan 60-100 min. Feb-harvest. (20% basal & 80% N in 3 equal splits at 30 DI, 30-35% N saving)
5	Castor/GCH -4 (60 x 60 x120)	Navsari	18	-	180	120	8	Water stress (20 day or 30 day + BPM, starting from 50 % emergence of main spike stage)
6	Banana/ Grand nine (240x120) with mulching	Navsari	40	13-21	240	60	4	Winter 2-3 hr Summer 3-4 hr
7	Papaya/Taiwan 786 (210 x 190)	Navsari	40		250	30 cm away from stem on either side	8	20-30 lit/plant winter 30-50 lit/plant Summer(14 equal splits of NK at 15 DI, starting from 30 DI)
8	Turmeric/*Sugandham* 3 rows (30 x 20) on raised bed of 90 cm of top width followed by a furrow of 30 cm depth	Navsari	32	20-25	135	100	8	45-60 min Sept-Dec 50-75 min Jan-March (9 equal splits of 50 % NK 9at 15 DI, starting cessation of monsoon, 20 % NK saving
9	Smooth gourd/Chetak (100 x 200) + STM (2.5 t/ha)	Navsari	33	37	200	100	8	40 % fertilizer saving

Table 7: Continue….

SN	Crop/Variety (Spacing:cm)	Location	WS (%)	YI (%)	Spacing		DD (Nos.)	Schedule
					Lateral	Dripper		
10	Bitter gourd/Hy. Namdhari (50 x 50 x 50)	Navsari	40	18	200	100	8	100 min
11	Little gourd/local (250 x 250)	Navsari	32	25-30	250	250	4	150-250 min. Mar-April 110-160 min. Oct-Dec
12	Pointed gourd/local (200 x 100)	Navsari	37	47	200	100	4	70-80 min Winter 80-155 min Summer
13	Round melon (*Tunda*) Summer (Local)	Navsari	5-7	-	200	100	8	165 min March 195 min April 210 min May to harvest (12 equal splits at 15 DI, starting after 45 DAP, 20 % N saving
14	Onion/pillipatti (10 x 15)	Navsari	39	35	80	80	8	20 min. Jan-Feb 25 min. March 40 min April
15	Brinjal/Surti Ravaiya(75 x 60 x 120) + BPM (25µ, 45 % coverage)	Navsari	40	40	180	100	8	90 min. Nov-Jan. 150 min. Feb-March 180 min. April-June
16	Gladious/Psittacinus hybrid (20 x 20 x 60)	Navsari	24		120	60	3	80-100 min. Nov-Jan 125-145 min Feb-March (10 equal splits of NK at 7 DI, starting from 30 DAP)
17	Rose/Gladiator (100 x 100 x 100)	Navsari	17	54	300	100	8	150-180 min Winter, 210-270 min Summer, 25 % fertilizer saving Drip + BPM
18	Spider lily/local (90 x 30)	Navsari	40		180	90	8	75-100 min Winter 60-80 min Summer

WS: Water Saving, YI: Yield Increase, DD: Dripper Discharge (lph), BPM: Black plastic mulch, DI: Days interval, DAP: Days after planting

Fig. 4: Drip + mulching technology

Sprinkler technology

Apart from drip irrigation technologies, for close grown crops like garlic, onion, wheat, cabbage *etc.* sprinkler (mini and macro) technologies were also developed (Tables 8 and 9). The water saving irrespective of crop and type of sprinkler was ranging from as high as 62 per cent in wheat irrigated by macro sprinkler to minimum of 17 per cent in cabbage irrigated by the same system of sprinkler. Similarly, the yield increase was minimum with cabbage (10.10 %) and that of maximum with garlic (51 % under minisprikler). Along with yield increase and water saving, saving in fertilizer up to 20 per cent was also achieved particularly with minisprikler.

Table 8: Minisprinkler technologies for garlic and onion under South Gujarat condition

SN	Crop/Variety (Spacing:cm)	% WS	% YI	NR/mm	No. of irrigation (D:mm)	Sprinkler spacing (m)	Schedule
1	Garlic (15 x 10) with Gypsum (2 t/ha)	20	51	224	12 (50)	2.5 x 2.5	10 DI in Nov-Jan 8 DI in Feb-upto harvest (5 equal splits of N as urea at 10-12 DI, starting 15 DAS, 20 % N saving
2	Onion/ Gujarat red (15 x 20)	42	23	200	5	2 x 2	I-AS, II-6to7 AS, rest at 15 DI (20 % N saving

NR/mm: Net return in Rs. Per mm of water applied

Table 9: Sprikler technology for cabbage and wheat crops grown under South Gujarat

SN	Crop/Variety (Spacing:cm)	Location	% WS	% YI	NR/mm	Depth (mm)	Sprinkler spacing (m)
1	Cabbage/Golden acre	Navsari	17	10	123	40	10-12 DI
2	Wheat/Lok-1	Danti	38			50	I: AS, II: CRI, III: Keen height, IV: Boot leaf
3	Wheat/Lok-1	Navsari	62	13	43	50	12 DI

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Mulching Technologies for Water Saving and Increasing Crop Yield

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Mulching is an age old agricultural practice primarily done for moisture conservation under rainfed farming situation. Earlier, the materials used for covering the soil surface (mulching) were crop residue, leaf litter, pebbles, loose soil (interculturing) *etc.* However, with an advent of synthetic materials suitable for mulching, its applicability has become more versatile than ever before. This is because of the reason that apart from moisture conservation, synthetic mulch material also control weed effectively, restricts upward movement soluble salts in soil, moderates soil temperature, increases soil air CO_2 content, induces early maturity in crop, improves nutrient availability in soil, repels certain insects, improves quality of produce, increases interval period between two irrigation *etc.* So, synthetic mulch can also be used effectively under irrigated agriculture. Not only this, but it is best suited along with drip method of irrigation. Among the different synthetic materials like LDPE, HDPE, flexible PVC, woven and non woven fabrics *etc.,* LLDPE film (Linear low density polyethylene) is widely used for mulching in different crops and seasons. As far as color of the LLDPE film used for mulching is concerned, black color film (black plastic) was found to be the best in most the crops and seasons. Though, this film has added advantages over natural or organic mulch materials, it has two major limitations *viz.*, costly and not biodegradable.

For reducing the cost of mulch film, numbers of experiments with varying planting geometry were conducted in different agroclimatic conditions. Based on the results, adoption of paired row planting in field crops and 10-30 per cent canopy area coverage in plantation crop was found to be the more cost effective than 100 percent coverage. Similarly, some private and government organizations are striving hard to develop biodegradable synthetic material which can be used as mulch film. In spite of cost and biodegradability limitations, commendable work using black plastic *vis-à-vis* grass or crop residue (sugarcane trash, paddy straw *etc.)* as mulch in different crops has been done under different agro climatic conditions of Gujarat. A brief account of such work done is discussed here.

Mulching in rainfed crops

Mulching with various materials was tried in variety of *kharif* and plantation crops at different locations in Gujarat. The results of some of the studies reported in table 1 clearly revealed that irrespective of crops and mulch material, the yield increase was ranging from 29 per cent with sugarcane trash mulch in pigeon pea at Achalia to 97 per cent with black plastic mulch in *ber* at Danti. As all the crops are long duration, mulching is laid only after cessation of monsoon. In spite of applying mulch even after half way of crop growth period, the mulching effect is quite remarkable. Irrespective of crops, the magnitude of increase in crop yield is more with black plastic than use of crop residue like, grass, castor shell, sugarcane trash *etc*. as mulch. In crops *viz.,* rainfed ber and cotton grown under coastal salt affected soil, the extent of increase in yield was more than 90 per cent. This was mainly due to lower concentration of soluble salts in root zone of the crop in mulching treatment than unmulched control. The reason for lower soluble salt content in root zone is due to restricted upward movement of soluble salts from lower layer to upper layer of soil due to mulching. Not only this, but in cotton fertilizer dose could also be reduced (Table 2). The yield of cotton obtained at 50 kg N/ha level with mulching was similar to that recorded with application of N @150 kg/ha to unmulched control.

Table 1: Mulching in rainfed crops

SN	Crop	Location (Zone)	Mulch material	Yield increase (%)	Remarks
1	Cotton	Danti (South Gujarat)	BP	93	- Coastal salt affected soil - Rainfall 1140 mm
			GM	60	
2	Cotton	Achhalia (South Gujarat)	SM	36	- Loamy soil - Rainfall 800-1000 mm
			GM	47	
			BP	58	
3	Castor	SK Nagar (North Gujarat)	Castor shell @ 15 t/ha	47	- Sandy soil - Low rainfall
4	Pigeon pea	Achhalia (South Gujarat)	SM	29	- Loamy soil - Rainfall 800 – 1000 mm
			GM	50	
			BP	78	
5	Brinjal	Achhalia (South Gujarat)	GM @ 5 t/ha	44	- Loamy soil - Rainfall 800 – 1000 mm
6	*Ber*	Danti (South Gujarat)	BP (40 % coverage)	97	- Coastal salt affected soil Rainfall 1140 mm

Note: GM: Grass mulch**, SM:** Sugarcane trash mulch, **BP:** Black plastic mulch

Table 2: Seed cotton yield under different treatments of N and mulching (pooled over 3 year)

N level (kg/ha)	Mulching		
	BP	**GM**	**Control**
50	640	534	345
100	757	683	339
150	983	746	550

Mulching in irrigated crops

As like rainfed, mulching technologies were developed for both surface and drip methods of irrigation for different crops and agroecological situations of Gujarat. The mulching technologies developed are discussed separately for surface and drip methods of irrigation.

Surface irrigated crops: Under surface method of irrigation, mulch materials tested were different colored plastic and sugarcane trash. The results presented in table 3 indicate that irrespective of mulch type, the water saving varied between 20 per cent with sugarcane trash in marigold and as high as 54 per cent with grass mulch in sapota crop. Similarly, the extent of increase in yield was ranging from 10 per cent with sugarcane trash in sugarcane to 62 per cent with black plastic mulch in chilies. In crop like groundnut, to facilitate pegging of pods, a transparent plastic film of 7 micron thickness was tested which increased the pod yield by 50 per cent however, it is necessary to follow effective weed control measure when transplant plastic mulch is used as mulch material. Similarly, this practice also enabled to prepond the sowing time of summer groundnut. Apart from water saving and yield increase, mulching with black plastic also control weed infestation up to 90 per cent. This reduces the labour required for weeding and thereby overall cost of cultivation. In crops like banana, mulching with black plastic also induces early maturity by about 20 to 30 days. This enables the banana growers to harvest the crop early which fetches higher price.

Table 3: Mulching in surface irrigated crops

SN	Crop	Location	Mulch material	Water saving (%)	Yield increase (%)	Remarks
1	Banana	Navsari	ST @ 15 t/ha	40	49	Due to BP early maturity up to 20-30 days
			BP	35	18	
2	Brinjal	Khandha	BP	-	27	80% Weed control
3	Chillies	Navsari	ST @ 10 t/ha	-	14	-
			BP	-	62	
4	Cauliflower	Navsari	BP	-	33	75% weed control
			GP	-	21	33% weed control
			YP	-	15	59% more weed infestation
5	Cotton	Navsari	BP	50	20	-
6	G'nut(S)	Navsari	7 micron TP	-	50	Sowing can be pre pond
7	Marigold	Navsari	ST @ 5 t/ha or BP	20	25	-
8	Pigeon pea	Navsari	ST @ 10 t/ha	-	47	-
9	Okra	Navsari	BP + 50 ppm NAA	-	25	90 % weed control
10	Sapota	Paria	GM (20% coverage)	54	25	-
11	S'cane	Khandha	ST @ 10 t/ha	34	10	-

Note: GP: Green plastic mulch**, YP:** Yellow plastic mulch, **TP:** Transparent plastic mulch

Drip irrigated crops: In Gujarat, area under drip method of irrigation is increasing by lips and bound. Though, drip method of irrigation itself has number of advantages, yet these benefits can be further enhanced with the combined use of drip irrigation and mulching. The combined adoption of drip and mulch have added advantage of covering only wetted zone area *i.e*., about 40 to 50 per cent as against the 100 per cent in surface method of irrigation. So, in drip + mulch technology, there is reduction in cost of mulch material. Under Precision Farming Development Centre, Soil and Water Management Research Unit, Navsari Agricultural University, Navsari number of crops have been tested with drip + mulch technologies at research farm as well as at farmers' fields in few crops on large scale. These experiments and demonstrations were conducted by adopting paired row planting except banana and papaya crops which are basically planted at wider spacing of 2.4 m. Because of adoption of paired row planting, the system cost of drip is reduced almost by 40 per cent. Not only this, but it also facilitate laying of mulch easier than single row planted crop. In term of water saving, it varies between 20 and 50 per cent across the crops (Table 4). Similarly, the yield enhancement achieved was ranging from 7 per cent in castor with 20 to 30 days system off schedule starting from main spike emergence stage at Navsari (sub humid) to 71 per cent in castor at Achalia (semi arid). In vegetable crops *viz.*, chilies and tomato, the increase in yield was of the order of 50-60 per cent. Apart from effective control of weed up to 90 per cent, adoption of drip + mulch technology could also save fertilizer up to 40 per cent without any reduction in yield. Based on results of drip + mulching technology, farmers have started using mulching with drip in crops like banana, water melon, vegetables *etc.*

Mulching technology for usage of saline water

In Gujarat, the ground water quality in general is poor and more so in coastal area. Under the such situations, drip + mulch technology proved to be viable solution for achieving optimum yield level by using marginally poor quality waters for irrigation purpose. Otherwise, such waters can not be used for irrigation purpose by conventional method of irrigation even for salt tolerant crops. Some experiments were conducted on this aspect. Result of one such experiment is presented in table 5. The results clearly revealed that the brinjal fruit yield of 29.68 t/ha recorded with treatment receiving irrigation with best available water through drip was less than the mulching treatment irrigated with 8 dS/m salinity water (32.83 t/ha)through drip system. Even sugarcane trash mulch treatment irrigated with 8 dS/m salinity water also registered higher yield as compared to no mulch treatment irrigated with good quality water. Similarly, at each level of salinity, black plastic mulch showed superiority over sugarcane trash mulch as well as no mulch control.

In addition to yield, soil properties were also determined. The soil properties did not change much due to saline water used for irrigation particularly when mulching was applied to brinjal (*rabi*) followed by *kharif* transplanted paddy. This implies that adoption of drip + mulch in brinjal grown even on high clay containing soils enable to use poor quality water (up to 4-8 dS/m) for irrigation without much deleterious effect on soil properties.

Table 4: Mulching in drip irrigated crops

SN	Crop/spacing	Location	Mulch material	Water saving (%)	Yield increase (%)	Remarks
1	Banana (2.4 x 1.2 m)	Navsari	BP	40	13-21	20-40 % fertilizer saving
2	Bitter gourd (0.5 x 0.5 x 1.5 m)	Navsari	BP	40	18	Only with 25 % mulching area coverage
3	Brinjal (0.6 x 0.6 x 1.2 m)	Navsari	BP	40	40	20 % N saving
4	Bottle gourd (0.4 x 1.0 x 2.6 m)	SKNagar	Castor shell @ 5 t/ha	27	45	-
5	Castor (0.6 x 0.6 x 0.75 m)	Achhalia	BP	39	71	40 % N saving
6	Chillies (0.45 x 0.6 x 0.75 m)	Navsari	GP	34	59	-
7	Rose (1.0 x 1.0 x 2.0 m)	Navsari	BP	20	40	90 % weed control + 30 % fertilizer saving
8	Papaya (2.5 x 2.5 m)	Navsari	BP	40	20	Only with 20 % mulching area coverage
9	Smooth gourd (1.0 x 2.0 m)	Navsari	ST @ 2.5 t/ha	50	-	-
10	Tomato (0.50x 1.0 m)	Navsari	ST	45	57	40 % fertilizer saving
			BP	45	52	
11	Castor (0.6 x 0.6 x 1.2 m)	Navsari	BP	40	7	Stress 30 days after 50 per cent emergence of main spike stage

BP: Black plastic mulch**, ST:** Sugarcane trash mulch, **GP:** Green plastic mulch

Table 5: Fruit yield of brinjal (t/ha) under different treatments of irrigation on water salinity and mulching (Pooled over three years)

Treatment	**Irrigation water salinity (dS/m)**		
	BAW	**4**	**8**
No mulch	29.68	31.17	28.63
Sugarcane trash mulch	34.40	35.36	30.45
Black plastic mulch	37.28	36.06	32.83

Mulching for improving soil health

In order to understand the reason for increase in yield due mulching, in some experiment soil air CO_2 content which gives an idea about soil microbial activity along soil temperature were also recorded and the results are given in table 6. As the soil microbial activity is directly related to soil fertility, an increase in soil air CO_2 content indicates the improvement in soil fertility. At Precision Farming Development Centre, Soil and Water Management Research Unit, Navsari Agricultural University, Navsari banana and papaya crops were studied in details. In banana under drip irrigation, soil air CO_2 content was almost doubled in black plastic mulch as compared to unmulched control. This was also true to some extent in sugarcane trash mulch. Similarly, in papaya under drip irrigation, the soil air CO_2 content under drip alone was 378 vpm and that in drip + mulch it was 868 vpm as against the 269 vpm in unmulched + surface irrigation control. This suggests that the soil air CO_2 concentration was found to increase tremendously by adopting drip + mulch technology. This seems to be a major reason for increasing the crop yield.

Table 6: Mulching for improving soil health

SN	**Crop**	**Mulch material**	**Yield increase (%)**	**Soil CO_2 Content (vpm)**
1	Banana	BP + drip	21	683
		ST + drip	16	608
		Control	-	371
2	Papaya	Drip	28	378
		Drip + BP	40	868
		Control	-	269

Economics of mulching

Though, research and extension effort are being done by different institute, University, Govt. organizations, NGOs *etc*., yet mulching technology is not spread up to a desired level. This is mainly due to cost factor, high labour requirement for laying and removal, not biodegradable, availability of LLDPE film in local market, inadequate knowledge about mulching among the farmers *etc.* With respect to cost, it can be reduced to almost half by adopting paired row planting in crops like vegetable, flower, castor, pigeon pea, water melon *etc.* While in widely spaced crops (about 2.4 m row spacing) like banana, papaya *etc.* under drip method of irrigation, it is necessary to cover only wetting zone *i.e.,* around 40 to 50 per cent mulch coverage. This also helps in reducing the cost of mulching. Similarly, for minimizing labour requirement, mulch laying machines are now available in the market and becoming popular among the farmers. As on today, 100 per cent biodegradable films are not available in the market for which research is in progress. Further, for enhancing awareness among the farmers, there is a need to scale up the training programs at state level.

The results reported in table 7 show that mulching with black plastic is economical even in crops like castor. The additional net income realized only due to mulching is around Rs. 15000/ha. While in high value crops like papaya, banana, rose, bitter gourd *etc.,* the magnitude of increase in net realization varying between Rs. 28000/ha in bitter gourd and Rs. 40000/ha in banana. These data clearly suggest that adoption of mulching along with drip method of irrigation is found to be remunerative in most of the crop.

Table 7: Economics of mulching in different crops under drip method of irrigation

SN	Crop (Spacing)	Mulching material (area coverage %)	Yield increase (%)	Additional net realization over control (Rs/ha)	Net realization only due to mulch (Rs/ha)
1	Papaya (2.5 x 2.5 m)	BP (20)	40	73800	39000
2	Banana (2.4 x 1.2 m)	BP (50)	21	72000	40000
3	Rose (Pair:1x 1x 2 m)	BP (50)	40	78000	32000
4	Brinjal (Pair0.6 x 0.6 x 1.2 m)	BP (55)	32	40000	18000
5	Bitter gourd (Pair: 0.5 x 0.5 x 1.0 m)	BP (25)	18	65000	28000
6	Castor (Pair: 0.6 x 0.6 x 1.2 m)	BP (55)	22	35000	15000

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Studies on Water Pollution and Their Management in Gujarat

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Water is a prime natural resource, a basic human need and is a precious national asset. Water is an abundant natural resource, covers three fourth of the earth's surface with it but only 2.7per cent of the global water available is fresh in quality and only 30 per cent of this is available to meet the human and live stock demands. With only 4per cent of the fresh water resources, India supports more than 16% of the world population on only 2.3 per cent of the world land. Water is a crucial component in any socio-economic planning and development all over the world. The progress and development with sustainable environment is the need of day. In India, agriculture has been and will remain to be a major user of water resources but due to growing demands of fresh water supplies for industries, urban and civic uses, the per capita water availability of fresh water for agriculture is likely to decrease further (Patel and Singh, 2003).

As reported by Rana and Raman *et al.* (1999), irrigation potential in Gujarat has been created in 33 lakh ha of which 14 lakh ha are in canal command and 19 lakh ha through groundwater. The annual available ground water recharge in the state is about 12 lakh ha m, out of which 4 lakh ha m is in Saurashtra. But the net draft is only 7 lakh ha m amounting far below the potential recharge, yet in North Gujarat zone, it is more than 90 per cent which is mainly due to the over exploitation (194%) in Mehsana district. In South Gujarat region, canal water contributes to 50 to 60 per cent of irrigated area. On the other hand, in North Gujarat, Saurashtra and Bhal areas, more than 90 per cent of irrigated area is through groundwater. In North - West zone, out of 80 per cent contribution from the underground (lift irrigation), 16 per cent is contribution through tanks. Generally, the quality of well water is good in southern part of the state, while it tends to become poorer in northern part. In Saurashtra area, it is normally good in the mid plain and rocky areas and highly saline in the coastal belt. Fluoride problem is encountered in some pockets of North Gujarat and Saurashtra.

The total utilizable ground water recharge in the state is 15079.77 MCM per annum, out of the gross annual recharge of 15,873.44 MCM. The Saurashtra region has the highest annual recharge of about 5,822 MCM, followed by North 3,743 MCM and Central Gujarat with 3,147 MCM, South Gujarat with 2,439 MCM and Kachchh with 723 MCM. The ground water recharge rate (recharge per unit area) is highest for South and central Gujarat (0.235 MCM km^{-2}), followed by Saurashtra and North Gujarat (0.188 MCM km^{-2}) and lowest for Kachchh (0.015 MCM km^{-2}). During the last twenty years, there has been a steady increase in the use of ground water in Gujarat to meet domestic, irrigation and industrial water requirements, especially in the water scarce

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regions of North Gujarat, Saurashtra and Kachchh. Gross annual ground water extraction in the state increased from 4,689 MCM in 1978 to 9,569 MCM in 1997. Clearly, North Gujarat had shown tremendous increase in the ground water extraction.

The problem is particularly severe in Mehsana, Banaskantha and Ahmedabad districts where there is an increase in pumping depths and a reduction in bore well yields. Mehsana farmers are pumping up water even from the depths of 205-300 m using bore-wells fitted with powerful submersible pumps. The Gujarat Water Resources Development Corporation (GWRDC) monitors the ground water situation in state. It classifies district and talukas as white or safe, grey or semi-critical, dark or critical and overexploited, depending on the level of ground water development (actually meant by extraction level). This is defined as the ratio of net annual withdrawal (draft) over total utilizable recharge. If in a talukas/district net annual draft of ground water is more than 100 per cent of the utilizable recharge, then it is called "overexploited", if it is 90-100 per cent then is called "dark"; 70-90 per cent is "grey" and less than 70 per cent is "white".

At the state level, the groundwater development is almost complete with about 75.03 per cent of the utilization potential. However, there are several pockets in the state where the gross annual withdrawal either already exceeds the utilizable groundwater recharge to that level. According to report of the Government of Gujarat (Gujarat Water Resource Estimation 2002), in five out of the 25 districts, the gross annual withdrawals exceeded and hence they were rated as "over-exploited" districts. There are four districts where the gross annual withdrawal is between 70 per cent and 90 per cent of the utilizable groundwater withdrawal. In the remaining nine districts, the gross withdrawal is below 70 per cent of the utilizable annual recharge, *i.e.,* they are "white". These districts are in Saurashtra, South and Central Gujarat. There is further scope for exploitation of groundwater in these districts. There are 30 "over-exploited" talukas. They include 7 talukas from districts, namely Junagadh, Kachchh, Sabarkantha and Vadodara. There are 12 "dark" talukas from districts other than the "dark" districts of Ahmedabad, namely, Banaskantha, Sabarkantha and Junagadh. There are in all, 63 "grey" talukas in the State.

Over a period of time, the problem of over- development of groundwater has increased in terms of both magnitude and intensity. The districts and talukas that were earlier classified as "white" are now in the "grey", "dark" and "over-exploited" categories. For instance, the number of "over-exploited" talukas has increased from a mere one in 1984 to 30 in 2002. The number of "grey" talukas increased from 13 to 43 over the same period of time. Going by official estimates, over-exploitation of groundwater is mostly occurring in the alluvial areas of North and central Gujarat, especially in Mehsana, Patan, Ahmedabad, Gandhinagar and Banaskantha. For instance, the average rate of decline in water levels in 28 selected observation tube wells of GWRDC ranged from 0.95 to 6.02 m per year.

Water Pollution

The six corporation cities of the state release about 933 MLD of waste water into the rivers, while other towns release about 1,400 MLD. In addition, nine coastal towns dispose of an average of about 77 MLD, which is dumped into ponds and lakes.

Sewage treatment is woefully inadequate in most of cities. Industries contribute 35.6 per cent of the Net State Domestic Product (NSDP) in Gujarat. There are 14, 6140 factories and 1,26,900 small industries registered in the state. Water is a critical input for production purposes in many of these industries. Industries discharge partially treated effluents into natural water courses and other water bodies. As per the survey conducted by Gujarat Pollution Control Board (2004-05), there are 5270 water polluting industries in the state, having effluent treatment plants. They belong to the following industrial categories; textiles, organic chemicals petrochemicals, pharmaceuticals, pulp and paper, inorganic chemicals, pesticides and insecticides, paints and dye stuffs, sugar factories, dairies and manmade fibres. Majority of them are located in the region of Golden Corridor, between Mehsana and Valsad. The situation is bit difficult with respect to the small scale units.

While the industrial effluents deteriorate the surface water quality, they also cause serious ground water contamination. The ground water pollution problem is found in 26 villages of the six districts falling in the Golden Corridor region. The main reason for ground water contamination by industrial effluents is discharge of at times inadequately treated effluents. The problems of discharging effluent in ground water through bore well are also reported in many areas, although concrete data on this is not available.

The waters are being contaminated either at source (point source pollution) before discharged and/or polluted at various outlets (non-point source pollution) in unplanned manner leading to pollution, toxicities and spread of diseases in water-soil-plant-animal- human chain. Thus, nature and extent of water pollution depends upon anthropogenic activities or geogenic contamination. Therefore, there is an urgent need to look on various issues and future challenges related to monitoring the level of pollution in water, sewage, industrial effluents, study their impact on soils, plants, animal and human and environment health and develop suitable eco-friendly decontamination technologies for sustaining finite natural resources, environment and crop production.

Water pollution is caused by wastes generated from urban, agricultural and industrial sectors. When these effluents are discharged into a water body, the biological and chemical oxygen demands (BOD/ COD) of receiving water bodies goes up resulting in loss of aquatic flora and fauna. According to an estimate, municipal sewage accounts for 80 per cent of polluting effluents in our country. In Gujarat, the situation is still worse in the industrial cities such as Vadodara, Ahmedabad. The Ahmedabad city generates about 165 million gallons per day (MGD^{-1}) of liquid waste of which more than 35 per cent is due to the industries. More than 4000 industrial units in Gujarat need a large volume of good quality water in production units per day. A survey estimated that liquid hazardous waste effluent discharged by Ankleshwar Industrial area is about 250-270 MLD^{-1} and about 383 MLD^{-1} in Ahmedabad industrial area. Nandesari industrial estate near Vadodara in Gujarat is focal point of industrial growth. It includes GSFC, IPCL, Gujarat Refinery, GIDC, microcosm of about 300 industries discharging nearly 145-218 MLD^{-1} effluent to Mahi besides huge quantities of solid wastes and by-products annually. According to State Pollution Control Board officials, of 153 MGD^{-1} collected effluent, many times only half is treated and the rest is released into the river Sabarmati, although there is a growing awareness for keeping effective treatment plants by the industries. With increasing industrialization and population burden the situation is fast deteriorating in other cities like Surat, Rajkot, Bharuch and Ankleshwar. The Ministry of Environment and Forest (MoEF) has recently declared Vapi, Ankleshwar, Ahmedabad (Naroda & Odhav), Vatva (Vatva & Narol), Bhavnagar and Junagadh as critically polluted areas and prohibiting furthur industrial growth in these critically polluted clusters and the same in Vadodara and Rajkot also.

The mechanisms affecting the migration of pollutants are convection, mechanical dispersion, molecular diffusion, solid-solute interaction and various chemical reactions and decay phenomenon, which may be regarded as source-sink phenomenon for the solute (Bear, 1979). The pollutants after affecting soils and surface water seep down to the groundwater system along the entire courses of liquid flow. In hard rocks areas fractures, fissures and joints provide additional pathways for a fast movement of pollutants into ground water systems.

Standards for monitoring the ground water quality

The ground water in and around landfill site shall not be used for drinking purposes or otherwise, unless it meets specified standard for that particular use. The ground water quality shall conform to the Central Pollution Control Act 1986 with following standards given in table 1.

Table 1: General ground water quality standards for India as per Central Pollution Control Act amendment (Environment Protection Law 1997)

SN	Parameters	Maximum Acceptable limit
1	Arsenic	0.02 mg L^{-1}
2	Cadmium	0.01 mg L^{-1}
3	Chromium (hexavalent)	0.02 mg L^{-1}
4	Fluoride	1.5 mg L^{-1}
5	Lead	0.05 mg L^{-1}
6	Mercury	0.001 mg L^{-1}
7	Nitrate	10.0 mg L^{-1}
8	pH	6.5-7.5
9	Conductivity	100-200 u mhos/cm
10	Total dissolved solids	500 mg L^{-1}
11	Chlorides	250 mg L^{-1}
12	Sulphates	1000 mg L^{-1}
13	Colour	5 Hazon units
14	Bio-chemical oxygen demand	30 mg L^{-1} or lower
15	Chemical oxygen demand	250 mg L^{-1} or lower

The chemical quality of shallow ground water is being monitored by Central Ground Water Board once in a year (April/May) through a network of 15640 observation wells located all over the country. In Gujarat, 966 observation wells in different districts are being monitored for electrical conductivity, chloride, fluoride, iron, arsenic and nitrate (Table 2). Common pollutants/elements in Gujarat, their maximum permissible limits and health risk are reported in table 3.

Table 2: List of districts of Gujarat showing localized occurrence of different pollutants/elements in groundwater

Pollutants	Districts
Salinity	Ahmedabad, Amreli, Anand, Bharuch, Bhavnagar, Banaskantha, Dahod, Porbandar, Jamnagar, Junagadh, Kachchh, Kheda, Mehsana, Navsari, Patan, Panchmahals, Rajkot, Sabarkantha, Surendranagar, Surat, Vadodara
Chloride (>1.5 mgL^{-1})	Ahmedabad, Amreli, Anand, Bharuch, Bhavnagar, Banaskantha, Dahod, Porbandar, Jamnagar, Junagadh, Kachchh, Mehsana, Patan, Panchmahals, Rajkot, Sabarkantha, Surendranagar, Surat, Vadodara
Fluoride (>1.5 mgL^{-1})	Ahmedabad, Amreli, Anand, Banaskantha, Bharuch, Bhavnagar, Dahod, Junagadh, Kachchh, Mehsana, Narmada, Panchmahals, Patan, Rajkot, Sabarkantha, Surendranagar, Surat, Vadodara
Iron (>1.0 mgL^{-1})	Ahmedabad, Banaskantha, Bhavnagar, Kachchh, Mehsana, Narmada
Nitrate (>45 mgL^{-1})	Ahmedabad, Amreli, Anand, Bharuch, Bhavnagar, Banaskantha, Dahod, Jamnagar, Junagadh, Kachchh, Kheda, Mehsana, Narmada, Navsari, Panchmahals, Patan, Porbandar, Rajkot, Sabarkantha, Surendranagar, Surat, Vadodara

Source: Anon. (2010)

Table 3: Common pollutants/elements in Gujarat, their maximum permissible limits and health risk

Parameter	Maximum permissible limit	Health impact
Fluoride	1.5 mg L^{-1}	Immediate symptoms include digestive disorders, skin diseases, *dental fluorosis* Fluoride in larger quantities (20-80 mg/day) taken over a period of 10-20 years results in crippling and *skeletal fluorosis* which is severe bone damage
Arsenic	0.05 mgL^{-1}	Immediate symptoms of acute poisoning typically include vomiting, *oesophageal* and abdominal pain, and bloody 'rice water' *diarrhea*

		Long-term exposure to arsenic causes cancer of the skin, lungs, urinary bladder, and kidney There can also be skin changes such as lesions, pigmentation changes and thickening (*hyperkeratosis*)
Nitrate	100 mg L^{-1}	Causes Methamoglobinemia (Blue Baby disease) where the skin of infants becomes blue due to decreased efficiency of haemoglobin to combine with oxygen. It may also increase risk of cancer.
Salinity	2000 mg L^{-1}	Objectionable taste to water; may affect osmotic flow and movement of fluids
Heavy metals	Cd-0.01 mg L^{-1} Zn- 15 mg L^{-1} Hg- 0.001 mg L^{-1}	Damage to nervous system, kidney and other metabolic disruptions
Persistent organic pollutants	None	High blood pressure, hormonal dysfunction and growth retardation.
Pesticides	Absent	Weakened immunity, abnormal multiplication of cells leading to tumour formation. They contain chlorides that cause reproductive and endocrinal damage.

Characterization of groundwater quality

The current assessment report of groundwater quality in Gujarat by GPCB indicated that most of the ground water samples contained very high TDS, however, the dissolve oxygen (DO) was slightly on an increasing trend in 2010 over 2008 content. Similarly, chemical oxygen demand (COD) values were also found decreasing indicating about some improvement in the quality of ground water. However, the samples of Surendranagar district showed an increase in NO_3 pollution at the same time there was a reduction in F content, while the samples of Rajkot district showed some increase in F content of the ground water samples. It indicated the necessity of constant monitoring of ground water samples for their possible pollution due to anthropogenic activities besides effect of climate on geogenic nature of contaminants like salts and F content in groundwater (Table 4).

Analysis of ground water samples collected from various locations of Bhavnagar region revealed that water quality parameters (turbidity, Mn, Zn and Cu) were within permissible limit (PL) as per IS-10500 standard (Table 5). However, total dissolve solid (TDS), total hardness, chloride, fluoride and chromium were observed beyond PL in some samples, The Fe content was found beyond permissible limit in most of the samples. Groundwater in Bhavnagar region requires precautionary measures before drinking so as to prevent adverse effect on human health (Mishra *et al.*, 2009).

Table 4: Status of ground water quality of few bore wells/hand pumps in the state of Gujarat

Place/City	Location	Parameters													
		pH		TDS		D.O.		COD		NO_2-N		NO_3-N		Fluoride	
		08-09	10-11	08-09	10-11	08-09	10-11	08-09	10-11	08-09	10-11	08-09	10-11	08-09	10-11
Jamnagar	Shankar Tekari	7.9	7.8	1492	1129	2.4	2.3	6.2	6	1.66	0.017	0.64	0.12	0.41	0.2
Jamnagar	Ramehswarnagar	7.9	7.7	1152	815	2.3	2.7	6.5	6	1.62	0.027	0.59	0.09	0.42	0.17
Bhavnagar	Chitra GIDC	7.6	7.6	650	747	4.18	3.6	08	9	1.15	0.092	0.03	0.19	0.51	0.40
Bhavnagar	Haluria Chowk	7.6	7.5	1297	1033	3.61	3.5	07	9	1.96	0.086	0.12	0.18	0.57	0.38
Bhavnagar	Sihor GIDC-II	7.8	7.6	871	856	4.3	3.7	10	9	0.09	0.12	1.28	0.26	0.41	0.39
Bhavnagar	Talaja Naka	7.81	7.7	1093	1853	2.86	3.4	11	9	0.03	0.126	2.17	0.28	0.40	0.46
Amreli	Pitan para	7.9	7.6	950	10002	3.6	3.6	10	9	0.21	0.097	1.74	0.16	0.31	0.45
Rajula	Koteshwar temple	7.3	7.5	877.5	966	3.85	3.6	08	9	0.46	0.155	1.18	0.20	0.30	0.42
Mahua	Kuberbaug	7.4	7.6	997.5	1034	3.75	3.6	10	10	0.82	0.84	1.35	0.22	0.35	0.43
Chotila, Surendranagar	Parmeshwar Timber mart	7.4	7.6	3307	3921	3.17	3.1	9	12	0.01	-	0.12	1.60	0.97	0.90
Limbdi, Surendranagar	Nagarpalika	7.6	7.4	2538	2665	3.06	3.2	13	12	0.01	-	0.18	1.30	1.24	0.90
Surendranagar	Bhavani plastics, Wadhavan GIDC	7.5	7.8	2872	3518	2.73	2.7	10	14	0.01	-	0.76	3.50	1.19	0.50
Surendranagar	Tower chowk	7.6	7.6	1641	1619	3.10	2.9	10	13	0.01	-	0.13	1.80	1.44	0.90
Shapar-Veraval, Rajkot	Nr. Patel Viha Lodge	7.8	7.5	1113	1908	2.92	2.9	13	10	0.01	0.013	0.16	1.44	0.92	0.80
Gondal, Rajkot	Santhoshima Templ	7.7	8.1	612	644	2.92	2.9	10	10	0.01	0.013	0.75	1.43	0.64	0.64
Virpur, Rajkot	Saubhagya Hotel	7.8	7.7	1478	1155	3.53	2.8	10	10	0.00	0.015	0.10	1.67	0.55	0.76
Jetpur, Rajkot	Krishna park, N Bhadar	7.6	7.5	1059	839	3.03	2.8	13	10	0.01	0.012	0.11	1.34	0.57	0.63
Lalpur, Rajkot	Hanuman Dha Temple	7.7	7.5	1669	2211	2.99	2.8	12	11	0.01	0.013	0.12	1.32	0.25	0.66

Source: Anon. (2008-09 and 2010-11)

Table 5: Percent of ground water samples in relation to desirable and permissible limits

Parameter	DL	PL	Summer			Post monsoon			Winter		
			WD	BD	BP	WD	BD	BP	WD	BD	BP
Turbidity, NTU max	5	10	83.3	16.7	Nil	75	25	Nil	50	50	Nil
pH value	6.5-8.5	NR	All values in range								
Total hardness (as $CaCO_3$)	300	600	33.3	16.7	50	66.6	16.7	16.7	33.3	33.3	33.3
Iron (Fe), mg/L max	0.3	1.0	Nil	Nil	100	100	Nil	Nil	Nil	8.3	91.7
Chlorides, mg/L max	250	1000	25	25	50	25	58.3	16.7	25	50	25
Dissolved solids, mg/L max	500	2000	Nil	42	58	8.0	75	17	Nil	58	42
Copper (Cu), mg/L max	0.05	1.5	75	25	Nil	100	Nil	Nil	100	Nil	Nil
Manganese, mg/L max	0.1	0.3	100	Nil	Nil	91.7	8.3	Nil	91.7	8.3	Nil
Sulphate (SO_4), mg/L max	200	400	33.3	50	16.7	83.3	8.3	8.3	58.3	25	16.7
Nitrate (NO_3), mg/L max	15	100	100	Nil	Nil	100	Nil	Nil	100	Nil	Nil
Fluoride (F), mg/L max	1.0	1.5	25	25	50	11.7	33.3	25	25	16.7	58.3
Cadmium (Cd), mg/L max	0.01	NR	All values non-detectable in range								
Lead (Pb), mg/L max	0.05	NR	91.7	8.3	100	Nil	75	25	-	-	-
Zinc (Zn), mg/L max	0.5	1.5	100	Nil	Nil	100	Nil	Nil	100	Nil	Nil
Chromium (Cr^{6+}), mg/L max	0.05	NR	58.3	41.7	83.3	16.7	100	Nil	-	-	-
Alkalinity, mg/L max	200	600	Nil	91.7	8.3	Nil	100	Nil	Nil	83.3	16.7

As per IS:105000, 1991; WD-within desirable; BD-beyond desirable; BP-beyond permissible; DL-desirable limit; PL-permissible limit; NR-no relaxation

Characterization of sewage and industrial effluent

The sewage is characterized as a complex heterogeneous multifaceted matrix. The physical, chemical and microbiological composition of sewage depends upon its origin and production, which mainly decides its reuse and worthiness. Sewage generated in rural areas and small cities do not cause serious concern and reported to be fit for its recycling in agriculture due to its high organic matter, major and micronutrient content. Contrary, urban sewage represents the admixture of sewage, agro industrial waste effluents, and industrial effluents. The mixed sewage gets contaminated with heavy metal pollutants and toxic substances making its composition more complex. Urban sewage cum industrial effluent was found to carry relatively higher amounts of heavy metals such Ni, Cr, Pb, Cd, Co, salt load, *etc.*, that causes salinity, alkalinity hazards, and heavy metal pollution in soil and deteriorates the quality of soil and crops produced on irrigation with it.

The industries release their effluents on open land either in the form of solid waste through wastewater or in small stream lets. This kind of disposal introduces heavy or toxic metals into the soil. These metals migrate into the soil horizontally as well as vertically and cause ground water pollution that depends upon factors like mobility of metals and soil conditions. The mobility of trace metals in soil increases due to complex formation by dissolved inorganic and organic legends. The mobility of the metals in soil is also influenced by pH, soil cation exchange capacity, soil redox potential and organic matter (Maliwal and Patel, 2011). Presence of fulvic acid and humic acid in soil helps the metals to form complexes and leach out the metals to contaminate the groundwater resources. India, being a tropical country, the decomposition rate of organic matter is very high. A combination of low pH and tropical climate play a major role in transporting heavy metals to groundwater through the soil.

In a survey carried out in effluent irrigated area to assess the quality of industrial effluent and level of contamination of soil and crop plants compared to adjoining non- contaminated area with toxic metal along the effluent channel in Vadodara district, Ramani (2006) found that industrial effluents which were intercepted by the farmers for the irrigation purpose contained higher amounts of soluble salts especially of chloride and sulphate of sodium, calcium and magnesium compared to tube well water. In general, the overall quality of tube well water was medium to poor and effluent water was poor so far as suitability for irrigation is concerned. The mean COD and BOD values of effluent water were above the prescribed limits for field application. Since the effluents are released from different industries after treatment, the soluble salts in the effluents are expected (Table 6 and Figs. 1 & 2). The ground water of the area is also saline, which further adds soluble salts as the same water is used for the treatment of effluents.

Table 6: Quality parameters of effluent and tube well water near industrial area of Vadodara

Parameter	**Effluent water**	**Tube well water**	**Critical limit**
COD (mg L^{-1})	338.80	--	100.00
BOD (mg L^{-1})	40.40	--	30.00
EC (dSm^{-1})	5.18	1.51	--
SAR	8.05	6.15	--
Suitability class	C_4S_3	C_3S_2	--
Total content of metals (mg L^{-1})			
Fe	3.90	0.85	5.00
Mn	1.10	0.10	0.20
Zn	1.16	0.07	2.00
Cu	0.67	0.09	0.20
Cd	0.02	0.01	0.10
Co	0.14	0.04	0.05
Cr	0.26	0.04	0.10
NI	0.16	0.05	0.20
Pb	0. 17	0.09	5.00

The reports of Maliwal *et al.* (2004) also showed that ground water of the area was saline. Similar observations have also been reported by Joshi *et al.* (1994) and Ashok Kumar *et al.* (1998). Further, the results revealed that the quality of effluents water was poor mainly due to contamination with heavy metals like Ni, Cd, Co, Cr, Pb *etc*., besides presences of very high quantity of trace elements *viz*., Fe, Mn, Zn and Cu.

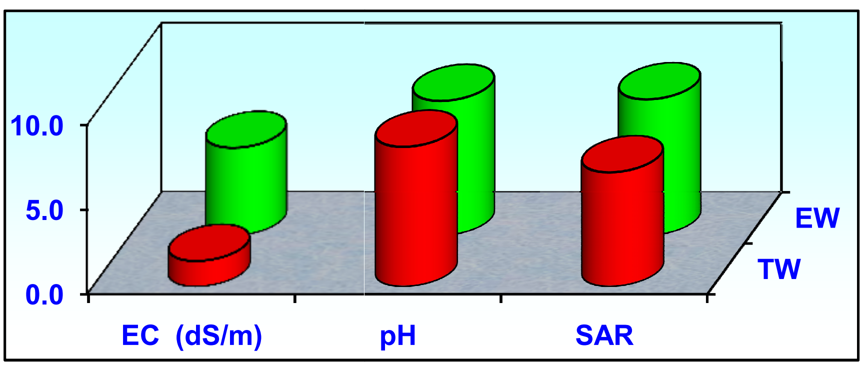

Fig. 1: Quality of effluent water (EW) and tube well water (TW) near effluent channel in Vadodara district

The higher quantity of metals could be mainly ascribed to the introduction of metals from different industries during the process of manufacturing and some quantity of metals remains even after treatment. Several workers have also found that such waste water contained high amounts of toxic amounts of toxic elements (Singh *et al.,* 1985 and Sharma and Kansal, 1986).

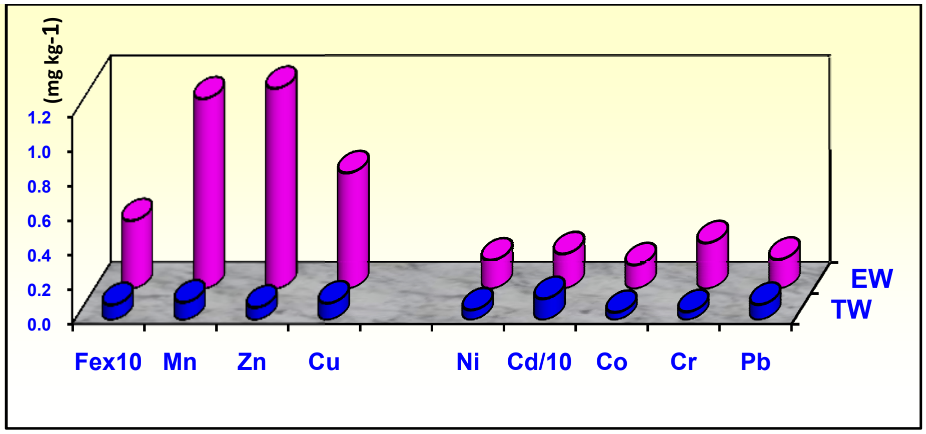

Fig. 2: Micronutrient and heavy metal contents in effluent (EW) and tube well (TW) water near effluent channel in Vadodara district

The metal content also vary greatly with the raw material and processes involved in manufacturing. The industrial wastewater collected from 17 different industries in central Gujarat revealed that the heavy metals *viz.* Co, Cd and Ni were higher than permissible limit (Maliwal *et al.*, 2005). They have further reported the variation in diurnal sampling. The concentrations of Cd and Co were higher than permissible limit (0.01 and 0.05 mg L^{-1}) during winter and summer in all industries samples, while Cr was higher than permissible limit (0.10 mg L^{-1}) during winter (Table 7).

Patel *et al.* (2003a) reported that the refinery effluent contain high concentration of Cd, Cr and Ni whereas fertilizer industry contain Cu and Cr in the higher range of concentration. Patel *et al.* (2004) further reported that content of heavy metals, in the effluents of paper mill at Ahmedabad, fertilizer and refinery at Vadodara and fertilizer at Bharuch and mixed effluent of industries at Ankleshwar were higher than permissible limits in all industries (Table 8).

The effluents contain high amount of trace elements and other pollutant heavy metals, it is imperative to characterize and assess their suitability for irrigation. In such an effort Patel *et al.* (2004) reported that the COD value of effluents from Ankleshwar site was extremely high, while the BOD values were within the safe limit in all the cases. The effluents from Ankleshwar site were the most polluted with respect to different elements *viz.* Fe, Cu, Mn, Cd, Ni, Co and Cr. The dissolved oxygen was observed only in well water and not in effluents. The results of relative availability of trace and heavy metals indicated that Cu, Pb, Zn and Cd were the most available elements in different soils. However, the soils continuously irrigated with effluents showed the highest Cu availability and Mn, Cd and Ni moderately available, while Fe and Cr indicated low availability. The availability of Pb was highest in soils near Ahmedabad and Ankleshwar irrigated with sewage mixed with industrial effluent.

Table 7: Toxic elements (mg L^{-1}) in the effluents waters of different industries in Vadodara and Bharuch districts

Type of industry	Cd		Co		Cr		Ni		Pb	
	W	**S**	**W**	**S**	**W**	**S**	**W**	**S**	**W**	**S**
Fertilizers	0.02	0.02	0.20	0.25	0.19	0.05	0.13	0.45	0.18	0.18
Mixed effluent	0.04	0.02	0.16	0.14	0.17	0.05	0.94	0.31	0.07	0.05
Refinery	0.04	0.02	0.63	0.10	0.13	0.01	0.08	0.06	0.04	0.26
Chemical-I	0.07	0.08	0.90	0.15	0.20	0.04	0.20	0.08	0.19	0.18
Mixture of dyes and chemicals	0.07	0.04	0.75	0.15	0.31	0.06	0.23	0.14	0.64	0.31
Chemical-II	0.07	0.03	0.15	0.13	0.28	0.04	0.19	0.10	0.38	0.13
Dyes	0.07	0.09	0.13	0.20	0.20	0.04	0.18	0.12	0.68	0.23
Mixture effluent	0.08	0.03	0.90	0.15	0.20	0.06	0.17	0.10	0.65	0.17
Gelatin	0.92	0.10	0.39	0.44	0.25	0.13	0.50	0.38	0.56	0.56
Mixed effluent	0.09	0.03	0.30	0.17	0.26	0.07	0.34	0.16	0.32	0.17
Pharmaceutical	0.09	0.03	0.20	0.18	0.22	0.13	0.22	0.18	0.22	0.27
Mixed effluent	0.10	0.03	0.23	0.15	0.23	0.09	0.29	0.15	0.14	0.23
Mixed effluent	0.10	0.04	0.21	0.22	0.22	0.18	0.27	0.30	0.18	0.15
Gases, chemicals	0.13	0.02	0.48	0.06	0.31	0.04	0.53	0.07	0.53	0.14
Mixed effluent of polymer, chemicals and dyes	0.09	0.02	0.18	0.11	1.08	0.03	0.19	0.09	0.18	0.20
Petrochemicals	0.07	0.01	0.14	0.07	0.48	0.01	0.13	0.08	ND	0.09
Mixed effluent of dyes, chemicals and agro industries	0.07	0.03	0.08	0.06	0.19	0.01	0.01	0.09	0.10	0.05

W=Winter sampling (January, 02); S=Summer sampling (May, 02); ND= not detected

Table 8: Comparison of quality and trace element composition (mg L^{-1}) of well water and effluents in industrial areas of Gujarat

Parameters	Ahmedabad			Vadodara			Bharuch		Ankleshwar	
	Sewage and Industrial	Paper mill effluent	Well	Refinery	Fertilizer	Well	Fertilizer	Well	Industry	Well
pH	7.8	7.8	8.1	7.7	8.2	8.1	7.1	7.9	7.1	8.0
EC(dSm^{-1})	2.4	2.5	3.4	1.3	2.7	2.0	1.3	4.6	2.5	1.5
TDS(mg L^{-1})	1608	1700	2251	858	1743	1300	1048	3032	1625	1000
TSS(mg L^{-1})	296.0	561.0	ND	193.5	279.5	ND	169.5	10.0	1630.0	9.0
DO(mg L^{-1})	ND	ND	8.8	ND	ND	7.5	ND	7.2	ND	4.4
COD(mg L^{-1})	510	1495	10	318.5	385.0	31.0	525.5	18.0	12810.0	39.0
BOD(mg L^{-1})	111	285	0.3	47.5	68.5	3.0	39.0	2.3	560.0	1.2
Cl^{-1}(me L^{-1})	12.0	11.0	26.0	4.7	11.0	15.0	5.5	39.0	12.0	3.5
CO_3^{2-}(me L^{-1})	0.4	2.0	1.0	ND	0.4	0.6	ND	ND	ND	1.0
HCO_3^- (me L^{-1})	8.0	11.0	6.0	6.0	7.5	3.8	4.0	4.0	3.5	9.0
PO_4^{3-}(me L^{-1})	7.5	ND	ND	ND	6.7	ND	25.7	0.9	1.1	0.4
SO_4^{2-}(me L^{-1})	168	37	75	42	382	8	129	114	495	47
Ca^{2+}(me L^{-1})	2.0	1.4	0.8	1.1	3.0	1.1	2.0	1.4	3.1	3.0
Mg^{2+}(me L^{-1})	2.4	2.4	5.2	3.0	4.1	5.2	7.0	21.0	47.2	0.2
Na^+(me L^{-1})	18.2	19.5	27.1	7.2	18.0	12.0	4.0	22.2	12.0	8.1
K^+(me L^{-1})	52.7	43.6	43.6	18.2	49.9	45.0	19.1	76.4	98.2	43.6
SAR	12.3	14.1	15.6	5.1	9.6	6.8	2.0	6.6	5.3	6.4
RSC (me L^{-1})	4.0	9.2	1.0	1.9	0.8	-ve	-ve	-ve	-ve	-VE
Class	C_4S_3	C_4S_4	C_4S_4	C_3S_1	C_4S_3	C_3S_2	C_3S_1	C_4S_3	C_4S_2	C_3S_2
Trace elements										
Fe	3.77	7.50	0.19	6.85	1.60	0.20	6.34	0.84	25.55	5.05
Zn	6.00	0.48	0.02	0.13	0.70	0.01	0.25	ND	0.34	0.01
Cu	0.13	0.34	0.04	0.09	0.09	0.02	0.12	0.01	0.70	0.04
Mn	0.18	0.27	0.03	0.13	0.10	0.04	0.29	0.02	4.83	0.12
Cd	0.01	0.01	0.01	0.05	0.01	ND	0.03	0.01	0.10	0.01
Co	0.02	0.04	0.02	0.24	0.08	0.01	0.15	0.02	0.56	0.02
Cr	0.13	0.67	0.01	1.19	0.21	0.04	1.10	0.13	2.76	0.02
Ni	0.09	0.11	0.06	0.35	0.06	0.01	0.55	0.03	0.73	0.01
Pb	0.13	0.17	0.03	0.30	0.04	0.01	0.17	0.03	0.84	0.01

Besides, effluent treatment, distance plays a significant role in the reduction of polluting elements. The results on analysis of effluent water samples from effluent channel project (ECP) representing refinery and fertilizer effluent (Ampad) revealed that the effluent water samples collected from Koyali and Ampad near the source of refinery and fertilizer effluent, respectively, contained higher level of all quality parameters as well as heavy metals than the samples collected from far distance Sherkhi (refinery and Lakhdikoi (fertilizer) sites effluent waters (Table 9).

Table 9: Quality parameters of well water and industrial effluents (Vadodara)

Parameters	**Refinery Koyali**	**Fertilizer**	
		Ampad	**Dagipura**
pH	7.76	8.32	8.10
EC(dS m^{-1})	1.20	2.80	2.00
TDS(mg L^{-1})	817.00	800.00	1300.00
TSS(mg L^{-1})	285.00	377.00	ND
DO(mg L^{-1})	ND	ND	7.50
COD(mg L^{-1})	381.00	456.00	31.00
BOD(mg L^{-1})	64.00	97.00	3.00
Cl^{-1}(me L^{-1})	5.90	11.50	15.00
CO_3^{2-}(me L^{-1})	ND	0.40	0.60
HCO_3^- (me L^{-1})	4.00	8.00	3.80
PO_4^{3-}(me L^{-1})	ND	6.50	ND
SO_4^{2-}(me L^{-1})	52.00	383.00	7.50
Ca^{2+}(me L^{-1})	1.20	3.20	1.10
Mg^{2+}(me L^{-1})	2.00	4.20	5.20
Na^+(me L^{-1})	7.40	18.50	12.00
K^+(me L^{-1})	21.80	50.90	45.00
SAR	5.85	9.62	6.76
RSC(me L^{-1})	0.80	1.00	-ve
Class	C_3S_1	C_4S_3	C_3S_2
Total trace elements (mg L^{-1})			
Fe	6.74 (0.03)	1.99 (0.01)	0.20 (ND)
Zn	0.15 (ND)	0.85 (ND)	0.01 (ND)
Cu	0.12 (0.01)	0.09 (0.02)	0.02 (ND)
Mn	0.16 (0.01)	0.13 (0.01)	0.04 (ND)
Cd	0.05 (ND)	0.01 (ND)	ND (ND)
Co	0.25 (0.02)	0.08 (0.02)	0.01 (ND)
Cr	1.16 (ND)	0.28 (0.01)	0.04 (ND)
Ni	0.40 (ND)	0.07 (0.02)	0.01 (ND)
Pb	0.31 (ND)	0.04 (ND)	0.01 (ND)
Figures in parenthesis indicate the water soluble trace elements (mg L^{-1})			

This might be due to the dilution effect of further addition of large quantity of other effluent in channel over distance. Maliwal *et al.* (2005) also observed the contamination of Co and Cd in underground waters near the complex of industries and pollution extended up to 2 km on the left side of the effluent channel in Vadodara district where industries effluents are used indiscriminately for irrigation since 20 years. In a study Patel *et al.* (2003a) observed that the industrial effluents collected from different cities (Bharuch and Ankleshwar) were found contaminated with all major polluting metals especially at Kasbatiwad site near Ankleshwar (Ambalakhdi). It contained TSS, COD, and BOD above standard permissible limits for irrigation. The well water from Bharuch site was mainly contaminated with Cr and Mn whereas those from Ankleshwar site contained Fe above permissible limits for irrigation. The well water has shown salinity and alkalinity hazards also (Table 10).

Heavy metals contamination of water with use of agro-chemicals

A considerable amount of toxic metals such as As, Cd, Co, Cr, Pb, Hg, Mo and Ni are added through agro-chemicals *viz.*, fertilizers and pesticides (Table 11). The main issues concerning these potentially harmful elements are i) soil accumulation and possibility of the long term effects on crop yield and groundwater quality ii) plant uptake and the content of the element in animal feed and human diet, iii) potentially damage to the soil microflora and iv) direct exposure to humans through contact and ingestion. The famous incidences of *itai-itai* and *minamata* diseases due to Cd and Hg toxicity, respectively, are the examples of potential threat of heavy metals pollution. So far not even a single case of metal toxicity in agricultural land due to application of either fertilizers or soil amendments has been reported in the state or India.

Table 10: Quality parameters of well water and industrial effluents (Bharuch / Ankleshwar)

Parameters	Bharuch				Ankleshwar	
	Fertilizers		Well		Industrial	Well
	Kantharia	Sherpara	Umdaj-I	Umdaj-II	Kasbatiwad	Punagam
pH	7.34	6.95	7.94	7.81	7.14	8.07
EC (dSm^{-1})	1.60	1.00	4.60	5.20	2.50	4.50
TDS ($mg\ L^{-1}$)	1301.00	796.00	3032.00	3379.00	1625.00	1000.00
TSS ($mg\ L^{-1}$)	255.00	84.00	10.00	ND	1630.00	9.00
DO ($mg\ L^{-1}$)	ND	ND	7.20	6.00	ND	4.40
COD ($mg\ L^{-1}$)	731.00	320.00	18.00	16.00	12810.00	39.00
BOD ($mg\ L^{-1}$)	55.00	23.00	2.30	1.20	560.00	1.20
$C1^{-1}$ ($me\ L^{-1}$)	8.50	2.50	39.00	44.00	12.00	3.50
CO_3^{-2} ($me\ L^{-1}$)	ND	ND	ND	0.80	ND	1.00
HCO_3^- ($me\ L^{-1}$)	3.50	4.50	4.00	4.60	3.50	9.00
PO_4^{-3} ($me\ L^{-1}$)	36.70	14.60	0.90	ND	1.10	0.40
SO_4^{-2} ($me\ L^{-1}$)	132.00	126.00	114.00	217.00	495.00	47.00
Ca^{++} ($me\ L^{-1}$)	ND	2.00	1.40	2.00	3.10	3.00
Mg^{++} ($me\ L^{-1}$)	10.00	4.00	21.00	21.00	7.20	0.20
Na^+ ($me\ L^{-1}$)	5.00	3.00	22.20	26.60	12.07	8.10
K^+ ($me\ L^{-1}$)	23.60	14.50	76.40	56.40	98.20	43.60
SAR	2.24	1.73	6.63	7.84	5.32	6.40
RSC ($me\ L^{-1}$)	-ve	-ve	-ve	-ve	-ve	-ve
Class	C_3S_1	C_3S_1	C_4S_3	C_4S_3	C_4S_2	C_3S_2
Total trace element ($mg\ L^{-1}$)						
Fe	10.51 (0.05)	2.17 (0.09)	0.84 (0.02)	0.33 (0.01)	25.55 (0.05)	5.05 (0.01)
Zn	0.40 (0.03)	0.10 (0.03)	ND (ND)	0.07 (ND)	0.34 (0.08)	0.01 (ND)
Cu	0.22 (0.02)	0.03 (0.02)	0.01 (0.01)	0.04 (0.01)	0.70 (0.04)	0.04 (0.01)

Table 10: Continue….

Parameters	Bharuch				Ankleshwar	
	Fertilizers		Well		Industrial	Well
	Kantharia	Sherpara	Umdaj-I	Umdaj-II	Kasbatiwad	Punagam
Mn	0.50 (0.30)	0.09 (0.06)	0.02 (0.01)	0.21 (ND)	4.83 (3.02)	0.12 (ND)
Cd	0.04 (ND)	0.01 (ND)	0.01 (ND)	0.01 (ND)	0.10 (ND)	0.01 (ND)
Co	0.29 (0.03)	0.02 (0.01)	0.02 (0.01)	0.02 (ND)	0.56 (ND)	0.02 (0.01)
Cr	2.01 (ND)	0.19 (ND)	0.13 (0.01)	ND (ND)	2.76 (0.02)	0.02 (0.01)
Ni	0.98 (0.28)	0.13 (0.12)	0.03 (0.01)	0.02 (0.03)	0.73 (ND)	0.01 (ND)
Pb	0.32 (0.03)	0.02 (0.01)	0.03 (0.03)	0.04 (0.04)	0.84 (0.01)	0.01 (0.01)

Table 11: Heavy metal contents (average) in fertilizers

Fertilizer	Heavy metals (mg kg^{-1} fertilizer)					
	Cu	Zn	Mn	Mo	Cd	Pb
Single super phosphate	26	115	150	3.3	187	609
Diammonium phosphate	-	-	-	109	188	-
Muriate of potash	3	3	8	0.2	14	88
Calcium ammonium nitrate	0.2	6	11	-	6	200
Urea	0.4	0.5	0.5	0.2	1	4
Ammonium sulphate	0.5	0.5	70	0.1	-	-
Triple super phosphate	7	75	200	0.1	-	-
Ammonium phosphate	3	80	160	2	-	-
Complex fertilizer	22	276	-	-	6	128
Rock phosphate	100	200	0.5	-	-	-

In order to quantify the presence of different pesticides in sewage and industrial effluents, a study was undertaken in four industrial channel nearby Vadodara which is surrounded by dyes, chemicals, fertilizers, petrochemicals, pharmaceuticals, gelatin, polymers, resins, plastic, *etc.*, industries. Sewage water of Vadodara city was also collected for the study (Maliwal *et al.* 2003). The analysis showed the presence of HCH while DDT and other organochlorine compound *viz.* endosulfan and chlorpyriphos were absent. The maximum allowable limit set is 1 ppb for individual HCH isomers. The effluents collected from Ekalbara and Karkhadi mix effluents had high β-HCH while other HCH isomers in all effluent samples as well as in sewage water had lower content than permissible limits. High level of β-HCH in these samples is a matter of concern because these HCH-isomers are lipophilic in nature and get deposited in adipose tissue of human being and animals (Table 12).

Table 12: Concentration (ppb) of different pesticides in sewage water and industrial effluents

Compound	**Sewage water**	**Industrial effluents Center**			
		Koyali mix	**Refinery**	**Ekalbara mix**	**Karkhadi mix**
α-HCH	0.118-0.831	ND	0.039	0.417	0.040
γ-HCH	0.580-0.629	0.034	0.077	Tr.	Tr.
β-HCH	Tr.-0.027	0.543	0.280	8.801	9.196

Remedial measures for minimizing water pollution

In *Peri urban* areas, water and soils are being regularly contaminated or polluted with sewage and industrial waste waters through anthropogenic activities. Geogenic activities forced us to live with it or altering management practices. Most often, it is difficult to decontaminate or ameliorate such waters or soils fully pollution free. Since domestic sewage as such does not contain so much pollution and provides sufficient quantities of major and micronutrients, helps in sequestering organic matter in soil. Therefore, sewages are reported to be a good source of nutrients. But once the heavy metals and city wastes are discharged in it through industrial effluents, their quality gets deteriorated and effluent becomes unfit for agricultural use. Heavy metals contamination can be reduced by several techniques such as physical separation, mechanical and chemical treatment, bio- and phytoremediation besides adapting various agronomic practices. These include use of amendment, organic manures, heavy application of phosphorus and micronutrients like zinc, growing supra accumulator and inefficient translocator to economic produce, segregation and biocomposting, sewage sludge, garbage, industrial effluents / wastes *etc*., and using site specific agronomic practices. Hence, it is suggested that either pollution is to be controlled at point source of industry level or to be reclaimed using different technologies for minimizing pollution. Some of these technologies are discussed here under.

A. Land disposal of sewage and industrial effluents

Karnal technology provides an efficient way to discharge large amount of sewage and utilizes contaminated water through biopumping. Growing of high water demanding agro-forestry crops *viz*., eucalyptus and popular on ridge and furrow system can reduce the pollution load and helps in carbon sequestration. Irrigation scheduling and mixing sewage and ground waters or alternate irrigation is found useful in harnessing water and nutrient potential of sewage effluent for raising cultivated crops and vegetables. Soil is a sink to hold on contaminants like organic matter, salts, nutrients and heavy metals *etc*., depending upon soil properties, crop and management.

B. Improvement in sewage quality through treatment

In towns and small cities due to absence of large scale industries, the raw sewage produced is largely from domestic activities does not invite serious concern and these are reported to be fit for its reuse in agriculture by adopting proper agronomic practices. Contrarily, urban sewage represents an admixture of waste water, contaminated with heavy metal pollutants and composition becomes more complex and needs primary and secondary treatments. So origin, nature and composition of the sewage will have distinction between domestic and urban sewage for its safe disposal and accordingly strategies for their use are to be planned.

i) Raw sewage

Raw sewage from urban cities is a rich source of organic matter, high amount of solids (mostly organic), Raw sewage possesses high manurial values. Based on mean NPK content, contribution was to the level of 11.3, 4.87, 5.56 kg ha^{-1} per cm of sewage; micronutrients value was also relatively high by way of contributing 1.56, 0.24, 1.12, 0.29 kg ha^{-1} of Fe, Mn, Zn, Cu kg ha^{-1} per cm of sewage irrigation. Long term regular use of mixed sewage and effluents poses threat to soil environment and reduces yields and quality of crops.

ii) Primarily treated domestic sewage

The primary treatment of sewage effluent involves simple lagooning and subsequent natural oxidation whereby suspended colloidal particles of the sewage get partly or wholly coagulated and flocculated, reduces dissolved salts by 50-75 per cent before discharge. Treatment process reduces the BOD, COD, EC and improves water quality parameters, however, undesirable effect was observed despite reduction in total content of heavy metal, the levels were critical for use in agriculture due to their high initial load (Patel and Singh 2003).

iii) Secondary treated urban sewage and effluents

Secondary treatment involves further refining of the primarily treated sewage by way of chemical and biological treatments including oxidization through aerators. As a result of this, the hazardous nature of sewage is further reduced in term of heavy metal and then suspended colloidal load for agricultural use. It is apparent that after secondary treatment the sewage undoubtedly transformed in to a highly potential irrigation water source posing minimal pollution in the soils and environment. Dilution 1 : 4 diminishing the salt concentration BOD, COD value and brings out the favorable improvement in water quality parameters, reduction in organic colloidal material load and minimizing the pollutant hazards.

C. Recycling and reuses of waste water

Since processor industries are major users of fresh water, so effort are needed to recycle or reuse waste waters more economically and efficiently by adopting proper design system at initial phase itself. As per recent survey conducted by CPCB, about 85 per cent of the total number of large and medium water polluting industries in the country has effluent treatment plant but their performance in most cases was found to be far from satisfactory.

Recycling of waste water is defined as the internal use of waste water by the original user prior to discharging it to treatment point or other point of disposal. The term reuse implies to waste waters that are discharged and then withdrawn by a user other than the discharger. Efforts are needed to recover waste water treated or untreated. These waste effluents, if recycled or reused used within the industry, would help in minimizing water pollution and reducing fresh water requirements. The case of Madras Refineries Limited is an eye opener where it is acquiring water from the local municipality for utilizing in refinery after treatment.

D. Phytoremediaton

Phytoremediaton is an emerging cleanup technology for restoration of clean environment through green plants. It exploits plant potential to immediate soil and water contaminated with a variety of organic and inorganic compounds. The technology is slow and time requiring but is much more eco-friendly. It is gaining considerable importance and is on the brink of commercialization in India and globally owing its success on several case studies in real world ecosystem. Variety of strategies are being followed for field remedial uses *i.e.,* constructed wetlands, beds and floating-plant systems are quite common for the treatment of various types of waste waters (Saxena *et al.,* 1999). Certain plants like bamboo, typha, sugar cane, brassica species and spinach and amaranthus are good scavenger of heavy metals from contaminated soils. These plants extract the metals from metallic residues, reclamation of waste sites, decontamination of toxic residues and stabilization of mine tailings and spoils.

Studies on suitability of effluents/waste water for irrigation

Wastewater is gaining popularity as a source of irrigation water in different countries around the world. This is especially true in India, where it has been in use for a long time. Its economic benefits and its importance as a coping strategy for the poor have had little recognition. Sewage water though is a good source of major and micronutrients for plants but is also a potential source of carcinogenic substances and toxic trace elements. The rural areas downstream of Vadodara in Gujarat, India, present an interesting case where wastewater supports annual agricultural production worth more than Rs. 266 million. Both food crops and cash crops are irrigated by domestic wastewater and industrial effluent. In this area one of the most lucrative income-generating activities for the lower social strata is the sale of wastewater.

The lack of alternative sources of water has generated viable markets for wastewater. Increased disposable incomes have resulted from the catalytic use of waste water that was formerly not socially acceptable *i.e.*, the farmers considered it unhealthy and unclean. The use of waste water to grow food crops poses uncertain risks to the health of both consumers and those who actually handle the wastewater. With increasing urbanization, large quantities of sewage water are produced. This waste water can be used in agriculture for irrigation while the dissolved nutrients can improve soil fertility. However, sewage can also contain undesired substances such as heavy metals, which may result in undesired effects when applied in large quantities. Heavy metals (broadly defined as a group of toxic metals and metalloids associated with pollution and toxicity) are the ones having density of more than that of 6 Mgm-3 and atomic weight more than that of iron (Alloway, 1990).

Operationally, all the micronutrient cations *viz*., Fe, Mn, Zn, Cu and Ni are classed as the heavy metals and depending on levels in the plants/organisms exhibit both deficiency and toxicity. In addition, Pb, Cd, Cr, Hg. Se and Ar are the other heavy metals and metalloids which exhibit only toxicity to animals including human beings and plants. Heavy metals may build-up in the soil while the crop may take them up, thus resulting in high concentrations of heavy metals in consumable products (Sharma and Kansal, 1986). The composition of sewage, and thus its quality varies with the type or source of urban waste. Zalawadia *et al* (1997) studied the effect of irrigation with spent wash of sugar industries diluted to 25 (S_{25}), 50 (S_{50}) and 100 (S_{100}) times along with tube well water (S_0) on Typic chromustert. The spent wash diluted to any of these levels increased the sugarcane yield, nutrient uptake and available nutrients in soil significantly over S_0 without increasing heavy metal accumulation very high in soil or the plant (Table 13).

Table 13: Effect of irrigation with diluted spent wash on biomass yield, heavy metal uptake by sugarcane and soil properties

Character	Treatment				CD (0.05)
	S_0	S_{25}	S_{50}	S_{100}	
Dry biomass (g pot^{-1})	210	277	243	228	11.7
Total uptake (mg pot^{-1})					
N	1436	3002	2261	1803	402
S	380	790	587	442	49
Zn	4.69	11.77	8.40	5.90	0.77
Cu	1.37	2.88	2.16	1.76	0.33
Pb	0.12	0.18	0.16	0.14	0.02
Cd	0.01	0.02	0.02	0.01	0.00
Ni	1.46	2.75	2.24	1.86	0.28
Soil quality					
Organic C (g kg^{-1})	6.4	9.8	8.7	7.7	0.5
N (mg kg^{-1})	123.0	240.0	188.0	174.0	16.0
S (mg kg^{-1})	30.0	108.0	69.0	33.0	4.0
Zn (mg kg^{-1})	0.63	1.73	1.33	0.84	0.10
Cu (mg kg^{-1})	4.13	6.98	5.60	4.62	0.25
Pb (mg kg^{-1})	0.98	1.22	1.11	1.05	NS
Cd (mg kg^{-1})	0.013	0.028	0.020	0.015	NS
Ni (mg kg^{-1})	1.03	1.64	1.46	1.25	0.16

In a study on suitability of industrial effluent water for irrigation around Vadodara industrial zone of Gujarat, Maliwal *et al.* (2005) found that the effluent water quality falls under high SAR saline and saline (Table 14). These effluent waters as suitable for tolerant crops under coarse to fine soils depending upon total salts and SAR where rainfall occur between 550 and 700 mm. The presence of high concentration of heavy metals *viz.,* Cd, Co, Cr in all the industries located nearby Vadodara city and Ni in fertilizer, gelatin and chemical industries above permissible limit priscribed by FAO (1992) and the use of the effluent waters for irrigation will be hazardous. The excessive organic and inorganic load in effluent waters beyond the cumulative capacity of soil might create problems of salinity and sodicity. The study also revealed that the use of these effluent waters for irrigation will pollute the irrigated lands as the effluent waters are of high SAR saline and saline as well as contain high concentration of toxic elements.

Table 14: Suitability of effluent water for irrigation considering salinity, sodicity, texture, crop tolerance and rainfall

Type of effluent	**Water quality** (550-700 mm rainfall)	**Suitability under** (me L^{-1})	**RSC**
Fertilizers	High SAR saline	TC-MC	-ve
Mixed effluent	High SAR saline	STC-MC, TC-MC	-ve
Reflanery	High SAR saline	TC-MC	-ve
Chemical-1	High SAR saline	STC-MC, TC-MC	-ve
Mixture of dyes and chemicals	High SAR saline	TC-MC	-ve
Chemical-II	Saline	TC-F	-ve
Dyes	High SAR saline	TC-C	123.9
Mixed effluent	High SAR saline	TC-MF	-ve
Gelatin	Saline	TC-C	-ve
Mixed effluent	High SAR saline	TC-MC	-ve
Pharmaceutical	High SAR saline	TC-C	15.1
Mixed effluent	High SAR saline	TC-MC	-ve
Mixed effluent	Saline	TC-MC	-ve
Gases chemicals	High SAR saline	TC-C	-ve
Mixed of dye, chemical and polymer	High SAR saline	TC, STC-MC	-ve
Petrochemicals	High SAR saline	TC-MC	-ve
Mixture of dye, chemicals and agro industries	High SAR	SC-F	-ve
TC-Tolerant crop; STC-Semi tolerant crop; SC-Sensitive crop ; F-Fine (>30 day) ; C-Coarse (<10 days) ; MF-Moderately fine (20-30 days) ; C- Moderately coarse (10-20 days)			

Patel *et al.* (2003b) also observed that the accumulation of the pollutant elements was more in surface (0 – 15 cm) than in lower (15 – 30 cm) depth. Besides, much variation in their content was not noticed between the two sewage water and normal water irrigated soils. The maximum value noticed for Cd, Co, Cr, Ni and Pb in the sewage-irrigated soil was 0.12, 0.44, 0.34, 0.54 and 3.84 ppm, respectively. The corresponding values for normal water irrigated soil were 0.06, 0.44, 0.32, 0.88 and 1.30 ppm. The profile distribution of heavy metals indicated that the DTPA- extractable fraction of these metals was found to decrease in sewage irrigated soils except for Cd and Pb. The effect was more pronounced under the soils irrigated with big industries waste water than small and medium. This may be attributed to the continuous addition of organic matter through sewage water. The organic and total fractions are supposed to be enriched as a result of continuous use of contaminated sewage irrigation water (Table 15).

To minimize the threat of land and ground water contamination, accurate estimation of vertical and horizontal movement of heavy metals is important. In order to assess these movements, soil samples were collected from various depths of profiles near to effluent channel where mixed effluents are used for irrigation especially in winter and summer as well as paddy crop in monsoon since last 17-20 years (Table 16).

While three profiles at different distance from effluent channel were collected from Nani Serkhi, Mujpur and Majatan villages which are subjected to irrigation with underground tube well water for studying the vertical and horizontal distribution of DTPA extractable metals in soils (Maliwal *et al.,*2004). The results revealed that higher content of Pb at 2 km distance was observed at the depth of 0.15-0.30, 0.30-0.45 and +0.60 m as compared to 0.5 km distance. The horizontal movement to these layers may be one of the reasons for increase in Pb content. This is due to the contamination of tube well water with Pb content even up to 2 km distance left side of effluent channel.

The main source of irrigation in Nawagam area is open well, bore well and village ponds. However, the village ponds are receiving effluent water through Khari canal/channel, which carries industrial effluents discharged from the industrial area of Naroda and Vatva. These effluents may or may not be biodegradable. It is also observed that there were approximately 1600 units of which about 5258 units generate effluents (Parmar and Patel, 2010). The well water contaminated area contained higher amount of soluble salts compared to uncontaminated tube well water. The SAR and RSC values also were high in tube well water in contaminated area (Table 17).

While the soluble salts were higher in uncontaminated tube well water from uncontaminated area. In general, the overall quality of tube well water of uncontaminated area was medium to poor while that of contaminated area was poor for irrigation purpose. Therefore, the ground water of the area was found as saline as well as sodic in nature. Further, it was noticed that the water of contaminated area containing appreciable quantity of micronutrients and heavy metals from water soluble and acid extract as well. This indicated that the ground water contamination was laterally extended below ground even up to about 1 to 2.5 km away from the open channel carrying mix industrial effluents into *Khari River*. The results further stressed on possible risk of contamination of ground water not only in the affected but nearby surrounding area also.

Table 15: Depth wise distribution of heavy metal contents (ppm) in soils irrigated with normal (reference) and sewage water (Jan.-Feb. 2002)

Cate gory	Location	Depth (cm)	Cd		Co		Cr		Ni		Pb	
			Sewage	Ref.	Sewage	Ref.	Sewage	Ref.	Sewage	Ref.	Sewage	Ref.
Small	Anand	0-15	0.04	0.04	0.32	0.44	0.30	0.30	0.42	0.32	1.00	0.20
		15-30	0.02	0.04	0.28	0.42	0.14	0.30	0.38	0.26	0.64	0.34
		30-45	0.02	0.04	0.36	0.40	0.24	0.32	0.34	0.30	0.50	Tr
		45-60	0.04	0.02	0.40	0.42	0.20	0.26	0.34	0.24	0.72	Tr
		+ 60	0.02	Tr	0.36	0.44	0.26	0.28	0.36	0.22	0.52	0.34
	Kapdvanj	0-15	0.02	Tr	0.34	0.30	0.12	0.22	0.20	0.22	1.18	0.72
		15-30	0.04	Tr	0.36	0.32	0.14	0.24	0.22	0.20	1.70	0.28
		30-45	0.04	Tr	0.40	0.40	0.08	0.22	0.18	0.16	0.90	0.30
		45-60	0.02	Tr	0.36	0.38	0.08	0.28	0.14	0.22	1.24	0.20
		+ 60	0.02	Tr	0.32	0.36	0.02	0.18	0.12	0.20	1.00	0.30
Medium	Vadodara	0-15	0.02	0.06	0.44	0.36	0.18	0.10	0.42	0.88	0.78	1.30
		15-30	Tr	0.02	0.32	0.42	0.08	0.10	0.40	0.54	0.78	1.00
		30-45	0.04	0.06	0.28	0.38	0.08	0.20	0.54	0.50	0.90	0.96
		45-60	0.04	0.04	0.32	0.34	0.18	0.30	0.52	0.44	0.84	0.92
		+ 60	0.02	0.04	0.36	0.34	0.16	0.24	0.42	0.44	0.80	0.84
Big	Ahmedab ad	0-15	0.12	0.02	0.30	0.28	0.34	0.06	0.26	0.64	3.84	0.28
		15-30	0.08	0.04	0.22	0.42	0.06	0.08	0.22	0.70	3.70	0.58
		30-45	0.10	0.02	0.24	0.62	0.04	0.04	0.22	0.56	3.78	0.58
		45-60	0.04	0.02	0.26	0.38	Tr	0.03	0.14	0.46	1.86	0.51
		+ 60	0.02	0.01	0.24	0.35	Tr	0.03	0.18	0.45	1.48	0.43

Table 16: Spatial changes in chemical composition of tube well water

Location	Side of the channel	Horizontal distances from effluent channel	EC (dSm^{-1})	pH	Cations ($Cmol\ L^{-1}$)				Anions ($Cmol\ L^{-1}$)		
					Na^{+}	K^{+}	Ca^{+2}	Mg^{+2}	HCO_3-	CO_3^{-2}	CI-
Koyali	R	500 m	1.2	8.0	6.6	1.6	1.2	3.1	3.6	1.8	4.0
Nani Serkhi	R	1 km (Ref.)	1.3	7.9	4.3	1.0	1.2	10.8	3.6	3.6	4.5
Nani Serkhi	L	500 m	1.1	8.1	6.8	1.6	0.5	6.9	1.8	7.2	2.0
Nani Serkhi	L	<100 m	1.1	8.3	4.9	1.3	0.7	7.4	3.6	1.8	6.0
Moti Serkhi	L	10 m	1.2	8.0	5.1	1.3	1.0	5.4	3.6	1.8	5.0
Moti Serkhi	R	1 km	2.9	7.6	13.3	3.5	1.7	5.9	Tr	7.2	2.0
Ampad	L	5 m	1.9	8.0	9.8	2.2	0.7	6.7	3.6	3.6	8.0
Ampad	R	500 m	2.3	8.0	17.2	3.8	0.7	3.4	3.6	3.6	10.0
Jaspur	R	5 m	2.4	8.1	11.3	9.1	0.7	3.1	5.4	3.6	12.5
Luna	L	15 m	1.3	8.1	5.5	2.2	0.7	5.3	3.6	3.6	4.5
Mujpur	L	500 m	1.3	8.0	3.3	0.9	1.0	3.4	1.8	3.6	5.5
Mujpur	R	500 m	5.0	8.0	32.0	10.5	6.0	12.1	7.2	3.6	33.5
Narsipura	L	5 m	4.1	7.9	30.8	9.8	3.1	11.2	5.4	3.6	29.0
Mazatan	L	2 km (Ref.)	1.9	8.3	9.3	4.2	1.0	4.0	3.6	7.2	9.0
Karkhadi	R	25 m	2.9	8.1	18.5	5.2	1.2	3.4	7.2	3.6	16.0

Continued…..

Table 16 Contd.

Location	**Side of the channel**	**Horizontal distances from effluent channel**	**Micronutrients and heavy metals (mg L^{-1})**							
			Zn	**Fe**	**Cu**	**Mn**	**Co**	**Ni**	**Pb**	**Cd**
Koyali	R	500 m	0.007	0.06	0.015	0.005	0.04	0.03	0.15	0.01
Nani Serkhi	R	1 km (Ref.)	0.005	0.06	0.007	0.001	0.00	0.01	0.00	0.00
Nani Serkhi	L	500 m	0.001	0.01	0.007	0.011	0.02	0.00	0.00	0.00
Nani Serkhi	L	<100 m	0.018	0.01	0.015	0.011	0.01	0.01	0.20	0.00
Moti Serkhi	L	10 m	0.016	0.01	0.001	0.001	0.07	0.00	0.17	0.02
Moti Serkhi	R	1 km	0.009	0.02	0.015	0.001	0.06	0.07	0.20	0.03
Ampad	L	5 m	0.016	0.01	0.001	0.001	0.05	0.01	0.19	0.04
Ampad	R	500 m	0.012	0.03	0.001	0.017	0.05	0.03	0.14	0.05
Jaspur	R	5 m	0.014	0.03	0.015	0.001	0.08	0.02	0.09	0.03
Luna	L	15 m	0.011	0.06	0.001	0.011	0.08	0.01	0.19	0.04
Mujpur	L	500 m	0.016	0.07	0.001	0.005	0.06	0.00	0.09	0.04
Mujpur	R	500 m	0.0230	0.06	0.001	0.023	0.11	0.05	0.27	0.04
Narsipura	L	5 m	0.007	0.03	0.001	0.001	0.05	0.02	0.21	0.08
Mazatan	L	2 km (Ref.)	0.014	0.06	0.007	0.001	0.07	0.04	0.13	0.06
Karkhadi	R	25 m	0.012	0.06	0.015	0.011	0.05	0.00	0.15	0.05

Table 17: Chemical composition of tube well water in Nawagam –Vatava region

Parameter	**Un-contaminated range (Mean)**	**Contaminated range (Mean)**	**Parameter**	**Un-contaminated range (Mean)**	**Contaminated range (Mean)**
pH	7.10-9.36 (48.07)	6.40-8.56 (7.8)	Cl (me L^{-1})	11.5-38.5 (22.6)	12.0-52.5 (29.3)
EC(dSm^{-1})	1.80-4.40 (2.21)	2.20-6.80 (3.80)	CO_3^{2} (meL^{-1})	0.0-4.0 (1.1)	0.0-4.0 (1.9)
Na^+(me L^{-1})	4.0-25.4 (14.6)	13.4-43.6 (25.2)	HCO_3 (meL^{-1})	1.3-9.0 (4.1)	2.0-8.0 (6.0)
K^+(me L^{-1})	1.0-13.9 (8.2)	0.3-10.8 (6.2)	SAR	3.2-22.0 (11.2)	11.3-31.3 (18.0)
$Ca^{2+}Mg^{2+}$ (me L^{-1})	2.8-22.0 (7.6)	2.8-15.0 (6.5)	RSC	-ve-8.6 (1.8)	0.7-8.1 (4.5)
Water soluble content of micronutrients and heavy metals (ppm)				**Total content of micronutrients and heavy metals (ppm)**	
Fe	ND-0.130 (0.036)	ND-0.100 (0.022)	Fe	0.070-3.490 (0.690)	0.060-0.760 (0.306)
Mn	ND-0.200 (0.021)	ND-0.090 (0.026)	Mn	ND-0.590 (0.116)	0.010-0.410 (0.091)
Zn	ND-0.110 (0.035)	ND-0.040 (0.006)	Zn	0.010-0.500 (0.115)	ND-0.500 (0.065)
Cu	ND-0.020 (0.008)	ND-0.100 (0.015)	Cu	ND-0.030 (0.016)	0.010-0.190 (0.031)
Cr	0.004-0.060 (0.028)	0.020-0.100 (0.062)	Cr	0.024-0.080 (0.048)	0.040-0.120 (0.084)
Cd	ND-0.010 (0.007)	ND-0.040 (0.01)	Cd	ND-0.020 (0.016)	ND-0.080 (0.021)
Co	ND-0.070 (0.029)	0.010-0.080 (0.043)	Co	0.030-0.120 (0.070)	0.010-0.190 (0.077)
Ni	ND-0.070 (0.018)	ND-0.090 (0.038)	Ni	ND-0.700 (0.080)	ND-0.900 (0.114)
Pb	ND-0.120 (0.040)	ND-0.100 (0.047)	Pb	ND-0.200 (0.088)	0.020-0.500 (0.104)

Nitrate Pollution

The ground water pollution with NO_3- N in middle Gujarat region was assessed. The well water samples were collected from three different agro- eco situations having three different types of soil *viz*., medium black, light texture and salt affected. The cropping system followed in these areas is also different. Therefore, the NO_3^- N leaching will be at variable level depending upon the crop management practices and soil types. The pH of the water samples was in the alkaline range in all the cases. The EC and SAR were quite high in samples collected from the paddy area indicating the poor quality of the water in this area (Fig. 3). The quantity of NO_3- N was not high in any of the cases, though the area having sandy soils showed higher NO_3-N contents (Patel *et al*., 2010).

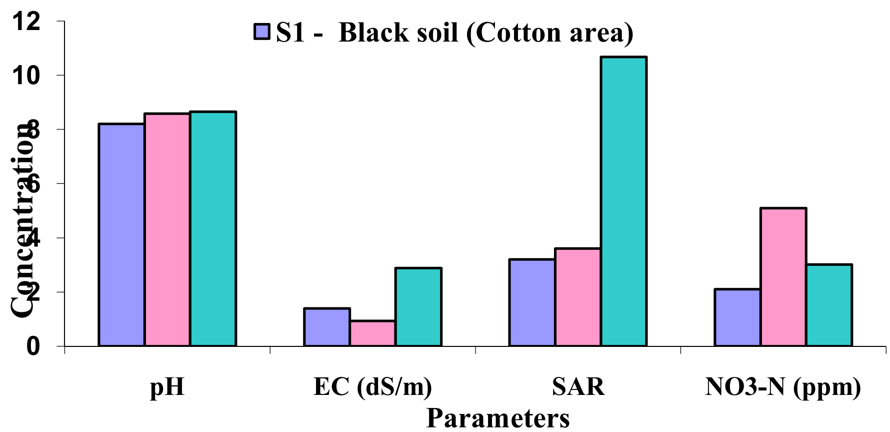

Fig 3: Ground water chemical composition of well water of middle Gujarat region

Fluoride Pollution

Fluoride is a common geogenic contaminant of drinking water and its' effect on human beings have been recognized in both the industrialized and developing countries of world. Fluoride (<1.5 mg kg^{-1}) is important for bones and tooth formation. The main source of fluoride for human body is usually drinking water. The concentration of fluoride in ground water is principally governed by the climate, the composition of host rock and the hydrology. Areas with semiarid climate, crystalline rocks and alkaline soils are mainly affected (Kundu *et al.,* 2001). Fluoride is released to the soil and groundwater by the process of weathering of primary rocks. Apart from natural sources, a considerable amount of fluoride may be contributed due to anthropogenic activities. It is only the last 3-4 decades that high concentrations of fluoride in groundwater have been noticed in North Gujarat (Gupta *et al.,* 2005). The occurrence and development of endemic fluorosis has its roots to high fluoride content in air, soil and water, of which ground water is the major contributor.

The concentration of fluoride in the ground water varies in the districts of North Gujarat region. It varies from 0.99 to 5.48 ppm in Sabarkantha district, 1.96 to 10.85 ppm in Patan district, 3.82 to 12.08 ppm in Mehsana district and 2.77 to 6.64 ppm in Banaskantha district. In about 80per cent of the ground water samples from Sabarkantha district contain fluoride above the maximum permissible limit and 20per cent are between the safe limit (0.99 to 1.25ppm). In Patan district about 95per cent ground water samples contain fluoride above permissible limit and only five per cent within the safe limit. (0.99 to 1.5ppm), in Mehsana district also, 95 per cent samples having higher fluoride level and in Banaskantha district, 92 per cent samples having fluoride concentration above permissible level and only eight per cent samples were found within safe limit. The positive correlation of pH with fluoride indicates that alkaline groundwater is likely to have a higher amount of fluoride, suggesting that the pH of the groundwater is more important in determining the concentration of fluoride (Table 18).

The problem of high fluoride increased up during the last few decades, its origin involved prevalence of a more arid climate and prolonged over exploitation of groundwater. High fluoride in drinking water has resulted in dental fluorosis and skeletal fluorosis in the local residents. It is significant that a positive correlation between fluoride level and morbidity of dental and skeletal fluorosis among people mostly in children exists. In fact, if the fluoride level in drinking water is more than 1.5 ppm, risk of endemic fluorosis will exist. The high fluoride content is therefore causing serious environmental degradation. In this regard, deflouridation of drinking water or supply of clean drinking water from tube wells for the inhabitants of the North Gujarat region is essential (Patel and Bhatt, 2008).

High salinity, fluoride, nitrate and pollution from industrial effluents have caused contamination of aquifers in different parts of Gujarat. The Mahi right Bank command (MRBC) aquifer is the southern tip of the alluvial North Gujarat aquifer. The drinking water requirement of Anand and Kheda districts that overlay this aquifer is dependant mainly on groundwater. The general lack of awareness of water quality allows the spread of water-borne diseases, especially during the monsoon season. The current levels of nitrate studied from some samples taken just after monsoon and repeated 4 months later are below the safety limit in the deeper aquifer which is used for drinking water. However, total dissolved solids (TDS) and salinity are above potable limits with trend of increasing towards the coastal parts; the causes are attributed to inherent salinity and coastal sea water intrusion.

Table 18: Results on different quality parameters of ground water samples from districts of North Gujarat

Parameters	Sabarkantha		Patan		Mehsana		Banaskantha	
	Mean and SD	**Range**	**Mean and SD**	**Range**	**Mean and SD**	**Range**	**Mean and SD**	**Range**
pH	7.26±0.38	6.45-8.5	7.42±0.32	6.9-8	7.48±0.38	6.8-8	7.92±0.27	7.2-8.3
EC	1533±470	870-2400	4458±1581	2500-7100	6342±2588	2500-10500	7307±2492	1000-12000
TDS	1284±433	779-2380	4408±1609	1610-7200	6342±2547	2450-10000	7149±2495	990-1840
DO	3.81±1.01	2.4-5.78	3.6±0.93	0.93-5.5	3.42±0.95	1.2-2.5	3.28±1.03	1.5-5
BOD	1.43±0.82	0.56-3.96	1.05±0.45	0.44-2.56	3.4±1.34	0.7-5	1.86±0.83	0.65-3.7
COD	0.58±0.29	0-1.05	0.64±0.43	0.42-2	0.73±0.29	0.1-4	0.68±0.25	0.1
Fl^-	2.62±1.21	0.99-5.48	5.66±2.23	2.82-10.85	7.33±1.79	3.82-12.08	4.39±1.14	2.18-6.64
Nitrate	74.61±11.34	51.25-89.25	54.68±14.39	14.38-72	60.4±1045	41-81	54.35±9.68	33.68
Na^+	181.95±12.75	151-203	437±191	191-820	38.98±14.84	112-278	327.5±101	186-580
K^+	1.75±1.6	1.09-7.53	3.58±1.06	1.058-5.6	2.11±0.59	1.12-3.1	3.17±1.28	0.98-5.6
Ca^{+2}	25.05±7.91	12-42	65.2±14.07	14.07-92	12.36±8	35-84	53.18±24.2	20-95
Mg^+	11.38±4.57	4.5-20	26.65±8.74	8.73-43	12±7.4	12.41	18.16±7.12	8.5-33
EC is expressed as microSiemens/cm and all other parameters are expressed as mgL^{-1}								

Major issues and future challenges

With increase in urbanization and industrialization the share of fresh water allocation to irrigation is decreasing day by day while its share for domestic and industrial sectors is likely to increase by 10-15 per cent in next two decades. Therefore, there is immense need for efficient conservation, optimum utilization and recycling of water both at off-farm and on-farm. Since effluents/sewage produced can be a good source of water and nutrients, if properly utilized with efficient and economical technologies without creating soil and environmental hazards. In view of this major issues and challenges for containing and managing water pollution appears to be as follows:

1. Increased demand and competition of good quality water for domestic, industrial and other civic uses besides agriculture
2. Depletion in ground water table
3. Increased water pollution and deterioration in fresh water quality
4. Increased geogenic contamination and trace elements toxicities
5. Problem of inefficient utilization, protection and conservation
6. Inadequate information about point and non-point source water pollution and quality assessment
7. Inadequate public awareness about efficient use and water laws
8. Lack of consortium approach for minimizing industrial water pollution
9. Limitation in strict enforcement of legal pollution control law
10. Inefficient economic cleanup technologies for recycling and reuse
11. Limitation on all resources

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13

Status and Prospects of Brackishwater Aquaculture in Coastal Area of Gujarat

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Fish and fishery products fetch high commercial value than other non-vegetarian products in the market due to their increasing demand worldwide. This can be made available through capture or culture fisheries. In Gujarat, the capture fishery is rather overexploited and has reached to the Maximum Sustainable Yield (MSY). The catches are dwindling and the low rate of returns from capture fisheries have forced the coastal people to migrate to other places for their livelihood. So to maximize fisheries production of the state and earn foreign exchange, culture fisheries is the only alternative left. Aquaculture is the blooming industry in the state and has enormous potential. Shrimp is one of the fishery products which are greatly consumed in countries like Japan, America and Europe. Shrimps are called the "Pinkish Gold" of the sea because of its universal appeal, unique taste, high unit value and increasing demand in the global market. The increasing population, food demand and the health consciousness, there is a growing demand for fish and fishery products all over the world. The export value of shrimp is the highest among the edible marine products. Brackishwater shrimp farming started in a big way during 1991-94 especially in the coastal districts of Andhra Pradesh and Tamil Nadu. Subsequently due to disease problems, litigation in Supreme Court, other social and environmental problems, the sector suffered a huge set back and most of the corporate farms were closed. However, the small units continued to do farming adopting extensive prawn farming systems. The shrimp farming has now been regulated with the establishment of Aquaculture Authority of India (AAI) as per directives from Supreme Court for issuing licenses and overall supervision. Gujarat state is developing master mapping plan in a systematic and sustainable manner. Further, apart from existing waste/ salt affected lands in coastal areas of state, there is possibility of increasing area under such land due to rise in MSL (Mean Sea Level) coupled with exhaustive pumping of ground water. Agriculture on such lands is not economically viable and sustainable as well. Hence, aquaculture is one of the ways by which these resources can be used in most profitable manner. This activity will improve the financial status of the farmers located in fragile coastal ecosystem of the state.

Potential of brackishwater aquaculture in Gujarat

Fishery resources

The Department of Fisheries, GoG has estimated 8934 ha area suitable for the brackishwater aquaculture out of the total 3.76 lakh ha brackishwater area available in the state. Gujarat is the second highest with respect to brackishwater potential after West Bengal which is having 4.055 lakh ha. The state has a longest coastline of 1600 km amongst the different state of India. The ownership of almost all the coastal lands rests with the state government. The particulars related to brackishwater aquaculture in Gujarat are given in table 1.

Table 1: Particulars of brackishwater aquaculture of Gujarat

Sr.	Item	Unit	Details
1	Coastline	km	1600
2	Continental shelf	Sq km	1,64,183
3	Area of EEZ	Sq km	2,14,000
4	Brackish water area	Ha	3,76,000
5	Potential brackish water area	Ha	89000
6	B.W.area allotted for Shrimps culture	Ha	4762.95
7	Fishing villages / towns	No.	1058 (Census -2007)
8	Fishermen house hold	No.	1,03,072 (Census -2007)
9	Fishermen population	Person	5,58,691 (Census -2007)

In all, 12 districts of Gujarat possesses coastal area. Among these, Kutch has the maximum coastal stretch of 406 km and Bharuch district possesses the maximum adjacent coastal area (32,208 ha) suitable for development of coastal aquaculture The total land allotted so far to the farmers is 4996.39 ha. Presently, brackish water aquaculture is beingcarried out by the local fishermen and entrepreneurs predominantly in the southern districts of the state *viz*., Valsad, Navsari, Surat and Bharuch. The detailed description of the brackishwater resources and the percentage of area developed for shrimp farming is depicted in fig.1.

Facilitative role of state government: Looking at the potentials for aquaculture in these coastal regions and a land lease policy was initially framed in the year 1987 which was further simplified in 1994 and 2007 by the State Government to allot brackishwater lands to the aquaculturists. Work of Master Mapping of *Kharland* is given to M/S. WAPCOS, New Delhi. The State Government has introduced new schemes / programmes from the year 2006-07. Special attention has been given to provide infrastructure facilities for this activity. These productive efforts put in by Government of GoG have resulted in an increase in the level of aquaculture production. These developments are indicative of an optimistic scenario for the further expansion of shrimp farming in the state.

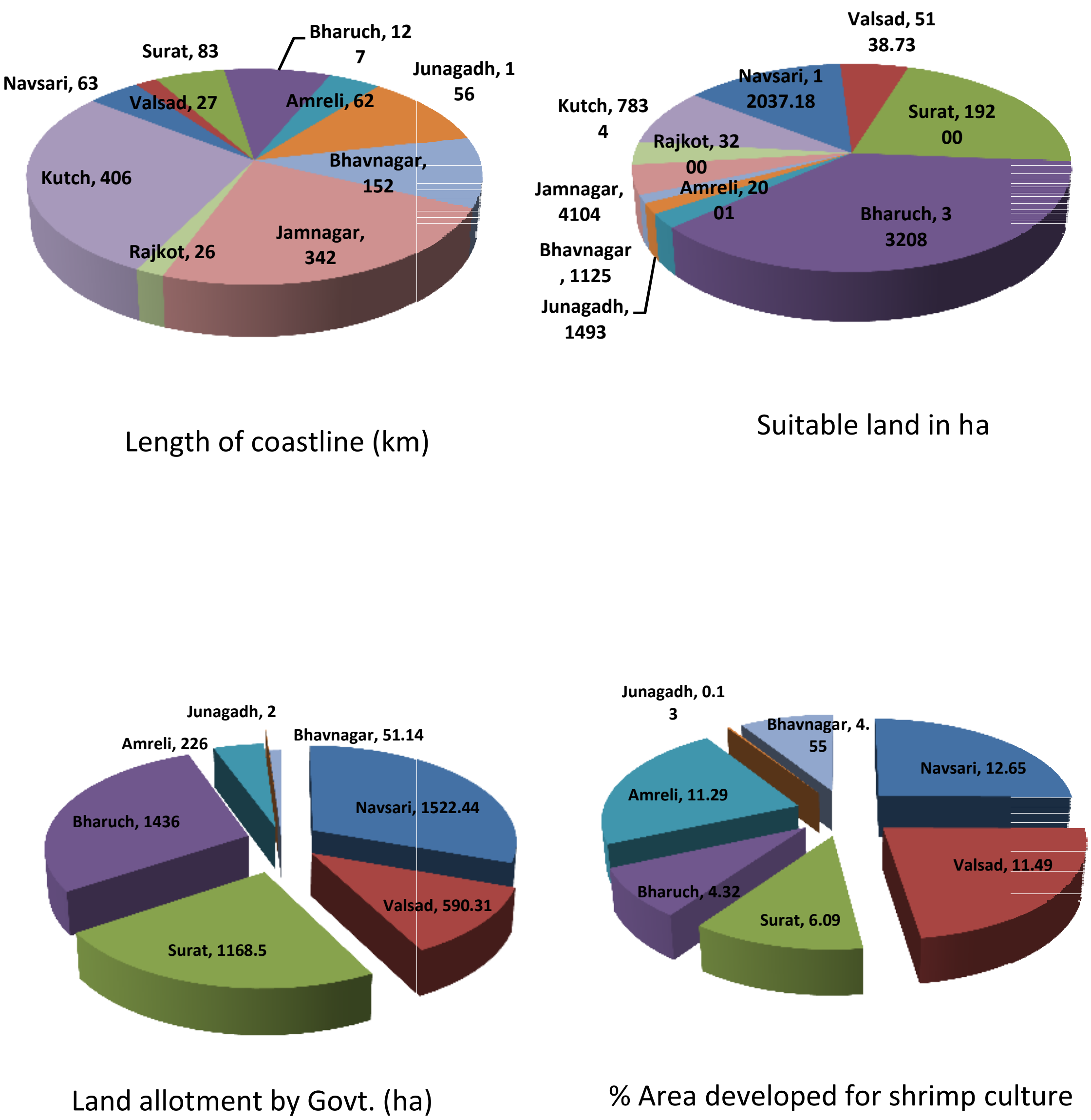

Fig. 1: Brackishwater resources, the land allotment by GoG and the area developed for shrimp farming

Fisheries infrastructure development in the state

The state has 970 fish landing centres 675 ice factories, 265 cold storages and 61 frozen storage facilities, two processing plants, two fish meal plants and three diagnostic and analytical laboratories for soil and water analysis. The seed requirement of the state is mostly procured from the other states. At present, three shrimp hatcheries are operating in the state. Of these, Evergreen Seeds and Feeds Pvt. Ltd., Madhavad district and Western Lotus Hatchery, Kotda (Junagadh district) with production capacities of 35 and 60 million PL, respectively are the two major suppliers. The third hatchery is at Kakwadi village in Valsad district, which is owned by M/s. Dutt Aquaculture Pvt. Ltd. with 30 million seed production capacity. While there is no breeding facility attached to these hatcheries, they function with tiger shrimp nauplii brought from Chennai.

About 11 to 12 private companies are supplying feeds, probiotics, feed additives, chemicals, disinfectants *etc*. to the shrimp farmers. Hitech equipments and instruments are also available in the region which caters the needs of shrimp farmers. Because of the infrastructure available in the state, 5 to 6 private companies have ventured in shrimp farming in South Gujarat region covering about 370 ha area.

Present status of shrimp farming

Brackishwater aquaculture in Gujarat started with few takers, during the year 1991-1992 with only 4.5 ha. area under culture and with an average production of 377.80 kg/ha, but slowly the culture activity has got momentum. There are two seasons, namely summer (February to June) and Monsoon (May to October). The shrimp crop is dominated mostly by a single species *viz.,* tiger shrimp (*Penaeus monodon)*. Most of the farmers take one crop per year (closed season is winter). Few farmers have attempted to culture mullets by collecting wild seeds from brackishwaters. Even white shrimp (*P. indicus)* and banana shrimp (*Fennerropenaeus merguiensis)* have been tried. One farmer from Valsad district has been farming white shrimp for the last four years with feed conversion ratio of 2.0. Only two farmers undertook farming of banana shrimp culture in 1994. Improved traditional farming is adopted by the farmers with standard stocking ratio up to 6-15 nos. / m^2. Today shrimp culture is being undertaken in more than 3500 ha area with highest production level up to 3500 kg / ha and an average production of 1645 kg/ha. The above information has been generated from a random survey of the State conducted during November 2009 and 2011.As on 31/3/2011, 522 shrimp farms had been registered under CAA-Act 2005 of the state. Coastal Aquaculture Authority has permitted to undertake culture of new variety of shrimp "*Litopenaeus vannamei*" in the country. This species is specific pathogen free variety and can be cultured in higher stocking density. The farmers can culture this species after obtaining the permission from CAA. A farmer from Surat region undertook *L. vannamei* culture as per the guidelines set by CAA and got 85 tonnes production from 5 ha area.

Because of the proactive involvement of government and private agencies in the field of brackish water aquaculture, the productivity has increased from 378 kg/ha during 1991 – 1992 to 1654 kg/ha during 2009 – 2010 (Fig.2). Ultimately, the production has increased from 176 tonnes during 1998 to 4017 tonnes during 2010 – 2011. If the entire suitable land is brought under shrimp culture with an available productivity of 1.5 tonnes/ha, then expected production come to about 1.34 lakh tonnes.

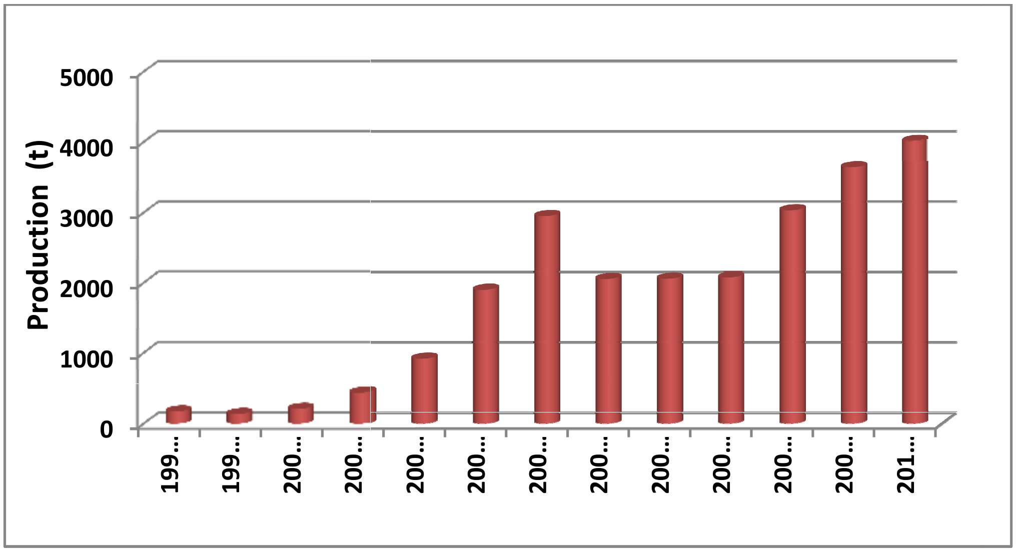

Fig. 2: Brackishwater shrimp culture production of last 13 years

Present status of aquaculture

In order to assess the present status of aquaculture in Gujarat, a collaborative survey on brackishwater shrimp farming in Gujarat was undertaken by Central Institute of Brackishwater Aquaculture, Chennai, Tamil Nadu and Navsari Agricultural University, Navsari, Gujarat. **The highlights of the joint survey are as follows.** As per the survey, it was found that almost all the farmers have received training either by the State Department of Fisheries or MPEDA centre. They also attended various seminars and exhibitions organized by various feed supplying companies.

The farmers do not use antibiotics but apply various types of probiotics (soil, water and gut) and feed supplements. Some farmers use fermented mixture of jaggery (10 kg), rice bran (10 kg) and yeast (100 g) for developing good pond color. Only few farmers resort to liming. Agricultural lime is mostly used during pond preparation with varying quantities ranging from 250 to 750 kg/ha and the cost of feed used by the farmers varies from Rs. 60 to 65 /kg. Farmers have reported obtaining FCR of 1.3 to 1.7 for tiger shrimp. Farmers obtained shrimp production of 1.2 to 2.5 t/ha. The average count was 27 and the current price realization was Rs.

350/- for 30 count shrimps. The production cost varied from Rs. 160 to 180/kg. About 7 to 10 per cent of the total cost is spent on probiotics. Probiotics are applied normally after 15 to 20 days of farming.

Scope for diversification of species

In general, there is good scope for other shellfish and finfish culture in the area. Similarly, scope of seabass, mullet, milkfish *etc*. farming in some areas where the farmers are not ready to take risks by continuing shrimp culture or have given up tiger shrimp culture is good. Seabass farming is currently done by farmer by collecting and stocking wild seed in their farm ponds. Apart from local sale, seabass is sent to West Bengal and Orissa markets. The survey has revealed that there is plenty of scope for *Hilsa* farming. *Hilsa* has a very good local market as well as it fetches higher selling price in West Bengal and Orissa. The major problem in finfish farming is non-availability of seed and feed and the apprehension about the returns.

Winter season is a fallow period in most areas in the State due to higher temperatures and extremely low temperatures prevailing during the season. The banana shrimp (*F.merguiensis)* was experimented and demonstrated at field level under the collaborative project between Navsari Agricultural University, Navsari, Gujarat and Central Institute of Brackishwater Aquaculture, Chennai, Tamil Nadu. The species thrived well in the conditions and have reached harvestable size (15-20 g) in just 90-100 days at stocking density of 15-20 nos./sq.m. Coastal Aquaculture Authority has permitted to undertake culture of new variety of shrimp "*Litopenaeus vannamei*" in the country. This species is well accepted by the big and progressive farmers due to its high productivity and is gaining momentum.

Research activities undertaken at Navsari Agricultural University (NAU)

To serve the farmers of the region, a model brackishwater farm with all the biosecurity protocols has been established at Coastal Soil Salinity Research Station, NAU, Navsari. Low density farming technology of tiger shrimp has already been demonstrated on a trial basis to the farmers of the region. Through experimental and field level trials *Fenneropenaeus merguiensis* (Banana shrimp) have shown positive results in the region during winter period where extreme low temperatures and high salinity of water prevails. This species thrives well in these conditions and grows better. On the contrary, the widely preferred shrimp species *P. monodon* (tiger shrimp) culture is severely affected due to these conditions prevailing during winter season, leading to slow growth, lesser production and disease outbreaks. Euryhaline finfishes like Milkfish, Pearl spot and Asian seabass are also under experimental trials at university farm.

This fishes also have shown good scope for its culture in the region as pond culture systems as well as for small scale cage farming.

Figure 3: Species diversification in brackishwater aquaculture

Transfer of Technology (TOT) initiatives of NAU

- The aquaculture diagnostic laboratory at NAU is providing the required services to the needy farmers. Farmers meet and Seminars are organized every year to address the problems faced by them in shrimp farming.
- Organize farmers' meet seminars, workshop to address the problems faced by the farmers
- Demonstration trials of potential aquaculture species of shrimp/fish
- Demonstration of new aquaculture technologies at farmers' field.

Conclusions

Gujarat state has large brackishwater resources. The capture fishery is rather overexploited and has reached to the Maximum Sustainable Yield (MSY). The catches are dwindling and the low rate of returns from capture fisheries have forced the coastal people to migrate to other places for their livelihood. So to meet the global demand and to maximize fisheries production of the State, culture fisheries is the only alternative left. The State is supporting the aqua farmers by legislating an Act on the subject and introduction of productive policies and action plans. Special attention has been given to provide infrastructure facilities to this activity. But there are some constraints which need to be addressed systematically so that the development takes place in a sustainable manner. This will help to increase employment generation, utilization of waste (saline) lands, foreign exchange and export earnings. Most of the farmers take one crop per year (closed season is winter) and prefer single species (*P. monodon)* culture. Recently, some progressive farmers have even taken up *L. vannamei* culture. Of course, there is a need for diversification of species so that the risk involved due to monoculture gets minimized. There is urgent need for improved land leasing policy, supply of quality seed, cost effective feed, and establishment of cold storages, processing plants, financial and technical support to the farmers. Through a collaborative project mode, Central Institute of Brackishwater Aquaculture, Chennai, Tamil Nadu and Navsari Agricultural University, Navsari, Gujaratare making best efforts to address some of the issues related to production and diversification of species with the cooperation of all the stakeholders.

Two days awareness training on "Brackishwater aquaculture" for the ST farmers of Gujarat at KVK, Navsari on 27th-28th Aug.2011

Farmers' Day at ARS, Danti-Umbharat farm, NAU, Navsari on 3rd Oct. 2009 during tiger shrimp harvest

One day awareness and demonstration programme for tribal farmers on cage farming of finfishes, 20th May 2012 at village pathri, Ta.Gandevi, Dist.Navsari

Hon. Vice Chancellor Dr. A.R.Pathak and CIBA scientists releasing leaflets of new technologies in shrimp/fish culture during the occasion of interaction meet on "Management of Shrimp health and Pond Environment" organized on 21st May 2012

Training and field visit of MPEDA participants at ARS, Danti-Umbharat farm, NAU

Cage culture demonstration in irrigation canal Village Mahuvas, Ta.Vansda, Dist.Navsari

Sr.No	Particulars	Details
1	WSA (ha)	0.6
2	Culture Period(days)	113
3	Number of stocking(pcs)	105000
4	Stocking Density(Pcs/m2)	17.5
5	ABW(g)	9.90
6	Size (pcs/kg)	101
7	ADG	0.09
8	Biomass(Harvested)	725
9	Total Accumulated Feed (kg)	928
10	Survival Rate (%)	70
11	FCR	1.28
12	Production(kg)/ha	1208.3

First successful culture demonstration of diversified shrimp species - Banana shrimp at farmer's pond Winter crop (2011)

Figure 4: Transfer of Technology (TOT) initiatives of NAU