AICRP (GWU)

वार्षिक प्रतिवेदन
ANNUAL REPORT
2009-2010

भूजल उपयोग के अखिल भारतीय समन्वित अनुसंधान परियोजना
All India Coordinated Research Project on Groundwater Utilization

जल प्रबंधन निदेशालय
(भारतीय कृषि अनुसंधान परिषद)
भुवनेश्वर, उड़ीसा, भारत

Directorate of Water Management
(Indian Council of Agricultural Research)
Bhubaneswar, Orissa, India

Citation

Annual Report, AICRP on Groundwater Utilization 2009 - 2010,
Directorate of Water Management, Bhubaneswar, Orissa - 751 023, India, pp80.

Edited by

M.J. Kaledhonkar & Mausumi Raychaudhuri

Hindi Translation

Mr. B.S. Parswal

Published by

Dr. Ashwani Kumar
Director
Directorate of Water Management
Bhubaneswar, Orissa, 751 023, India
Phone : 91- 674 - 2300060, 2300010, 2301815
Fax : 91 - 674 - 2301051
Email : ashwani_wtcer@yahoo.com
Website : www.wtcer.ernet.in

Printed by

Capital Business Service & Consultancy
B-51, Saheednagar, Bhubaneswar-751 007

वार्षिक प्रतिवेदन
ANNUAL REPORT
2009-2010

भूजल उपयोग के
अखिल भारतीय समन्वित अनुसंधान परियोजना

All India Coordinated Research Project on
Groundwater Utilization

जल प्रबंधन निदेशालय
(भारतीय कृषि अनुसंधान परिषद)
भुवनेश्वर, उड़ीसा, भारत

Directorate of Water Management
(Indian Council of Agricultural Research)
Bhubaneswar, Orissa, India

PREFACE

Groundwater utilization has played an important role in poverty alleviation, stabilizing Indian agriculture and as a means for drought management. Though the overall stage of ground water development is about 58%, the average stage of groundwater development in North Western Plain states is much higher (98%) when compared to the Eastern Plain States (43%) and Central Plain States (42%). The intensive agriculture, industrialization, increasing population and development activities are depleting and degrading this key natural resource at abnormal rate. At the national level, a marginal fraction of the actual groundwater potential has been exploited but spatio-temporal exploitation patterns are skewed. It is being over-exploited in several states including, Punjab, Haryana, Gujarat, Rajasthan, Andhra Pradesh, and Tamil Nadu. On contrary, it is least exploited in eastern states. It is very much true, in many states; the net result of increased groundwater use has been an increase in total irrigated area, increased cropping intensity and crop productivity. While the past strategies paid off in realizing the goal of increased production, unsustainable resource use is threatening the future of agriculture and food security of the nation. In addition to falling water tables, the degradation of the groundwater quality from fluoride, nitrate, arsenic, salinity, alkalinity, sea water intrusion and other forms of pollution has serious repercussions on agricultural productivity and quality as well as on human and animal health. Drinking water is a grave problem in a number of urban pockets of country due to concentrated pumping. Sustainable development of ground water resource has become a complex challenge in India.

The All India Coordinated Research Project on Groundwater Utilization is striving to make humble contributions in the field of groundwater. In the project, research is being conducted in the different fields of groundwater management for its optimal utilization, namely, assessment, planning and optimal utilization of groundwater resources on regional levels, optimal plans for conjunctive water use, artificial groundwater studies, and groundwater pollution through agrochemicals and industrial effluent, etc.

I am privileged to present the annual report of AICRP on "Groundwater utilization" for the year 2009-10. This report is the compilation of research activities, results obtained and recommendations made in the field of groundwater planning and management including its utilization in different network centres of AICRP on groundwater utilization.

During the period under report, nine network centres at Ludhiana, Pantnagar, Rahuri, Jabalpur, Coimbatore, Junagadh, Udaipur, Raipur, and Pusa accomplished research work through various experiments under each of the five themes of model technical program of the project. The different research programs are being conducted in the different fields of groundwater management namely, assessment, planning and optimal utilization of groundwater resources on regional levels, optimal plans for conjunctive water use, artificial groundwater recharge studies, groundwater pollution assessment and finding its remedial measures, and demonstration of the developed technology on a limited scale for the actual users.

The undersigned is grateful to Dr. S. Ayyappan, Director General (ICAR) and Secretary (DARE), Government of India and Dr. Mangala Rai, former Director General (ICAR) & Secretary (DARE) for their constant support and encouragement for executing this project effecting. The undersigned also expresses his sincere gratitude to Dr. A.K. Singh, Deputy Director General (NRM) for his keen interest in conducting network research and guidance from time to time and monitoring. The undersigned sincerely acknowledge the timely cooperation received from the project. Dr. P.D. Sharma, ADG (Soils). Chief scientists and other scientists/ professors working in the network centres deserve wholehearted appreciation for their constant hard work and cooperation. The undersigned sincerely places on record the hard work done by Dr. M.J. Kaledhonkar, Principal Scientist and Dr. M. Raychaudhuri, Senior Scientist working for the Coordinating unit, in compiling and editing the Annual Report and efficiently managing the activities of coordinating unit at DWM, Bhubaneswar.

Bhubaneswar
April 2010

(Ashwani Kumar)
Director

TABLE OF CONTENTS

भूजल उपयोग पर एआईसीआरपी का कार्यकारी सारांश

भूजल उपयोग के अनुकूलीकरण पर अखिल भारतीय समन्वित अनुसंधान परियोजना (एआईसीआरपी) के तहत 9 केन्द्रों द्वारा कार्य किया गया । इन केन्द्रों द्वारा क्षेत्रीय भूजल का मूल्यांकन एवं प्रतिरूपण; नहरी क्षेत्रों में सतही जल एवं भूजल का संयोजी उपयोग; कृत्रिम भूजल पुनःभरण अध्ययन; भूजल प्रदूषण अध्ययन; तथा विभिन्न केन्द्रों पर विकसित तकनीकों के हस्तांतरण से संबंधित अनुसंधान एवं विस्तार कार्य किया गया । एआईसीआरपी केन्द्रों की वर्ष 2009-10 की प्रमुख अनुसंधान उपलब्धियाँ यहाँ दी जा रही हैं ।

क्षेत्रीय भूजल मूल्यांकन एवं प्रतिरूपण

पंजाब राज्य में 1998-2006 की अवधि के लिए GIS के माध्यम से अध्ययन किया गया भौम जलस्तर का व्यवहार यह दर्शाता है कि धान–गेहुँ चक्रण के बडे पैमाने पर अपनाये जाने से जलस्तर में 52 cm प्रतिवर्ष की दर से कमी हुई है । भौम जलस्तर की 3-10 m गहराई वाला क्षेत्र घटकर 75 से 40 प्रतिशत रह गया है, जबकि क्रांतिक गहराई (10-20 m) से परे का क्षेत्र बढकर 20 से 58 प्रतिशत हो गया है । यह इस बात का सूचक है कि सेन्ट्रीफ्यूजल पम्प के स्थान पर सबमर्सिबल पम्प लगाने हेतु अतिरिक्त खर्च करना होगा और पम्पिंग के खर्च में भी वृद्धि होगी । पंजाब के मध्य का क्षेत्र इस समस्या से बुरी तरह प्रभावित है । प्रभावित जिले हैं–कपूरथला, जलन्धर, संगरुर, फतेहगढ साहिब, मोगा, लुधियाना, अमृतसर और नवांशहर । गुरुदासपुर और रोपड जिले में न्यूनतम दोहन हुआ है । दक्षिण–पश्चिम पंजाब (मुक्तसर, फिरोजपुर और फरीदकोट जिले) में जलाक्रांतता की समस्या कुछ हद तक कम हुई है ।

जलस्तर विचलन विधि का उपयोग करके मध्यप्रदेश के अपर नर्मदा बेसिन (UNB) के लिये भूजल पुनःभरण के आकलन का प्रयास किया गया । पूरे बेसिन में मानसून के पहले से लेकर मानसून के बाद तक का औसत जलस्तर विचलन 3.4 m से 3.8 m रहा । अध्ययन की अवधि में भौम जलस्तर में कमी हुई । पुनःभरण संबंधी विचलन को प्राप्त करने के लिये जलस्तर विचलन, भूविज्ञान संबंधी सूचनाएं, एक्वीफर गुण दोष जैसे–विशिष्ट उपज, का उपयोग किया गया । अपर नर्मदा बेसिन का सकल पुनःभरण 4.449 M ha-m आकलित किया गया, जो बेसिन के कुल भौगोलिक क्षेत्र के 35,03,811 ha के एकसमान गहराई के पुनःभरण 12.84 cm के समतुल्य था । इसमें बेसिन से संबंधित सभी 6 जिले शामिल हैं । यह पुनःभरण बेसिन के क्षेत्र में हुई सामान्य वर्षा का 10 प्रतिशत था ।

कोयम्बटूर केन्द्र द्वारा पराम्बीकुलम–अलियार बेसिन में विकास के लिये उपलब्ध जल की मात्रा का आकलन करने के लिये भूजल संतुलन पर अध्ययन किया गया । दीर्घीकरण अनुपात के आधार पर यह पाया गया कि पालर और अलियार बेसिन लम्बा है, वलायार बेसिन अंडाकार है तथा शोलयार बेसिन वृत्ताकार है । क्षेत्र के अधिकांश भाग में उथले और गहरे जल भरे क्षत्रों के बीच जलस्तर में कोई विशेष अन्तर नहीं पाया गया । इससे स्पष्ट होता है कि दोनों क्षेत्रों के भूजल धारक स्तर एक दूसरे से जुडे हुए हैं । प्रि–मानसून, दक्षिण–पश्चिम मानसून और उत्तर–पूर्व मानसून के दौरान भौम जलस्तर में वृद्धि होती है तथा दिसम्बर माह में जलस्तर अधिकतम उथला रहता है । बेसिन के लगभग सभी कुओं में जलस्तर बढने और घटने

की प्रवृत्ति 21 वर्ष से भी अधिक समय से नोट की गयी है । इससे स्पष्ट है कि जलस्तर का विचलन मुख्य रूप से वर्षा की तीव्रता और इसके साथ भूजल के दोहन से नियंत्रित होता है ।

उदयपुर केन्द्र द्वारा लगातार पांच वर्ष (1999-2003) के लिये राजस्थान के राजसमंद जिले के सात खण्डों के लिये जल संतुलन समीकरण के घटकों का आकलन किया गया । GIS और दूरस्थ संवेदन का उपयोग करके मृदा, नैसर्गिक जल निकास, भूमि उपयोग आदि बिषयों के अनुसार नक्शे तैयार किए गये । विकसित की गयी थिमेटिक लेयर्स से वाकल नदी के बेसिन की भूआकृति तथा मृदा के स्थानस्थ वितरण, जल निकास और भूमि उपयोग की जानकारी प्राप्त हुई । ये थिमेटिक नक्शे टोपोशीट्स से जनरेट किये गये । जो स्केन, प्रमाणित और डिजिटाइज्ड किये गये । उदयपुर जिले के वकाल नदी के बेसिन में भूजल के संभावित क्षेत्रों की पहचान की गयी ।

छत्तीसगढ के रायपुर जिले के भूजल संबंधी छोटे बेसिन अर्थात छोकरानाला वाटरशेड के ऊपरी भाग का चयन एक अध्ययन के लिये किया गया और इसमें भूजल के बहाव का अध्ययन तथा विजुअल मॉडफ्लो मॉडल का उपयोग करके छोटे कृषि वाटरशेडों की मास ट्रान्सपोर्ट मॉडलिंग का अध्ययन किया गया । समान भूविज्ञानी स्थितियों में ये परिणाम लाभकारी हो सकते हैं ।

दक्षिण–पश्चिम सौराष्ट्र क्षेत्र की 14 तालुकाओं के भूजल संभाव्यता को 24 खुले कुओं के आंकडे के आधार पर निकाला गया । कन्टूर मेप्स तैयार करने के लिये मानसून के पहले (जुन 2009) तथा मानसून के बाद (अक्टुबर 2009) की अवधि के लिये भौम जलस्तर, कुओं की विमाएँ, कुए के स्थल के देशांश एवं अक्षांश को दर्ज किया गया । गुणवत्ता प्राचलों को जानने के लिये जल के नमूनों का भी विश्लेषण किया गया । मंगरोल तथा समुद्र तटीय पट्टी के साथ के कुछ भीतरी क्षेत्र को छोडकर पूरे दक्षिण–पश्चिम क्षेत्र में जल की गुणवत्ता अच्छी पायी गयी । क्षेत्र की कुल भूजल संभाव्यता 6540.578981 MCM निकाली गयी, किन्तु वर्ष 2009 जो कि सूखे का वर्ष रहा, के लिये यह संभाव्यता 3841.25758 MCM आकलित की गयी ।

पूसा केन्द्र द्वारा बुरही गंडक नदी में पायलट आधार पर सिंचाई के लिये भूजल स्त्रोतों के मूल्यांकन का कार्य किया गया । बेसिन के क्षेत्र से संबधित सात जिलों–पूर्वी चम्पारन, पश्चिमी चम्पारन, सिवान, सारन, गोपालगंज, मुजफ्फरपुर तथा समस्तीपुर के वार्षिक भूजल पुनःभरण की गणना की गयी । परिणाम दर्शाते हैं कि इन जिलों का कुल वार्षिक पुनःभरण 54,929 ha-m से 2,18,361 ha-m है, जिसमें से 3,818 ha-m से 1,82,845 ha-m तक मानसून की अवधि का है तथा 16747 ha-m से 35,516 ha-m तक गैर मानसूनी अवधि का है । बुरही गंडक बेसिन के चुनिंदा जिलों के लिये सकल वार्षिक दोहन 27,296 ha-m से 80,008 ha-m के बीच रहा ।

भूजल का संयोजी उपयोग

पंजाब के बिष्ट दोआब के क्षेत्र में जल संसाधनों की खंडो के अनुसार मांग और उपलब्धता का अध्ययन किया गया ताकि मांग और आपूर्ति के बीच के अन्तर का आकलन किया जा सके । इसके लिये नहरी जल आपूर्ति, प्रभावी वर्षा, फसल की जल आवश्यकता और नेट पम्पिंग के आँकडों का प्रयोग किया गया । सिंचाई के लिये उपलब्ध कुल जल संसाधन 505 mm आंके गये जिसमें से भूजल, वर्षा और नहरी जल का योगदान क्रमशः 68, 26 और 6 प्रतिशत है । क्षेत्र की औसत मौसमी ET (वाष्पोत्सर्जन)

मांग खरीफ के लिये 521mm तथा रबी के मौसम के लिये 275mm है, इस प्रकार 291mm की कमी है । कपूरथला और जालन्धर जिले के लगभग सभी खण्डो में आपूर्ति और मांग के बीच अन्तर है जिसका कारण धान–गेहूँ फसल चक्रण है । खरीफ में अधिकतम जल का घाटा 543 mm और रबी में अधिकतम जल का घाटा 231mm क्रमशः मुकेरियान और बलाचुर खण्ड में पाया गया ।

पंजाब के किसान विभिन्न फसलों में लेसर लेवलिंग द्वारा जल संसाधनो में 22 से 33 प्रतिशत तक बचत कर सकते हैं । राज्य में लेसर लेवलिंग को 10, 25, 50, 75 और 100 प्रतिशत तक अपनाकर सिंचाई जल में क्रमशः 146563, 366408, 732816, 1099224 तथा 146531 ha-m तक बचत की जा सकती है । केवल धान–गेहूँ फसल चक्रण में ही लेसर लेवलिंग के अपनाये जाने से 1344840 ha-m सिंचाई जल की बचत हो सकती है और भूजल का दोहन 19 cm कम हो सकता है ।

उत्तराखण्ड के उधमसिंह नगर में कगरसेन नहरी तंत्र के जफरपुर माइनर नहरी क्षेत्र के लिये अनुकूलतम सस्य प्रणाली तैयार की गयी । इसके लिये क्षेत्र में जल की कुल उपलब्धता, नहरी क्षेत्र में लगायी गयी विभिन्न फसलों की सिंचाई जल आवश्यकता और कृषि संबंधी खर्च को ध्यान में रखा गया । सस्य क्षेत्र की बाधाओं का प्रभाव देखते समय नहरी क्षेत्र की मानव जनसंख्या तथा पशु संख्या को भोजन और चारा आवश्यकता पर भी ध्यान दिया गया । फसल क्षेत्र संबंधी बाधाओं के होते हुए जो फसल श्रेष्ठतम फसल नियोजन के अन्तर्गत आयी वे लाही, गेहूँ, ग्रीष्म धान, बरसीम तथा खरीफ धान हैं जिनका स्तर क्रमशः 7.5, 484, 70, 5 तथा 551.5 ha है । प्रचलित नियोजन के ऊपर शुद्ध लाभ में 21.70 प्रतिशत की वृद्धि हुई । अध्ययन से यह भी पता चलता है कि खरीफ के दौरान अतिरिक्त नहरी जल को जल संग्रहण संरचनाएँ बनाकर संचित किया जा सकता है तथा रबी फसलों की सिंचाई के लिये प्रयुक्त किया जा सकता है अथवा जब नहरी जल की आपूर्ति बंद हो तब प्रयुक्त किया जा सकता है । इस प्रकार भूजल की आवश्यकता को कम किया जा सकता है ।

मध्यप्रदेश में रानी अवंती बाई सागर परियोजना के लेफ्ट बैंक केनाल की चार छोटी उपनहरों का अध्ययन यह दर्शाता है कि ऊपरी भाग में प्रयोग दक्षता अधिक थी जबकि दूर के छोर वाले क्षेत्रों में कम थी । सभी माइनर कमान्डस में वितरण दक्षता अधिक पायी गयी । लेकिन परिवहन दक्षता कम थी । नहरी क्षेत्र में तकनीकी श्रम शक्ति, धन की उपलब्धता और संरचनाओं के रखरखाव में सुधार की आवश्यकता है । वहाँ जलाक्रांतता की समस्या नहीं है जिससे स्पष्ट होता है कि नहरी क्षेत्र में पुनःभरण भूजल खिंचाव से अधिक नही है और नहरी एवं भूजल का संयोजी उपयोग काफी प्रचलित है । अधिकांश किसान नहर की सफाई में और पूरे तंत्र को ठीक से चलाने के लिये योगदान देने के इच्छुक थे ।

कोयम्बटूर केन्द्र द्वारा परम्भीकुलम अलियार परियोजना (PAP) के नहरी क्षेत्र में सतही जल एवं भूजल के संयोजी उपयोग पर कार्य किया गया । चौबीसों घंटे कार्य करने के लिये चक्रीय जल आपूर्ति (RWS) का सूत्रपात किया गया और रात के घंटो में जल का अपव्यय जरा भी नहीं होने दिया गया । परिचालन की योजना काफी अच्छे ढंग से बनायी गयी जिसका आधार सिंचाई का मौसम, सस्य विधि और फसल की जल आवश्यकता था । बारबंधी जल आपूर्ती का कार्यक्रम किसानों से बिचार विमर्श करके बनाया गया तथा केनाल रोस्टर्स किसानों के संघ को सौंप दिये

गये । इन कार्यक्रमों के क्रियान्बयन की देख–रेख कम से कम दो मौसमों के लिये की गयी ताकि वाराबंधी का ठीक से काम करना सुनिश्चित किया जा सके ।

उदयपुर केन्द्र द्वारा बुन्दी जिले की चुना मिश्रित मृदा के तहत गेहूँ की खेती के लिये नहरी जल और थोडे लवणीय भूजल के संयोजी उपयोग पर कार्य किया गया । परिणाम दर्शाते हैं कि अच्छी गुणवता का 33 प्रतिशत जल (नहरी जल) गेहूँ के अनाज व भूसे की उपज में बिना किसी कमी के बचाया जा सकता है । इसके लिये नहरी जल से दो सिंचाई तथा फिर भूजल से एक सिंचाई चक्रीय आधार पर की गयी ।

जुनागढ में गेहूँ की फसल के लिये जल का संयोजी उपयोग यह दर्शाता है कि इस फसल के लिये भूजल का खिंचाव 131.01 cum कम किया जा सका । भूजल से सिंचित फसल की तुलना में यहाँ शक्ति का उपभोग (बिजली की बचत) कम करने में मदद मिली । पैन वाष्पीकरण विश्लेषण दर्शाता है कि चैक डेम से 110.11 mm की वाष्पीकरण हानि को बचाया जा सकता है । इसके लिये गेहूँ की बुवाई 15 नवम्बर तक कर देना चाहिए और संग्रहित किये गये उपलब्ध सतही जल का प्रयोग 21 नवम्बर या उससे पहले प्रभावी रूप से किया जाना चाहिए । सामान्य वर्षों में चैक डेम से दो सिंचाई संभव हैं ।

पूसा ब्लॉक के हरपुर गाँव के नौ किसानों के खेतों में उगाये गये धान की जल उत्पादकता संबधी मानों के मूल्यांकन किया गया । फसल की सिंचाई भूजल से की गयी थी और सिंचाई की औसत संख्या संकर धान के लिये 3.8 थी जो MTU-7029 के लिये 2.75 की तुलना में है । इससे यह निष्कर्ष निकलता है कि धान की MTU-7029 प्रजाति की सिंचाई जल उत्पादकता धान की संकर प्रजाति 6444/MPH-55 की तुलना में 21.15 प्रतिशत अधिक है ।

कृत्रिम भूजल पुनःभरण

लुधियाना केन्द्र द्वारा गुरुत्व पुनःभरण कुएं के लिये कम्पोसिट फिल्टर फिर से डिजाइन किया गया । इसका उद्देश्य अच्छी गुणवत्ता के जल की छनन दर बढाने के लिए अधिक क्षेत्रफल को सामने लाना था । यहाँ रेती के स्थान पर पी ग्रेवल्स का प्रयोग किया गया क्योंकि पी ग्रेवल्स से अच्छी छनन दर सुनिश्चित होती है । छनन इकाई की डिजाइन में सुधार करके पुनःभरण दर 32 l/sec तक प्राप्त की गयी । सामान्य तौर पर पुनःभरण दर 26 l/sec से अधिक थी । पहले वाली डिजाइन से संवर्धित डिजाइन की कुशलता अधिक थी । ऊपरी शुष्क उथले एक्वीफर्स को रिजार्च करने के लिये दो नलकूप लगये गये । नलकूपों की रिचार्ज दर बढाने के लिये इस वर्ष फिल्टर पिट की गहराई और छेदित पाइप की लम्बाई में वृद्धि की गयी । इन सुधारों के कारण पुनःभरण की दर में सुधार हुआ ।

उत्तराखंड के टिहरी गढवाल क्षेत्र के लिये उपलब्ध जल आधारित अनुकूलतम फसल नियोजन तथा उपयुक्त जल संग्रहण संरचनाओं की डिजाइन सुझायी गयी । यह पाया गया कि रबी के मौसम में लाही तथा गेहूँ लगाया जा सकता है । जबकि खरीफ के मौसम में धान, ज्वार और मक्का लगाये जा सकते हैं । झरने के जल को संग्रहित करने के लिये फार्म पोण्ड (खेत पर तालाब) का सुझाव दिया गया । इस तालाब का आकार झरने से पानी का बहाव और घरेलु तथा फसल संबंधी जल आवश्यकताओं को समझकर निश्चित किया गया ।

महाराष्ट्र के तीन विभिन्न स्थलों पर कृत्रिम भूजल पुनःभरण का अध्ययन अन्तःस्रवण तालाबों के माध्यम से किया गया । इसका उद्देश्य 1993 से 2005 की अवधि के दौरान अन्तःस्रवण तालाबों के माध्यम से भूजल पुनःभरण की मात्रा ज्ञात करना और इन तालाबों की निचली धारा वाले क्षेत्र में भूजल पुनःभरण के प्रभाव (वितरण) के क्षेत्र का मूल्यांकन करना था । यह पाया गया कि अन्तःस्रवण तालाब 1500m निचली धारा तक प्रभाव डालते हैं और तालाब से पुनःभरण की दर 1.27 cm से 6.0 cm प्रतिदिन के बीच विचलित रही ।

महाराष्ट्र के राहुरी में सिंचाई कुओं के माध्यम से कृत्रिम भूजल पुनःभरण के लिये विकसित किये गये सेन्ड ग्रेवल फिल्टर की कुशलता का अध्ययन किया गया । भिन्न-भिन्न मोटाई व ग्रेड के छनक पदार्थों से बहाव का वेग, छनने का समय, डिस्चार्ज और छनन-दक्षता प्रभावित हुए । छनन पदार्थ की मोटाई में वृद्धि करने से छनन दक्षता में वृद्धि हुई । उच्च प्रवाह (डिस्चार्ज) के लिये तीन परत वाला छानक संस्तुत करना चाहिए जबकि कम प्रवाह के लिये चार परतों वाले छानक का प्रयोग करना चाहिए ।

यदि ठीक से योजना बनायी जाए तो हवेली फील्डस में संग्रहित जल को सबस्ट्राटा में पहुँचाया जा सकता है । मानसून के पहले और बाद की अवधि के दौरान रिजार्च शाफ्ट के माध्यम से हवेली में संग्रहित जल को स्ट्राटा में डालने की अच्छी संभावना है । हवेली प्रणाली की जल उत्पादकता को रबी (गेहूँ) के फसल के साथ 'सिंघाडा' लगाकर बढाया जा सकता है । इस सुधारित विधि के तहत शुद्ध लाभ 59900 रूपये था जो पारम्परिक प्रणाली (खरीफ हवेली व रबी गेहूँ) के अंतर्गत मात्र 23000 रूपये था ।

कोयम्बटूर केन्द्र द्वारा तमिलनाडु के कोयम्बटूर और वैल्लौर जिले के अन्तःस्रवण तालाबों में निर्मित कृत्रिम पुनःभरण संरचनाओं का मूल्यांकन किया गया । यह पाया गया कि वैल्लोर जिले का पुनःभरण 18 प्रतिशत वर्षा के समतुल्य था जो उत्तर-पूर्व मानसून के दौरान हुई । यह भी पाया गया कि दक्षिण-पश्चिम मानसून की अवधि में हुए पुनःभरण की तुलना में उत्तर-पूर्वी मानसून की अवधि में हुआ पुनःभरण 10 प्रतिशत अधिक है । कोयम्बटूर जिले में उत्तर पूर्वी मानसून के दौरान कलापट्टी में वर्षा के 9 प्रतिशत के समतुल्य पुनःभरण हुआ और वैल्लानीपट्टी मं 11 प्रतिशत के समतुल्य हुआ । दक्षिण-पश्चिमी और उत्तर-पूर्वी अवधि की तुलना करते समय यह पाया गया कि उत्तर-पूर्वी मानसून की अवधि में पुनःभरण 4 प्रतिशत अधिक था ।

जलस्तर विचलन तकनीक का उपयोग करके उदयपुर केन्द्र द्वारा राजसमंद जिले के सात खण्डों के लिये पाँच वर्षों हेतु (1999-2003) वर्षा के संदर्भ में प्राकृतिक पुनःभरण का आकलन किया गया । यह देखा गया कि जिले में न्युनतम वर्षा पुनःभरण (28.22 मिलियन m^3) वर्ष 2002 में हुआ जब जिले की वार्षिक वर्षा मात्र 28 cm थी । अधिकतम वर्षा पुनःभरण (379.96 मिलियन m^3) बर्ष 2001 में हुआ जब जिले की वार्षिक वर्षा अधिकतम (56.5 cm) थी । इस प्रकार वर्षा पुनःभरण का वार्षिक वर्षा के साथ सीधा संबंध है ।

वर्ष 2006-07 के लिये दुरस्थ संवेदन आधारित $K_{c\ SAVI}$ मान जो 119.12 ha-m है का प्रयोग करके जूनागढ जिले के जमका माइक्रो वाटरशेड के 187 ha क्षेत्र में लगायी गयी गेहूँ की फसल की सकल सिंचाई आवश्यकता का आकलन किया गया । जल संग्रहण संरचनाओं द्वारा किये गये भूजल

पुनःभरण अर्थात 150.37 ha-m को 156 ha की गेहूँ की फसल की सिंचाई के लिये उपयुक्त पाया गया । फिर भी, वर्षा से और जल संग्रहण संरचनाओं से अनुमातित कुल भूजल पुनःभरण 407.12 ha-m था जिससे लगभग 422ha गेहूँ की फसल की सिंचाई की जा सकती है और 627 mm जल प्रयुक्त करके 65 प्रतिशत प्रयोग दक्षता प्राप्त की जा सकती है । जल संग्रहण संरचनाओं द्वारा बनायी गयी संग्रहण क्षमता का खर्च संग्रहण के रूपये 1.49 प्रति m^3 पाया गया । गेहूँ की फसल लगाने के लिये अनुमानित लाभ–लागत अनुपात 1.53 पाया गया जो जल संग्रहण संरचनाओं द्वारा हुए भूजल पुनःभरण को उपयोग में लाकर किया गया ।

भूजल प्रदूषण

सतही एवं भूजल का विश्लेषण यह दर्शाता है कि उत्तराखण्ड में पल्प और पेपर मिल के बहिस्राव के कारण सतही जल के प्रदूषण से भूजल पर प्रतिकूल प्रभाव पड रहा है । यह काफी गंभीर मामला है क्योंकि भूजल उथली गहराई पर है । सिंचाई के लिए भूजल की उपयुक्तता का मापदण्ड भिन्न है । सामान्यतः सारा भूजल C_2S_1 के तहत है, केवल गोरानाला के आसपास का छोडकर, जो C_3S_1 वर्ग के तहत था । सतही जल के नमूने उच्च SAR के कारण गंभीर वर्ग में थे । उत्तराखण्ड राज्य की तराइ बेल्ट में पल्प और पेपर मिल के बहिस्राव का कृषि में उपयोग संबंधी अध्ययन दर्शाता है कि बहिस्राव को सिंचाई के लिये सीधे ही प्रयुक्त नही किया जा सकता क्योंकि इसमें काफी विषैलापन होता है । 25 प्रतिशत सान्द्रता वाले बहिस्राव को सिंचाई के लिए प्रयुक्त किया जा सकता हैं क्योंकि 0, 50, 75 अथवा 100 प्रतिशत सान्द्रता वाले स्तरों की तुलना में इससे बेहतर परिणाम प्राप्त हुए ।

उत्तराखण्ड में प्राकृतिक झरनों का अध्ययन यह दर्शाता है कि झरने की प्रवाह दर में वृद्धि से कीचड स्राव वाले पानी की विद्युत चालकता कम होती है । जलग्रहण क्षेत्र में, आसपास और झुकाव पर वनस्पति उगाने से झरने के जल की गुणवत्ता पर कोई प्रभाव नहीं हुआ । पैतृक पदार्थ का भूविज्ञान झरने के बहाव और जल की गुणवत्ता के लिये उत्तरदायी है ।

महाराष्ट्र के राहुरी में प्याज की फसल की सिंचाई के लिये प्रदूषित भूजल का उपयोग दर्शाता है कि मृदा की विद्युत चालकता और PH में वृद्धि हो रही है । इसका आशय है कि मृदा की लवणता और सोडिसिटी दोनों ही गंभीर स्थिति पैदा कर सकती हैं यदि प्रदूषित जल से सिंचाई जारी रही ।

मध्यप्रदेश में अपर नर्मदा बेसिन के नरसिंहपुर जिले में भूजल की गुणवता के प्राचल स्वीकार्य सीमा में है तथा भूजल सिंचाई के लिये उपयुक्त है । किन्तु समय के साथ धीरे–धीरे इसकी गुणवत्ता में कमी हो रही है । इसी तरह मध्यप्रदेश में विभिन्न स्रोतों के चुनिंदा अपशिष्ट जल का विश्लेषण किया गया । इसमें यह पाया गया कि Na^+ सान्द्रता तीन स्थलों पर तथा एक स्थल पर RSC का मान उच्च था । जबकि अन्य अपशिष्ट जल के संबंध में सिंचाई के लिये जल की गुणवत्ता उपयुक्त थी । अपशिष्ट जल के स्रोत समीप में भूजल की गुणवत्ता पर प्रतिकूल असर डाल रहे थे । उन सभी स्थलों पर जहाँ अपशिष्ट जल का प्रयोग किया जा रहा था मृदा में आर्गेनिक कार्बन उच्च अथवा मध्यम था । इसमें ताम्बे की कमी थी । मृदा में उपलब्ध N की मात्रा अल्प थी, जबकि फास्फोरस अधिक तथा पोटेशियम मध्यम मात्रा में उपलब्ध था ।

कोयम्बट्रर केन्द्र द्वारा परम्बीकुलम अलियार बेसिन के खुलो कुओं, बोर वेल्स तथा खोदे–सह–वेधन कुओं से जल के

30 नमूने लिये गये और इनका विश्लेषण रासायनिक गुणधर्मों यथा– EC, PH, केटायन्स व एनायन्स के लिये किया गया । परिणाम बतलाते हैं कि कुछ स्थानों को छोडकर अन्य स्थानों में भूजल की गुणवत्ता की कोई गंभीर समस्या नहीं है । लेकिन बेसिन में लवणता है । अतः बेसिन के जल की गुणवत्ता का ठीक–ठीक पता लगाने के लिये अधिक संख्या में जल के नमूनों का विश्लेषण करना होगा ।

अहार नदी के सामीप्य में सब्जियों में भारी धातु संचयन पर उदयपुर केन्द्र द्वारा किये गये अध्ययन से पता लगा कि सभी स्थलों की तुलना में नदी के मध्य के भाग की पहुँच के भीतर का भूजल सर्वाधिक प्रदूषित था । इस प्रकार यह जल मानव उपभोग के लिये उपयुक्त गुणवत्ता का नहीं है । अध्ययन के परिणामों से यह स्पष्ट पता चलता है कि जिस क्षेत्र के खेतों में सीवेज वाटर के जल से सिंचाई की जा रही है वहाँ सुक्ष्मपोषक तत्वों और भारी धातु की मात्रा उपलब्ध है, हाँलाकि मृदा में भारी धातु की मात्रा स्वीकार्य सीमा में है । परणिाम यह भी दर्शाते है कि भूजल से की गयी सिंचाई के तहत उगायी गयी सब्जी की फसलों की तुलना में शहरी बहिस्राव से की गयी सिंचाई के तहत उगायी गयी सब्जियों में भारी धातु का संचयन उच्च है । भूजल से सिंचाई के मामले में अहार नदी के मध्य के तथा नीचे के क्षेत्रों के प्रदूषित भूजल से उगायी गयी सब्जी की फसलों में धातु की सान्द्रता उच्च पायी गयी जो उद्यानिकी फार्म पर भूजल के उपयोग से सब्जी की फसलों की सिंचाई की तुलना में है ।

जुनागढ केन्द्र द्वारा भूजल के नमूनों के विश्लेषण द्वारा समुद्र तट के निकट के भूजल में समुद्री जल प्रविष्ट हो जाने संबंधी अध्ययन किया गया । समुद्रतट के समीप के भूजल में लवणता काफी अधिक पायी गयी । यह पाया गया कि जल संरक्षण संबंधी कार्यों और अधिक भूजल पुनःभरण के कारण लवणता में 2005 से 2009 के बीच की अवधि में धीरे–धीरे कमी दर्ज की गयी । समुद्र तट से दूरी बढने के साथ भूजल की लवणता कम होती गयी और इसे अत्यधिक उच्च (C_5) से मध्यम (C_2) वर्गों में विभाजित किया गया ।

प्रौद्योगिकी हस्तांतरण

भूजल उपयोग संबंधी तकनीकों को प्रसारित करने के प्रयास में लुधियाना केन्द्र के वैज्ञानिकों ने 21 प्रशिक्षण कार्यक्रमों में संबंधित विभागों और किसानों के लिये 27 आमत्रिंत व्याख्यान दिये । प्रशिक्षण सामग्री के रूप में पाँच विस्तार आलेख, एक फोर्स कम्पेन्डियम व दो चैप्टर्स तैयार किये गये । केन्द्र द्वारा तैयार किया गया एक रियुसेबल लर्निंग ओबजेक्ट (RLO) भूजल के न्यायोचित उपयोग के निर्धारण में विस्तार कर्मियों / नीति निर्माताओं /किसानों के लिये काफी मददगार साबित हुआ है । वैज्ञानिकों ने चार किसान मेलों में भी भाग लिया ।

पन्तनगर केन्द्र द्वारा विभिन्न बिषयों के संबंध में किसानों को जानकारी दी गयी । इसमें पम्पिंग प्रणाली की उच्च दक्षता प्राप्त करने के लिये पाइप फिटिंग्स और पम्पस का चयन, उपलब्ध भूमि और जल संसाधनों का श्रेष्ठतम उपयोग जैसे विषय शामिल है । उत्तराखण्ड के ऊधभ सिंह नगर, नैनीताल, अल्मोडा, देहरादुन और चमोली जिले के विभिन्न स्थानों पर किसान बैठकें आयोजित की गयी । इससे 1312 किसान लाभान्वित हुए ।

राहुरी केन्द्र द्वारा 22-23 फरवरी 2010 को महात्मा फूले कृषि विद्यापीठ, राहुरी में 32 किसानों के लिये ''भूजल पुनःभरण एवं भूजल प्रदूषण'' विषय पर किसान प्रशिक्षण कार्यक्रम आयोजित किया गया ।

जबलपुर केन्द्र द्वारा मण्डला जिले से संबधित राज्य सरकार के अधिकारियों के लिये प्रशिक्षण कार्यक्रम आयोजित किया गया । इस प्रशिक्षण में संबंधित विभागों के लगभग 120 अधिकारियों और चुने गये स्थानीय प्रतिनिधियों ने 16 से 18 नवम्बर 2009 तक प्रतिभागिता की । 7 मार्च 2010 को हवेली फील्डस के लिये भूजल पुनःभरण एवं संरक्षण कार्यक्रम पर एक दिबसीय कृषक संगोष्ठी आयोजित की गयी । इसमें लगभग 150 किसानों ने भाग लिया । किसानों को हवेली फील्डस की जल उत्पादकता बढाने के लिये जानकारी दी गयी और खरीफ के दौरान सिंघाडा की फसल लगाने और रबी के दौरान गेहूँ लगाने को कहा गया । केन्द्र के वैज्ञानिकों ने पांच प्रशिक्षण कोर्स आयोजित किये, रेडियो वार्ताएं की और किसान मेलों में भाग लिया ।

कोयम्बटूर केन्द्र द्वारा पाँच किसान प्रशिक्षण आयोजित किये गये । विभिन्न पहलुओं पर फील्ड विजिट्स और निदर्शन भी आयोजित किये गये । कम होते हुए जल संसाधनों के श्रेष्ठतम उपयोग के लिये विभिन्न वैज्ञानिक विधियों पर चर्चा की गयी ।

उदयपुर केन्द्र द्वारा ''राजस्थान के झालावाड जिले के प्रगतिशील किसानों के लिए जल प्रबंधन'' विषय पर सद्गुरु वाटर एण्ड डेवलपमेंट फाऊण्डेशन द्वारा प्रायोजित पाँच दिवसीय प्रशिक्षण कार्यक्रम का आयोजन किया गया ।

पूसा केन्द्र द्वारा 3 किसान प्रशिक्षण आयोजित किये गये । किसानों को सीमीत जल के उपयोग से कृषि उत्पादन में वृद्धि के लिये उपलब्ध नयी तकनीकों से किसानों को परिचित करावाया गया । किसानों को फायदा पहुँचाने वाली सरकारी योजनाओं की जानकारी से भी किसानों को परिचित करवाया गया ।

रायपुर केन्द्र द्वारा विश्वविद्यालय में ''भूजल भरण प्रबंधन एवं उपयोग'' विषय पर तीन दिबसीय किसान प्रशिक्षण आयोजित किया गया ।

जुनागढ केन्द्र द्वारा एक बडे आयोजन ''कृषि महोत्सव-2009'' के तहत 'कतार फसलों में ड्रिप सिंचाई का प्रयोग' विषय पर एक सेमिनार का आयोजन किया गया ।

सभी केन्द्रों के वैज्ञानिकों ने राज्य/राष्ट्रीय स्तर की बैठकों/ कार्यशालाओं / सेमिनारों में तथा अर्न्तराष्ट्रीय संगोष्ठियों मे प्रतिभागिता की ।

उदयपुर केन्द्र के प्रभारी एवं एसोसिएट प्रोफेसर डॉ. पी. के. सिंह को USEFI से विजिटिंग लेक्चरर की फुलब्राइट फैलोशिप प्राप्त हुई और उन्होंने फ्लोरिडा अर्न्तराष्ट्रीय विश्वविद्यालय, मियामी का 15 सितम्बर 09 से 15 जनवरी 2010 तक भ्रमण किया ।

EXECUTIVE SUMMARY

Nine centres were operating under the All India coordinated Research Project on Groundwater Utilization for conducting research and extension work in the field of regional groundwater assessment and modeling; conjunctive use of surface and groundwater in canal command areas; artificial groundwater recharge studies; groundwater pollution studies and transfer of technologies developed at different centres. Salient research achievements of the AICRP centres during 2009-10 are given below :

Regional groundwater assessment and modeling

The long-term behaviour of water table in the state of Punjab for the period 1998-2006 using GIS indicated that water table has declined at the rate of 52 cm per annum due to largescale adoption of rice-wheat rotation. Area under water table depth of 3 –10 m has reduced from 75 to 40 percent whereas the area with the critical depth (10- 20 m) has increased from 20 to 58 per cent, indicating additional cost on replacement of centrifugal pump by submersible pump and additional cost of pumping. The worst affected area is of central Punjab. Affected districts are Kapurthala, Jalandhar, Sangrur, Fatehgarh Sahib, Moga, Ludhiana, Amritsar and Nawanshaher. Gurdaspur and Ropar are least exploited. The problem of water logging in south west Punjab (Muktsar, Ferozpur and Faridkot districts) has been decreased to some extent.

An attempt was made to estimate ground water recharge for Upper Narmada Basin (UNB) of Madhya Pradesh using water table fluctuation method. Average pre-monsoon and post-monsoon water table fluctuations over the basin varied from 3.4 m to 3.8 m. There was decline in the table during the study period. Water table fluctuations, information on geology, aquifer properties such as specific yield were used to get recharge variations within space. The total recharge for the upper Narnada basin was estimated to be 4.449 M ha m, which was equivalent to 12.84 cm uniform depth of recharge over 35,03,811 ha on total geographical area of the Upper Narmada Basin including all six districts, which was nearly 10 percent of the normal rainfall in the basin.

Study on groundwater balance to assess the quantity of water available for development in the Parambikulam-Aliyar basin was undertaken by Coimbatore centre. On the basis of the elongation ratios it is found that Palar and Aliyar basin is elongated, Valayar basin is oval and Sholayar basin is circular. No marked difference was found in the water levels between shallow and deep aquifers in most part of the area indicating that the two aquifers are hydraulically connected. The rise in water level takes place during pre-monsoon, south-west monsoon and north-east monsoon and the shallowest water table occurs during the month of December. Both increasing and decreasing trends have been noted over the period of 21 years almost in all the wells of the basin clearly indicating that the water level fluctuation is mainly controlled by the intensity of the rainfall as well as abstraction.

Components of the water balance equation for individual seven blocks of Rajsamand district, Rajasthan have been estimated by Udaipur Centre for five consecutive years (1999-2003). Thematic layers of soil, drainage and land use have been prepared using remote sensing and GIS. The developed thematic layers provide information about topography, spatial distribution of soil, drainage and land use in the Wakal River Basin. These thematic maps were generated from the toposheets which were scanned, rectified and digitized. The groundwater potential zones in Wakal river basin of Udaipur district was delineated.

The upper Chhokranala watershed, a small groundwater basin, located in Raipur district of Chhattisgarh state was selected for the study of groundwater flow and mass transport modelling of small agricultural watersheds using Visual Mod Flow model. The model was calibrated and validated with the help of groundwater levels and concentration of chemicals. It can be further used for optimization of groundwater use for sustainable crop production.

Groundwater potential of the south west Saurashtra region covering 14 Talukas was determined on basis of data from 24 open wells. The observations of water table, well dimensions, longitude and latitudes of well locations were recorded during pre-monsoon (Jun -2009) and post monsoon (Oct.-2009) to prepare contour maps. Water samples were also analysed for quality parameters. The water quality was found good in entire south west region except Mangrol and few inside pockets along the coastal strip. Total groundwater potential of region was calculated as 6540.58 MCM but for year 2009, being a drought year, potential was estimated as 3841.26 MCM.

Assessment of groundwater resource for Irrigation in Burhi Gandak River on pilot basis was carried out by Pusa centre. The annual groundwater recharge of seven districts viz. East Champaran, West Champaran, Siwan, Saran, Gopalganj, Muzaffarpur and Samastipur covering *Burhi* Gandak basin was calculated. The results depicted that total annual recharge among the districts ranged from 54,929 ha-m to 2,18,361 ha-m, out of which 3,818 ha-m to 1,82,845 ha-m and 16,747 ha-m to 35,516 ha-m from monsoon and non-monsoon period, respectively. The gross annual draft ranged from 27,296 ha-m to 80,008 ha-m for the selected districts of Burhi Gandak basin.

Conjunctive use of groundwater

Block wise availability and demand of water resources in Bist Doab tract of Punjab were studied to estimate the gap between demand and supply of water resources in the region considering canal water supply, effective rainfall, crop water demand and net pumping. The total available water resource for irrigation was 505 mm out of which groundwater, rainfall and canal water contribute 68, 26 and 6 percent, respectively. The average seasonal ET demand of the region was 521 mm for *kharif* season and 275 mm for *rabi* season, thus making deficit of 291 mm. In almost all the blocks of Kapurthala and Jalandhar district, there was gap between supply and demand due to rice-wheat rotation. Maximum water deficit of 543 mm in *kharif* and 231 mm in *rabi* season was observed in Mukerian and Balachur block, respectively.

Farmers of Punjab can save 22 to 33 percent water resources in different crops by laser levelling. Saving in irrigation water would be of 146563, 366408, 732816, 1099224 and 146531 ha-m at 10, 25, 50, 75 and 100 percent adoption of laser levelling in the state. Adoption of laser levelling in rice-wheat system alone can result in saving of 1344840 ha-m of irrigation water, reducing groundwater draft by 19 cm.

The optimal cropping pattern for Jafarpur minor command area of Kagarsen canal system in Udham Singh Nagar district of Uttarakhand was prepared by considering the total water availability in the area, irrigation water requirement and cost of cultivation of different crops grown in the command area. Crop area constraints were imposed considering the food and fodder requirement of the population of human and livestock of the command area. Crops appeared in the optimal crop plan, with crop area constraints, were *lahi*, wheat, rice summer, berseem and rice *kharif* at a level of 7.5, 484, 70, 5 and 551.5 ha, respectively. The net return increased by 21.70 percent over existing plan. Study also showed that excess canal water during *kharif* can be stored by constructing the water harvesting structures and would be used for irrigating *rabi* crops or when there is no canal water supply, thus reducing groundwater requirement.

The study in four minors of Left Bank Canal of RABS Project, Madhya Pradesh showed that application efficiency was higher in upper part while was lower in the tail area. The distribution efficiency was found quite high in all minor commands. However, conveyance efficiency was lower. Technical manpower, fund availability and maintenance of structures in command need to be improved. There was no problem of water logging indicating that recharge in the command was not exceeding groundwater draft and conjunctive use of canal and groundwater was well established in the command. Most of the farmers were willing to contribute towards canal cleaning and smooth functioning of the system.

Conjunctive use of surface and groundwater in the Parambikulam Aliyar Project (PAP) command was carried out by Coimbatore centre. Rotational Water Supply (RWS) was formulated to work round the clock and did not allow any water to run as waste during night hours. Operational plan was drawn in a holistic manner based on irrigation season, taking care of cropping pattern and crop water requirement. RWS schedules were drawn in consultation with the farmers. Canal roasters were handed over to farmers associations. The monitoring of the implementation of these schedules is being done for at least two seasons to ensure proper working of Warabandhi.

Conjunctive use of canal water and marginally saline groundwater for wheat cultivation on calcareous soil of Bundi district was carried out by Udaipur centre. The results revealed that 33percent good quality (canal water) could be saved without significant reduction in grain and straw yield of wheat by two irrigations with canal water followed by one irrigation with groundwater in cyclic mode.

Conjunctive water use for wheat crop at Junagadh showed that groundwater draft could be reduced by 131.01 cu.m. for wheat crop. It helped in reducing power consumption compared to groundwater irrigated crop. Pan evaporation analysis revealed that evaporation loss of 110.11mm might be saved from the check dam storage by sowing wheat latest by 15th November and utilizing available surface storage on or before 21st November effectively. In case normal years two irrigation from check dam are possible.

The water productivity values of paddy grown in nine farmers' fields in Harpur village of Pusa Block were evaluated. The crop was irrigated with groundwater and the average number of irrigation was 3.8 for hybrid paddy compared to 2.75 for *MTU-7029.* It can be concluded that irrigation water productivity of *MTU-7029* variety of paddy is higher by 21.15 percent than its hybrid *6444/ MPH-55*.

Artificial groundwater recharge

The composite filter of gravity recharge well was redesigned by Ludhiana centre to have more projected area so as to increase the filtration rate with reasonable recharging water quality. Pea gravels were used instead of sand as pea gravels ensure better filtration rate. Recharge rate up to 32 l/sec was achieved by modified design of the filtration unit. In general recharge rate was higher than 26 l/sec. The performance of modified design was better than earlier design. Two tube wells were installed to recharge the upper dry shallow aquifers. The depth of filter pit and length of perforated pipes of two tube wells were increased this year to enhance recharge rate of tube wells. There was improvement in recharge rate due to these modifications.

Optimal crop plan on the basis of available spring water and design of suitable water storage structure were suggested for Tehri Garhwal Region of Uttarakhand. It was found that *lahi* and wheat combination could be grown in the *rabi* season while paddy, sorghum and maize in the *kharif* season. Farm pond was suggested to store spring water. Pond size was decided on basis of spring's discharge, domestic and crop water requirements.

Artificial groundwater recharge study through percolation tank was conducted at three different sites in Maharashtra to quantify the ground water recharge through percolation tank and to assess the area of influence (distribution) of groundwater recharge in the downstream region of the percolation tank during the period from 1993-2005. It was observed that percolation tank can influence up to 1500 m downstream and recharge rate from tank varied from 1.27 cm/day to 6.0 cm/day.

The performance of sand gravel filter developed for the artificial groundwater recharge through irrigation wells was studied at Rahuri in Maharashtra. Different filter materials with different thickness and grades influenced the velocity of flow, time of filtration, discharge and filtration efficiency. The filtration efficiency increased with increase in thickness of filter material. The three layer filter should be recommended for the high discharge while the four layer filter should be recommended for low discharge.

Water stored in *Haveli* fields may be injected into substrata, if properly planned. There is a possibility of injecting *Haveli* storage water through recharge shaft during early and post monsoon periods. Water productivity of Haveli system could be improved by introducing a *Singhara* crop along with rabi (wheat). The net profit was Rs. 59900 for the improved system compared to Rs. 23000 for traditional rabi (wheat)- *Haveli* system.

Artificial recharge structures, constructed in percolation ponds of Coimbatore and Vellore districts of Tamil Nadu, were evaluated by Coimbatore centre. It was found that in Vellore district recharge equivalent to 18 percent of rainfall occurred during the North east monsoon. It was noted that recharge during north east monsoon was 10 percent higher compared to recharge during south west monsoon periods. In Coimbatore district, recharge equivalent to 9 percent of rainfall in Kalapatti and 11 percent in Vellanipatti took place during the north east monsoon. While comparing south west and north east periods, it was noted that the recharge was 4 percent more during north east monsoon.

Natural recharge in response to rainfall for five years (1999-2003) has been estimated by Udaipur centre for seven blocks of Rajsamand district by using water level fluctuation technique. It was seen that minimum rainfall recharge (28.22 million m^3) in the district occurred in the year 2002 when annual rainfall of the district was only 28 cm and the maximum rainfall recharge (379.96 million m^3) occurred in the year 2001 when the annual rainfall of the district was the maximum (56.5 cm). Thus, rainfall recharge has a direct relationship with the annual rainfall.

Gross irrigation requirement of wheat crop grown in 187 ha area Jamka micro watershed in Junagadh district was estimated using remote sensing based $K_{c\ SAVI}$ values as 119.12 ha m for year 2006-07. The groundwater recharge created by water harvesting structures i.e. 150.37 ha m was found adequate to irrigate 156 ha of wheat crop. However, total groundwater recharge estimated from rainfall and water harvesting structures was 407.12 ha m, which can irrigate about 422 ha of wheat crop by applying 627 mm water with 65 per cent application efficiency. The cost of storage capacity created by water harvesting structures was found to be Rs.1.49 per m^3 of storage. The estimated benefit-cost ratio was found to be 1.53 for growing wheat crop using the groundwater recharge by water harvesting structures.

Groundwater pollution

Studies on groundwater pollution due to industries showed that effluent from Lalkuam pulp and paper mill in Uttarkhand adversely affected the groundwater as well as the surface water quality. Suitability of groundwater for irrigation was assessed based on criteria. Overall groundwater was under C_2S_1 except near Goranala, where it was under C_3S_1 class. Surface water samples were under severe class due to high SAR. The study on use of effluent from pulp and paper mill in agriculture in the *Tarai* belt of Uttarakhand state showed that effluent could not be used as such for irrigation purpose due to high toxicity level. The effluent with 25 percent concentration could be used for irrigation as it gave the better results in comparison to 0, 50, 75 or 100 percent concentration levels.

Study of Natural Springs in Uttarakhand showed increase in discharge rate of spring decreased the electrical conductivity of the oozed-out water. Growing vegetation on the catchment, aspect and elevation have no effect on the water quality of the spring. Geology of the parent material is responsible for the water quality and flow of the spring.

Use of polluted groundwater for irrigating the onion crop at Rahuri in Maharashtra showed that electrical conductivity and pH of soil are increasing. It meant that both soil salinity and sodicity could be of serious threat, if irrigation by polluted water is continued.

The quality parameters of groundwater in Narsinghpur district of Upper Narmada Basin in Madhya Pradesh were well within the permissible limits and groundwater was found suitable for irrigation. However its quality is deteriorating with time at slow rate. Similarly, selected waste waters from different sources in Madhya Pradesh were analysed and it was found that Na^+ concentration at three locations and RSC at one location were high. For other waste waters, quality was suitable for irrigation. Waste water sources were adversely affecting the quality of groundwater in vicinity. Also all sites using waste waters had either medium or high organic carbon in soil. The copper was in deficit. Available N in soil was moderate; phosphorus was high and potassium was medium.

Thirty water samples were collected by Coimbatore centre from Parambikulam Aliyar basin from open wells, bore wells and dug cum bore wells and analyzed for chemical properties like EC, pH, cations and anions. The results indicate that there is no serious problem in groundwater quality except in few places. But salinity persists in the basin.

The study conducted by Udaipur centre on heavy metal accumulation in vegetables in vicinity of Ahar River indicated that groundwater of the middle reaches were found most polluted among all sites. Thus, these waters are not having appropriate quality for human consumption. The results of the study clearly revealed that soils of the fields receiving sewage water as irrigation contained appreciable quantities of micronutrients and heavy metals, although the contents of the heavy metals in the soil were within the permissible limits. Further, the results revealed that the heavy metal accumulation was higher in the vegetables grown under urban effluent irrigation as compared to vegetables grown under groundwater irrigations. In case of groundwater irrigation, higher metallic concentration was found in the vegetables grown with polluted groundwater along the middle and lower reaches of Ahar River as compared to vegetables grown under groundwater irrigation at Horticulture Farm.

The sea water intrusion in groundwater near to sea coast was studied by analyzing the groundwater samples by Junagadh centre. In the vicinity of seacoast high salinity was observed in groundwater and it was found that due to water conservation activities and increased groundwater recharge, it decreased slowly from 2005 to 2009. Salinity of groundwater also decreased with increased distance from seacoast and was classified under very high (C_5) to medium (C_2) classes.

Transfer of technology

In order to propagate the technologies related to groundwater utilization, scientists of Ludhiana centre delivered 27 invited lectures to user departments and farmers in 21 training programmes. Training material like five extension articles, one course compendium, two chapters in course compendium were prepared. A Reusable Learning Object (RLO), prepared by centre, is quite helpful for the Extension workers/Policy makers/farmers for making judicious use of ground water. Scientists also attended four Kisan melas.

Pantnagar centre educated the farmers about selection of pumps and pipe fittings to achieve high efficiency of the pumping system, optimal utilization of available land and water resources. Farmers' meetings were organised at different places in Udham Singh Nagar, Nainital, Almora, Dehradun and Chamoli districts of Uttarakhand and 1312 farmers were benefited.

Rahuri centre organised farmers' training programme on "Groundwater recharge and groundwater pollution", during 22-23 February, 2010 at Mahatma Phule Krishi Vidyapeeth, Rahuri for 32 farmers.

Jabalpur centre organised training for state government officials of Mandla district. About 120 officials from concerned state departments and elected local representatives attended the training during 16-18 November 2009. One day Krishak Sangosthi for "Ground Water Recharge and conservation Program for Haveli Fields" was organised on 7th March 2010. About 150 farmers participated in it. The farmers were convinced about improving water productivity of Haveli fields by introducing Singhara crop during *kharif* besides wheat during *rabi*. Scientists of centre organised five training courses, delivered radio talks and participated in Kisan Melas.

Coimbatore centre organised 5 farmers' trainings. Field visits/ demonstrations on various aspects were also organized. Various scientific approaches for making best use of scarce water resources were discussed interactively.

Udaipur centre organized 5 days training programme sponsored by Sadguru Water and Development Foundation on "Water Management for the progressive farmers of Jhalawar district, Rajasthan.

Pusa centre organised 3 farmers' trainings. Farmers were made acquainted with new technologies available for enhancing the agricultural production with limited water use and various schemes implemented by government for benefits of farmers.

Farmers' training for three days on "Bhujal Bharan, Prabandhan avm Upyog" was organized by Raipur centre at university

A Seminar on Application of drip irrigation system in row crops was organized under mega event *Krushimahotsav* -2009 by Junagadh centre.

Scientists from all the centres participated in state/ national level meetings / workshops/ seminars as well as international conferences.

Dr. P.K. Singh, Associate Professor and In-charge of Udaipur centre received prestigious Fullbright Fellowship of visiting Lecturer from USEFI and visited Florida International University, Miami 15th September to 15th January 2010.

1

ORGANISATION

1.1 Background of the Scheme

The scheme was sanctioned by ICAR/ planning commission in 1970 and became operational as AICRP on Optimization of Groundwater Utilization through Wells and Pumps at Water Technology Centre (W.T.C.), Indian Agricultural Research Institute (I.A.R.I.), New Delhi in 1971 with four cooperating centers. Since then, some adhoc centers were opened, some centers were discontinued and some adhoc centers were elevated to AICRP level depending upon the scientific and regional requirements of the Project. In the VIIth plan, Hyderabad center at Osmania University was discontinued and MPKV, Rahuri center was started. At the end of VIIth Plan, six cooperating centers were functioning, all being regular AICRP centers. In the IXth plan, it was proposed to discontinue the center located at Gujarat Engineering Research Institute, Vadodara. The Coordinating Unit of the AICRP was shifted from W.T.C. (I.A.R.I.), New Delhi to erstwhile Directorate of Water Management Research (DWMR), Patna in April 1998. Since then the coordinating unit was working under DWMR, Patna till its merger in newly established ICAR Research Complex for Eastern Region, Patna on 1st April 2001. It was later shifted to Water Technology Centre for Eastern Region, WTCER (Presently, Directorate of Water Management), Bhubaneswar in October 2003. Since then it is functional from Directorate of Water Management, Bhubaneswar. In the X plan the AICRP centre at IIH, Poondi got shifted to Water Technology Centre, TNAU, Coimbatore and four new centres at Udaipur, Raipur, Junagadh, Samastipur got approved. An overall outlay of Rs 905.02 lakh as ICAR share has been approved for the XI plan period (2007-12) as a whole for this project.

1.2 Location of Network Centres

At present nine cooperating centres are in operation as listed below. Out of the nine centres, five centres viz., Coimbatore, Udaipur, Raipur, Junagadh, and Pusa are new and their research activities started from 1st April 2004.

1. Punjab Agricultural University, Ludhiana;
2. Govind Ballabh Pant University of Agriculture & Technology, Pantnagar;
3. Jawahar Lal Nehru Krishi Vishva Vidhyalaya, Jabalpur;
4. Mahatma Phule Krishi Vidyapeeth, Rahuri;
5. Water Technology Centre, TNAU, Coimbatore;
6. Indira Gandhi Agricultural University, Raipur;
7. Maharana Pratap University of Agriculture and Technology, Udaipur;
8. Rajendra Agricultural University, Pusa, Samastipur;
9. Junagadh Agricultural University, Junagadh.

The Coordinating Unit of AICRP on GroundWater Utilization is presently stationed at Directorate of Water Management, Bhubaneswar.

1.3 Mandate

The scheme has been mandated to ensure optimum utilization of groundwater for sustainable agriculture through its proper assessment; modeling different use patterns; work out strategies for its efficient utilization and augmentation; develop efficient hardware and study groundwater pollution problems.

1.4 Objectives

The major objectives or themes of the scheme are:

i) To develop strategies for assessment of basin-wise groundwater potential and its quality through regional water balance studies and mathematical modelling techniques.

ii) To evolve management strategies for safe development and utilization of groundwater either as a single resource or in combination with rain and other sources of water in different soil and hydro-geological formations for sustainable crop production.

iii) To develop technologies for augmenting groundwater supplies through enhanced recharge in hydrologically critical areas.

iv) To study groundwater pollution arising from different sources (viz. agrochemicals, agro based industries, municipal and other waste waters, seawater intrusion etc.) and develop its control and ameliorative techniques for the safe use of polluted water in agricultural production system.

1.5 Staff Positions

The existing staff strength of the project is as shown in Table 1.1. The details of the positions are given in Annexure I.

Table 1.1 Existing staff strength of the project

Centre	Scientific			Technical (including driver, tracer)			Administrative			Supportive		
	Sanctioned	Filled	Vacant	Sanctioned	Filled	Vacant	Sanctioned	Filled	Vacant	Sanctioned	Filled	Vacant
Ludhiana	4	3	1	5	5	0	2	2	0	1	1	0
Pantnagar	4	4	0	5	2	3	2	1	1	1	1	0
Rahuri	2	2	0	4	3	1	2	1	1	1	1	0
Jabalpur	3	3	0	6	4	2	1	1	0	1	1	0
Coimbatore	3	3	0	3	3	0	2	2	0	1	1	0
Udaipur	3	3	0	3	3	0	2	2	0	1	1	0
Pusa	3	3	0	3	2	1	2	1	1	1	0	1
Raipur	3	3	0	3	0	3	2	1	1	1	1	0
Junagadh	3	3	0	3	1	2	2	1	1	1	1	0
Total	28	27	1	35	24	11	17	12	5	9	8	1

San. = Sanctioned; Fill.= Filled; Vac.= Vacant

1.6 Finance

In XI plan period (2007-2012) an outlay of Rs 1206.69 lakhs is approved by EFC, out of which the council's share is Rs 905.02 lakhs for implementation of ongoing research work in the AICRP.

1.7 Technical Program and Results

The findings of various studies conducted by different centres have been presented under the following six topics:

i) Regional Groundwater Assessment and Modeling

ii) Conjunctive Use in Canal Command Areas

iii) Artificial Groundwater Recharge Studies

iv) Groundwater Pollution

v) Transfer of Technology

vi) List of publications during the year 2009-10

2

REGIONAL GROUNDWATER ASSESSMENT AND MODELING

2.1 Assessment of Long-term Water-table Behaviour for the State of Punjab using GIS (Ludhiana Centre)

The state of Punjab with only 1.6 percent of the total geographical area of the country, is contributing 40-50 percent rice, 60-65 percent wheat and 20-25 percent cotton to the central pool since last three decades. During last 35 years the area under food grains has increased from 39200 sq km to 63400 sq km. It has negative impacts on water resources of state. The state is facing the twin problems of rise and fall of water table. Over-exploitation of ground water in almost all the Central Punjab covering about 80 per cent of the total area of the state having good quality ground water resulted in decline in water table, whereas in South-West Punjab, the water table has been rising due to under utilization of poor quality ground water and seepage from canals. There is an urgent need to study the water table behaviour at micro-level so as to efficiently utilize this resource for ensuring long-term sustainability in agriculture and food security. Hence long-term groundwater monitoring is also important to determine the extent of change and the trend over the years for groundwater fluctuation. With the above background, an attempt is made to assess the long term groundwater behaviour of the Punjab state using GIS to spatially analyze water level data obtained from the state and central agencies and to identify the districts with greatest depletion of groundwater. Groundwater monitoring network in Punjab state for water table fluctuation comprises 162 dug wells and 224 piezometer tubes (175 shallow and 49 deep) observed monthly by Water Resources & Environment Directorate; 456 dug wells and 133 piezometer tubes by Department of Agriculture biannually in June and October. The pre-monsoon data were procured from these agencies and carefully examined for discrepancies and finally 388 wells were digitized to prepare water level maps in GIS. The water table data of these observation wells was used to create a groundwater surface for different years, using universal kriging interpolation technique as it is preferred technique of interpolation for a non-stationery variable. The water table surface map was classified as 0- 3, 3-10, 10 – 20 and greater than 20 m. The classification was based on the fact that areas with water table depth between 0 – 3 m are either water logged or prone to water logging, water table depth between 3 – 10 m is ideally suited for installation of centrifugal pump and groundwater extraction i.e. safe limit, water table beyond 10 m depth is critical limit for shifting from centrifugal to submersible pump and beyond 20 m water table is deep. The spatial analyst extension was used for the analysis and the areas associated with different ranges of rise or fall of the water table were computed in GIS for each period and for each district. Spatial data analysis using GIS showed that the water table in the study area ranged between 1.4 to 30.8 m from the ground surface for the study period (Fig. 2.1). The long-term behaviour of water table for 1998-2006 reveals that water table has fallen in the entire state. The minimum and maximum water table depth ranges were from 1.37 – 2.02 m and 26.67 -30.83 m, respectively, during the study period. The average water table depth was 7.54 m in 1998 and 11.67 m in 2006 thus indicating an average annual fall of 52 cm, varying from 4 to 83 cm annually. Regional groundwater flow direction is from north east to southwest direction.

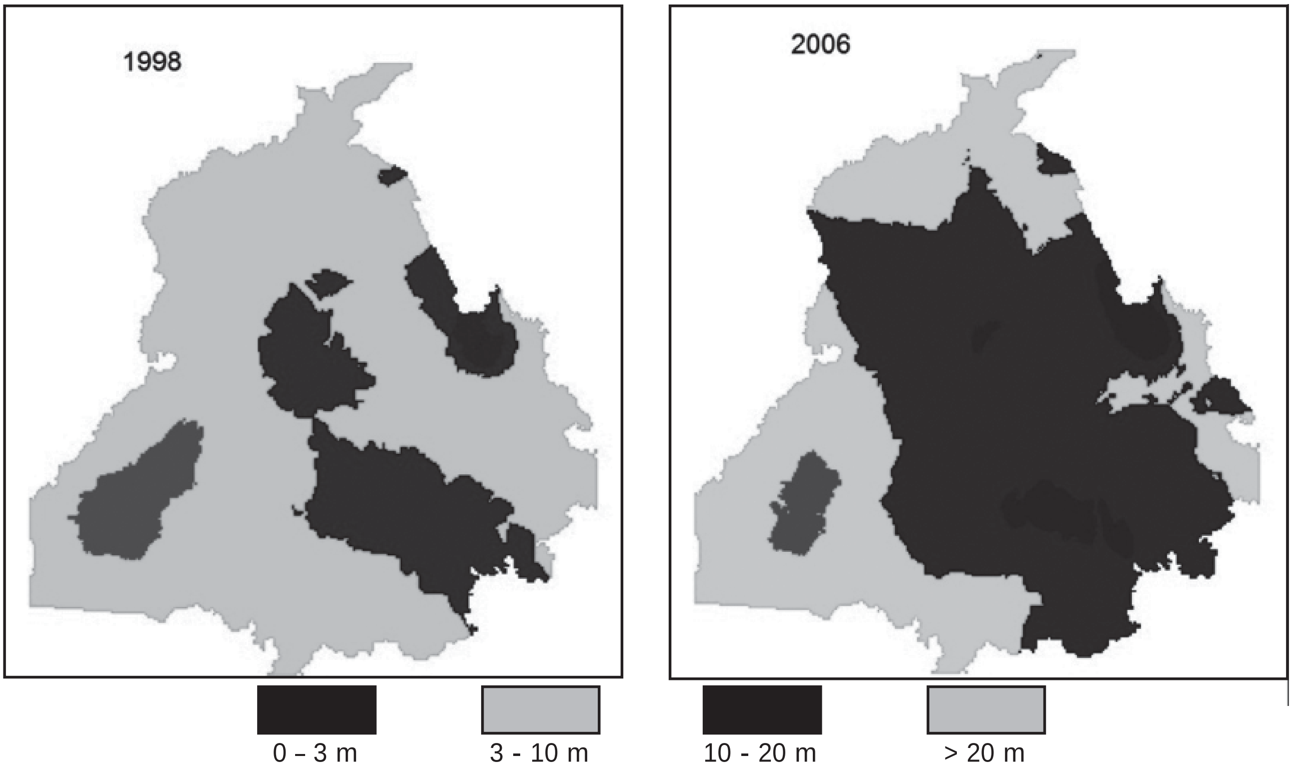


Fig. 2.1 Water table behaviour of Punjab state for the period 1998 and 2006

Based on the analysis of groundwater table maps, areas under different water table depths were computed using GIS and the results are presented in Table 2.1.

Table 2.1 Area ('000 ha) under different water table depths (m) for state of Punjab

Year	0 - 3	3 - 10	10 - 20	> 20
1998	239.41	3776.50	962.06	40.34
1999	206.89	3837.52	937.10	36.81
2000	165.91	3561.05	1264.63	26.73
2001	162.76	3224.43	1595.57	35.55
2002	142.71	2966.11	1863.86	45.64
2003	24.58	2587.64	2397.14	8.95
2004	68.21	2362.10	2532.92	55.09
2005	27.36	2214.46	2679.17	97.33
2006	108.04	1995.98	2724.05	190.24

Table 2.1 indicated that during span of 8 years, area of the state under water table depth of 3 – 10 m has reduced from 3.74 M ha (75 percent) to 1.98 M ha (40 percent), and area under water table depth greater than 10 m has increased from 0.95 M ha (20 percent) to 2.70 M ha (58 percent) indicating fall of groundwater beyond critical limit of 10 m has occurred mostly in areas that were earlier under the safe limit i.e 3 – 10 m. Also, the area that was susceptible to water logging or waterlogged has reduced from 0.24 M ha to 0.10 M ha (i.e. by 2.62 percent) during the study period. The waterlogged area in the state was less than 30,000 hectare in 2003 and 2005. The Table-2.1 also suggested that only 20 percent area was in need of submersible pump technology in 1998. However, 58 percent of area required it during 2006. It meant that farmers had to replace their centrifugal pumps by submersible pumps. Besides, additional burden of installation of submersible pump, they have to pay extra charges on account of electricity.

District wise analysis was also carried out in GIS to identify the worst affected and least affected districts in the state. The average annual decline in water table was above 50 cm in nine districts of the state viz. Jalandhar (94.5 cm), Sangrur (84 cm), Moga (80 cm), Kapurthala (77.7 cm), Patiala (75 cm), Fatehgarh Sahib (65.4 cm), Ludhiana (57.8 cm), Hoshairpur (51.3cm), Amritsar (50.4 cm) and Mansa (50 cm). District Muktsar showed an erratic trend in groundwater levels with rising behaviour in years 1998-99, 2000-2001, 2003 – 2004 and 2005 – 2006 and falling water levels in other years.

The study on long-term behaviour of water table for 1998-2006 for state of Punjab has finally revealed that water table has fallen in the entire state with an average decline of 52 cm annually. During the said period, area of the under water table depth of 3 – 10 m has reduced from 75 to 40 percent whereas the area, beyond the critical depth has increased from 20 to 58 per cent. All the districts are facing declining water table problem. The worst affected districts were identified as Kapurthala, Jalandhar, Sangrur, Fatehgarh Sahib, Moga and Ludhiana. Districts Amritsar and Nawanshaher are also facing sharp decline in groundwater resources. One of the reasons is the paddy- wheat crop rotation is followed in these districts since eighties. Gurdaspur and Ropar have been identified as potentially least exploited with maximum area under safe water table depth and good quality water.The problem of water logging in Muktsar, Ferozpur and Faridkot districts had decreased by 11, 9 and 37 percent although Muktsar had fluctuating water table behaviour for the period under study. Considering the present trend of fall in water table, it is estimated that by 2020, more than 80 percent of the state area would be clubbed to the area where water level is already beyond the critical level of 10 m depth. There is, thus, an urgent need to check the decline in water table in this zone by reducing the ground water draft and/or increasing ground water potential by artificial ground water recharge.

2.2 Groundwater Assessment in Alluvial Areas of Narmada River Basin (Jabalpur Centre)

Narmada basin (Fig. 2.2) extends over an area of 98,796 sq km in the states of Madhya Pradesh, Gujarat and Maharashtra. Narmada has a fairly heavy discharge because of moderately heavy annual average rainfall (1200-1500mm) in the basin, particularly in the upper catchment areas. The total length of the river from the head to its outfall into the Gulf of Khambhat is 1,312 km. The major districts covered are Dindori, Mandala, Jabalpur, Katni,

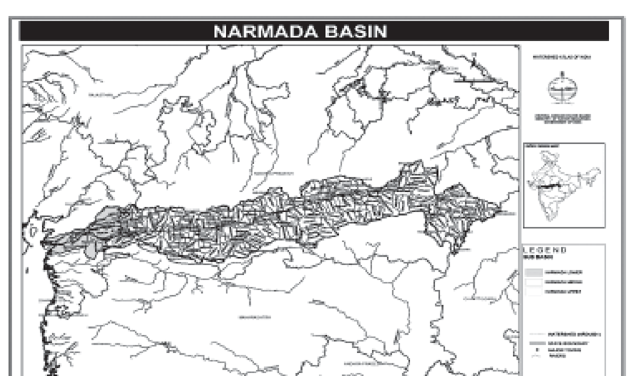


Fig. 2.2 Upper, middle and lower parts of Narmada basin

Narsinghpur, Hoshangabad, Dewas and Khandwa besides Bharuch in Gujarat State. There is low ground water development in 42 blocks of 6 districts lying in Narmda basin. In this study, attempt was made to estimate ground water recharge for Upper Narmada Basin (UNB) using water table fluctuation method.

The water table observations were collected for 2002 to 2008 during Pre-monsoon and Post-monsoon season for Dindori and Mandla, Jabalpur and Katni, Narsighpur and Hoshangabad districts. Dindori and Katni districts were included in undivided Mandla and Jabalpur district, respectively. Water level fluctuations from Pre-monsoon to Post-monsoon were worked out for all the observation wells in upper-Narmada sub basin. Trends of water level behavior for both the seasons were plotted for all the districts. Water table observations for both the seasons were analyzed for all the districts, namely Mandla, Jabalpur, Narsinhgpur and Hoshngabad. Longitude and latitude values were also collected for each observation well required for determining plotting position of well on the geographical map of the district. It was a necessary input for preparing the water table contour map of all the districts and computation of fluctuation map. The fluctuation maps were used for the recharge computation. The water table fluctuation and the area under different ranges of fluctuation were used to estimate ground water potential. Specific yield required for each area was taken from the Geohydrological reports of WRD, Madhya Pradesh. Appropriate value was taken after interpretation of reports for the study area. The geology of upper Narmada Basin is varying widely. Geological details for all the four districts were collected from the Geological Survey of India. The detailed information on geology was generalized into major categories i.e. hard-rock and alluvial formations. The alluvium area was about 10.26 lakh ha sharing 29.2 percent of the geographical area of the basin. Alluvium areas are mostly lying in Narsinghpur (67 percent) and Jabalpur (44 percent). District Mandla is dominated by hard rock area (96 percent) which is the origination of the river Narmada and rocks can be seen on the surface. More over Mandla is dominated by forest area and hilly region and contributing more runoff area rather than recharge area. Ground-water recharge in all the districts under study (UNB) was estimated using water table fluctuation method, with following formula:

Recharge to Ground Water (m) = Water table fluctuation (m) x sp. yield (%)

Volume of recharge (ha-m) = W.T. fluctuation (m) x sp. yield (%) x Area (ha)

Geology of the area was generalized into the categories i.e. hard-rock and alluvium, for these two formations the specific yield was considered as 3 and 10 percent, respectively, as per Geo-hydrological report of Water-Resources Department of Govt. of M.P. Using this information the recharge for the study area was calculated for the year 2008. In Mandla district two types of hard rock areas were considered with specific yield of 2 and 1.5 percent.

An interesting feature of Upper Narmada Basin, extended in about 3503811 ha, was that ground water level fluctuated between 3.4 m to 3.8 m on an average. With an increase from upper reach to lower reach of the Narmada river. It indicated that recharge space was more or less same. But owing to differential area under alluvium i.e. 37 percent in Jabalpur, 66.6 percent area in Narsinghpur and 62.7 percent in Hoshangabad district made the different recharge volumes in different districts. Total recharge for Mandla, Jabalpur, Narsingpur and Hoshanadad district was ranging from 0.094 to 1.308 M ha m. The total recharge for the upper Narnada basin was estimated as 4.449 M ha m, which was equivalent to 12.84 cm uniform depth of recharge over 35,03,811 ha on total geographical area of the upper Narmada basin including all six districts, which was nearly 10 percent of the normal rainfall in the basin.

2.3 Study on Groundwater Balance to Assess the Quantity of Water Available for Development in the Parambikulam-Aliyar Basin (Coimbatore Centre)

This study was undertaken to assess and evaluate the groundwater resources for irrigation using secondary data in the Parambikulam-Aliyar basin.

For this purpose, it was necessary to evaluate potential of deep aquifer system in alluvial and hard rock regions; to critically appraise and need based modification of some selected groundwater simulation models for their adaptability in different hydro-geologic conditions of the basin; to develop computer based decision support system for integrated water resources planning and to assess different components of the water budgeting in the basin; and to use GIS technology to assess the groundwater status and its problems.

Parambikulam-Aliyar river basin has an undulating topography with maximum contour elevation in the plain is 300m and the maximum spot height in the plain is 385m above MSL. One third of the basin area (822.73 km^2) is covered with hills and dense forest cover. The total area of the basin is 2388.72 km^2. This basin is bounded in north and east by Cauvery basin, south and west by Kerala State. This basin area lies (except the ayacut area) within the coordinates of 10°10'00" to 10°57'20" N latitudes and 76°43'00" to 77°12'30" E longitudes.

Understanding of different water balance components is necessary for estimation groundwater potential. Rainfall recharge mainly contributes to groundwater particularly in hilly area, where contribution of lateral flows to groundwater remains insignificant. Therefore, the first step in estimation of groundwater potential is to develop understanding about surface water hydrology and its connection with groundwater hydrology with the help topography, soil characteristics, geology and rainfall characteristics. It gives insight about recharge process in the basin.

The morphometric analysis of the basin is given in Table 2.2. The higher values of relief ratio (R_n) indicated higher overland flow and discharge in the basin due to hilly metamorphic formations associated with high slope configurations. Sholayar basin with a relief ratio of 0.0676 showed steep slope and it was an indicator of high intensity of erosion whereas Valayar basin indicated low intensity of erosion or no erosion because of its lowest R_n . The Palar sub

Table 2.2 Morphometric features of PAP basin

Parameter	I Aliyar	II Valayar	III Solaiyar	IV Palar
Mean Stream length ratio	0.883	1.348	0.376	0.7635
Bifurcation ratio (Rb)	1.57;10.5;0.4	2.142;3.267; 1.153	2.7;1.429;5.6	7.268;2.9 29;1.167
Mean Bifurcation ratio Rbm	3.708	2.187	3.243	1.841
Drainage density (D_d) (km / km^2)	0.543	0.563	0.759	0.579
Stream density D_s or frequency	0.231	0.2.09	0.432	0.325
Drainage texture	0.807	1.274	1.713	1.555
Form Factor (R_f)	0.144	0.496	0.974	0.195
Circulatory ratio (R_e)	0.254	0.5347	0.471	0.543
Elongation ratio	0.429	0.795	1.114	0.498
Length of overland flow	0.921	0.888	0.661	0.863
Constant channel maintenance	1.842	1.776	1.321	1.727
Slope (%)	3.5	0.635	6.37	2.96
Relief ratio (R_n)	1.012	0.005	0.0676	0.0206

basin has the maximum R_e of 0.543. By taking this as unity (1), Aliyar sub basin exhibits the lowest values of 1: 0.46. This shows, the region is prone to low flood hazard. The sub basins Valayar, Palar and Sholayar with 1:1, 1:0.98, 1: 0.86, respectively, showed higher values indicating high-flood hazard. Sub basins Sholayar and Valayar exhibited higher R_f indicating of higher peak flow for shorter duration and Palar basin having lowest R_f exhibited flatter peak flow for longer duration. On the basis of the elongation ratios, it was observed that Palar and Aliyar basin was elongated, Valayar basin was oval and Sholayar basin was circular.

The drainage density (D_d) of the area is coarse in texture and it covered due to the combination of relatively low rainfall intensity, relatively high permeability of rock strata, resulted high infiltration thick vegetation and relatively low relief.

A detailed analysis of hydro meteorological parameters such as rainfall, temperature, humidity, wind speed and sunshine was carried out for PAP basin. On the basis of the analysis of annual and seasonal rainfall of the 27 stations located in the study area, it was observed that there is very wide variation in the mean annual rainfall from 549.39 mm (Gomangalam) to 5171.20 mm (Upper Nirar). The Gomangalam is located in the plains and Upper Nirar is located in the hilly reserved forests. Almost half of the entire basin falls in the dry plain area of the rainfall regime, while the remaining part of the basin comes under 'wet mountain type' and the hilly region with reserved forests. In the plains, the post monsoon and pre monsoon season periods produced about 128.09mm and 220.77mm of rain whereas in the hills, the post monsoon and pre monsoon season periods produced about 197.77mm and 475.79mm of rain. Most of the rain is received during April and May. The first three months (January to March) form the dry period. The post monsoon and pre monsoon rains contribute 20 and 25 percent (plains) and 9 and 17 percent (hills) of the annual rainfall, respectively. The southwest and northeast monsoon rains contribute 15-17 and 60-63 percent, respectively for plains and 42-77 and 14-41 percent, respectively, for hills to the annual rainfall. Apart from high spatial variation in rainfall, there are high temporal variations also. The analysis of topographical and meteorological characteristics would be helpful to know rainfall-runoff relations, spatial infiltration and ultimately recharge contribution to groundwater.

Besides, above mentioned analysis, water table data were also recorded. There was no marked difference in the water levels between shallow and deep aquifers in most part of the area indicating that the two aquifers are hydraulically connected. The rise in water level takes place during pre-monsoon, south-west monsoon and north-east monsoon and the shallowest water table occurs during the month of December. Both increasing and decreasing trends have been noted over the period of 21 years almost in all the wells of the basin clearly indicating that the water level fluctuation is mainly controlled by the intensity of the rainfall and as well as abstraction. It proved the initial assumption that rainfall recharge mainly contributes to groundwater. Analysis of surface and groundwater balance components would finally help in quantification of recharge and ultimately the groundwater potential of the basin for irrigation purpose.

2.4 Estimation of Groundwater Potential of Rajsamand District (Udaipur Centre)

In this study, total groundwater potential of Rajsamand district was assessed on the basis of recommendations of Groundwater Resource Estimation Committee (1997), Ministry of Water Resources, Govt. of India. Total groundwater potential was again divided into dynamic and static groundwater potential.

Computation of dynamic groundwater potential

Dynamic groundwater represents that part of the subsurface zone, where fluctuations take place. Therefore, dynamic groundwater potential varies temporary depending upon the rainfall of particular year. Dynamic groundwater resource can be defined as a long-term average of annual recharge:

$$G_{rd} = R_{avg} = \sum\left(\frac{R_{rfi}}{P_i} \times P_{normal}\right) / N$$

Computation of static groundwater potential

Groundwater available below the zone of natural (dynamic) water level fluctuation is called static groundwater reserve. It will be estimated using the following formula given by Naik and Awasthi (2003):

$$G_{rs} = B \times A_e \times s_y$$

Where, G_{rs} = static groundwater potential; B = saturated thickness of the aquifer below the deepest water level in pre-monsoon period (m); A_e = effective area available for recharge (km^2); and s_y = specific yield of the aquifer.

Estimation of water balance components

Components of the water balance equation for seven blocks of Rajsamand district were estimated for five consecutive years (1999-2003). It was worth to note that groundwater recharge due to surface water irrigation could not occur during 2002 and 2003 due to severe droughts. The recharge to groundwater was taking place due to surface and groundwater irrigation, storage tanks and rainfall. The rainfall recharge was more significant compared to recharge from other sources. Also rainfall recharge influences the dynamic groundwater storage. Details of rainfall recharge for period 1999 to 2003 are given in Table 2.3.

Table 2.3 Rainfall recharge to dynamic groundwater storage during 1999-2003

Block	Type of Area	Zone	Potential Zone Area km^2	Monsoon recharge million m^3				
				1999	2000	2001	2002	2003
Amet	NC	Gn	465.19	10.02	2.44	60.71	5.96	26.60
Bhim	NC	Sc	232.78	14.39	10.93	28.00	2.11	19.61
	NC	Gn	104.38	6.02	8.02	15.67	0.00	14.54
Deogarh	NC	Sc	123.75	6.14	1.61	7.04	0.00	7.10
	NC	Gn	267.01	13.36	1.82	34.77	0.00	15.03
Khamnor	NC	Sc/Ph	236.77	9.95	11.69	29.01	4.26	14.78
	NC	Gn	395.99	10.73	18.49	44.99	4.49	34.95
	C	Gn	43.1	0.20	0.11	3.98	0.00	2.17
Kumbhalgarh	NC	Sc	372.49	19.56	24.53	41.33	6.94	38.11
	NC	Gn	164.07	5.01	3.86	24.21	1.22	7.19
Railmagra	NC	Sc	542.12	20.54	17.45	36.86	0.00	26.07
	C	Sc	58.06	1.69	1.21	4.19	0.71	1.82
Rajsamand	NC	Sc	133.1	2.81	2.23	12.08	1.55	1.68
	C	Sc	90.65	1.88	0.62	6.65	0.28	4.09
	NC	Gn 1	191.94	2.18	0.54	20.60	0.00	5.29
	C	Gn 1	31.19	0.61	0.19	5.39	0.00	0.90
	NC	Gn 2	53.16	1.10	0.01	2.36	0.70	0.57
	C	Gn 2	34.34	0.27	0	2.11	0.00	0.47

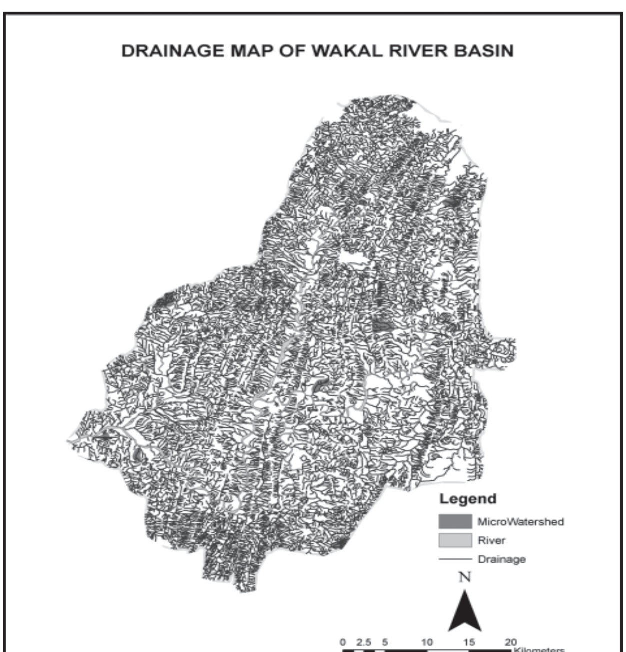
C= command; NC= Non-command

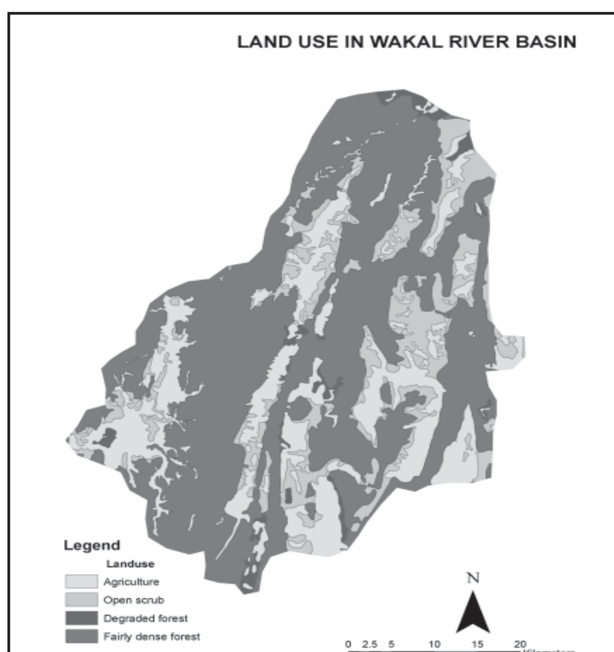
2.5 Delineation of Groundwater Potential Zones in Wakal River Basin of Udaipur District (Udaipur Centre)

In this study, the thematic layers on geomorphology, drainage, soil, land use, net recharge were used for the delineation of groundwater potential zones in the Wakal River Basin. To demarcate the potential zones, all the thematic layers were assigned suitable relative weights and then integrated using ILWIS GIS software. The weights of the different themes were assigned on a scale of 1 to 5 based on their influence on the occurrence of groundwater potential. Furthermore, different features of each theme have been assigned weights on a scale of 1 to 9 according to their relative influence on groundwater potential. At first level theme's contribution to groundwater potential would be recognized and at second level theme's individual standing/ level would be decided, thus it would be combined effect of two levels for each theme. Based on this scale, the qualitative evaluation of different features of a given theme was performed as: poor (weight = 1-1.5); moderate (weight = 2-3.5); good (weight = 4-5.5); very good (weight = 6-7.5); and excellent (weight = 8-9). The relative influence of the individual themes and features on groundwater potential will be decided based on the experts' opinion, information and local knowledge. The net recharge for the basin will be estimated using water table fluctuation method with point recharge value.

Different themes identified were drainage, land use and soil. Thematic maps were generated after the delineation of the basin map using topo-sheet. These maps were scanned, rectified and digitized. The drainage and land use maps of the basin are shown in Fig. 2.3. These maps of the basin were prepared under the GIS environment and whole area of the basin was categorized under four major classes viz. agriculture, open scrub, degraded forest and fairly dense forest. The major area of the Wakal basin falls under fairly dense forest. Soil map was also prepared for the basin. Most of the area of the basin falls under rocky soil group, in which soil depth and slope are the limiting factors. Average soil depth varied between 30 and 50 cm. These soils under hydrologic soil group D indicated the high runoff potential. In valleys, fine loam and clay soils with moderate slope of less than 8 per cent and soil depth up to 100 cm were present. The work is to be continued.

Fig. 2.3 Drainage and land use maps of Wakal River Basin





2.6 Groundwater Flow and Mass Transport Modelling of Small Agricultural Watersheds using Visual ModFlow Model (Raipur centre)

The upper Chhokranala watershed, a small groundwater basin located in Raipur district of Chhattisgarh state, was selected for the study. The Chhokranala watershed covers an area of 1731 ha. The altitude of the watershed varies from 290 m to 310 m above MSL. The topography of the watershed is almost flat (average slope 1.6 percent). The predominant soil of watershed is sandy clay loam. The watershed receives an average annual rainfall of 1400 mm. This watershed has gauging station at its outlet for recording the surface runoff, number of observation and pumping wells. Recording of water level and discharge measurements was done regularly. Visual MOD FLOW (VMOD Pro. 4.1) model was calibrated satisfactorily for simulating the groundwater flow under both steady state and transient state conditions for the watershed.

The calibrated values of K (1.9282×10^{-5} m/sec^{-1}) and storage (9.09×10^{-5} m^{-1}) for Layer 1 were found to be appropriate for modelling the groundwater levels satisfactorily under both steady and transient state conditions for a multilayer aquifer system. Similarly, respective values for the Layer 2 and layer 3 were 8.789×10^{-7} m/sec^{-1} and 1×10^{-9} m^{-1} as well as 1.3706×10^{-4} m/sec^{-1} and 3.31×10^{-4} m^{-1}.

Studies of hydro-geochemical properties indicated that almost all the chemicals present in the groundwater were within the prescribed limits as per the Indian Standard. Groundwater available in the watershed can be utilized for both drinking as well as irrigation purposes. Simulated concentrations were found in agreement with observed concentrations for the respective calibration periods of one and half year (1st January 2007 to 31st July 2008).

2.7 Assessment of Groundwater Resource for Irrigation in Burhi Gandak River on Pilot Basis (Pusa centre)

The annual groundwater recharge of seven districts viz. East Champaran, West Champaran, Siwan, Saran, Gopalganj, Muzaffarpur and Samastipur covering *Burhi* Gandak basin was calculated using the standard methodology suggested by Central Ground Water Board. Necessary information like rainfall data, block wise pre and post monsoon groundwater table data, number of shallow and deep tubewells, number of tanks/ponds and groundwater drafts were collected.

The results depicted that total annual recharge among the districts ranged from 54929 ha-m to 218361 ha-m, out of which 3818 ha-m to 182845 ha-m and 16747 ha-m to 35516 ha-m from monsoon and non-monsoon period, respectively. The gross annual draft ranged from 27296 ha-m to 80008 ha-m for the districts of Burhi Gandak basin. The net annual recharge available for irrigation development varied from 19510 ha-m to 29601 ha-m, indicating good availability of groundwater for further exploitation. The ground water balance was highest for W. Chamaparan district and lowest for Gopalganj district. The stage of development is highest for Siwan district (62 percent), and lowest for Samastipur district (20 percent). According to the definitions used by Central Ground Water Board all these districts fall in white category. Siwan and Gopalganj districts are rapidly approaching towards grey category suggesting a need for safe utilization of groundwater whereas in the other three districts viz. W. Champaran, E. Champaran and Gopalganj, Muzzafarpur, Samastipur, there is ample scope of groundwater exploitation for the economic development of the area.

Ground water development might be achieved with the help of shallow tubewells, bamboo boring and deep tubewells. The artificial ground water recharge including rain water harvesting should be taken up to augment the ground water reserve in Siwan and Gopalganj districts of the basin. Conjunctive use of surface and ground water resources should be encouraged for higher productivity. Drainage also should get adequate attention to save the land going under waterlogging and salinity.

2.8 Assessment of Ground Water Resources for Irrigation in Southern Districts of Bihar on Pilot Basis (Pusa Centre)

The study region (Nalanda district) is located in south Ganga plain, physiographic unit stretching between Precambrian Highlands in South and the Ganga River in North. Out of 20 blocks of Nalanda district, 18 blocks are having quaternary alluvium deposits, composed of multilayer sand, silt, clay, sandy clay and silty clay sequences. The Precambrian blocks are exposed as Rajgir hills (62 km^2) and as a small in liner (1 km$^{2)}$ near Biharsharif town. In Nawada district Quaternary alluvium and Precambrian Granite-Genesis rock formations are present in combination. In almost 11 blocks of the district, Quaternary alluvium and Precambrian Granite-Genesis rock formations are present in combination. The remaining three blocks namely Hilsa, Kasichak and Warisaliganj are having only quartenary alluvium deposits and are best suited for agricultural practices. These blocks are having better aquifers compared to other 11 blocks of the district. In Nawada district thickness of alluvial deposit is restricted to 150 m bgl. The sand zones are thin and less potential in comparison to North Bihar.

The average annual rainfall of Nalanda and Nawada district is 1003.6 and 1049 mm, respectively. The climate of both the districts represents a transition between dry and extreme climate of northern India and warm and humid of West Bengal with three distinct seasons viz., winter (Nov-Feb), summer (March –mid June) and monsoon (mid June – September) in a year.

The Groundwater Resource Estimation Methodology-1997 (GEC-97) was used for estimation of groundwater recharge. There are 20730 and 5463 dug wells, 21038 and 17478 shallow tube wells and 320 and 150 deep tube wells in Nalanda and Nawada district, respectively. The pre-monsoon (May 2008) water level generally varied from 3 to 9 m and 4 to 7 m below ground level in major part of the Nalanda and Nawada district, respectively. In Nalanda district, parts of Asthama, Biharsharif, Ranchi water level in pre-monsoon was upto 10 m bgl. The post monsoon (November 2008) water level generally varied from 1.8 to 5.5 m and 2 to 5 m below ground level in major part of the Nalanda and Nawada district, respectively. The long-term (decadal, 1998-2008) water level fluctuations in Nalanda and Nawada district varied from 2.21 to 2.83 m and 2.37 to 1.58 m with an average value of 2.56 and 1.58 m, respectively.

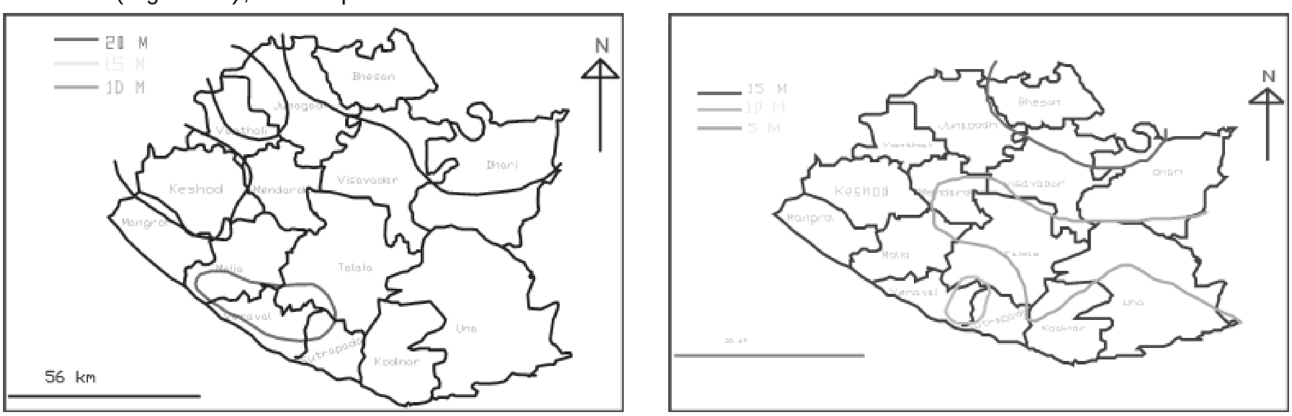
About 96 and 45 percent of shallow tube wells were having 4-6 HP pumps in Nalanda and Nawada district, respectively. The 18 percent of the total shallow tubewells were having 4 HP pumps in Nawada district. Diesel, electric and other pumps were 95, 3.8, 1.2 percent in Nalanda district. In Nawada district diesel, electric and other pumps were 45, 19, 4 percent, respectively. Nawada district had 31 percent wind mill operated pumps also. Non-availability of electricity was one of the reasons for lower number of pumps. The total annual groundwater recharge is 76898 ha-m and 53249 ha-m for Nalanda and Nawada district, respectively. The existing ground water draft for irrigation is 38226 ha-m for Nalanda district and 22366 ha-m for Nawada district. The ground water draft for all uses is 42327 ha-m for Nalanda district and 25495 ha-m for Nawada district.

The net annual replenishable groundwater resource is worked out to be 73054 ha-m for Nalanda district and 50586 ha-m for Nawada district. The net annual ground water available for future irrigation development is 25100 ha-m for Nalanda district and 20332 ha-m for Nawada district. The stage of ground water development is 58 percent for Nalanda district and 50 percent for Nawada district. According to definitions used by CGWB both Nalanda and Nawada district falls in safe category.

2.9 Determination of Ground Water Potential of the South West Saurashtra Region (Junagadh Centre)

The study area covered 14 Talukas of the south west part of Saurastra region. Total 24 open well sites were selected. The observations of water table, well dimensions, longitude and latitudes of well locations were recorded during pre-monsoon (June -2009) and post monsoon (Oct.-2009) from all 24 open wells and contour maps were prepared. Water samples were also collected from each well for analysis of water quality.

Referring to contour map of pre monsoon water table for 2009 (Fig 2.4 a), the depth to water table was more than 20 m in north eastern part of study area which is upland compared to remaining part. The depth to water table decreased towards western and southern side and in the central part it was less than 10 m. Contour map of post monsoon water table for 2009 (Fig 2.4 b), indicated few parts of north east having water table more than 15 m and the major part had less than 10 m. The contour map of maximum pre monsoon depth to water table indicated that it varied from 25 m to 10 m and in case of post monsoon it varied from 2.5 to 0.5 m. In both the cases the depth to water table decreased as moving towards west and south.



(a) (b)

Fig. 2.4 (a) Pre-monsoon and (b) post monsoon depth to water table

The map of pre monsoon minimum absolute head, in last 10 years showed that absolute head varied from 250 m to 0 m. In north east part head remained 250 m whereas near Mangrol it was recorded 0 m. The map of post monsoon maximum absolute head, in last 10 years showed that absolute head varied from 270 m to 10 m. In north east part the head remained 270 m whereas near Mangrol it was recorded 10 m. In both cases head decreased as moving towards west and south from north- east, it indicated ground water flow direction from north-east to south –west towards sea coast. During pre monsoon, some part had 0 m head indicating that further pumping could be dangerous.

Water quality contour maps of EC, SAR and TSS of year 2009 were prepared. The Pre monsoon EC varied from 1 to 8 dSm^{-1} and in case of post monsoon, it varied from 1 to 4 dSm^{-1}. Near coastal side especially in Mangrol Taluka, EC was high. In middle part it was less than 1 dSm^{-1}. The results depicted that major area has good water quality. SAR contours showed that it varied from 10 to 1 in both pre and post monsoon periods. The SAR was observed as 10 near Mangrol but in remaining area the SAR was less than 3. The contour map showed that TSS varied from 4 to 0.5 g/l during pre monsoon, whereas it varied from 2 to 0.5 g/l during post monsoon. The maximum TSS of 4 and 2 g/l was recorded during pre monsoon and post monsoon, respectively in Mangrol and it was less than 1 during pre and post monsoon in remaining part of region. The water quality was found good in entire south west region except Mangrol and few inside pockets along the coastal strip. Total groundwater potential of region was calculated as 6540.58 million cubic metre but for 2009 which is a semi drought year the potential estimated as 3841.26 million cubic metre.

3

CONJUNCTIVE USE IN CANAL COMMAND AREAS

3.1 Block wise Assessment of Water Resources in Bist Doab Tract (Ludhiana Centre)

The annual water available in the Punjab state is 3.13 M ha-m against the annual demand of 4.4 M ha-m. Thus there is deficit of 1.27 M ha-m of water, which is being met by overexploitation of underground water resources. The number of tube wells increased from 3.0 lakh in 1975 to 12.32 lakh in 2007. The trends, if not checked, may lead to an alarming situation. The study was aimed to assess the block wise availability and demand of water resources in Bist Doab tract so as to estimate the gap in demand and supply of water resources in the region. The seasonal and annual available water resource in each block was computed by adding the effective canal water, rainfall and the groundwater available in each block.

Study area

The area under Bist Doab tract, in the North East part of Punjab occupies 18 percent of the total state's area. On two sides it is bounded by Beas and Satluj river and on the third side it is bounded by the Katar Dhar ranges of Shivalik hills, thus clearly defined by hydraulic boundaries on all sides (Fig. 3.1). The total area of Bist Doab tract is 9.0 lakh ha,

Fig. 3.1 Location map of Bist Doab tract

comprising the districts of Hoshiarpur, Jalandhar, Nawanshaher, Kapurthala and Nurpur Bedi block of Ropar district. The area consists of 30 blocks, which includes some portion of *Kandi* area.

Assessing variation in supply and demand

In Bist Doab Tract the irrigation is done by surface water through Bist Doab canal system and Shah Nehar Canal System including branches, distributaries and minors. The Bist Doab Canal takes off from Ropar Head Works. It has four main branches; Jalandhar Branch and Nawanshehar Branch. Total length of Bist Doab canal system is 42.98 km. The Shah Nehar Canal System takes off from Talwara head works. Its total length is 19.47 km. Budhawar, Singowal, Shankar Wala, Dogran, Nangal, Nala Singh, Mukerian, Bishanpura distributaries emerge from Shah Nehar branch. The data regarding daily canal water releases, for the period 2002-2006, were analyzed to get season wise discharges and available canal water was taken as 50 per cent of canal water releases to account for losses due to canal seepage and return flow. Effective rainfall, contributing to crop evapotranspiration, was taken as 25 percent of total rainfall. Groundwater draft was calculated considering number of diesel and electric tube wells and some standard norms for the region. Reference evapotranspiration (ETo) was calculated for major *Rabi* and *Kharif* Crops of Bist-Doab tract of Punjab using Papadakis method (1965) and meteorological data from Regional Research Station, Kandi Area, Ballowal. Block wise estimation of the deficit/excess of water resources was obtained by taking the difference between the available water resources i.e canal water, rainfall and groundwater and evapotranspiration demand depending upon prevailing cropping pattern and climatic conditions for *Kharif* and *Rabi* seasons.

In terms of depth, total water available was 505 mm in Bist Doab tract out of which groundwater, rainfall and canal water contributed 68, 26 and 6 percent, respectively. The availability was in descending order in Kapurthala (729 mm), Jalandhar (654 mm), Nawanshaher (578 mm), Hoshiarpur (311 mm) and Ropar (224 mm) districts. The average annual groundwater withdrawal was maximum in Jalandhar district i.e. 167656 ha-m. The average annual canal water availability ranged from 25 – 63 mm in different districts of the study area. The average annual effective rainfall was calculated as 136 mm. The maximum water availability was in Nadala block i.e. 912 mm, whereas minimum water availability was in Talwara block i.e. 165 mm.

In Bist Doab tract, the average annual water demand exceeded average annual available water. The average seasonal ET demand of the region was 521 mm for *Kharif* season and 275 mm for *Rabi* season. There was average annual water deficit of 296 mm (i.e 255996 ha-m); 169 mm (145945 ha-m) in *Kharif* and 127mm (110052 ha-mm) in *Rabi* season, respectively. District wise variation in water availability and demand in Kapurthala, Jalandhar, Hoshairpur, Nawanshaher and Ropar was estimated to be -407 mm, -332 mm, -257 mm, -234 mm and -127 mm respectively (Fig. 3.2). Negative sign indicates water deficit whereas positive sign indicates water surplus to crop ET requirements. The analysis showed maximum water deficit of 202 mm and 129 mm in Jalandhar district during *Kharif* and *Rabi* season.

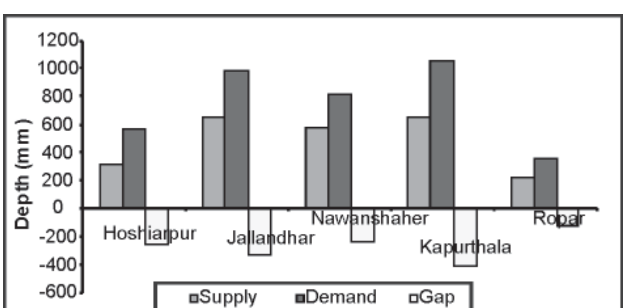


Fig. 3.2 District wise variation in supply and demand of water

In almost all the blocks of the area, net water was deficit in both seasons; except for Saroya, Hoshairpur and Mahilpur blocks, which showed surplus water availability of 23, 19 and 6 mm, respectively, during *Kharif* season and Banga block showed 12 mm surplus during *Rabi* season. Maximum water deficit of 543 mm during *Kharif* and 231 mm during *Rabi* season was observed in Mukerian and Balachur block, respectively. Minimum water deficit of 1 mm in Bhunga during *Kharif* and 43 mm in Bhunga and Aur during *Rabi* season was observed. Analysis revealed that thirteen blocks have water deficit greater than 250 mm, a water deficit of 100 mm or more was observed in six blocks and in remaining blocks the deficit was less than 100 mm during *Kharif* season. In *Rabi* season, a water deficit of 100 mm or more was observed in twenty two blocks. In almost all the blocks of Kapurthala and Jalandhar districts the gap between supply and demand of water was higher due to maximum area under paddy-wheat crop rotation. The water deficit was higher in Dasuya and Mukerian block of district Hoshairpur and Nawanshaher block in Nawanshaher district. The analysis revealed that the cropping pattern is the major factor responsible for higher water demand leading to water deficit in the Bist Doab tract.

3.2 Assessment of Saving in Water Resources through Precision Land Levelling in Punjab (Ludhiana Centre)

Declining irrigation water availability, sustainable crop production and increasing food demand necessitate quick adoption of modern scientific technologies for efficient water management. Land levelling at farmer's field is an important process in the preparation of land. It enables efficient utilization of scare water resources through elimination of unnecessary depression and elevated contours. Laser levelling is a laser guided precision levelling technique used for achieving very fine levelling with desired grade on the agricultural field. Recently laser levelling is becoming popular in almost entire state of Punjab. Precision land levelling must be treated as a precursor technology for improving crop yields, enhancing input-use efficiency and ensuring long term sustainability of the resource base in intensively cultivated areas. Keeping in view the benefits of laser leveling, the study was conducted to evaluate the performance laser leveller at farmers' fields and to estimate the saving in water resources at different level of adoption. Efforts were made to select those farmers who have laser levelled as well as traditionally levelled fields and they cultivate maximum number of crops(Fig. 3.3).

Fig. 3.3 Laser land leveling in operation

Water saving at farmers' fields

Water savings for different crops were estimated from the difference of time required to irrigate unit area of laser leveled and traditionally leveled field. Other conditions such as crop, soil and farmers' practices remained same for both the fields. It was observed that water saving at farmers' fields varied from 22 to 33 percent for different crops. Average water saving for maize, wheat, cotton, paddy, barseem and potato was 27.1, 26, 27.25, 26.33, 27, 25 and 26 percent, respectively. Water saving potential for different crops in the state of Punjab was estimated at different level of adoption of laser leveling technology (Table 3.1).

Table 3.1 Water saving in different crops at different level of adoption of laser leveler

Crop	Water saved (%)	Water Reqd. (cm)	Water saved (cm)	Area (ha)	Water saved (ha-m) at different level of adoption (%)				
					10	25	50	75	100
Maize	27.1	35	9.5	152560	1447	3618	7235	10853	14470
Wheat	26.0	35	9.1	3469520	31573	78932	157863	236795	315726
Cotton	27.25	20	5.5	541060	2949	7372	14744	22116	29488
Paddy	26.33	160	42.1	2625204	110595	276486	552973	829459	1105946
Total	26.25	81.3	21.3	6788344	146563	366408	732816	1099224	1465631

At different level of adoption of laser leveling the water saving potential is maximum in rice crop, followed by wheat considering areas under these two crops. Since rice-wheat is the major cropping pattern in the state, it was estimated that by laser levelling the entire area under rice -wheat system there is a potential to save 1421672 ha-m of water. The percentage irrigated area from canals and tubewells was observed as 29 and 71 percent, respectively. Therefore, 100 percent adoption of laser leveller in rice-wheat system the groundwater draft can be reduced by 19 cm at state level.

3.3 Conjunctive Use Planning of Surface and Ground Water in Jafarpur Minor Command Area of Kagarsen Canal System (Pantnagar Centre)

The present study of conjunctive use of surface and ground water was conducted in Jafarpur minor command area of Kagarsen canal system in Udham Singh Nagar district of Uttarakhand (Fig.3.4).

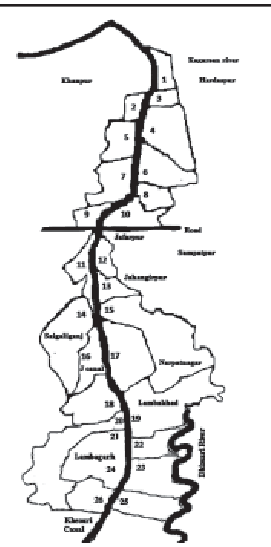


Fig. 3.4 Layout of Jafarpur minor.

Considering available land and water resources, crop water requirement and net returns from crops, an attempt was made to find more profitable cropping pattern using linear programming models. The Kagarsen canal system takes water supply from Kagarsen river and covers parts of Rampur district of Uttar Pradesh and Udham Singh Nagar district of Uttarakhand. The design discharge of the minor is 28 cusec. The length of the minor is about 7.2 km. The cultivable command area of Jafarpur minor is 559 ha.

The soil of the study area varied from loam to sandy loam; moderately to well drain. The parent material was medium to coarse textured alluvium. Soils of this area had been developed under sub-humid climate, high water table conditions and natural vegetation of tall grasses. The pH varied from 6.5 to 6.8 (normal soil pH varies from 6.5 to 7.5). The organic carbon was in medium range (between 0.15 and 0.61 percent). The available moisture content of the soil varied from 5.9 to 13.8 percent. The major crops grown in the command area of Jafarpur minor were paddy and sugarcane in the *kharif* season and wheat in the *rabi* season. Other crops grown in the command area were barely, gram, lentil, pea, *lahi*, summer rice, maize, *urad*, sunflower, soyabean and berseem. Beside rainfall, surface water supply from the Jafarpur minor and the ground water through tube wells were the major sources of the water in the command area. The biweekly canal and ground water availabilities for irrigation in Jafarpur minor command were estimated. The gross irrigation requirement of crop was computed dividing net irrigation requirement by overall irrigation efficiency of the Jafarpur minor. The biweekly crop water demand for existing cropping pattern in the command area was estimated considering overall irrigation efficiency of the Jafarpur minor as 33.5 percent for *kharif* and 24.5 percent for *rabi* season. Assuming overall efficiency of 80 percent for the ground water sources, the gross ground water pumped for irrigation was worked out. There was no need of ground water when assessed on annual basis, but there was a requirement of 149523 ha-mm of ground water on biweekly basis (Table 3.2).

Table 3.2 Crop water demand and supply scenario in Jafarpur minor command area.

Sl. No.	Particulars	Annual basis ha-mm	Biweekly basis ha-mm
1	Net canal water available	243153	112113
2	Net crop water demand	239207	239207
3	Net ground water requirement (2 - 1)	(-)3946	127094
4	Gross ground water requirement	-	149523
5	Ground water available in white category	255879	255879
6	Balance ground water (4 - 5)	255879	106356

There was sufficient ground water to meet crop water demand in the Jafarpur minor command for prevailing cropping system for which analysis was done. The excess canal water in rainy season could be stored by constructing the water harvesting structures in the command area for irrigating the crops in *rabi* season, when crop water demand was more than the availability of canal water or when there was no canal water supply.

The optimal cropping pattern was obtained for the command by considering the total water availability in the area, irrigation water requirement and cost of cultivation of different crops grown in the command area. Crop area constraints were imposed considering the food and fodder requirement of the human population and livestock of the command area. When crop area constraints were imposed, the crops in the optimal crop plan were *lahi*, wheat, rice summer, berseem and rice *kharif* at a level of 7.5, 484, 70, 5 and 551.5 ha, respectively. The aggregate net return obtained was Rs. 33.08 million. The increase in aggregate net return over existing plan was by 21.70 percent. It was also observed from the study that when maximum crop area constraint for rice summer was introduced the area under wheat crop is increased from 181.42 ha to 484 ha.

This plan allocated 551.5 ha land under rice *kharif* which was about 98.66 percent of the total cultivable command area of the minor. Rice transplanting was done manually, so it was difficult to manage transplanting of paddy in the area. Keeping this in view the maximum rice area constraint of 380 ha was introduced. The crops in the optimal crop plan were *lahi*, wheat, rice (summer), pea, berseem, sugarcane, soyabean and rice (*kharif*) at a level of 7.5, 371.57, 22.5, 99.95, 5, 79.95, 91.55 and 380 ha, respectively. The aggregate net return obtained was Rs. 29.86 million. The increase in aggregate net return over existing plan was by 9.86 percent. It showed that when maximum crop area constraint for rice (*kharif*) was introduced, the crops like pea, sugarcane and soyabean got the place in the optimal crop plan. The annual crop water demand of optimal crop plan on biweekly basis was about 159608 ha-mm and annual ground water requirement was about 75762 ha-mm. The net annual excess canal supply was about 135062 ha-mm. Study revealed, that sufficient quantity of canal water was available in the command area, if this excess canal water supply could be stored by constructing water harvesting structures in the command area. Then there would be no additional ground water requirement for irrigation. This stored canal water could be used for irrigating *rabi* crops or when there was no canal water supply.

3.4 Conjunctive Use Planning of Surface and Groundwater in Mula Command Area (Rahuri Centre)

The irrigation schemes in semi-arid tropics are designed for supplemental life saving irrigation for crops and mostly the surface irrigation methods are adopted with project efficiency around 40 percent. It is necessary to use all the surface and groundwater resources in the command area conjunctively, efficiently and optimally through integrated management of surface and ground water. Therefore, it is proposed to study the existing utilization pattern of surface and ground water in the Mula command area so as to identify the problem areas and to develop the location specific methodology accordingly for optimum utilization plan. The two outlets having 25 to 40 ha command areas under Mula (major) Irrigation Project will be chosen. The study also includes modeling by SWAB model. The developed methodology will be tested and validated before recommending it to whole command. The field study will initiated during the year 2010-2011.

3.5 Management of Canal Command - a Conjunctive Use Approach (Jabalpur Centre)

The study was conducted in part of Left Bank Canal (LBC) command of a Bargi major irrigation project, presently named as Rani Avanti Bai Sagar Project (RABSP) in Madhya Pradesh, built across river Narmada near the village Bijora. The LBC is 137.2 km long, out of which 65 km passes through Jabalpur and command covers Jabalpur and Narsinghpur districts. The climate of the study area is subtropical. The study area comprised of commands of four minors of LBC, namely, Dhulakheda, Pipariya, Jhansi and Jamuniya Minor. As per U.S.D.A. textural classification of the soil, the surface texture of majority of areas varied from clay to clay loam. The major crops grown in the area during *rabi* season are wheat, gram, lentil, pea, arhar and some vegetable crops and in *kharif* season the main crop is paddy. It was observed that the application efficiency in minor commands reduced with reach of minor. It meant it was higher in upper reach and lower in the tail area. It was considerably good in head and middle reach, attributing adoption of improved irrigation practices. Even tail reach the application efficiency was satisfactory in all minor except in Jamuniya. The distribution efficiency was quite high in all minors and in all three reaches showing awareness among the farmers. Modern irrigation system like sprinkler has been adopted by farmers. The comprehensive study of different efficiencies indicated that there was need to improve conveyance efficiency in all minors though application and distribution efficiencies were satisfactory. The seepage loss was measured as 0.03117, 0.03191, 0.02008, 0.01730 cumec per length of minor in Jamuniya, Jhansi, Pipariya and Dulhakheda minor, respectively. Performance of irrigation system was evaluated as per indicators given by David E. Nelson. Indicators were oriented toward items that directly or indirectly affect water deliveries, rather than indicators like crop yields that are also affected by other factors (Table 3.3).

Table 3.3 Performance indicators for the study area

Parameters	Performance Indicator	Name of Command Area			
		Jamuniya	Jhansi	Pipariya	Dhulakheda
Water	Tail-end Supply Ratio, TSR	0.208	0.25	0.58	0.416
Deliveries	Delivery Timeliness Ratio, DTR	1	1	1	1
	Carrying Capacity Ratio, CCR	0.918	0.940	0.993	0.811
Maintenance	Poor Structure Ratio, PSR	1	1	1	1
	Fee Collection Performance, FCP	0.95	0.90	0.80	0.82
	Maintenance Budget Ratio, MBR	Nil	Nil	Nil	Nil
Financial	Manpower Numbers Ratio, MNR	0.0142	0.0196	0.0066	0.0083
	Sustainability of Irrigated Area, SIR	0.325	0.246	0.416	0.436
Sustainability	Relative Ground Water Depth, RGWD	1.5	1.5	1.5	1.5
	Area/Infrastructure Ratio, AIR	21.53	22.66	40	27.58

The Delivery Timeliness Ratio and Carrying Capacity Ratio indicated betterment of minor as far as water availability was concerned. The head and middle reach farmers were in better position compared to tail end farmers. Poor Structure Ratio value of 1 indicated that all structures were in poor condition. The same was true for budget allotment for maintenance. Low Manpower Number Ratio was indicative of poor availability of manpower for maintenance. The value of 0.5 for Sustainability of Irrigated Area suggested that difference between created and utilized potential. Relative Ground Water Depth values were more than 1 and it indicated that safe water depth in all commands. There was no problem of water logging. It was also indication that recharge in the command was not exceeding ground water draft and conjunctive use of canal and ground water was well established in the command. The awareness of the farmers towards the problems of irrigation system was good. It was found that the 62, 65, 60, 58 percent farmers in the command of Jamuniya, Jhansi, Pipariya, and Dhulakheda minor, respectively, were keen to participate for making irrigation system better. They regularly maintained the canal system by cleaning it from vegetation and lining it, thus contributed towards smooth functioning of the system.

3.6 Conjunctive Use of Surface and Groundwater Sources in the Parambikulam Aliyar Project (PAP) Command (Coimbatore Centre)

Parambikulam Aliyar basin spreads over 3462 sq.km. out of which Hillock is 1480 sq.km. Coimbatore, Tiruppur and Erode districts share the basin area. The total command area worked out to 174553 ha. The Parambikulam – Aliyar basin is categorized into forest, barren, uncultivable, non-agricultural, cultivable waste, pasture, grazing land, fallows, etc. resulting to 346200 ha. Sub basins are Sholayar, Aliyar and Palar. Parambikulam Aliyar Project command comes under Aliyar and Palar sub-basins.

Pollachi main canal (new ayacut) of Aliyar sub-basin has been selected for detailed water management study, where the entire command has been divided into zone A and zone B with equal area and each zone gets canal supply once in alternate years. The designed discharge of the main canal is 298.00 cusec at head of the canal. It gets reduced to 53.81 cusec at 42.19 km. The distributary no.4 of Pollachi main canal was selected for water balance study.

Rotational water supply (or) Warabandhi

'WARA' means 'turn', 'BANDHI' means 'distribution' and the term 'WARABANDHI' implies distribution of water on turn basis or 'Rotational Water Supply'. Rotational Water Supply is designed as a system of equitable system of water by turns, according to predetermined schedule specifying the day, time and duration of each irrigation to individual farm holding in proportion to its area within an outlet command. The salient features of this system are outlined below:

- Rotational Water Supply is formulated to work round the clock and does not allow any water to run as waste during night hours.
- Irrigation is given only in pre determined and measured quantities to each and every farmer, thus safe guarding the interests of tail enders also.
- As a clear prior schedule is drawn for the supply of water, the farmers are able to plan the farming operations accordingly.
- Planned in such a way to deliver water to every individual farm holding from field channels through suitable control and delivery structures. This eliminates field –to-field irrigation and thus improves the irrigation efficiency.
- Operational plan is drawn in a holistic manner based on irrigation season, taking care of cropping pattern and crop water requirement.
- The farmers' views i.e., the view of major stakeholders, are given its due. In the event of deficit, this enables follow up corrective action leading to better liaison between the users and the suppliers of water.
- Creation of functional solidity through the summation of individual interest and peoples' participation in management instead of traditional authority.
- Localized planning based on location specific needs leading to increased productivity.
- RWS schedules are drawn in consultation with the farmers. Canal roasters are handed over to farmers' associations. The monitoring of the implementation of these schedules for at least two seasons are required to ensure proper working of Warabandhi.

3.7 Conjunctive use of Canal Water and Marginally Saline Groundwater for Wheat Cultivation under Calcareous Soil of Bundi District (Udaipur centre)

Field experiment was conducted with five conjunctive water use modes of canal water and marginally saline groundwater and four levels of zinc sulphate in randomized block design wth four replications. The treatments were I_1 - irrigation with canal water, I_2 - irrigation with groundwater, I_3 - One irrigation with canal water followed by one irrigation with groundwater (in cyclic mode), I_4 - Two irrigation with canal water followed by one irrigation with groundwater (in cyclic mode), I_5 - One irrigation with canal water followed by two irrigation with groundwater (in cyclic mode) and Zn_0 – Control, Zn_{15}- 15 kg zinc sulphate, Zn_{25}- 25 kg zinc sulphate and Zn_{35}- 35 kg zinc sulphate.

The observations on plant height of wheat revealed that increasing number of groundwater irrigations significantly decreased the plant height. The highest plant height (77.94 cm) was recorded under canal water irrigation (I_1) followed by I_4 (two irrigations with canal water followed by one irrigation with groundwater in cyclic mode) and the lowest (57.33 cm) was recorded under I_2 (irrigations with groundwater).There was a significant increase in plant height with increase in levels of $ZnSO_4$. However, this increase was significant upto 25 kg $ZnSO_4$ ha^{-1} which was at par with 35 kg $ZnSO_4$ ha^{-1} but was higher by 20.30 per cent over control (0 kg $ZnSO_4$ ha^{-1}).

The number of effective tillers of wheat per metre row length tends to decrease or decrease significantly with increasing number of groundwater irrigations. However, insignificant difference was obtained between I_1 and I_4. The maximum effective tillers were minimum under I_2. The pattern of effect of different conjunctive use modes of irrigation water on effective tillers per metre row length of wheat in descending order was found in order of: $I_1 > I_4 > I_3 > I_5 > I_2$. Application of zinc sulphate enhanced significantly the number of effective tillers per metre row length. The highest effective tillers were recorded under the application of 35 kg $ZnSO_4$ ha^{-1} that was higher by 25.98 per cent over control (Zn_0) but it was at par with 25 kg $ZnSO_4$ ha^{-1} (Zn_{25}).

The test weight, grain and straw yield are presented in Table 3.4. Different treatments of irrigation water did not influence the test weight of wheat significantly. However, the maximum test weight was obtained under the treatment I_1 and minimum under I_2. The levels of zinc influenced the test weight significantly. The application of 35 kg $ZnSO_4$ ha^{-1} recorded highest test weight (41.72 g) but it remained statistically at par with 25 kg $ZnSO_4$ ha^{-1} and the lowest (35.45 g) under control (Zn_0).

The grain yield of wheat decreased significantly with increasing proportion of groundwater irrigations. The reduction in grain yield due to I_2, I_3, I_4 and I_5 was recorded 25.60, 8.49, 1.00 and 12.53 percent, respectively, as compared to canal water irrigation (I_1). The application of zinc sulphate at increasing levels brought significant increase in grain yield of wheat. Zinc sulphate application @ 25 kg $ZnSO_4$ ha^{-1} gave significantly highest grain yield which was statistically at par with the yield fetched by 35 kg $ZnSO_4$ ha^{-1}. The application of zinc @ 25 kg $ZnSO_4$ ha^{-1} increased grain yield by 19.50 percent over control.

Table 3.4 Effect of conjunctive water use mode and zinc sulphate application on test weight, grain and straw yield of wheat

Parameters Treatment Irrigation water	Test Weight (g)	Grain Yield (q ha^{-1})	Straw Yield(q ha^{-1})
I_1 = CW	40.67	36.88	55.47
I_2 = GW	38.21	27.44	41.78
I_3 = 1CW+1GW	38.9	33.75	50.93
I_4 = 2CW+1GW	39.87	36.51	54.95
I_5 = 1CW+2GW	38.41	32.26	48.75
SEm $_\pm$	1.023	0.894	1.332
$CD_{(P=0.05)}$	2.896	2.531	3.771
Zinc Sulphate			
Zn_0	35.45	29.48	45.23
Zn_{15}	38.49	32.83	49.72
Zn_{25}	41.19	35.23	52.64
Zn_{35}	41.72	35.94	53.91
SEm $_\pm$	0.915	0.800	1.202
$CD_{(P=0.05)}$	2.59	2.264	3.374

3.8 Evaluation of Water Productivity of Common Crops in Pusa Block of Samastipur District (Pusa Centre)

The water productivity values of paddy grown in nine farmers' fields in Harpur village of Pusa Block were evaluated. The crop was irrigated with groundwater and the average number of irrigation was 3.8 for hybrid paddy compared to 2.75 for *MTU-7029.* The agricultural year 2009-10 was a drought year up to mid- August, 2009. There was rainfall deficiency of 43 percent. The yield of both varieties of rice was relatively lower this year. The crop yield was higher by 19 percent for hybrid paddy compared to *MTU -7029*.

The water productivity for gross inflow ranged from 0.22 kg/m^3 to 0.29 kg/m^3 for hybrid 6444/ *MPH-55* with an average value of 0.25 kg/m^3 and from 0.23 kg/m^3 to 0.30 kg/m^3 for *MTU-7029* with an average value of 0.26 kg/m^3. This indicated that 4000 litre water was used to produce one kilogram of hybrid variety of paddy whereas for *MTU 7029* variety of paddy 3846 litre water was required to grow one kilogram of rice. The water productivity determined, based on irrigation inflow was higher than that of gross inflow. The value of irrigation water productivity ranged from 0.37 kg/m^3 to 0.60 kg/m^3 for hybrid 6444/ *MPH-55* with an average value of 0.52 kg/m^3 and from 0.59 kg/m^3 to 0.69 kg/m^3 for *MTU-7029* with an average value of 0.63 kg/m^3.On comparison between the two varieties of paddy in terms of irrigation water productivity, it can be concluded that irrigation water productivity of *MTU-7029* variety of paddy was higher by 21.15 percent than *hybrid 6444/ MPH-55* variety of paddy. Process depletion is defined as yield divided by crop evapotranspiration. The process depletion was higher for hybrid 6444/*MPH-55* (0.65 kg/m^3) than *MTU-7029* (0.58 kg/m^3).

3.9 Conjunctive Water Use Planning of Salud Distributary Command of Tandula Canal in Durg District (Raipur Centre)

Tandula Twin reservoir was constructed during the year 1920 across the river Tandula and Sukha nalla with common un-gated spillway for an irrigation of 56,070 ha both for *Kharif* and *Rabi* crop (Fig. 3.5). Due to non cultivation of *rabi* crop it was proposed to supply water during only k*harif* crop for an increased irrigation of 68219 ha.

As the dam was constructed to meet the increased demand for industrial needs water was also supplied for more irrigation area through canal networking. There is only one main canal in the Tandula dam which is used to meet the needs of water of the Bhilai Steel Plant, its length is 68.80 miles and width 5954 feet. The main canal has 18 sub canals 47 division and 8 distributaries. The length of lined main canal is 42.75 km and the total area to be irrigated by the Tandula dam is 103705 ha. The water spread area at FTL (full tank level) in the Tandula dam is 10848 acres. The total length of Tandula dam is 4419.3 m, its maximum height is 24.9 m and the top width of dam is 3.65 m. There are 500 villages under 14 commands. The gross area under these commands is 257960 ha out of which the total cultivable area is 246360 ha. In addition, an area of 13,896 ha area also got irrigated.

The total command area of Selud distributary is 13969.49 ha. The distributary takes off at 38.423 miles of the Tandula main canal and the discharge at the head of the distributary is 11.33 cumecs. The total length of the distributary is 17100 m. The canal parameters and salient feature of Slud distributary has been studied. There are 13 minors and 37 numbers of direct outlets from the distributary for supplying irrigation water to the command area. The different minors are Kapsi, Magarghatta, Roohi, Jheet, Karga, Saoni, Tulsi, Batang, Lohasi, Patan, Bendri, Punaidih, and Chhuya. There are also ponds, wells, tubewells from where irrigation water is taken conjunctively in the command area. In selud distributary command there are four functional water user associations, taking care separately of Bendri minor, Batang minor, Magarghatta minor and Kapsi minor. Concentration of tube wells is higher in SW Quadrant followed by SW, NW and NE quadrant.

Survey indicated that only canal water is not sufficient to grow the crop round the year. Farmers are using ground water other than surface water especially from canal, water harvesting ponds, village tanks for raising the crops during both the seasons i.e. *kharif* and *rabi*. The cropping pattern and irrigation requirement of crop grown are presented in Table 3.5 and 3.6, respectively.

Table 3.5 Cropping pattern of the Tandula canal command

Main crop	Soil requirement	Water requirement	Duty	Delta
Kharif (Paddy)	Heavy redentive soil and clay content of 40%	More amount of water	775 ha/cumec	120 cm (6"x 6"x 6")

Table 3.6 Irrigation requirement of crop grown in Tandula canal command

Crop	Period of growth	Average depth required	Irrigation requirement & remark	Average quantity of seed required in kg/ha	Average quantity of yield in kg/ha
Paddy	July to November	125-150 cm	Standing water of 5-8 cm gives best results	30-35	4500

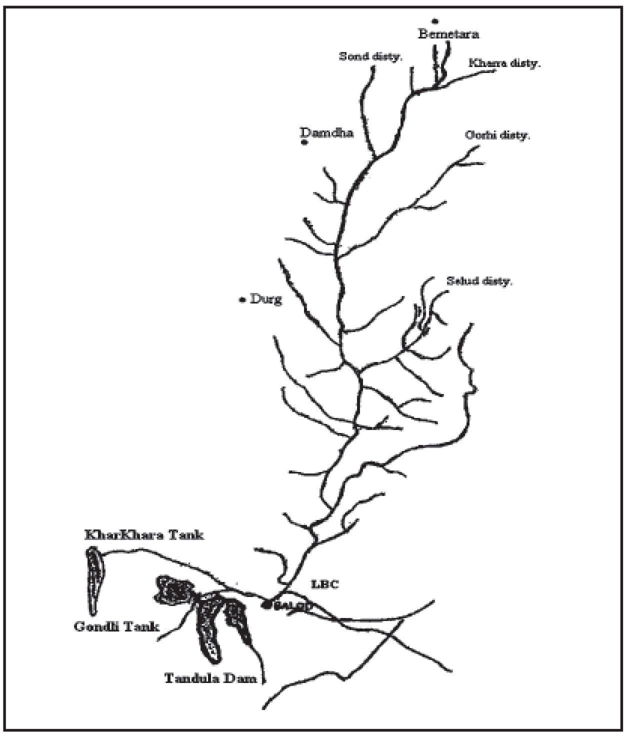


Fig. 3.5 Canal networking of Tandula dam

3.10 Conjunctive Use of Surface Water with Groundwater for Irrigating Wheat Crop (Junagadh Centre)

The Gujarat state is divided into eight Agro Ecological zones. Average annual rainfall is 800 mm and wheat is the major crop grown in winter in Gujarat. The state is mainly divided in four major regions Saurashtra, kutchh, North Gujarat and South Gujarat. In three parts viz., Saurashtra, Kutchh and North Gujarat mostly groundwater is used for winter crops. Only South Gujarat part of Gujarat has good irrigation facilities through canal network of Mahi, Narmada and Tapti. To meet the water requirement, conjunctive use of surface and ground water for wheat crop in winter season is planned. Experiment was initiated at Instructional farm of College of Agricultural Engineering & Technology-JAU-Junagadh under wheat crop (GW-366) with two treatments viz., A and B i.e. with and without conjunctive water use, respectively. The two water sources were : 1) check dam and 2) tube well. For treatment A water was supplied initially from check dam and later on from tube well and for treatment B water was supplied through tube well only.

The crop coefficient Kc curve of wheat GW-366 crop was developed for Junagadh station as per the procedure described in FAO 56 Penman- Monteith method and presented in Fig 3.6.

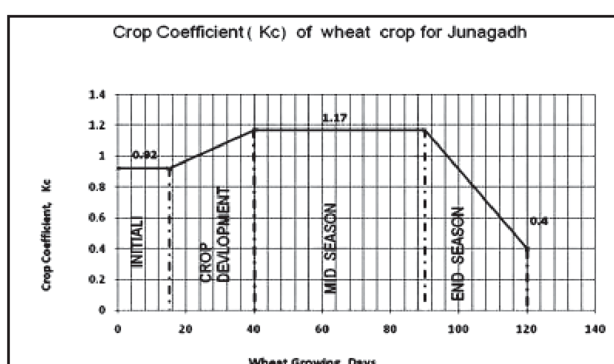


Fig.3.6 Crop coefficient (Kc) of Wheat crop for Junagadh

Based on daily Kc values, nine years mean values of ET_0 and considering 60 percent application efficiency of border method the Irrigation Depth and scheduling was prepared and presented in Table 3.7. The recommendation for irrigation interval for wheat crop by JAU, Junagadh is 5-7 days during the initial period and 8-10 days during later season. As water was directly delivered to experimental fields by pipe line so conveyance losses were kept at minimum.

Effect of sowing date on evaporation loss (mm) from open water surface for Junagadh was analysed by using nine years' pan evaporation data, collected from Junagadh Agricultural University Observatory of Junagadh station. The data revealed that total evaporation from end of monsoon (October 15) to probable drying date of check dam (December 15) is 295.21 mm. Evaporation loss of 162.36 and 138.41 mm from the check dam can be saved by adopting sowing date as 10th and 15th Nov, respectively, when water of check dam was utilized for basal irrigation.

It was observed that evaporation loss of 134.00 and 110.11 mm can be saved by these sowing dates (10th and 15th Nov, respectively) when two (basal and 1st) irrigations were given from check dam. Evaporation loss of 79.06 and 59.37mm can be saved by sowing dates (10th and 15th Nov, respectively) when three (basal, 1st and 2nd) irrigations were given from check dam. It can be inferred from the above results that in case of small farm holding and mixed cropping pattern, two irrigations from check dam are advisable for 15th Nov sowing and evaporation loss of 110.11 mm may be saved from the check dam storage by utilizing it on or before 21st Nov effectively. Total water supplied from both the sources and power consumed were estimated and it was found that groundwater draft reduced by 131.01 m^3 in case of wheat crop grown under conjunctive water use and power consumed is less than that required for irrigating without conjunctive use.

Table: 3.7 Wheat irrigation scheduling and irrigation depth (Date of sowing : 12-11-2009)

Days After sowing	Date	Mean ETo	Kc	ETc, (mm) (mm)	ΣETc for irrigations interval(mm)	Water applied at 60 % Border Effi., (mm)	No. of irrigations
1	2	3	4	5	6	7	8
1	12/11/09	3.44790	0.92	3.17206			Basal
2	13/11/09	3.49315	0.92	3.21370			
3	14/11/09	3.38197	0.92	3.11142			
4	15/11/09	3.23492	0.92	2.97612			
5	16/11/09	3.29680	0.92	3.03306			
6	17/11/09	3.33226	0.92	3.06568	18.57204	30.95341	First
7	18/11/09	3.22756	0.92	2.96936			
8	19/11/09	3.17345	0.92	2.91958			
9	20/11/09	3.52805	0.92	3.24580			
10	21/11/09	3.32647	0.92	3.06035			
11	22/11/09	3.06898	0.92	2.82346			
12	23/11/09	3.04996	0.92	2.80597			
13	24/11/09	2.98398	0.92	2.74526			
14	25/11/09	3.25013	0.92	2.99012			
15	26/11/09	3.20032	0.92	2.94430			

16	27/11/09	3.19911	0.93	2.97394			
17	28/11/09	3.26613	0.94	3.06765			
18	29/11/09	3.47515	0.95	3.29738			
19	30/11/09	3.47955	0.96	3.33501	39.17817	65.29694	Second
20	1/12/09	3.21360	0.97	3.11100			
21	2/12/09	3.21246	0.98	3.14079			
22	3/12/09	3.09105	0.99	3.05181			
23	4/12/09	2.80355	1.00	2.79492			
24	5/12/09	2.93249	1.01	2.95166			
25	6/12/09	3.02006	1.02	3.06883			
26	7/12/09	3.09738	1.03	3.17718			
27	8/12/09	2.96846	1.04	3.07348			
28	9/12/09	2.93046	1.04	3.06232	27.43198	45.71997	Third
29	10/12/09	3.16520	1.05	3.33805			
30	11/12/09	3.30381	1.06	3.51600			
31	12/12/09	3.35196	1.07	3.59947			
32	13/12/09	3.42591	1.08	3.71182			
33	14/12/09	3.14378	1.09	3.43637			
34	15/12/09	3.07910	1.10	3.39527			
35	16/12/09	3.34162	1.11	3.71689			
36	17/12/09	3.23575	1.12	3.63024			
37	18/12/09	3.29320	1.13	3.72635	32.07046	53.45077	Fourth
38	19/12/09	3.43356	1.14	3.91819			
39	20/12/09	3.32053	1.15	3.82113			
40	21/12/09	3.22877	1.16	3.74659			
41	22/12/09	2.95179	1.17	3.45359			
42	23/12/09	3.21770	1.17	3.76470			
43	24/12/09	2.96524	1.17	3.46933			
44	25/12/09	3.05100	1.17	3.56967			
45	26/12/09	3.32623	1.17	3.89169			
46	27/12/09	3.36050	1.17	3.93178			
47	28/12/09	3.02131	1.17	3.53494	37.10162	61.83603	Fifth

4

ARTIFICIAL GROUNDWATER RECHARGE

4.1 Development of an Efficient Composite Filter for Groundwater Recharge Using Surface Runoff through Gravity Well (Ludhiana Centre)

The number of tube wells has increased manifolds. Total number of tube wells in the state has reached to about 12.46 lakhs in the year 2008. The rainfall has been showing a decreasing trend during the last decade but fortunately in the year 2009 good rainfall was observed in all most all parts of Punjab. Water table in the state especially in central Punjab is declining at alarming rate and at some places at the rate of more than 1m per annum. Groundwater recharging through gravity well is solution to the problem. However, it is necessary to ensure the quality of recharging water before recharging. For this purpose, horizontal composite filter (coir + gravel +sand) was designed. Quality of filtered water was significantly improved because of it but filtration rate i.e. recharge rate was drastically reduced. Hence, composite filter was redesigned to have more projected area so as to increase the filtration rate with reasonable recharging water quality. Pea gravels were used instead of sand as pea gravels ensure better filtration rate. Modified filtration unit acted as a supplement to the earlier unit, so that observations could be continued from the existing set-up. The performance of modified composite filter using surface runoff through gravity well was studied for two years and this year's performance was similar to previous year. It was estimated that recharge rate up to 32 l/sec can be achieved by modified design of the filtration unit. In general recharge rate was higher than 26 l/sec was observed. It is observed that performance of modified design was better than earlier design. There is need to regularly monitor the filtration unit especially during rainy season to avoid clogging.

4.2 Recharging Dry Shallow Aquifers Using Surface Runoff (Ludhiana Centre)

Surface water logging adversely affects crop yields in case of non paddy crops. To control the surface water logging and to utilize surface runoff for recharging, an experiment was planned to evaluate the performance of gravity well as a recharge structure by using surface runoff from agricultural land/roadside. Two gravity type recharge tube wells were installed near university Gate No.4 and Gate No. 6. The recharge well consists of a 9 inch bore excavated upto about 80 ft depth (8-10 ft above the existing water table) from the ground surface having a 7 inch diameter PVC pipe with 20 ft length in between having perforations covered with nylon mesh, matching with sand layers. A semi circular pit of about 8 ft diameter and 9 ft depth from the ground surface was excavated around the pipe for providing graded filter material in order to filter the surface runoff before being recharged into the aquifer. The depth of semi circular pit was 7 ft for both the structure but to enhance the recharge rate, it was increased to 9 ft for the recharge structure at Gate no. 4 this year after the rainy season. It was observed that the rate of recharge through structure at Gate No. 4 was 2 to 3 times higher than the structure at Gate No. 6 during 2009. Thus increasing the depth of pit and increasing length of perforated pipe had positive impact on recharge rate. Keeping in view the performance of structure at Gate No. 4, depth of semi circular pit of structure at Gate no. 6 was increased from 7 ft to 10 ft. The additional 3 ft depth was filled with brick blast to enhance the filtration rate. Also the filter length for this recharge structure was increased to 6 ft from existing 2 ft (Fig. 4.1).

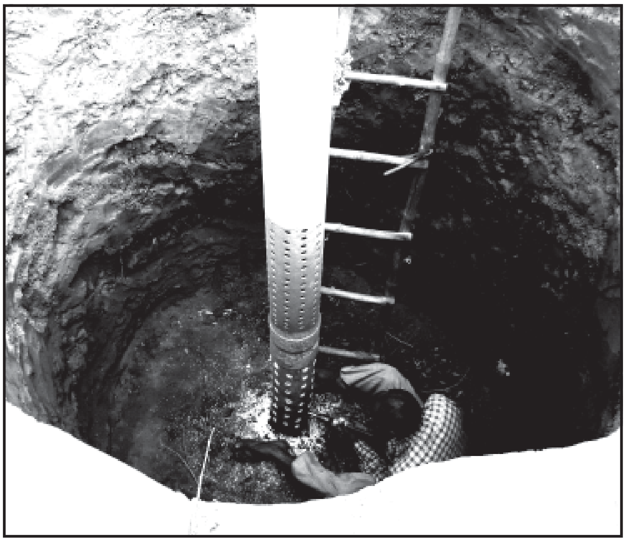


Fig. 4.1 Increasing size of the filter

4.3 Optimum Utilization of Natural Spring Water in Tehri Garhwal Region of Uttarakhand (Pantnagar Centre)

Hilly areas are facing a serious water availability crisis due to various developmental and economic activities, which result in reduction of protective vegetation cover and forests. Viable sources of water like springs, which were plenty in hills, are drying up because of inadequate recharge of flow domain of springs and there is great disturbance in hydrologic cycle of hilly areas. Therefore, study was carried out near Ranichauri, on Rishikesh-Uttarkashi route, in Tehri Garhwal district of Uttarakhand. The watershed, drains into Henval river in Tehri Garhwal district, is located between 78° 22' 28" to 78° 24' 57" E longitude and 30° 17' 19" to 30° 18' 52" N latitude. The elevation varied from 960 to 2000 m above mean sea level. The soils of micro-watershed of Henval river were brown to grayish brown and dark gray in colour, besides being non-calcareous and neutral to slightly acidic in reaction. The climate of this region was humid temperate but variations existed which largely depend upon the altitude and geological differences. The average rainfall in study area varied from 1200 to 1400 mm of which 70 to 80 per cent was received between June to September. In the present study, an attempt has been made to suggest suitable crop plan on the basis of available spring water resources and design of suitable water storage structure.

The discharge of selected spring was monitored on daily basis and other related data were collected by field visits. Toposheet (53 J/7) of Survey of India, of the scale 1: 50, 000 for the study area, was used for the analysis of slope-area classification and watershed delineation. Base maps were prepared using Survey of India (SOI) toposheet No. 53 J/7 of 1: 50,000 scale. Base maps including contour, drainage network, village location, spring location and watershed boundary were extracted from the toposheet. Major crops grown were *lahi, lentil,* wheat, barley, gram, potato and pea in *rabi* and paddy, sorghum and maize in *kharif* season. The water requirements of crops were estimated on weekly basis as per standard meteorological weeks. For the estimation of reference evapo-transpiration (ET_o), FAO Penman-Monteith method was used. Before estimating the total water requirement, crop evapo-transpiration and effective rainfall were also determined. Weekly spring discharge and domestic water requirement were considered for estimating the required design storage capacity. The pond was designed for the capacity of 139 m^3 for drip irrigation and a free board of 15 cm was also provided to avoid overtopping of water. For flood irrigation method the required storage capacity of structure was found to be 360 m^3 including 5 percent evaporation losses. Two ponds of 180 m^3 were suggested in place of one pond of larger capacity for border irrigation. The maximum areas available for the crops, using linear programming model, were estimated.

It was found that *lahi* and wheat combination could be grown in the *rabi* season while paddy, sorghum and maize in the *kharif* season (Table 4.1). Irrigation was ensured by spring water. The results of the present study might be useful for planning, design, and management of water resources of the region.

Table 4.1 Maximum available area for the crops

Season	crops	Maximum available area (ha)
Rabi	Lahi	3.39
	Wheat	1.86
Kharif	Paddy	0.61
	Sorghum	17.14
	Maize	10.61

4.4 Artificial Groundwater Recharge through Percolation Tank (Rahuri Centre)

In the State of Maharashtra, 81.5 percent of the geographical area is occupied by hard rock like Deccan Trap. Sixteen percent of the total cultivable area is irrigated and out of this, about 50 percent area is irrigated by ground water through wells. The government is constructing percolation tanks to augment groundwater since 1964 and by now there are more than 12000 percolation tanks in the State. Therefore, it is necessary to quantify the groundwater recharge through the percolation tank and to assess its area of the influence in the downstream and indirect help by tanks in creating irrigation potential. For this purpose, three percolation tanks namely, Shingave percolation tank; Pimpalgaon Ujaini percolation tank-I and Pimpalgaon Ujaini percolation tank-II were selected. The percolation tank at Shingave is located on the outskirts of the Central Campus, MPKV, Rahuri. Pimpalgaon Ujaini Percolation Tank-I (Fig. 4.2) and Tank-II are located in Pimpalgaon Ujjaini village in Ahmednagar District. It is located about 45 km from the M. P. K. V., Rahuri in the East direction. The reconnaissance survey was carried out for all three sites to locate the wells at downstream of tank, pumps installed by the farmers on their wells, natural stream etc. Water level recorder was installed in each tank. The water surface area- stage relation and water storage- stage relationship were developed for all three percolation tanks (Fig. 4.2). The storage capacity of the Shingave tank, Ujaini Percolation Tank-I and Tank –II was 52.5, 69.6, 21.6 ha-m, respectively. The water spread of was 20, 20.5 and 11.5 ha, respectively. The relationships were developed between water level fluctuations (drop) in the wells from May to July of the following year and the distance of respective wells from the percolation tank. The influence of Shingave percolation tank with maximum storage capacity of 52.5 ha-m was found in the range of 194.28 to 1514 m during the period 1993 to 2005 with average distance of influence as 1214 m. Recharge rate from the tank during 1993-2005 ranged from 1.27 cm/day to 6.0 cm/day with average of 2.53 cm/day. Similarly distances of influence of Tank No. I and Tank No.II at Pimpalgaon Ujjaini were 654 m (range from 399.65 to 978.63 m) and 654.80 m (range 218.54 to 1012.61 m), respectively.

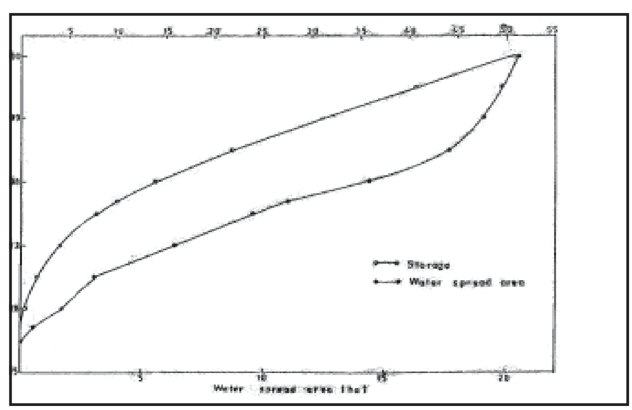


Fig. 4.2 Shingave percolation tank, its stage -water spread area and stage-storage area relations

4.5 Development of the Technique for Recharge through Irrigation Wells (Rahuri Centre)

Recharge through existing open wells and tube wells or abandoned wells appear to be good proposal in case of Maharashtra. The surface runoff water, available for recharging, contains impurities of physical, biological and chemical nature and hence it is necessary to remove all impurities before using it for recharging. In present investigation, hydraulic parameters of the sand gravel filter developed for the artificial groundwater recharge through irrigation wells were studied so as to provide optimal design of filter chamber which can give higher recharge rate with minimal clogging of the filtration bed and higher filtration efficiency. The experiment was conducted with laboratory models and subsequent operation of the models with turbid water of varying sediment concentrations. The locally available filter materials such as sand of different sizes, pea gravel of different sizes, angular gravel of different sizes and coal of different sizes were tested at different thicknesses of filter material with 200NTU concentration of suspended load (runoff water) for efficient designs of sand and gravel filter against the best filtration efficiency of the filter material. There were four types of filter i.e. single layer filter, two layer filter, three layer filter and four layer filter. The observations were replicated three times for all filters. Sand grade I (0.6 to 2.0 mm) single layer filter of 45cm thickness gave 68.77 percent filtration efficiency while two layers with sand grade I (0.6 to 2.0 mm) + coal grade I (4.0 to 8.0 mm) having thickness as 45 cm and 15 cm gave 75.88 percent efficiency. Three layers filter having angular gravel grade I (9.5 to 15.5 mm) + pea gravel grade II (6.0 to 10.0mm) + coal grade I (4.0 to 8.0 mm) in 45+ 45 cm + 15 cm thickness gave 69.19 percent efficiency. If sand grade I layer of 45 cm is added at top to three layer filters, efficiency increased to 88.25 percent. The major findings of the research are listed below.

- Different filter materials with different thickness and grades influenced the velocity of flow, time of filtration, discharge and filtration efficiency.
- The filtration efficiency increased with increase in thickness of filter material
- The four layer filter has given the better hydraulic performance and maximum filtration efficiency amongst all other filters.
- The three layer filter comprising of Angular Gravel Grade I (9.5 to 15.5 mm) and Pea Gravel Grade II (6.0 to 10.0mm) of 45 cm thickness each and Coal Grade I (4.0 to 8.0 mm)of 15 cm thickness should be recommended for the high discharge while the four layer filter comprising Sand Grade I (0.6-2.0 mm), Pea Gravel Grade I (2.0-6.0 mm) and Angular Gravel Grade I (9.5-15.5 mm) of 45 cm thickness each and Coal Grade I (4.0-8.0mm) of 15 cm thickness should be recommended for low discharge.

4.6 Enrichment of Ground water Bank through Haveli Recharge (Jabalpur Centre)

Water stored in *Haveli* fields might be injected down the strata, if properly planned. The soil of the study area was vertisol with clay to clay loam texture having infiltration rate between 2.5 mm hr^{-1} to 4 mm hr^{-1}. The percentage of clay varied between 54.5 to 65.2 percent, the silt varied between 20.8 to 25.2 percent and sand content varied from 14.1 to 20.3 percent. The hydraulic conductivity was 0.143 m/day to 0.196 m/day. The bulk density varied between 1.42 to 1.46 g cm^3. Three perforated injection shafts of PVC of 150 mm dia and 6 m long were drilled in the *Haveli* fields with appropriate gravel envelope. Intake behavior of underground strata below *Haveli* fields were studied and tests were performed by pouring water into the injection wells before (in early), during and after monsoon/ rainy season. During a period of 26-30 SMW, owing to greater availability of dry soil depth, the intake rate was found faster which became almost constant at 7.9 cm h^{-1}. During mid monsoon (SMW 31 to SMW 36) the water level came closer to the surface and intake rate was found drastically fallen to 0.8 cm h^{-1} and during post monsoon period (SMW 37 to 42), when water level reduced to 2.4 m, the intake rate increased to 4.9 cm h^{-1}. Thus, there is a possibility of injecting *Haveli* storage water just in early period of monsoon and after withdrawal of monsoon, which could be a great help to increase ground water bank with system like *Haveli*. Trend lines were drawn to represent behaviour of intake capacity of strata beneath Haveli fields in different parts of study period. The characteristic equation of each are: $Y = 0.0214X + 1.4256$ ($R^2 = 0.78$) for early monsoon; $Y = -2E\text{-}0.5X^2 + 0.004X + 0.53$ ($R^2 = 0.77$) for mid monsoon and $Y = 0.007X + 1.1426$ ($R^2 = 0.69$) for post monsoon. Rainfall data for 40 years period of Jabalapur were analyzed by Weibull formula to get rainfall amount for purpose of *Haveli* recharging. Rainfall amount at 20, 30, 40, 50, 60 and 70 percent probability level was found as 1865, 1051, 528, 224, 99 and 26.5 cm, respectively. The maximum recharge estimated accordingly was 34, 26 and 4.83 cm at 20, 30 and 40 percent probability, respectively. At higher level of probability, say at 50 or 70 percent, enough *Haveli* storage couldnot be generated. It meant that there would not *Haveli* storage every year. However, runoff from fallow fields, cropped fields, uncultivated lands and non *Haveli* fields might be diverted to the *Haveli* fields to have *Haveli* system every year. In this situation, runoff generating catchment should be at least twice the *Haveli* fields. Water samples from *Haveli* fields were collected and analyzed. It was found that all samples showed safer values for irrigation water.

The potential areas for *Haveli* system in different blocks of Katni, Satna, Seoni, Jabalpur, Sidhi and Rewa districts were determined and groundwater recharge possibilities at 20, 30, 40 percent level of probability were estimated. It was also observed that *Haveli* storage is generally available till first week of October and thereafter water is drained to prepare the fields *rabi* crops. If this storage water, instead of draining, is put into aquifers, ground water availability can increase. For this purpose, recharge shaft within the Haveli field is proposed and laboratory tests for suitable filter materials for shaft are going on at centre. Also an attempt was made to improve water productivity of Haveli system by introducing a *Singhara* crop. The net profit was Rs. 59900 for kharif (Singhara)- rabi (wheat)- *Haveli* system compared to Rs. 23000 of rabi (wheat)- *Haveli* system.

4.7 Evaluation of Artificial Recharge Structures Constructed in Percolation Ponds of Coimbatore and Vellore districts, Tamil Nadu (Coimbatore centre)

Artificial recharge through recharge bore well in percolation pond was taken up. Runoff water was allowed to pass through silt detention tank, channel and filtering chamber before entering into borewell. Two case studies are discussed here.

Vellore district

The study area falls in Elavambadi village of Vellore district. The network of observation wells was identified to monitor the water levels and water quality. Water level depths were recorded from a temporary datum during monsoon in all 12 observation wells during 2009 (Fig 4.3). The decrease in water levels of all observation bore holes were observed during summer and slightly increased during month of June due to rainfall of 80.9 mm during May. Further, in month of June, water level decreased in all the observation wells from 0.6 m to 1.5 m. Due to 416.3 mm of rainfall in the study area during the south west monsoon, water level increased in all bore wells and average rise was 1.24 m. The water level rise of 1.1 to 2.1 m was observed during the north-east monsoon in all the observation wells. The average water level fluctuation during the North east monsoon was 1.76 m, respectively.

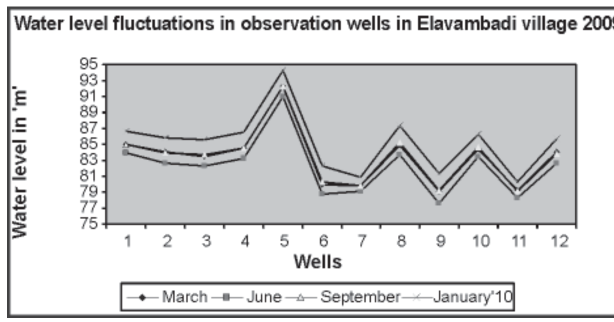


Fig 4.3 Water level fluctuations of Elavambadi village- 2009

Total amount of rainfall received in the study area during 2009 was 799.89 mm. The season wise rainfall details of the study area revealed that 52 percent of rainfall was contributed by Southwest monsoon and 48 percent by north east monsoon during 2009. The total rainfall received during the year 2009 was 799.89 mm, which was 134.81 mm lesser than previous year.

Recharge estimation

The study area received 0.2, 11.89, 52.04 and 35.87 percent of the total rainfall during winter, summer, southwest and north east monsoon, respectively during 2009. The rainfall during summer was 95.1 mm. It was found that there was no recharge during summer season and there was no significant contribution of runoff water. About 8.78 percent of recharge was observed during southwest monsoon due to rainfall of 416.3 mm. During the north east monsoon, significant recharge of 18 percent occurred due to rainfall of 286.89 mm. While comparing south west and north east periods, it was noted that the recharge during north east was 10 percent higher compared to south west. Even though both the monsoon received more or less equal amount of rainfall, the recharge was less in south west monsoon due to high evaporation losses. The water level starts rising in all the observation wells from September onwards and reaches peak level during December. Thereafter, decline of water table started in a gradual manner. When compared to the previous year, the recharge during southwest monsoon was less even though the rainfall was more. But at a same time, the recharge during northeast monsoon was 1 percent higher during the year 2009 when compared to 2008, despite of low rainfall.

Water quality

A total of 10 water samples were collected in the Elavambadi village, Kudisai, Vellore district during October 2009 and January 2010 and analyzed for pH, EC, cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and anions (CO_3^-, HCO_3^-, Cl^-). The results depicted that the medium level (0.25 – 0.75dS m^{-1}) of salinity was observed in majority of the ground water samples collected from Elavambadi village. Most of the groundwater used for irrigation purpose was found within the safe level with respect to Residual Sodium Carbonate (RSC) and Sodium Adsorption Ratio (SAR) values. The chloride concentration of the groundwater samples were also in the safe limit (<5 me L^{-1}). This study implied the better suitability of groundwater in Elavambadi village for irrigation purpose in both the seasons.

The seasonal effects on ground water quality were observed in some of the samples. EC values were increased in well No. 2,6,7,8 and 9 during January 2010 when compared to Oct 2009. Bicarbonate values increased in well No 1,2,6,9 and 10. Variations in chloride values were observed in well No. 8, 10 and 11. Variation in Ca and Mg were also observed in well No. 1,2,6,8, and 11. Increases in EC values have shifted the some samples under medium category to high.

Coimbatore district

The study areas are located at Vellanipatty village and Kalapatty village in S.S.Kulam block which is northern part of Coimbatore district. The observation well net work was defined in a smaller area with greater well density. In both the areas 8 wells in downstream up to a distance of 1000 m from the shaft and 3 wells in upstream up to a distance of 600m were identified for the evaluation. A repeated water level observation were taken before and after monsoon to determine the water level fluctuations in the study area and presented in Fig 4.4 and Fig. 4.5).

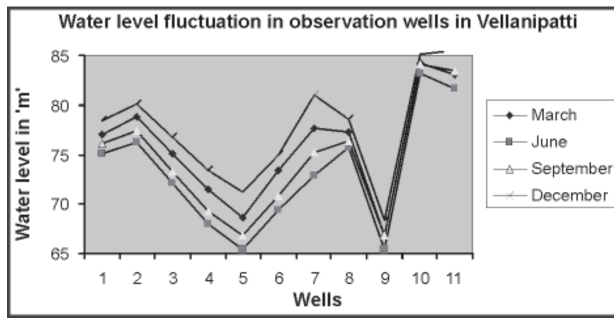


Fig 4.4 Water level fluctuations of Vellanipatti village- 2009

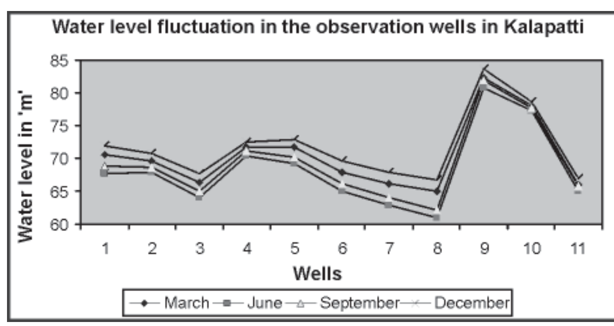


Fig 4.5 Water level fluctuations of Kalapatti village- 2009

Water level depths were recorded from a temporary datum on a monsoon basis in all the eleven observation wells during 2009 both in Kalapatti and Vellanipatti study area. In Kalapatti, the water level decline in the observation bore holes were observed during the period of summer and slightly increased during the month of June due to rainfall of 91 mm occurred in May. Further water level was decreased in all the observation wells from 1.3m to 4.1m. Due to 176.1 mm of rainfall in the study area during the south west monsoon, water level increased in all bore wells and average rise was 0.93m. The water level rise of 1.2 to 4.5 m was observed during the northeast monsoon in all the observation wells. The average water level fluctuation during the North east monsoon was 2.5m. There was a fluctuation in upstream wells also in a range of 0.4m to 1.1m during south west and 0.9m to 1.8m during north east monsoon. The fluctuation effect was significant in upstream wells upto the distance of 600m.

In Vellanipatti, The water level decrease in the observation wells were observed during the summer and slightly increased during the month of June march due to minimum rainfall of 91 mm occurred in May. Water level observations during January to June 2009 revealed that water level decrease of 1 m to 4.8 m is observed in the observation wells. The maximum decrease was in well no 7 and the minimum decrease was in well no 8 in upstream side. Due to 176.1mm of rainfall in the study area during the south west monsoon, water level increased in all bore wells and average rise was 1.3m. The water level rise of 1.1 to 5.8 m was observed during the northeast monsoon in all the observation wells. Minimum rise is observed in well no 8 and Maximum rise was observed in well no 7 in upstream side. There was a fluctuation in upstream wells also in a range of 0.8m to 1.8m during south west and 1.1m to 2.1m during north east monsoon. The fluctuation effect was significant in upstream wells upto the distance of 600m

Meteorological parameters viz., rainfall, temperature, relative humidity, solar radiations were recorded in Coimbatore Airport weather station. Total amount of rainfall received in the study area during 2009 was 555.6 mm. There was no rainfall during winter. Among the total rainfall, summer rainfall contributed 18 percent, south west rainfall contributed 32 percent and the maximum rainfall of 50 percent was contributed by north east monsoon. The maximum temperature 36.1 ^{0}C was observed during the month of April and minimum temp to 18.7^{0}C during the month of January. Maximum relative humidity observed during November was around was 85.9 and minimum relative humidity was 23.54 percent during the month of February. The maximum wind speed observed during the month of June (10.60 kmph) and minimum wind speed during the month of January (2.48 kmph).

Recharge estimation

The study area received 0, 17.98, 31.70 and 50.32 percent of the total rainfall during winter, summer, Southwest and north east monsoon, respectively, during the year 2009. The rainfall during summer was 99.9 mm. It was found that there was no recharge during summer season and there was no significant contribution of runoff water. About 5.32 percent of recharge in Kalapatti and 7.47 percent in Vellanipatti were found to occur during southwest monsoon due to rainfall of 176.1mm. It was found that during the north east monsoon, there was a significant recharge of 9 percent in Kalapatti and 11 percent in Vellanipatti occurred due to rainfall of 279.6 mm. While comparing south west and north east periods, it was noted that the recharge was 4 percent more during north east monsoon. Even though both the monsoon received more or less equal amount of rainfall, the recharge was less in south west monsoon due to high evaporation losses. The water level started rising in all the observation wells from September onwards and reached peak level during December and thereafter declining in a gradual manner.

Water quality

Vellanipatti

Nine water samples were collected from the Vellanipatti village and analyzed for chemical properties. From the observations, it was revealed that the high salinity (0.75 – 2.25 dS m^{-1}) was observed in majority of the ground water samples collected from Vellanappatti village. pH was observed neutral but one sample exhibited alkaline condition (>8.5). The study revealed that most of the groundwater used for irrigation purpose was within the safe level with respect to Residual Sodium Carbonate (RSC) except sample No. 11. In the study area, all the SAR values (<10) were within the safe limit and RSC value (<1.25 me l^{-1}) were within the safe limit, which indicated that groundwater could be used for irrigation purpose. The chloride concentration of the groundwater samples in well No. 4, 5, 6, and 7 found to be on higher side. It showed that the groundwater could be used for irrigation, but salinity needs to be managed.

Kalapatti

Eleven water samples were collected from the Kalapatti village and analyzed for chemical properties. From the observations, it was revealed that the very high salinity (>2.25 dS m^{-1}) was observed in majority of the ground water samples collected from Kalappatti village. There were no drastic variations in pH. The study revealed that all the groundwater used for irrigation purpose was within the safe level with respect to Residual Sodium Carbonate (RSC) and Sodium Adsorption Ratio (SAR) values. In the study area, all the SAR values (<10) were within the safe limit and RSC values (<1.25 me L^{-1}) were within the safe limit, which indicated that the groundwater could be used for irrigation. The chloride concentration of the groundwater samples in well No. 1,3,5,6,7,10 and 11 was on higher side. Chloride sensitive crops might face severe chloride toxicity

4.8 Preparation of Guidelines for Implementing Artificial Recharge Structures in Recharging Groundwater in the Hard Rock Regions of Tamil Nadu (Coimbatore centre)

Detailed literature survey is being conducted to understand the problems related to groundwater occurrence and recharge. Tamil Nadu is one of the water starved states in India. The problem of siltation in reservoirs has become alarming, since the silt deposited in the reservoirs or tanks decreases the capacity of the reservoirs thereby reduces the utility of them for various purposes. The studies on the sedimentation problems carried out in 33 reservoirs in Tamil Nadu revealed that there was a loss in capacity of more than 50% in two reservoirs viz., Kundha and Glenmorgan, more than 30% capacity loss in 8 reservoirs. Majority of the rivers, dams are affected by the sedimentation problem, which in turn reduce the capacity as well as the functional utility of the structure for which they are built.

Excess abstraction of water for domestic, industrial supply and agricultural uses without proper planning and priorities will adversely affect the surface water. The groundwater table is being depleted year after year due to the failure of monsoon, inadequate recharge of the aquifers and excessive pumping of water from the wells over and above the annual recharge of the aquifers. Keeping this in mind, to enhance recharge in the hard rock region of Tamil Nadu an attempt has been initiated to prepare guidelines for implementation of artificial recharge structures based on the research done.

The aim of this study is to produce and disseminate guidelines on the application and operation of schemes that aim to augment groundwater resources by artificial recharge in hard rock regions.The data and research findings of the research projects are being collected and identification of critical hydrological areas is in progress.

4.9 Computation of Natural Groundwater Recharge for Rajsamand District of Rajasthan (Udaipur centre)

The natural recharge of Rajsamand district was estimated for all the seven blocks for the years 1999-2003. Block-wise natural recharge of the district was estimated by using water balance technique and water level fluctuation technique. It was observed that the maximum recharge (district total of 379.96 million m^3) occurred in the year 2001 in all the blocks of Rajsamand district and the minimum recharge (district total of 28.22 million m^3) occurred in the year 2002. The year 2002 was a severe drought year in the southern Rajasthan and occurrence of the low rainfall was the main cause for low amount of rainfall recharge. Barcharts of the total annual rainfall and annual natural recharge for the district over 5-year period (1999-2003) are shown in Fig 4.6. It can be seen from that recharge from rainfall has a direct relationship with annual rainfall.

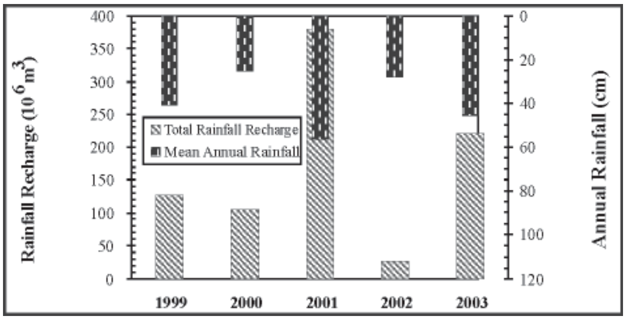


Fig. 4.6 Rainfall and recharge bar charts for five years

4.10 Artificial Groundwater Recharge through Various Soil and Water Conservation Structures in the Semi Critical Areas (Raipur Centre)

This study was undertaken in one of the sub-watershed of Gajra watershed called as Kurudihnala to monitor the groundwater recharge through various recharge structures. Water table was recorded with the help of water level indicator during the year 2006, 2007, 2008 and 2009 in 5 existing tube wells and 2 open wells. Analysis was done as per the guidelines of GEC, 1997 and water table fluctuation during pre and post monsoon season of some of the wells are given in Table 4.2.

The modeling results indicated that the artificial recharge structures are adequate to recharge rain water during monsoon season of the year 2006 to 2008. Fortnightly water level was recorded during the 1st January 2006- 31st July 2008 from the observation wells located nearby the different recharge structures (i.e. percolation tank, stop dams and boulder check dams). These observed data were utilized to compare the simulated water level for the respective observation wells.

Survey and direct interview with farmers in the vicinity of recharge structures revealed increasing yield from tube wells. It resulted in better protective irrigation to *kharif* crop during water scarcity period and doubled cropped area along the Kurudihnala.

Table 4.2 Pre and post monsoon depth to water table in Kurudiahnala watershed during 2006, 2007, 2008 and 2009

S. No.	Tube well code	Water level (mbgl)											
		(2006)			(2007)			(2008)			(2009)		
		Pre monsoon (1st May)	Post monsoon (1st Nov.)	Fluctuations (m)	Pre monsoon (1st May)	Post monsoon (1st Nov.)	Fluctuations (m)	Pre monsoon (1st May)	Post monsoon (1st Nov.)	Fluctuations (m)	Pre monsoon (1st May)	Post monsoon (1st Nov.)	Fluctuations (m)
1	TW1	11.8	1.3	10.5	10.5	4.8	5.7	11.7	1.4	10.3	7.3	5.2	2.1
2	TW2	11.7	1.1	10.6	12.7	3.0	9.7	10.6	3.1	7.5	8.1	2.7	5.4
3	TW3	12.5	3.0	9.5	13.2	8.2	5.0	10.9	7.4	3.5	8.5	2.0	6.5
4	TW4	9.0	1.2	7.8	6.5	1.6	4.9	10.1	7.1	3.0	6.3	2.1	4.2
5	TW5	11.4	0.4	11.0	13.2	2.5	10.7	12.7	6.7	6.0	10.5	2.1	8.4
6	OW1	6.1	0.6	5.5	3.6	0.6	3.0	10.6	5.1	5.5	10.8	2.6	8.2
7	OW2	5.6	1.2	4.4	4.5	1.7	2.8	10.0	4.1	5.9	10.6	2.4	8.2

4.11 Assessment of Groundwater Recharge from Rainfall and Water Harvesting Structures in a Selected Watershed of South Saurashtra Region using Remote Sensing and GIS (Junagadh Centre)

Groundwater is the largest available source of fresh water lying beneath the ground. Besides targeting groundwater potential zones it is also important to augment the natural as well as artificial groundwater recharge. The Government of Gujarat has implemented the scheme known as "Sardar Jal Sanchay Abhiyan" in Gujarat to construct water harvesting structures on *nalas* and small rivers with people's participation. By reducing the runoff and enhancing the water stagnation/ opportunity time, these structures are increasing the groundwater recharge. However, there is a strong need to have more scientific monitoring and assessment of these rainwater harvesting and groundwater recharge practices and impact analysis at regional level.

In present study groundwater recharge was estimated in Jamka watershed of Saurashtra region, where water harvesting structures were constructed by people's participation. The annual rainfall of the region for last 38 years (1970-2007) was analysed and the recharge through the rainfall was estimated by using various empirical equations. The groundwater recharge through rainfall as well as through water harvesting structures was estimated through established methods and using remote sensing techniques. The cost of structures, their benefits and benefit cost ratio were also determined. For suggesting efficient utilization of recharged water, the evapotranspiration requirement of wheat crop prevalent in study area was also estimated by FAO 56 Pennman-Monteith method and using remote sensing and GIS.

Results of groundwater recharge estimation using five empirical approaches revealed that natural groundwater recharge through rainfall in the study area varied from 11 to 16 percent of annual rainfall. Remote sensing and GIS techniques were applied to estimate water spread area of 49 water harvesting structures and used for estimation of groundwater recharge from water harvesting structures and found as 150.37 ha m. The total groundwater recharge through rainfall, water harvesting structures and return flow of irrigation water in the study area was estimated as 407.12 ha m. The groundwater recharge in the area was also estimated using water table fluctuation method and was found less than the total recharge estimated through rainfall and recharge from storage structures. This indicated that groundwater outflow from micro-watershed. Cumulative crop evapotranspiration (CET_c) of wheat crop in the study area was found as 52.8, 86.8, 120.0 and 81.2 mm in month of November 2006, December 2006, January 2007 and February 2007, respectively. The maximum water requirement of wheat crop was found in January as crop evapotranspiration was the maximum in this month.

Gross irrigation requirement of wheat crop grown in 187 ha area estimated using remote sensing based Kc SAVI values was found 119.12 ha m for year 2006-07. The groundwater recharge created by water harvesting structures i.e. 150.37 ha m was adequate to irrigate 156 ha of wheat crop. However, total groundwater recharge estimated from rainfall and water harvesting structures was 407.12 ha m, which could irrigate about 422 ha of wheat crop by applying 627 mm water with 65 per cent application efficiency. The cost of storage capacity created by water harvesting structures was found to be Rs.1.49 per m^3 of storage. The estimated benefit-cost ratio was found to be 1.53 for growing wheat crop using the groundwater recharge by water harvesting structures.

4.12. Water Balance and Assessment of Groundwater Recharge in Meghal River Basin of Saurashtra Region (Junagadh Centre)

Government of Gujarat has declared Junagadh district as 'Dark Zone' i.e. a zone where groundwater resources have been over exploited. Meghal is one of the major river of Gujarat that recharges the nearby areas. Most of the rivers dry up soon after the rainy season and hardly any water is seen during the month of January. The gradually drying up of Meghal River has aggregated and highlighted water related problems affecting people's livelihood and has led to a decline and uncertainty in agricultural income. The Meghal river basin has been identified for implementation of groundwater recharge techniques to improve the groundwater table and thus quality of groundwater which in turn will reduce the rate of seawater intrusion in the region. The river originates from Keshod Taluka and covers major parts of Maliya Taluka and in downstream it covers Mangrol Taluka before joining Arabian Sea (Fig 4.7). Total length of the river is about 72 km. It has two tributaries which enhance its flow. The river flows about 8 to 10 months in the year and become dry in summer season. By using Remote Sensing and GIS suitable artificial recharge sites were identified. It would also help to suggest efficient utilization of groundwater available through the water harvesting structures in study area.

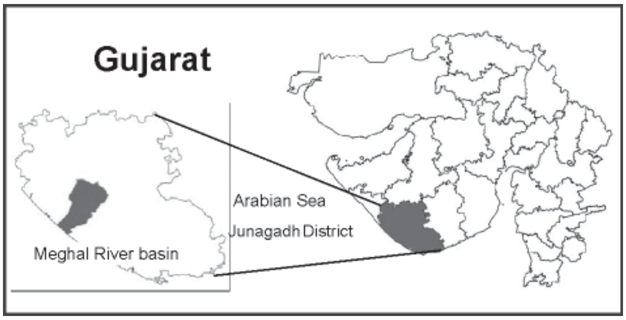


Fig. 4.7 Location Map of Meghal River basin

The basic maps of Meghal river basin were collected. Using Remote Sensing and GIS the thematic maps were prepared. This study was conducted in collaboration with NGO Aga Khan Rural Support Programme, India (AKRSP (I)). The detail maps of area were collected and rainwater harvesting structures were re located in the area. The size and design specifications of the structures were taken from AKRSP (I) and the govt. of Gujarat agencies working in the area. The basic maps were digitized using GIS tools for further study. The weekly rainfall amounts of rainy season of Junagadh district at different probability levels were estimated using best fit distribution functions. These estimations would help to predict the rainfall at different probability levels and thus the groundwater recharge in that week to be occurred in the region. It is observed that 29th week resulted the maximum mean weekly rainfall of 124.5 mm with Normal distribution, which gave the best fit results. The 22nd week gave the minimum mean weekly rainfall of 11.9 mm with Gumbel distribution.

The natural recharge from rainfall occurred in different Talukas of Junagadh District, which included the study area was estimated using annual rainfall of 38 years (1970-2007) and shown in Table 4.3. The results showed that the average natural recharge in the study area, which included *Keshod, Maliya and Mangrol* Talukas was 11.35, 11.51 and 19.61 percent, respectively. The yearly estimation of natural recharge in Junagadh District using annual rainfall of 38 years (1970-2007) was conducted. The data revealed that the average annual rainfall of the district was 837.10 mm, which generated an annual groundwater recharge of 16.79, 5.57, 16.67, 11.44 and 14.55 percent using Chaturvedi, UPRI, Bhattacharjee and Krishnarao and Kumar & Seethapathi formulae, respectively.

Table 4.3 Groundwater recharge estimation of various Talukas of Junagadh district for year 2005

Taluka	Rain-fall mm	Groundwater Recharge by different empirical models in Percent						
		Chatur vedi	UPRI	Amritsar	Bhatt acharjee	Krishna Rao	Kumar and Seetha pathi	Aver-age
Bhesan	943	18.59	17.49	30.95	18.45	14.40	17.68	19.59
Keshod	1063	17.82	17.02	0.00	17.68	15.59	0.00	11.35
Kodinar	1155	0.00	0.00	0.00	0.00	16.34	0.00	2.72
Maliya	907	18.82	17.61	0.00	18.68	13.97	0.00	11.51
Manavadar	1020	0.00	0.00	0.00	0.00	15.20	0.00	2.53
Mangrol	913	18.79	17.59	31.06	18.64	14.05	17.51	19.61
Mendarada	635	20.10	17.91	30.00	19.96	9.25	14.19	18.57
Sutrapada	653	20.08	17.97	30.30	19.95	9.69	14.56	18.76
Talala	732	19.84	18.03	31.06	19.70	11.34	15.84	19.30
UNA	1260	16.64	16.24	29.22	16.51	17.06	18.66	19.05
Vanthali	1094	17.63	16.90	30.20	17.49	15.86	18.30	19.40
Veraval	578	19.94	17.55	28.56	19.82	7.70	12.77	17.72
Visavadar	1395	15.91	15.72	28.40	15.79	17.83	18.80	18.74
Avg.	949.85	15.70	14.62	20.75	15.59	13.71	11.41	15.30
SD	250.1939	7.091209	6.522647	14.42281	7.040847	3.213758	8.119151	
Cs	0.076859	-2.02452	-2.12954	-0.93376	-2.02273	-0.71064	-0.77481	
Ck	-0.7646	2.795993	3.085541	-1.34355	2.791452	-0.69893	-1.4129	

4.13 Effect of Watershed Treatment on Quality of Groundwater (Junagadh Centre)

The water harvesting structures such as check dams, nala plugs and ponds were constructed in the watersheds of Saurashtra region for improving groundwater recharge. A study has been conducted to monitor the quality improvement of groundwater in three watersheds on the western coast in Saurashtra region of Gujarat, where watershed development works have been undertaken by various organizations. The three selected watersheds were Bantwa kharo, Mangrol and Kodinar. Forty two wells distributed in treated and untreated areas of these three watersheds were selected for collection of pre monsoon and post monsoon groundwater samples for years 2005, 2006, 2007and 2008 . The collected water samples were analyzed for quality parameters viz. total soluble salt content (electrical conductivity, EC), pH, carbonates (CO_3^{--}), bicarbonates (HCO_3^-), chlorides (Cl^-), sodium (Na^+), calcium (Ca^{++}), magnesium (Mg^{++}), sodium absorption ratio (SAR), residual sodium carbonate (RSC) and soluble sodium percentage (SSP) using standard methods.

The water samples from 42 wells during pre and post monsoon season from treated watershed areas and non treated wastrshed areas were analysed for different quality parameters.The four years averages for different parameters are presented in Table 4.4.

The results depicted that in Kodinar area, the salt content decreased by 52.22 percent in treated area (TA) before monsoon (BM) and by 55.69 percent after monsoon (AM) compared to non treated area (NTA) which showed that there was positive effect of watershed treatment in Kodinar area. The salinity class was observed high (C4) in NTA and fall in medium to high category (C3) in TA. This may be due to groundwater recharge in treated area of watershed. Sodium Absorption Ratio (SAR) decreased by 46.18 perecnt due to watershed treatment. The negative RSC value was observed but 66.75 percent reduction was found in the area due to treatment. SSP value was found in safe limit but further decreased by 22.92 percent due to construction of recharge structures.

In case of Bantva Watershed salt content decreased by 2.45 percent due to treatment before monsoon while it was by 18.53 percent after monsoon. This showed that watershed development works had reduced the salt content of groundwater in the region.

In case of Mangrol Watershed the average EC of TA before monsoon was higher by 59.29 percent and by 37.95 percent after monsoon so in this area reverse trend was observed. This event might be due to high salinity ingess of sea water in the watershed area coupled with excessive use of saline irrigation water which nullified the treatment effect. In this area SAR increased from 4.86 to 8.37 (72.04 percent) with treatment. RSC value was found in negative but it increased by 38.76 percent before monsoon season. The reduction in SSP was observed from 50.96 to 41.36 percent (by 22.20 percent).

It can be inferred from the above results that the Mangrol watershed area is highly exploited and continuous pumping of groundwater resulted in sea water intrusion. Though, some groundwater recharge has been occurred by the watershed treatment, but the withdrawal has exceeded the recharge and the area continued to suffer from sea water intrusion, damaging the crops and soil in the region. Hence, there is an urgent need to schedule the pumping with limits and to adopt the skimming well technology to overcome water intrusion problem.

Table: 4.4 Year wise and location wise impact of watershed treatment on quality of groundwater

Location	Sample No	2005	2006	2007	2008	AV.	2005	2006	2007	2008	AV.	% Change
		Before monsoon (BM)					After monsoon (AM)					
E.CdS/m Treated area												
Kodinar	6	1.7	1.4	1.8	1.7	1.7	1.1	1.5	1.2	1.5	1.3	20.6
Bantva	5	3.3	3.8	5.3	5.5	4.5	2.7	4.3	4.9	3.5	3.9	13.8
Mangrol	10	7.2	6.8	6.4	4.8	6.3	4.8	5.2	5.7	5.1	5.2	17.6
E.C ds/m Non Treated area												
Kodinar	6	3.4	3.4	3.8	3.5	3.6	2.5	2.9	3.4	3.1	3.0	16.2
Bantva	5	6.0	4.4	3.4	4.7	4.6	5.6	4.2	4.3	4.2	4.6	0.4
Mangrol	10	4.4	3.8	3.6	4.0	4.0	3.6	3.3	3.1	2.9	3.3	18.5
pH Treated area												
Kodinar	6	8.6	7.9	7.9	8.1	8.1	7.9	8.5	8.5	7.9	8.2	-0.68
Bantva	5	8.0	7.8	7.9	7.9	7.9	7.7	8.3	8.3	7.9	8.0	-1.92
Mangrol	10	7.9	7.3	7.8	7.7	7.7	7.4	8.0	7.9	7.7	7.8	-1.34
pH Non Treated area												
Kodinar	6	8.3	7.9	7.8	7.9	8.0	7.6	8.4	8.0	7.7	7.9	0.58
Bantva	5	8.1	7.8	8.1	7.9	8.0	7.7	8.4	8.3	7.8	8.1	-1.21
Mangrol	10	8.0	7.5	7.9	7.7	7.8	7.5	7.8	8.1	7.8	7.8	0.10
Na me/l Treated area												
Kodinar	6	6.5	5.2	6.7	7.1	6.4	4.7	12.4	6.2	7.3	7.6	-19.8
Bantva	5	17.2	19.1	25.9	32.4	23.6	15.8	29.3	46.8	25.3	29.3	-24.0
Mangrol	10	34.9	34.8	33.7	34.8	34.5	22.4	35.3	30.7	31.4	29.9	13.4
Na me/l Non Treated area												
Kodinar	6	15.5	15.8	18.0	18.9	17.0	12.4	16.3	17.9	18.2	16.2	4.9
Bantva	5	26.0	20.3	19.1	29.6	23.7	24.9	29.7	31.3	27.7	28.4	-19.5
Mangrol	10	12.6	11.6	12.0	26.2	15.6	10.0	11.0	10.2	10.5	10.4	33.1
Ca me/l Treated area												
Kodinar	6	2.9	3.5	2.0	5.3	3.4	3.7	3.9	2.9	2.9	3.4	1.80
Bantva	5	6.1	4.2	9.1	12.0	7.8	5.2	3.3	12.5	7.6	7.1	9.24
Mangrol	10	19.3	5.5	18.8	11.8	13.8	18.2	4.5	16.3	13.9	13.3	4.20
Ca me/l Non Treated area												
Kodinar	6	5.1	4.4	5.7	6.0	5.3	5.1	2.9	6.4	7.4	5.5	-2.89
Bantva	5	14.1	11.9	5.4	10.5	10.5	14.1	4.5	11.8	7.8	9.5	8.91
Mangrol	10	18.2	12.2	11.3	10.7	13.1	18.2	4.4	14.1	11.2	12.0	8.41

5

GROUNDWATER POLLUTION STUDIES

5.1 Studies on Groundwater Pollution from Agrochemicals (Ludhiana Centre)

The present study was taken up to monitor the movement of NO_3 –N after application of nitrogenous fertilizers to field crops, and to quantify NO_3 –N in the soil profile and groundwater. The concentration of nitrates in the groundwater of Ludhiana district was also been monitored.

5.1.1 Movement of agro-chemicals

In order to have better understanding of the fate of nitrate movement from the unsaturated zone to groundwater under paddy-wheat rotation, three sites were selected last year and observation wells were installed at different depths to monitor the Nitrate-N movement more precisely. The two sites were selected at the PAU farm and the third site was chosen at farmer's field near Village Hassanpur (about 7 km from the university). Total 15 observation wells were installed at different depths i.e. 0.5, 1, 2, 3, 4, 5, 10, 20, 30, 40, 50, 60, 70, 80 and 90/92 feet from the ground surface i.e. up to the depth beyond the anticipated water level (in the near future). The observation wells were installed in a circular pattern. The observation wells were prepared from a 40 mm diameter PVC pipe and having 1 feet perforation covered with nylon mesh and leaving a margin of 1 feet as blind pipe from the bottom end so that it can trap the down moving contaminated water entering into the observation well. At all three sites, paddy crop was grown with tube well water. Rainfall details were also recorded. Standard recommended practices were followed regarding land preparation, fertilizer application, irrigation and other cultural practices. The initial dose of urea (20 kg) and DAP (20 kg) was applied at the time of transplanting. Second and third doses of urea were applied at appropriate times. Water / leachate samples were collected periodically from all the three sites from various depths and analyzed for NO_3- N concentration.

The results of all three sites based on data of 2009 revealed that the concentrations of NO_3-N at various depths was within permissible limits (Table 5.1) and it indicated that there is no immediate threat of groundwater contamination due to N fertilization under paddy.

Table 5.1 Nitrate N Concentrations(mg/l) in the soil profile at site 1 during rice crop

Depth (ft)	Days after transplanting					
	15.6.09	24.7.09	21.8.09	20.9.09	24.10.09	8.11.09
0.5	10.50	5.34	4.08	4.85	3.25	**
1.0	17.01	6.79	4.66	2.99	6.79	3.56
2.0	11.97	5.50	4.70	**	6.47	3.44
3.0	7.57	**	**	1.86	1.8	5.70
4.0	29.81	9.40	7.43	4.56	**	6.03
5.0	**	**	**	8.50	**	**
10.0	14.90	**	6.23		**	**
20.0	11.48	12.67	7.00	6.31	**	4.10
30.0	14.18	7.89	6.12	**	**	**
40.0	**	**	**	**	**	**
50.0	7.32	**	**	5.78	**	5.13
60.0	**	15.00	**	**	**	6.51
70.0	**	10.56	13.41	11.20	6.66	4.75
80.0	10.95	9.80	10.80	5.87	6.70	4.91

Fertilization: DAP 20 kg/acre on 24.7.09, Urea 20 kg/acre on 24.8.09
Date of transplanting: 24.7.09 (Basmati 1121) Date of Harvest: 25.10.09

5.1.2 Nitrate-N in groundwater of Ludhiana district

Thirty five water samples from 114 villages using a square grid of 6 km×6 km superimposed on the map of Ludhiana district were collected and analysed. Pre-monsoon (second fortnight of June) and post monsoon (first fortnight of November) samples were collected from centrifugal or submersible pumps. Results depicted that concentration ranged from 0.1 to 7.65 mg/l during pre monsoon and from 0.26 to 7.02 mg/l during post monsoon period which was within the permissible limit of 10 mg/l for drinking purpose as recommended by WHO. Mangat block recorded the minimum NO_3- N of 0.79 mg/l and Jagraon recorded the maximum amount of NO_3- N of 4.72 mg/l during pre monsoon period whereas minimum NO_3- N of 1.42 mg/l was recorded in Mangat block and Doraha block recorded the maximum amount of NO_3- N of 3.81 mg/l during post monsoon season. The average post monsoon values showed dilution effect in almost all the blocks (except in Sudhar, Pakhowal, Ludhiana, Mangat, Machhiwara and Doraha blocks). However, average pre monsoon(2.85 mg/l) and post monsoon (3.0 mg/l) values of NO_3- N concentration for Ludhiana district were almost same.

5.2 Study on Groundwater Pollution due to Industries in the *Tarai* Region of Uttarakhand (Pantnagar Centre)

The pulp and paper mill located at Lalkua in U.S.Nagar district of Uttarakhand state discharges effluent through different channels in nearby Gola River, which is the main source of irrigation in the area. There were two channels/ paths for effluent to reach to Gola River (Fig. 5.1). A study was carried out to investigate in details the water quality as affected by pulp and paper mill effluent and to find out its suitability for irrigation, and equip our farmers with the latest technology to enhance agricultural productivity following eco-friendly and sustainable measures. To study the groundwater contamination along the effluent flow channel, groundwater samples were collected from 11 different sites and surface water samples were collected from 7 different sites from Lalkua to Kiccha, during Dec,09 –Jan' 2010 and analysed. Observation points for groundwater sampling were State tube well, Deorampur, Halduchaud, in front of temple, Bidukhatta in front of Dainik Jagaran Office, Near Gola river crossing, Sanjaynagar at Hanuman Mandir, Shantipuri -2 at Mr.M.S.Mehata's house, Khuriyakhatta -12 at Mr.Chandramani's house, Shivpuri -6 at Hanuman Mandir, Near Kichha Mazar and Near Ghodanala

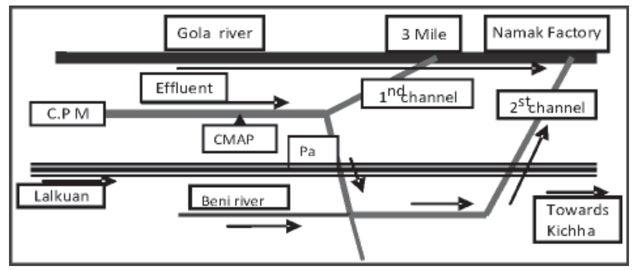


Fig 5.1 Path of effluent movement (not to the scale)

5.2.1 Physico-chemical Characteristics of Surface and Groundwater

It was observed that the pH of surface water varied from 6.05 at Ghodanala to 6.63 at Kichha Mazar. The pH was less than the permissible limit of 6.5 from Ghodanala to Pa canal, beyond that it increased. The average pH of groundwater varied from 6.33 at Bindukhatta and Gola river crossing to 6.90 at Shivpuri. The pH at Halduchaud, Bindukhatta, Near Gola river crossing, Sajnjay Nagar and Near Ghodanala was less than 6.5 i.e. less than the permissible limit for drinking water.

The electrical conductivity of groundwater varied from 253.33 to 801.00 µS/cm at Gola river crossing whereas EC value of surface water varied from 541 µS/cm at Kichha Mazar to 1650 µS/cm at Ghodanala. The value of EC decreased with the distance, away from the outlet of the paper mill. The mill discharges its effluent into Ghodanala which had highest EC value of 1650 µS/cm, it decreased up to 541 µS/cm at Kichha Mazar, as the effluent gets diluted with the addition of water from Beni River. After Mazar it increases up to 879.67 µS/cm near Namak factory. The EC of the effluent was found within the permissible limit required for discharging into water bodies i.e. less than 3400 µS/cm.

Turbidity of the surface water varied from 40.84 NTU near Namak Factory to 197.20 NTU at Ghodanala which was beyond the permissible limit of 25 NTU. In case of groundwater it varied from 0.5 NTU to 25.13 NTU near Kichha Mazar (beyond the permissible limit of 5-10 NTU). It was observed that hardness and the cations (Ca, Mg, Na, and K) of the surface water as well as the groundwater were within the permissible limit.

The nitrate content in groundwater varied from 15.30 mg/litre at Shivpuri to 49.97 mg/litre at Halduchaur and Sanjaynagar which was beyond the permissible limit of 10mg/l for drinking purpose (WHO). In case of surface water it varied from 49.47 mg/litre at Kichha Mazar to 253.65 mg/litre at Ghodanala which was much beyond the permissible limit of irrigation water requirement of 45 mg/l.

The results revealed that the TDS, acidity, calcium and chloride contents in groundwater were maximum near Ghodanala, whereas turbidity, alkalinity, sodium and potassium contents were maximum near Kichha Mazar. This was because these points received maximum concentration of effluent which affected the groundwater more in comparison to other places. Therefore, it can be inferred from the study that the polluted surface water is contaminating groundwater as the *Tarai* belt is very shallow watertable i.e. less than 5 m deep. It was observed that quality of surface/ river water improved because of dilution as water travelled from CMAP to 3 mile point. Similar trends were also observed for second path.

5.2.2 Suitability of effluent water and groundwater for irrigation

On the basis of criteria given by Richards 1954, Wilcox 1955 and Westcot and Ayers 1984 the suitability of groundwater samples for irrigation was assessed. On the basis of SAR value the groundwater of DEO Rampur, Bindukhatta and near Gola rivers crossing might be classified as excellent water for irrigation. The groundwater at Sanjay Nagar, Shantipuri No.-2, Khuria Khatta-12 and Shivpuri was under good quality. On the basis of alkali hazard all the water samples were found under low alkalinity hazard classes. On the basis of salinity hazard the groundwater near Ghoranala only was found under the Class "high" for salinity hazard whereas other samples were under "medium" salinity hazard classes. The overall class of all the groundwater was $C_{2-}S_1$ except near Goranala which is under $C_{3-}S_1$ class.

On the basis of specific ion toxicity, which depends on SAR value, showed that groundwater at Halduchaud, in front of Dainik Jagaran office, near Gola river crossing, Sanjaynagar, Shantipuri -2, Khuruyakhatta and Shivpuri – 6 has no restriction for its use in irrigation whereas slight to moderate restriction is required for groundwater near Ghodanala, Shantipuri Dam, and near Mazar for its use in irrigation. Severe restriction for irrigation is recommended for surface water at Mazar, Godana, CMAP, Pa Canal, Shantipuri, Namak factory and 3 mile. On the basis of Permeability criteria (SAR and EC values) slight to moderate restriction for irrigation is observed for the surface water samples collected from near Mazar, CMAP, Ghodanala, Pa Canal, Shantipuri, Namak factory and 3 Mile whereas severe restriction for irrigation was observed for the surface water sample (effluent) near Mazar, and groundwater samples near Ghodanala and Shantipuri.

5.2.3 Effect of paper effluent on growth and production of wheat

On an average the small paper mill consumes about 250 m^3 of water per ton of paper production and discharges about 200 m^3 of effluent full of highly toxic chemicals. The large integrated pulp and paper industries consume around 300-350 m^3 of water per tonne of production. The major types of pollutants originating in the effluents include: colour, pH, total suspended solids (TSS), heavy metal ions, organic substances, and toxic substances. The effluent from pulp and paper mill located in the *Tarai* belt of Uttarakhand state was found to be severely restricted for irrigation. Therefore, an attempt was made to study the effect of different effluent concentrations such as 0, 25, 50, 75 and 100 percent (raw effluent) on seed germination, seeding establishment, vegetative growth and productivity of wheat crop (HD 2283) as well as the irrigation potential of effluent.

Results showed that germination was 93.3 percent with the use of raw effluent of pulp and paper Mill. However, germination percentage of test seed i.e., wheat remained same as that of control with 25 and 50 percent effluent treatment. The vigor index for effluent was 641.3, 708.3, 799.67 and 988.0 with 100, 75, 50 and 25 percent concentrations, respectively; while control was 920. The maximum numbers of tillers were observed at 25 percent effluent concentration. The effluent influenced the node number significantly. Diluted effluent (25 percent) had some beneficial effect on the number of nodes, the highest number of 7.15 was recorded at 25 percent effluent concentration and lowest of 5.35 in 100 percent effluent treated wheat plant. The maximum plant height at all the stages of crop growth was observed at 25 percent concentration of the effluent. Higher concentration of the effluent (25 percent onward) treatment affected the height negatively. The minimum height was recorded at 100 percent effluent treatment. Maximum spike length was observed at 25 percent effluent treatment and it was significantly higher than control. The grain number per spike ranged from 31.59 in 25 percent to 17.52 at 100 percent effluent treatment. However, the control showed intermediate value (25.07). Maximum number of grains was obtained for 25 percent treated plants (1.12 gm per spike) and minimum for 100 percent treatment (0.771 mg per spike). The grain yield of wheat was significantly influenced by effluent treatment at different concentrations. The value ranged from the maximum 10.64 gm per pot for 25 percent treated effluent and minimum 4.84 gm per pot for 100 percent treated effluent.

The study showed that the effluent as such (i.e. raw) could not be used for irrigation purpose, due to high toxicity level. The effluent with 25 percent concentration was recommended for irrigation for its beneficial effect in comparison to 0, 50, 75 or 100 percent concentration levels.

5.3 Water Quality and Performance of Natural Springs in Uttarakhand (Pantnagar Centre)

In the most of the springs in Himalayan area, flow has decreased by 50 percent within last 30 years and piped drinking water in hill area is failing due to drying up of springs. It has also adversely affected the irrigation water supply resulting in migration of people. The spring may get water supply by free water moving under the control of the water-table slope (water-table spring), by confined water rising under hydraulic pressure (artesian spring), or by water forced up from moderate or great depths by other forces than hydraulic pressure (geysers, volcanic and thermal springs). There is no systematic study of the spring flows for developing these springs as dependable and sustainable sources of water for rural population in remote hilly areas of Uttarakhand state. Understanding the characteristics of a spring such as its nature (i.e. perennial, seasonal or periodic), discharge rate and water quality is very much necessary to plan its full use and these characteristics depend on natural phenomenon such as rainfall, geology of the porous media and catchment area. In the present study an attempt was made to select springs situated at different elevations, different aspects, different slopes, different vegetation and different geologies in the Kumaon Himalaya for measuring their discharge rates fortnightly for period of 20 months. Following conclusions were drawn on the basis of observations of six springs viz. Kosi, Kosi-Katarmal, Ranibagh, Patwadangar, Kalimath and Chaubatia.

i. Kosi, Patwadangar and Chaubatia springs are classified as contact springs, whose driving force is gravity. Ranibagh and Kosi-Katarmal springs are classified as artesian springs, whose driving force is hydrostatic pressure. Only Kalimath spring is classified as impervious rock spring, which is oozing flow with gravitational force.

ii. Classification, on the basis of discharge rate (after Meinzer, 1927), placed Kosi, Kalimath and Chaubatia in "seventh magnitude with discharge ranging from 0.6 to 6 litre per minute" whereas Kosi-Katarmal, Ranibagh and Patwadangar were placed in the "sixth magnitude with discharge ranging from 6 to 60 litre per minute".

iii. On the basis of maximum to minimum discharge rate, it appeared that Patwadangar spring's catchment had high hydraulic conductivity (or in other terms, catchment was having very less retention capacity), whereas Chaubatia spring's catchment had less hydraulic conductivity.

iv. Springs selected for the study were situated at elevations ranging from 591 m (Ranibagh spring) to more than 2000 m (Chaubatia spring). It was observed that altitude of the spring did not affect the spring discharge rate or its perennial behavior.

v. On the basis of perennial behavior of springs, it was observed that Kosi spring was periodic in nature whereas all other five springs were perennial.

vi. Increase in discharge rate of spring caused decrease in electrical conductivity of the oozed-out water. This behavior of springs (decrease in EC with more discharge rate) could be attributed to the lesser residence time of water molecules in the porous media of the spring catchment. Growing vegetation on the catchment, aspect and elevation had no effect on the water quality of the spring. Geology of the parent material found responsible for the water quality of the spring and flow through this porous media was responsible for the periodic change in quality of water.

5.4 Effect of Polluted Groundwater by Municipal Wastewater on Yield and Quality of Onion Crop and Soil Properties (Rahuri Centre)

With scarcity of freshwater resources, use of urban waste water for irrigation appears to be promising. However, major challenge is to optimize the benefits of waste water as resource of the water and the nutrients it contains, and to minimize the negative impacts of its use on human health. Therefore, an experiment was initiated to find out the best conjunctive use of wastewater and normal water and to study its effect on quality and yield of onion (Variety N-2-4-1). Experimental design was RBD with five treatments (T1: Irrigation with polluted groundwater; T2: Irrigation with normal well water; T3: One irrigation with normal well water followed by two irrigations with polluted groundwater; T4: One irrigation with polluted groundwater followed by two irrigations with normal well water; T5: Alternate irrigation-One irrigation with polluted groundwater other irrigation by normal well water) and 4 replications. Sowing was done in 1st fortnight of October, 2009 and transplanting in 1st fortnight of December, 2009.

The initial physico-chemical properties viz., pH (7.43 and 7.19), Electrical Conductivity (2.49 and 0.56 dSm^{-1}), calcium (11.6 and 9.70 me/l), magnesium (4.2 and 3.30 me/l), sodium (10.40 and 2.20 me/l), potassium (2.10and 0.90 me/l), sulphate (3.70 me/l), carbonates (nil), bicarbonates (0.60 and 0.80 me/l) and chlorides (9.20 and 4.80 me/l), micronutrients and heavy metals viz., iron (0.029 and 0.008 mg/l), manganese (0.082 and 0.036 mg/l), copper (0.029 and 0.008 mg/l) and zinc (0.010 and 0.012mg/l) were estimated for polluted groundwater and normal water respectively and was classified under C_2S_1 and C_4S_1 types respectively as per the criteria of Richards (1954). The experimental soil was clayey in texture having pH, EC, available N, P, and K as 7.54, 0.39 dSm^{-1}, 142.2 kg/ha, 15 kg/ha and 360.7 kg/ha, respectively. Six irrigations were provided and the quality of leachate was monitored after each irrigation. It was observed that the electrical conductivity and pH of the leachate increased with the use of polluted groundwater.

5.5 Studies on Groundwater Pollution (Jabalpur Centre)

The maximum groundwater use is in Bhopal district followed by Satna and Narsinghpur. Besides, the Narsingpur district has many sugar mills and soybean plants which also contribute towards groundwater pollution. Studies have been taken up to assess the water quality of Narsingpur district. In another study quality of wastewater from different sources were estimated and the impact of wastewater on soil was also evaluated.

5.5.1 Water quality assessment in Narsinghpur district

An attempt was made to evaluate the quality of groundwater of Narsinghpur district in Upper Narmada Basin as well as the suitability of groundwater for irrigation. The district was divided into uniform grids of 15' on longitude and latitude. Samples were collected from 14 locations; including

6 from near sugar mills, 1 near soybean mill, 6 from hand pumps and one from open well. The chemical analysis of samples showed that pH ranged from 6.70 to 7.41 and EC was less than1.5 dSm^{-1}. Total hardness (concentration of Ca^{++} and Mg^{++}) ranged from 2.15 to 6 me/l and alkalinity ranged from 6.25 to 11.5 me/l. The RSC ranged from 1.15 to 5.00 me/l and only 15 percent of samples had RSC more than 3 me/l. The 85 percent of waters were found suitable for irrigation on the basis of the RSC. All other parameters were well within the limits and the quality of groundwater was found suitable for irrigation. The water quality parameters of last 40 years were compared with the present situation and it was observed that groundwater quality was deteriorating, though, at slow rate.

5.5.2 Quality of selected wastewaters at sources

In this study, samples were collected from different sources of waste waters such as Dairy waste, Municipal waste (Urdana Nala and Moti Nala), Industrial waste (Vehicle Nala), Agro-based Industrial waste (Sugar mill) and Agro-chemical site (Krishi Nagar Farm). The samples were analyzed for chemical properties. The pH and EC of samples varied from 7.42 to 7.61 and EC from 1.03 to 1.66 dSm^{-1}, respectively. The results of analysis are given in Table 5.2.

Table 5.2 Chemical properties of waste waters at sources

Location	Cu	Cr	SO_4	Fe	NO_3	Cl	TH	TA	Na
	(mg/l)								
Dairy Waste	0.26	0.08	43	0.92	1.86	42	300	717	488
Urdana Nala	0.13	0.07	12	0.39	4.8	36	240	790	380
Moti Nala	0.90	0.23	60	0.48	0.71	50	235	900	520
Vehicle Factory	0.40	0.08	47	0.52	0.45	75	280	710	130
KrishiNagar Farm	0.12	0.04	18	0.29	0.62	45	260	520	128

The copper content of all samples were within the permissible limit as per WHO but on higher side as per FAO for sites near dairies, Motinala and drains from Vehicle factory. The Cr of Moti Nala was exceeding the FAO limit of 0.1 mg/l. The SO_4 concentrations were within the prescribed limits of WHO and FAO. The iron was within permissible limit as per WHO and on higher side as per FAO limit of 0.5 mg/l. The chloride and Nitrate were within permissible limits as per both WHO and FAO, and Total Hardness as per WHO limit. Total Alkalinity (TA) was higher in most of the samples. RSC was found very high at Moti Nala and was fair for irrigation purpose at other locations. SAR is excellent for all sources for irrigation purpose.

5.5.3 Soil impairment due to waste water irrigation

Soil samples were collected from areas where irrigation from different polluting sources are in practice. The physico-chemical properties of these samples were determined. The pH value ranged from 6.9 to 8.0 in surface soil and at 30 cm depth it was from 6.3 to7.5. EC ranged from 0.18 to 0.24 dS/m at the surface soils for all sites except at Moti nala (0.56 dS/m) and vehicle factory nala site (0.85 dS/m). At all sites organic carbon was under either medium or high category. Available N in soil was moderate (263-385 ppm), phosphorus was high (22.4 - 31.3 ppm) and potassium was medium (417.4 - 578.5 ppm). The zinc, iron and manganese content ranged between 0.81-4.18 ppm, 7.82-44.22 ppm and 7.19-32.50 ppm, respectively. Higher amount of Zn (4.18 ppm) was recorded at Vehicle Nala site. Higher content of Iron (44.22 ppm) was found in soils at Dairies. The Copper deficit was recorded in almost all soils.

5.5.4 Effect on groundwater due to polluting sources

Groundwater samples were collected and analyzed to understand the influence of waste water sources in polluting the groundwater. The possible effect on groundwater due to source was calculated in the terms of change in water quality i.e. Ratio = value in groundwater / value at source. The pH of the groundwater from all the sites was found varying from 7.43 to 7.54 as against at sources with 7.42 to 7.61. EC value of groundwater was found between 0.50 to 1.22 dS/m. Copper was found ranging between 0.06 mg/l to 0.36 mg/l in groundwater sample, which was 87 to 50 percent lesser than that of waste water sources. Similarly, Chromium (0.02-0.04 mg/l), Sulphate (7-48 mg/l), Iron (0.18-0.34 mg/l) and NO_3 (0.19-3.63 mg/l) in groundwater were lesser compared to their concentrations at sources. It was quite obvious. The value of Total hardness in the groundwater of all sample was found to vary between 200.00 - 362.85 mg/l with maximum at Sugar Factory site and minimum at Moti Nala site. On the basis of Water Quality Index by Brown et al (1975), waste water of Moti Nala with index of 76.65 was found more contaminated and followed by Dairy waste site (66.93) and Urdana nala(61.53). For groundwater, quality index of 51.52 at Moti Nala site showed the poorest quality and index of 31.2 at Krishi Nagar farm indicated the less polluted groundwater amongst all sites.

5.6 Assessment and Management of Groundwater Quality in the PAP basin (Coimbatore Centre)

Parambikulam-Aliyar river basin lies within the coordinates of 10° 10' 00" N to 10°57'20" and 76°43'00" to 77° 12'30" E. It has an undulating topography with maximum contour elevation in the plain is 300m and the maximum spot height in the plain is 385m above MSL. One third of the basin area (822.73 sq.km) is covered with hills and dense forest cover. The total area of Parambikulam-Aliyar Palar (PAP) basin is 2388.72 sq.km. This basin is bounded in north and east by Cauvery basin, south and west by Kerala State. The basin area lies (except the ayacut area) within the Coimbatore district only and the ayacut area is extended beyond Coimbatore district upto Vellakoil –Erode district.

Groundwater Quality Status

Groundwater quality is affected due to the discharge of poor quality water from various industries and urban waste water to the natural water courses. Industries like dairy unit, Rubber factory, Paper boards, Spinning mill, Pesticide units, Soya factory, tea, Sugar factory, Vegetable oil, Chemicals, Cotton mills, Hatcheries, distilleries are located in the basin. Cottage industries like Appalam production, cane furniture, country bricks and pottery are also present. The requirement of water for large and medium scale industries was taken as 2500 m^3 per day and the wastewater generated was assumed as 80% of the water utilized which leads to the deterioration of groundwater quality.

Irrigation with poor quality water through the extraction of groundwater from deep aquifers leads to salinisation of the agricultural soils. The impounded surface water from Upper Aliar is also very soft with low mineral matter content but however shows somewhat higher figures compared to other dam sources. Surface water is getting contaminated due to coconut fibre soaking. The units of textile industry are contributing most of the contamination and pollution. The groundwater quality is generally alkaline with pH values ranging from 7.2 to 9. The quality of water in the major part of the area is moderate. The poor quality of water is noted in Unjavelampatti, Chinnapoolanginar, Dhali, Udumalpet and Poosaripatti villages. The highest value of EC of >8.0 dSm^{-1} is observed in Chinnapoolanginar. Excessive concentration of nitrate in groundwater is found in Udumalpet, Pollachi, Negamam, Anamalai and Kottur. In Anamalai, there is a large fluctuation in the nitrate concentration in groundwater over a period of time. Some of the areas with excess fluoride in groundwater are Eachanari, Vadachiittoor, Sangampalayam, Vedasandur, Unjavelampatti, Kolarppatti, Devanurpudur, Erisanampatti, and Karamadaiyur. The occurrence of fluoride is attributed to appetite rich granite gneiss.

Thirty water samples were collected from Parambikulam Aliyar basin from open wells, bore wells and dug cum bore wells and analyzed for chemical properties like EC, pH, cations and anions. Electrical conductivity values ranged from 0.34 to3.93 dsm^{-1}. Most of the samples fall under medium salinity class (C_2) (56.7%) followed by low salinity class (C_1) high salinity class (C_3) and very high salinity class (C_4) with 16.7, 13.4 and 13.3 percent, respectively. The pH value ranged from 7.13 to 8.12. Calcium content ranged from 1.04 to11.20 me l^{-1}. Magnesium content varied from 1.52 to13.84 me l^{-1}. Sodium content was observed between1.87 to18.26 me l^{-1}. Potassium content varied from 0.05 to1.84 me l^{-1}. Magnesium content exceeded the calcium content in most of the water samples. Magnesium toxicity will be exhibited in continuous use of water to crops.

Mostly carbonates were absent in the samples except one. Bicarbonates found to dominate and it ranged from 3.60 to15.60 me l^{-1}. Sulphate concentration varied from 0.05 to 10.13 me l^{-1}. Chloride concentration varied from 1.20 to 20.80 me L^{-1} and most of the samples (56.7%) come under excellent (<5 me l^{-1}) followed by injurious (23.3%) (>10 me l^{-1}) and Good (20.0%) (5-10 me l^{-1}).

Total hardness in the study area varied from 16.03 to 78.14 me l^{-1}. RSC values varied from -14.72 to 5.28 mel^{-1}. Most of the samples are coming under safe category (83.3%) followed by moderate (10%) and unsafe (6.7%). SAR values ranged from 0.91 to 7.49. All the samples come under low, sodium category (S_1 < 10). There is no sodicity in irrigation waters. Permeability Index ranged from 26 to 87. Majority of the samples exhibit there is no permeability hazard. The Langlier Saturation index (LSI) were calculated and it ranged from 0.68 to 2.18. It shows that probabilities of salt encrustation in irrigation pipes are common in the study area.

5.7. Heavy Metal Accumulation in Vegetables in Vicinity of Ahar River through Groundwater (Udaipur Centre)

Soil, groundwater, urban effluent and vegetable samples of four selected sites in middle and lower reaches of Ahar river viz. Manva Kheda (S_2), Kanpur-Madri (S_3) and Matoon (S_4); and the Horticulture Farm (situated three km away from Ahar river and irrigated with groundwater was taken as control S_1) were analysed for Fe, Mn, Cu, Zn, Cd and Ni content. It is observed that the metallic cations are present in trace amounts in the soil of control site (S_1) and the groundwater is also free from any metallic contamination (Table 5.3).

Further it is also observed (Table 5.3) that the soil and groundwater are highly contaminated with the heavy metals in the middle reach sites S_2 and S_3 as compared to S_1. This may be mainly due to the presence of higher amounts of heavy metals in wastewater because of continuous discharge of effluent from tanneries, distillery and other small industries situated at both the banks of Ahar River along with domestic effluent. Hence, the continuous irrigation with such contaminated wastewater and groundwater is likely to accumulate heavy metals

Table 5.3 Heavy metal content (mg kg^{-1}) in soil, groundwater and urban effluent at different sites during 2009

Metallic cation	Horticulture Farm (S_1)		Manva Kheda (S_2)			Kanpur-Madri (S_3)			Matoon (S_4)		
	Soil	Ground water	Soil	Ground water	Urban effluent	Soil	Ground water	Urban effluent	Soil	Ground water	Urban effluent
Fe	1.102	0.030	2.811	0.183	0.188	4.702	0.180	0.196	3.834	0.160	0.184
Mn	1.244	0.020	4.482	0.024	0.194	6.804	0.030	0.202	5.886	0.032	0.190
Cu	0.975	ND	2.044	0.036	0.111	2.401	0.038	0.110	2.271	0.030	0.110
Zn	1.024	ND	4.008	0.016	0.190	4.821	0.022	0.211	4.012	0.023	0.182
Cd	0.010	ND	0.072	0.013*	0.162	0.104	0.014*	0.168	0.090	0.012*	0.142
Ni	ND	ND	0.198	0.087*	0.188	0.264	0.080*	0.202	0.218	0.048	0.200

* More than safe limit, ND = Not detectable

gradually in the fields. The increase in heavy metal contamination of groundwater is dependent on the rate of metal loading and chemical composition of urban effluent as well as *in situ* properties of the soil.

The metallic concentration is considerably higher in the vegetables grown in the middle and lower reaches as compared to the control site (S_1). The highest accumulation of heavy metals was observed (Table 5.4) in the vegetables grown in Kanpur-Madri village (S_3) irrigated through urban effluent as well as groundwater. The groundwater of this site is highly polluted through urban effluent.

Table 5.4 Heavy metal content (mg kg^{-1}) in edible parts of vegetables irrigated with different water sources at Kanpur-Madri (S_3)

Source	Groundwater						Urban effluent					
Metal	**Fe**	**Mn**	**Cu**	**Zn**	**Cd**	**Ni**	**Fe**	**Mn**	**Cu**	**Zn**	**Cd**	**Ni**
Vegetable												
Cauliflower	37.64	72.00	8.14	43.55	0.038	0.452	72.72	135.68	16.38	86.75	0.064	1.060
Cabbage	58.96	98.34	10.18	50.30	0.062	0.680	92.52	170.00	18.44	76.36	0.064	1.011
Brinjal	94.14	61.11	4.72	13.18	ND	0.328	142.24	142.06	16.36	36.22	0.058	0.954
Spinach	388.01	95.95	10.25	80.12	0.072	0.744	522.74	159.54	18.74	132.00	0.134	1.464
Tomato	241.08	160.04	8.56	70.08	0.072	0.639	482.38	333.88	16.22	128.20	0.122	1.360
Radish	266.37	135.38	10.45	81.88	0.068	0.896	532.00	262.24	17.38	128.21	0.134	1.588

ND = Not detectable

5.8 Study on Groundwater Pollution Arising from Different Sources (Pusa Centre)

The study on groundwater pollution from different sources continued in Patna by pass area (irrigation through sewage water), Barauni (industrial effluent) and Samastipur (intensive use of agrochemicals) and about 47 groundwater pre-monsson samples were collected for qualitative assessment of groundwater quality.

5.8.1 Groundwater pollution through sewage water at Patna by-pass

The physico-chemical characteristics of sewage water being used by the farmers at Patna bye-pass area revealed higher content of Fe and Cr beyond the permissible limit for irrigation water. Hence plants growing on such soils accumulate excess amount of Fe and Cr in their tissues which upon entering in the systems of animal and human being create clinical problem.

Groundwater samples of different sources in surrounding areas of sewage treatment plant receiving sewage water for a period of over 50 years was monitored. In general, all water bodies were considerably rich in iron content which varied from 1.18 to 1.96 ppm beyond the permissible limits for drinking purposes (> 0.5 ppm). It was also observed that water bodies from the site nearer to sewage discharge point contained appreciably high amount of iron as compared to farther places. The concentrations of Cd, Cr, and Ni were in the range of 0.0 to 0.63, 0.0 to 0.067 and 0.0 to 0.086 ppm, respectively. It is evident from the data that some deep tube well and hand pumps located away from the discharge point contained high Cr content (i.e. >0.05 ppm) beyond permissible range for drinking water. The concentrations of other metal cations like Cd, Co and Ni were also beyond permissible range. No definite trend could be seen on spatial distribution of the concentration of these cations.

The pH and EC of groundwater samples collected from various sources at different locations of Patna by-pass area ranged from 7.37 to 8.7 and 0.26 to 3.36 dSm$^{-1,}$ respectively. The well water showed high EC values beyond permissible range (i.e.>2.2) as proposed by WHO (1984) and FAO (1985) compared to other sources. The sodium content varied from

1.26 to 11.6 (me/l). Sodium, calcium + magnesium content were found to be higher than permissible limit in open well and found to be unsuitable for drinking, domestic and industrial purpose. Carbonate and bicarbonate content ranged from 0.80 to 3.80 (me/l). Total dissolved solid (TDS) varied from 166 to 2157 (mg/l) amongst the sources. It was noticed that open well yielded high TDS (i.e.>1000 and 2000 ppm), indicating that water of these wells are unsafe for potable and irrigation purpose, respectively.

The chloride content varied from 2.60 to 22.8 (me/l). The open wells showed higher Cl^- content (>10.0 me/l) might be due to pollution from sewage water of urban and domestic origin. The nitrate-nitrogen content ranged from 1.20 to 48.3 ppm and it is found that water samples of hand pump and well yielded high content of nitrate-nitrogen throughout the area.

Most of the groundwater samples studied fall under medium saline with low sodium (C_2S_1), whereas well water is of C_4S_1 class which comes under very high saline category and this water can be used under very special condition i.e. controlled irrigation for salt tolerant crops. The provision of adequate drainage facility is essential for soils, incorporation of organic manures, use of green manures; soil amendments followed by crop rotation must be practiced for management of these soils under the use of such irrigation water.

5.8.2 Groundwater pollution through industrial effluents at Barauni

The pH and EC of groundwater samples of different sources in the industrial zone of Barauni, Dist. Begusarai ranged from 8.23 to 8.7 and 0.32 to 1.72 dSm^{-1}, respectively. The hand pump nearby to Thermal Plant showed high EC values (1.72 dSm^{-1}) than that of deep tube well. The quality parameters viz. sodium, carbonate, bicarbonate, calcium, magnesium, TDS and SAR were found to be within the safe limit. Two hand pumps nearby thermal power plant showed higher Cl^- concentration beyond the permissible limits (i.e.> 10.0 me/l). High content of chloride may cause severe damage to the crops and limit the availability of water and fertilizers to the plant.

The nitrate-nitrogen concentration was found to be in the range of 0.11 to 4.15 ppm among the sources and was found within safe limit. Considering the irrigation classes, it was observed that majority of the sources fall under medium salinity and need moderate leaching of land. Some hand pumps nearby to thermal plant and Fertilizer factory showed considerably high salinity which needs special management for salinity control and requires controlled use of water with salt tolerant crops.

Groundwater samples from different sources contained variable amounts of metal cations such as Fe, Zn, Cd, Cr, Ni, Pb, Co. The water bodies contained considerable amount of iron which varied from 1.17 to 3.31 ppm beyond the safe limit for drinking water. The hand pump located nearby the thermal power plant (Barauni) has considerable high levels of Fe (i.e. 2.17, 2.18, 3.31 ppm**)** which might be due to fly ash content of thermal power plant. The chromium (Cr) content varied from 0.073 to 0.161 ppm beyond the permissible limit for potable water. Most of the hand pumps showed Cr content beyond 0.10 ppm indicating that water of these sources is not suited for irrigation purpose. The content of other metal cations were found to be within the safe limit.

5.8.3 Groundwater pollution through intensive use of agro-chemicals and high density cattle operations

This study was undertaken to assess the impact of agro-chemicals and high density cattle maintenance on groundwater quality at Masina farm (Samastipur) and Cattle farm (Pusa), Samastipur, respectively. The pH and EC varied from 8.26 to 8.75 and 0.48 to 2.60 dSm^{-1}, respectively. The well water located at Masina Farm and Bharawn, Pusa yielded higher EC (2.60 and 2.07 dSm^{-1}, respectively) compared to other sources. High values of EC (2.37), noticed in one hand Pump located at centre of the cattle Farm, Pusa, might be due to domestic operation of habitat since a longer period. The cations like Na and Ca + Mg varied from 1.42 to 6.60 and 1.8 to 14.9 (me/l), respectively, amongst the sources.

It is observed that open well located at Masina Farm and Pusa Bharawn and one hand pumps neareby cattle farm, Pusa, contained high Ca + Mg content (i.e.>12 me/l), indicating, hardness of water and can be considered unsafe for domestic, drinking and industrial purposes. The carbonate and bicarbonate content in various sources were found to be within acceptable range.

Total dissolved solids (TDS) in various sources were in the range of 307 to 1664 ppm. The water of all the wells and the hand pump at cattle farm Pusa have high TDS values (i.e.>1000 ppm) beyond the permissible range of drinking water. The similar trend of data was obtained in case of chloride content, which varied from 2.00 to 16.6 me/l amongst the sources. It was also noticed that hand pump at cattle farm, Pusa and well located at Masina farm and Pusa Bharawn yielded Cl^- content beyond the permissible limit (i.e.>10 me/l) of drinking as well as irrigation purpose.

The nitrate-nitrogen content in water samples of various sources varied from 0.98 to 97.0 ppm. It is evident from the data that some hand pumps at surrounding area of *Masina* Farm, *Magardahi* Ghat on the bank of *Burhi Gandak* river, and cattle farm Pusa and all open wells were found contaminated with NO_3-N content having more than 10 ppm. The hand pump nearby Masina Farm and cattle farm, Pusa recorded 97.4 and 37.2 ppm NO_3-N content, thereby indicating that such water are not suited for both drinking as well as agricultural use. Based on the categorization of irrigation classes, majority of the sources come under medium salinity hazard (C_2S_1) except wells and hand pumps at cattle farm which fall under very high salinity hazard (C_4S_1). Hence, water samples of these sources require more attention towards salinity control and other irrigation management practices.

The magnitude of micronutrients and heavy metal cations in various water bodies as influenced by intensive use of agrochemicals were assessed. The concentration of Fe and Zn varied from 0.08 to 0.23 and 0.0 to 0.009 ppm, respectively in different water bodies which is considered to be safe. The Chromium (Cr) concentration was found much higher (i.e.>0.10 ppm) which is beyond permissible limit for drinking as well as irrigation purposes. It was also observed that concentrations of other metal cations like Cd, Ni and Co were found to be within the safe limit.

The microbial analysis of the water sample collected from the shallow tube well and deep tube well of cattle farm Pusa indicated the presence of coliform bacteria (*Faecal coliform*) warning the use of this water for drinking purpose.

5.8.4 Effect of pollution sources on groundwater quality

The impact of various sources of pollution (viz. sewage, industrial effluents and agrichemicals/ high density cattle operation) on groundwater quality was assessed. The study showed that agrochemicals/high density cattle operations influenced average pH and EC values to the greater extent in all water bodies in comparison to other sources. Similar trend was obtained in case of other quality parameters like Ca+Mg and TDS content. It was obvious from the data that chloride and nitrate – nitrogen, were highly influenced by sewage water which might be due to presence of un-decomposed soluble organic and inorganic nitrogen in sewage. Similarly it was also noticed that sewage water is a rich source of trace metal cations viz. Fe, Cd, Cr (Fig 5.2), Ni and Co which are contaminating the groundwater to the greater extent as compared to the other sources. It can be depicted that the industrial effluents/fly ash content of thermal power were highly responsible to increase iron content than that of other sources.

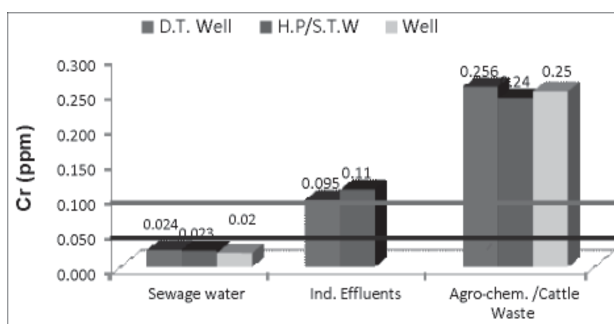


Fig 5.2. Effect of pollution sources on groundwater quality

5.9 Groundwater Quality Assessment around *Somni Nala* of *Gajra* Watershed (Raipur Centre)

Groundwater samples from different tube wells and surface water samples from upper, middle and lower reach of the stream of Somni watershed was collected each month and analysed. The hydro-geochemical properties including SAR, SSP, RSC, KSR and pH are presented in Table 5.5 and 5.6. It was found that the entire chemicals are within the prescribed limit of the Indian Standard for drinking as well as for irrigation.

Table 5.5 Chemical properties of surface and groundwater along Somninala (Monsoon seasons of the year 2008 and 2009)

Code	Particular	me/l						
		CO_3	HCO_3	Cl	Ca^{++}	Mg^{++}	Na^+	K^+
SN_U	Somninala upper reach	Nil	1.12	1.40	0.84	7.20	1.04	1.16
SN_M	Kurudih Somninala	Nil	1.72	1.72	0.84	7.95	1.33	1.24
SN_L	Somninala lower reach	Nil	4.00	2.16	0.88	7.35	1.27	1.32
STW_U	Somni handpump	Nil	3.08	0.96	0.84	6.68	3.00	0.04
STW_M	Chhunu Verma Aundhi	Nil	2.94	1.08	2.00	12.83	0.65	0.02
STW_L	Kurudih Santosh	Nil	2.66	0.76	1.48	9.02	0.09	0.01

Table 5.6 Chemical properties of surface and groundwater along Somni nala (Monsoon Seasons of the year 2008 and 2009)

Code	Particular	pH	EC	me/l			
				RSC	SAR	SSP	KSR
SN_U	Somninala upper reach	7.50	0.46	-	0.73	10.15	0.12
SN_M	Kurudih Somninala	7.30	0.50	-	0.89	11.70	0.15
SN_L	Somninala lower reach	8.52	0.60	-	0.44	11.73	0.15
STW_U	Somni handpump	7.60	0.55	-	2.18	28.40	0.39
STW_M	Chhunu Verma Aundhi	7.30	0.58	-	0.33	4.19	0.04
STW_L	Kurudih Santosh	7.40	0.37	-	0.05	8.86	8.95

5.10 The Impact of Sea water Intrusion on the Qualitative Parameter of Groundwater (Junagadh Centre)

The study has been undertaken to assess the impact of seawater intrusion in the coastal belts of Junagadh and Porbandar district of South Saurashtra. 52 water samples from different open wells situated in farmers' fields at 0-5, 5-10, 10- 15 and 15-20 km away from seacoast were collected during pre and post monsoon. All samples were analyzed for quality parameter viz, Electrical conductivity (EC), pH, Carbonate (CO_3^-), Bicarbonate (HCO_3^-), Chloride (Cl^-), Calcium (Ca), Magnesium (Mg) and Sodium (Na) by standard methods.

In the vicinity of seacoast high salinity was observed in groundwater and it was found that due to water conservation activities and increased groundwater recharge it decreased year wise from 2005 to 2009. Salinity of groundwater also decreased with increased distance from seacoast and it can be categories in very high (C5) to medium (C2) classes; none of samples fall in low (C1) or safe category. The groundwater salinity level for all year, distance and seasons were exceeding safe limits and posing a serious problem for the crops grown in the season. There is a need of water conservation, reduced withdrawal of groundwater and efficient water utilization through improved methods of water application to sustain agriculture in the region.

In most of the cases pH increased with distance from seacoast. High amount of Na^+ observed in 0-5 km, it was decreased with increase in distance from sea coast. The higher concentration of Na^+ is indication of sodicity alkaline hazards near seacoast. The Ca content fluctuation during pre-monsoon period was observed from 16.74 to 2.45 me/l in distance of 0-5 and 15-20 km, respectively. Higher value of Ca was observed in 0-5 km belt near seacoast. Little amount of Ca diluted due to rains. While in case of Mg, results showed, high value followed by Ca. The Mg content fluctuation during pre-monsoon period was observed 22.11 to 3.54 me/l in different distance 0-5 to 15-20 km, respectively. Higher value was observed in 0-5 km belt near seacoast. Mg content was decreased with increase of distance. The higher Ca+Mg content decreased the effect of Na hazard near seacoast. In case of anions (Cl, CO_3 & HCO_3), the amount of Cl^- was found higher (76.68 me/l) during pre-monsoon period followed by HCO_3(1.95 me/l) and CO_3 (0.47 me/l) near the sea coast. It was observed that Cl content decreased slightly during post monsoon period, while CO_3 & HCO_3 increased with increase of distance from seacoast. The content of CO_3 and HCO_3 influence the pH of the area. The increased amount of CO_3+ HCO_3 has resulted in increased pH with distance from seacoast.

The SAR value is an important criterion for studying the sodium hazard in irrigation water. The SAR values of groundwater near sea coast in both the seasons pre and post monsoon were found close to critical limit of 10. This indicates that over exploitation of groundwater may lead to sodium hazard in soils of the area. In categorization most of the samples fell in lower class of SAR i.e. S1. The RSC values were found negative, which is due to high content of Ca+Mg in comparison to CO_3+HCO_3.The RSC increased with distance from sea coast in both pre and post monsoon samples. RSC values were categorised in Good, Fair and Bad classes. Few samples fall in Fair & Bad classes in the interior area away from sea coast i.e. > 15 km. The higher SSP values were found 62.93 and 55.95%, respectively, in pre and post monsoon seasons near seacoast. These results indicate that near seacoast the SSP is closer to the safe limit of 60%, which is creating sodium hazard. Away from the seacoast the value of SSP was found in safe limit. Year wise per cent categorisation of groundwater samples on the basis of EC before and after monsoon is presented in table 5.7.

5.11 Assessment of Groundwater Contamination Surrounding the Industrial Area of Jetpur town (Junagadh Centre)

The Jetpur town is famous for its cotton textile dyeing industry in India. The effluent of the industry is polluting the Bhadar and Uben rivers of the region. The groundwater in surrounding region is contaminated. The farmers are irrigating their crops using lift irrigation from these rivers as well as by groundwater through pumping from the open and tube wells surrounding the rivers. The study has been undertaken to determine the severity of the pollution created in surface and groundwater by the dyeing industry in the area. Water samples were collected from river flow of Uben and Bhadar rivers from Jetpur town to Choki village of South Saurashtra region. Similarly, the groundwater samples were collected from different wells located in surrounding the GIDC area of Jetpur town (about 10 km) up to Choki village. All the collected water samples were analyzed as per the standard procedures. From wells in the vicinity of Uben and Bhadar river and river flow, 41 groundwater and surface water samples were collected and analyzed for pH, Electrical Conductivity (EC), Carbonate (CO_3), Bicarbonate (HCO^-_3), Chloride (Cl^-), Calcium (Ca), Magnesium (Mg) and Sodium (Na). and micronutrient and heavy metals I.e. Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Lead (Pb), and Nickel (Ni),

The results obtained from chemical analysis of outlets of washing ghats, river flow and groundwater samples before monsoon (BM) and after Monsoon (AM) showed that the flow in Bhadar river was more salty than Uben river both in BM and AM season by 63% and 47.6% respectively. The samples collectred from wells in vicinity of rivers shown higher salt content than that of away from rivers in BM and AM. In case of pH, minor changes observed in

Table 5.7 Year wise per cent categorisation of groundwater samples on the basis of EC before and after monsoon

Percentage of samples													
	Category	Class	Limit	Before Monsoon					After Monsoon				
				05	06	07	08	09	05	06	07	08	09
A1	Low	C1	0-0.25	0	0	0	0	0	0	0	0	0	0
	Medium	C2	0.25-0.75	0	0	0	0	0	0	0	0	0	0
	Med.to High	C3	0.75-2.25	7.7	15.4	0	0	0	7.5	7.5	23.1	0	0
	High	C4	2.25-5.0	15.4	7.5	15.4	15.4	30.8	30.8	30.8	30.8	38..5	61.5
	Very High	C5	5.0-20.0	76.9	76.9	84.6	84.6	69.2	69.2	69.2	53.8	61.5	38.5
A2	Low	C1	0-0.25	0	0	0	0	0	0	0	0	0	0
	Medium	C2	0.25-0.75	0	7.5	0	0	0	0	0	0	0	7.5
	Med.to High	C3	0.75-2.25	3.8	30.8	38.5	46.2	53.8	38.5	46.2	38.5	46.2	38.5
	High	C4	2.25-5.0	46.2	46.2	38.5	46.2	30.8	38.5	38.5	38.5	38.5	30.4
	Very High	C5	5.0-20.0	23.1	15.4	23.1	7.5	15.4	23.1	15.4	23.1	15.4	15.4
A3	Low	C1	0-0.25	0	0	0	0	0	0	0	0	0	0
	Medium	C2	0.25-.75	0	15.4	0	0	15.4	7.5	15.4	0	0	23.1
	Med.to High	C3	0.75-2.25	69.2	53.8	76.9	76.9	61.5	53.8	46.2	69.2	84..6	53.8
	High	C4	2.25-5.0	15.4	23.1	7.5	7.5	15.4	23.1	30.8	7.5	0	15.4
	Very High	C5	5.0-20.0	15.4	7.5	15.4	15.4	7.5	15.4	7.5	23.1	15.4	7.5
A4	Low	C1	0-0.25	-	-	0	0	0	-	-	0	0	0
	Medium	C2	0.25-0.75	-	-	23.1	23.1	23.1	-	-	15.4	23.1	0
	Med.to High	C3	0.75-2.25	-	-	76.9	76.9	76.9	-	-	69.2	69.2	92.3
	High	C4	2.25-5.0			0	0	0			15.4	17.5	7.5
	Very High	C5	5.0-20.0			0	0	0			0	0	0

A1=0-5 km, A2=5-10 km, A3=10-15 km and A4=15-20 km distance from seacoast.

groundwater sample (7.59 to7.96) while in case of Uben River higher pH value of 9.31 and 9.85 was obtained during pre and post monsoon period, respectively. Ca+Mg contents were diluted in rainy season. It was observed that in vicinity of Uben River groundwater samples show higher Ca+Mg value of 44.52 + 47.37 and 52.95 + 17.78 percent during pre and post monsoon period, respectively, decreasing the alkalinity hazards. Higher Sodium content was observed in both river as well as stream water during pre-monsoon season. The lower content of CO_3^{--}, and HCO_3^{-}, were observed in groundwater sample than that of in surface water i.e. in both the rivers. Higher values of Cl were observed in groundwater samples in the vicinity of both rivers. The value of SAR was found higher (>18) under S3 class in case of both river's surface as well as stream water, and the rest falls in safe category, S1 class (<10 SARvalue). Same trend was also found in case of RSC and SSP of groundwater samples.

Micronutrient Fe, Mn, Zn and Cu and heavy metal Cd, Co, Pb and Ni content in the water samples were detected. In Uben area, Fe content of stream was 1.32 ppm and surface water samples of three year average value were 1.18 ppm was found higher in comparison to groundwater samples collected near Uben River (0.49ppm) before monsoon and 0.44 ppm after monsoon (Table 5.8). While in Bhadar area groundwater samples contained higher amount of iron than stream 0.46 and surface water 0.81ppm whereas no changes for Mg, Cu and Zn content were observed in Uben area and similar trend was observed for Cd, Co, Cr, Pb and Ni content of water samples.

It is suggested that the effluent from the textile dying industry should be added in river water after proper effluent treatment. This may help in reducing futher deterioration of groundwater quality.

Table:5.8- Assessment groundwater contamination surrounding of Uben and Bhadar river (Fe, Mn, & Zn)

River Area	Code	Before monsoon (BM)				After monsoon (A M)				% Change due to season
		2006	2007	2008	Av.	2006	2007	2008	Av.	
Fe (mg/l)										
Uben	C1	1.17	1.81	0.57	1.18	0.72	0.51	0.55	0.59	49.8
	C2	0.66	0.46	0.36	0.49	0.57	0.55	0.48	0.53	-8.2
	C3	0.65	0.31	0.36	0.44	0.63	0.43	0.35	0.47	-6.6
	C01	0.31	2.15	1.49	1.32	0.53	0.47	3.15	1.38	-5.2
	Av.	0.71	0.65	0.44	0.60	0.62	0.49	0.55	0.55	7.8
Bhadar	C1	0.47	0.39	1.56	0.81	0.37	0.48	0.23	0.36	55.7
	C2	0.46	0.40	1.99	0.95	0.54	0.37	0.26	0.39	59.2
	C3	0.34	0.30	2.42	1.02	0.58	0.20	0.27	0.35	65.9
	C02	0.31	0.58	0.48	0.46	0.22	0.35	0.27	0.28	38.8
	DAM	0.44	0.36	0.57	0.45	0.27	0.15	0.46	0.29	35.3
	Av.	0.42	0.38	1.82	0.87	0.46	0.34	0.26	0.35	59.5
Mn (mg/l)										
Uben	C1	0.04	0.26	0.03	0.11	0.04	0.01	0.03	0.03	73.2
	C2	0.08	0.04	0.02	0.05	0.04	0.01	0.04	0.03	41.3
	C3	0.08	0.03	0.02	0.04	0.04	0.01	0.05	0.03	18.8
	C01	0.05	0.00	0.33	0.12	0.04	0.01	0.19	0.08	39.2
	Av.	0.07	0.07	0.03	0.06	0.04	0.01	0.05	0.03	41.2
Bhadar	C1	0.12	0.02	0.02	0.05	0.03	0.01	0.03	0.02	57.1
	C2	0.03	0.01	0.03	0.02	0.04	0.01	0.02	0.02	-1.4
	C3	0.03	0.01	0.05	0.03	0.03	0.01	0.01	0.02	36.8
	C02	0.05	0.01	0.03	0.03	0.03	0.01	0.06	0.03	-18.8
	DAM	0.09	0.07	0.02	0.06	0.04	0.01	0.04	0.03	52.9
	Av.	0.06	0.02	0.03	0.04	0.04	0.01	0.02	0.02	36.4
Zn (mg/l)										
Uben	C1	0.03	0.08	0.05	0.05	0.04	0.05	0.05	0.05	12.5
	C2	0.07	0.06	0.05	0.06	0.05	0.03	0.06	0.05	15.5
	C3	0.04	0.05	0.04	0.05	0.05	0.03	0.05	0.04	8.7
	C01	0.05	0.06	0.06	0.05	0.05	0.06	0.12	0.07	-38.7
	Av.	0.05	0.06	0.05	0.05	0.05	0.03	0.06	0.05	12.5
Bhadar	C1	0.04	0.04	0.09	0.06	0.04	0.02	0.05	0.03	41.4
	C2	0.03	0.05	0.10	0.06	0.03	0.02	0.05	0.03	44.4
	C3	0.03	0.04	0.13	0.07	0.03	0.02	0.04	0.03	54.4
	C02	0.05	0.07	0.05	0.05	0.03	0.02	0.10	0.05	6.2
	DAM	0.04	0.03	0.03	0.03	0.04	0.02	0.07	0.04	-36.8
	Av.	0.04	0.04	0.10	0.06	0.03	0.02	0.05	0.03	44.4

C_1= Sample collected from contaminated surface water of river
C_2= Sample collected from well located in the vicinity of river
C_3= Sample collected from well located away from river
Co_1= Sample collected from 'washing ghat' stream joining Uben river
Co_2= Sample collected from effluent stream of textile industry joining Bhadar river

6

TRANSFER OF TECHNOLOGIES

6.1 Transfer of Technology to Farmers (Ludhiana Centre)

6.1.1 Installation of recharge structures

In order to propagate the groundwater recharge techniques, eleven more structures were installed at RIMIT, Mandi Gobindgarh, PNB Farmers' Training Centre, Fatechgarh Sahib. Four structures were installed at Ludhiana, which include two at PAU Campus, Govt. Sr. Sec. School Dehlon and one at Machhiwara . With this, the total number of such structures installed by this centre has gone to thirty seven. People from rural areas have also started taking interest in rainwater harvesting. The structure established at Thapar Hall (Administrative Block) at PAU, campus alone contributes 10 lakh litre of groundwater recharge annually.

Plate 6.1 Rainwater harvesting Structure at Thapar hall of the University

6.1.2 T.V/ Radio Talk Talks:

Sr. No.	T.V Talk Topic	Date of Recording	Location
1.	The gas problem in tube well pits during rainy season	7 July 2009	PAU, Ludhiana

6.1 3 Field Day:

Demonstration of laser leveling at village Birmi, Dist. Ludhiana on 10th June, 2009.

6.1.4. Participation in seminars, conferences, symposia, workshops, etc.

Sr. no	Programme	Venue	Date	Name of Scientist
1	Chief Scientists' Meet of AICRP on Groundwater Utilization	MPUA&T, Udaipur	27-29th April,2009	Dr. R.Aggarwal Dr. S.Garg
2	Research and Extension Specialists Workshop for *Rabi* Crops.	PAU, Ludhiana	18-19 August,2009	Dr. R.Aggarwal
3	IIInd World Aqua Congress Enhancing water use efficiency	India Habitat Centre, New Delhi	2-4th December, 2009	Dr. R.Aggarwal
4	Research and Extension Specialists Workshop for Vegetable, Fruit and Flower crops.	PAU, Ludhiana	16-17th December, 2009	Dr. R.Aggarwal
5	9th Agricultural Science Congress under Technological and Institutional Innovations for Enhancing Agricultural Income organised by NAAS	SKAUST, Srinagar	June 22- 24, 2009	Dr. Sunil Garg

6.1.5 Invitation Lectures

Sr. no	Programme	Venue	No. of lectures	Date	No. of participants	Name of Scientist
1.	Field Evaluation of Drip Irrigation System under Training Course Conducted by PFDC	PAU, Ludhiana	1	20/02/09 10/03/09 21/08/09	20	Dr. Sunil Garg
2.	Drip Irrigation and Groundwater Recharge for Efficient Water Management	PAU, Ludhiana	2	02/03/09 to 04/03/09	13	Dr. R.Aggarwal
3.	Recharging of Rainwater	PAU, Ludhiana	1	04/03/09	80	Dr. R.Aggarwal
4.	Groundwater Recharge Techniques and Various Rainwater Harvesting Structures.	PAU, Ludhiana	1	04/03/09	6	Dr. R.Aggarwal
5	Field Evaluation of Drip Irrigation System under Training Course Conducted by PFDC	PAU, Ludhiana	1	10/03/09 21/08/09	20	Dr. Sunil Garg
6	Best Practices for Agricultural Pump sets and Rural Demand side Management Distribution Reforms, Upgrades and Management (DRUM) Training Program	BBMB, Nangal	2	25/03/09	17	Dr. R.Aggarwal
7	Importance of Water and Soil Testing, Judicious Use of Water, Drip and Sprinkler Irrigation and Soil Conservation	PNB Training Center, Fatehgarh Sahib	1	20/04/09	15	Dr. R.Aggarwal
8.	Importance of Water and Soil Testing , Judicious Use of Water, Drip and Sprinkler Irrigation and Soil Conservation	PNB Trg. Center, Fatehgarh Sahib	1	14/05/09	10	Dr. R.Aggarwal
9	Training Programme on " Natural & Human Resource Management"	PAMETI, Ludhiana	1	18/05/09	22	Dr. R.Aggarwal
10	Introduction of Drip Irrigation	KVK, Samrala	1	15/06/09	25	Dr. R.Aggarwal

11	Best Practices for Agricultural Pump sets and Rural Demand side Management distribution reforms, upgrades and management (DRUM) Training Program	BBMB, Nangal	2	17/06/09	9	Dr. R.Aggarwal
12	Importance of Water and Soil Testing , Judicious Use of Water, Drip and Sprinkler Irrigation and Soil Conservation	PNB Training Center, Fatehgarh Sahib	1	23/06/09	21	Dr. R.Aggarwal
13.	Recharging of Groundwater	Bandala	1	23/07/09	25	Dr. R.Aggarwal
14	Field Evaluation of Drip Irrigation System under Training Course Conducted by PFDC	PAU, Ludhiana	1	21/08/09	20	Dr. Sunil Garg
15	Lecture delivered on "Water management through latest irrigation techniques under Training programme for Field Functionaries of DAAWAT Foods Ltd. Bhopal (MP) on "Organic Farming for Sustainable Agriculture along with Advance Agricultural Practices and Farm Mechanization	Kairon Kisan Ghar, PAU, Ludhiana	1	26/08/09	20-25	Dr Sunil Garg
16	Field Problems and Remedial Measures in Micro Irrigation System	Deptt. of Soil & Water Engg., PAU, Ludhiana	1	21/08/09	18	Dr. R.Aggarwal
17	Best Practices for Agricultural Pump sets and Rural Demand side Management distribution reforms, upgrades and management (DRUM) Training Program	BBMB, Nangal	2	15/09/08	15	Dr. R.Aggarwal
18	Groundwater Recharging through Rainwater Harvesting	KVK, Samrala, Ludhiana	1	29/10/09	50	Dr. R.Aggarwal

19	Best Practices for Agricultural Pump sets and Rural Demand side Management Distribution Reforms, Upgrades and Management (DRUM) Training Program	BBMB, Nangal	2	15/12/08	15	Dr. R.Aggarwal
20	Laser Leveler Technology	KKG, PAU, Ludhiana	1	17/12/09	15-20	Dr Sunil Garg
21	Engineering Technologies for Crop Production & Environmental Control	PAU, Ludhiana	2	28/01/10	5	Dr. R.Aggarwal

Plate 6.2 Field visit of Russian delegates for rainwater harvesting structure

6.1.6 Kisan melas

All the scientists of the scheme participated in Kisan Melas at the main campus and regional stations twice the year to show various technologies developed in the scheme.

Plate 6.3 Demonstration of agricultural pumpsets

6.1.7 Exhibitions

- Exhibition was arranged on State Level Function on Energy Conservation organized by PSEB on 14th December, 2009 at PAU, Ludhiana
- Exhibition was arranged on State Level Function on Research and Extension Specialists Workshop for vegetables, Fruit and Flower crops.16-17th December, 2009 at PAU, Ludhiana

6.1.8 REC recommendation

REC recommendation for "Paired row trench planting for sugarcane saves irrigation water" included in Package of Practices, PAU, Ludhiana by Dr. Sunil Garg, Dr. MP Kaushal and Dr. Arun Kaushal

6.2 Transfer of Technology to Farmers (Pantnagar Centre)

6.2.1 Survey of irrigation pumping sets

A survey of irrigation pumping sets owned by the farmers around G.B. Pant University of Agriculture and Technology, Pantnagar was conducted to identify possible items of improvement in the overall efficiency of pumping units. The average efficiency of pumps was found as 36 percent. The main reasons for low efficiency of installed pumping units, on basis of survey, were identified as follows:

1. The pumps are not selected according to well conditions.
2. The drive units are not matching the pump requirement.
3. Excessive length of delivery pipe is used.
4. Standard and good quality pipe fittings are not used
5. Adequate technical help on the purchase, selection, installation and operation of pumping set is not available to the farmers.

The study indicated need for improving the efficiency of existing pumping units and caution for providing adequate technical guidance to farmers for selection of a matching pump and drive as per well conditions, their proper installation and operation to achieve an overall efficiency of 50 % for the system. This would help the country in saving large amount of petroleum and electricity used in irrigation.

Keeping above in view, a "Transfer of the Developed Technology to the Farmers" programme was taken up. The farmers were educated on the above mentioned aspects. During this programme defective pumping units of the farmers were also identified and in a few cases the rectification of defective pumping units was taken up. The farmers were demonstrated the performance of their pumping systems before and after the rectification, saving in fuel consumption and increase in discharge. The details of the study are as follows.

6.2.2 Educating farmers about pumps

To acquaint the farmers of the region with the development of propeller pump, foot valves, to educate them regarding the selection of pumps and pipe fittings to achieve the high efficiency of the pumping system, to optimize utilization of available land and water resources and their efficient management, meetings with the farmers were organised at different places in Udham Singh Nagar and Nainital districts of Uttarakhand, as per scheduled tabulated in section 6.2.3. In these meetings total 1312 farmers participated who were educated on the following aspects.

6.2.3 Details of farmers' trainings on land and water management

Location		Duration	No. of
District	**Village**		**Farmers**
U.S. Nagar	Kiratpur	August 06-12, 2009	52
	Khanpur	August 06-12, 2009	50
	Lakhipur	August 19-25, 2009	35
	Dhimari block	August 19-25, 2009	39
	Pantnagar	August 27- September 09, 2009	26
	Jhankat	September 01-07, 2009	47
	Balkheda	September 01-07, 2009	52
	Nandpur	September 20-26, 2009	60
	Haripura	September 20-26, 2009	52
	Pantnagar	October 27- November 09, 2009	31
	Pantnagar	December 14-27, 2009	20
Almora	Sheetala Khet	May 25 - 31, 2009	57
	Salla Rautela	May 25 - 31, 2009	51
Nainital	Bajaunia Haldu	January 2-8, 2009	69
	Pawalgarh	February 5-11, 2009	61
	Kamola	February 5-11, 2009	54
	Sonjala	March 12-18, 2009	53
	Ranikota	June 7-13, 2009	43
	Dechauri Degaon	June 7-13, 2009	60
	Chhoti Haldwani	November 10-16, 2009	51
	Bindukhatta	January 18-24, 2010	50
	Jamnipur	February 23 - March 1, 2009	52
	Prateetpur	February 23 - March 1, 2009	59
Dehradun	Anfield	September 27, 2009 to October 3, 2009	47
	Dharmawala	September 27, 2009 to October 3, 2009	51
Chamoli	Gwaldam	November 23-29, 2009	48
	Taal	November 23-29, 2009	42
	Total number of farmers trained		1312

6.2.4 Selection of pumps for efficient operation

The farmers were educated that a pump is designed for a particular head and capacity, therefore, it is important to select pumps well adopted to the particular conditions of operation, so as to obtain relatively high efficiency. If the quantity of pumped water is appreciably less than the quantity for which the pump is designed and the head is excessive, a low efficiency results. Likewise, the pump may deliver more water than the designed capacity at a head lower than the normal and cause the efficiency to be low. Thus a particular pump will result maximum efficiency for a set of conditions of head and discharge for which it has been designed. The farmers were also demonstrated use of characteristics curves or performance tables to select a proper pump set.

6.2.4.1 Selection of prime mover

Since a prime mover has its highest range of efficiency at 3/4 to full load, use of an oversize drive in pumping sets causes reduction in the overall efficiency of the system. The reduction may be 10 to 20 %. Hence a matching prime mover as recommended by the manufacturer should be selected.

6.2.4.2 Selection of pipe size

The size and length of the suction and delivery pipes play an important role in the head loss due to friction in the system. Improper size and excessive length of suction and delivery pipes result in much higher frictional losses than the losses in normal case. The size of the suction and delivery pipe of the pump should be such that it offers minimum frictional losses. The size of the suction or delivery pipe should not be smaller than the size of the suction and delivery sides of the pump. For example, if the pump is of the size of 10 x 10 cm the suction or delivery pipe should not be selected having diameter less than 10 cm.

6.2.4.3 Selection of foot valve/ reflux valve

The foot valves and reflux valves of different makes, material and qualities are available in the market. An improperly designed valve would offer many fold more frictional head loss in comparison to a good quality, properly designed valve. The Pantnagar foot valve was shown to the farmers and it was told that a foot valve which has open area in the strainer portion 3 times of the cross sectional area of the suction pipe with its valve opening almost 90E so that it may not cause obstruction in the passage of flow, should be purchased. One should insist for a good quality foot valve/ reflux valve even if it is costlier.

6.2.4.4 Selection of bends and other fittings

Each of the fittings offer frictional head loss and adds to the expenditure per unit of pump discharge. Care should be taken that the number of bends, tee and valves is kept minimum. 90^0 sharp bend and elbows offer maximum head loss and, therefore, should preferably be avoided. Long radius bends of smooth surface and good quality should be used. The delivery pipe should not be longer than actually required. Excessive length of pipe causes higher frictional loss and more power consumption.

6.2.4.5 Selection of pump for high discharge against low heads

The Pantnagar Propeller Pump of 22.5 cm size was shown to the farmers. They were explained that for efficient handling of large quantities of water against low heads (heads less than 4 m: such as lifting of water from rivers, canals, ponds or open wells with shallow water table) the propeller pump is best suited. It has relatively high discharge capacity and high efficiency, compared to other pumps for lifting water against low heads ranging from one to four meters. Components of propeller pump such as casing, propeller and diffuser were also shown to farmers. They were also educated on the operation and installation of the pump.

6.2.5 Conjunctive use of canal and ground Water

Farmers were also educated on the conjunctive use of canal and ground waters so that the problems of waterlogging in some areas and declining water table in other areas (where overexploitation of groundwater is taking place) may be solved. It may help in proper plant growth and yield.

6.2.6 Use of micro-irrigation for water conservation

In the water scares areas the farmers were trained on the use of micro-irrigation so that the optimum use of ground water can be achieved through the efficient and water saving irrigation methods and the over exploitation of ground water for irrigation purposes may be reduced.

6.2.7 Proper management of land and water resources

The benefits of proper management of land and water resources were described and farmers were educated about the efficient management of these resources so that they can get better yields and can have their lands in good health.

6.2.8 Rectification of defective pumping systems

On the basis of the survey conducted from the point of view of taking up rectification measures. The following, common defects were identified:

1. Maximum farmers were using defective pumping sets and were using nipple of 10 cm x 8 cm fitted on outlet end of delivery pipe of 10 cm diameter. This is done with the impression that it increases the discharge of the pump in view increased velocity of throw and higher length of nappe.
2. Most of the farmers were using elbows or short radius bends on suction as well as on delivery sides, which increase friction losses resulting in reduced discharge and more fuel consumption.
3. In some cases farmers were using longer delivery pipe than the actual requirement so that they can see from a long distance that pump is functioning or not. It also increases the head loss due to friction.
4. The survey revealed that the foot valves, being used by the farmers were very inefficient. In a study conducted by us showed that the open area in the foot valve should be more than three times of the cross sectional area of the suction pipe, whereas the open area in the foot valves of pumping sets of the farmers was less than the cross sectional area of the suction pipe. Due to this frictional head loss was more resulting in decrease in discharge rate and more consumption of fuel.

Out of these defects the rectification measures with respect to removal of nipple and re-placement of short radius bend with long radius standard bend were carried out on 18 pumping systems owned by the farmers. Information collected on these pumps include the general information, bore specifications, depth of water table and specifications of pipe and pipe fittings used on suction and delivery sides. The performance of pumps was evaluated with respect to increase in the discharge rate and saving in the fuel consumption. The owners of the defective pumping units were advised to change the concerned defective components and demonstrated the comparison of the existing performance with the performance after rectification by replacing the defective components. For this purpose the pump was run for a period of about 30 minutes. The discharge and fuel consumption before and after carrying out the rectification measures were recorded. The rectification resulted in the increase of discharge rate of the pumps by about 4.68 % (2504 lit/ hr) and saving in the fuel consumption by about 185 lit/ year assuming on an average 2000 hours per year of operation of the pump sets, the additional quantity of water as a result of the rectification comes out to be 5008 m^3 per annum.

6.3 Transfer of Technology to Farmers (Rahuri Centre)

6.3.1 Farmers' training

The farmers' training programme was organized on, "Groundwater Recharge and Groundwater Pollution", during 22-23 February, 2010 at Central Campus, Mahatma Phule Krishi Vidyapeeth, Rahuri and 32 farmers participated in it.

Plate 6.4 Farmers' training programme at Rahuri

6.3.2 Participation of scientific staff in national conference/training

1. Dr. S. D. Dahiwalkar attended the National Workshop on, "Water and Land Productivity Enhancement for Sustainable Irrigated Agriculture", organized by Acharya N. G. Ranga Agril. University, Hydrabad at Tirupati during March 9-10, 2010.
2. Dr. S. D. Dahiwalkar, Er. S. A. Kadam and Er. K. G. Pawar attended the 23rd National Convention of Agricultural Engineers on, "Agricultural Mechanization through Entrepreneurial Development", held at Dr. A. S. College of Agril. Engg., MPKV, Rahuri during 6th and 7th February, 2010.
3. Dr. S. D. Dahiwalkar, Research Engineer attended the State level Seminar on, "Soil Management for Food Security", organized by Rahuri Chapter, ISSS, Dept. of SSAC, MPKV, Rahuri at Solapur during February 26-27, 2009.
4. Dr. S. Dahiwalkar, Research Engineer attended International Conference on Food Security and Environmental Sustainability, FSES-2009 held at Agril. and Food Engineering Dept., IIT, Khargpur during December 17-19, 2009.

6.4 Transfer of Technology to Farmers (Jabalpur Centre)

6.4.1 Training to master trainers at tribal district Mandla- 16-18 Nov. 2009

Jabalpur centre organized training for state government officials of Mandla district at Mandla. It included topics like rain water harvesting, ground water recharge, water productivity crop diversification and change in cropping pattern. About 120 officials from concerned state departments and elected local representatives attended the training during 16-18 November 2009. About 120 officials of Department of Agriculture, Department of Forest, Department of Water Resources, Department of Rural Development, Department of Fisheries, Department of Sericulture along with the Chief Executive Officers (CEOs) of Jila Panchayat and Janpad Panchayat and the elected members of these local bodies attended the training for three days from 16 to 18 Nov 2009 in the conference hall of Jila Panchayat. This training was conducted by the scientists of the centre

6.4.2 Krishak sangosthi on "Groundwater Recharge and Conservation Program for Haveli Fields"

One day Krishak Sangosthi for "Ground Water Recharge and Conservation Program for Haveli Fields" was organised on 7th March 2010. About 150 farmers from Bandha, Katra, Gosalpur, Panagar, Sihora, Majholi and surrounding rural villages participated in the programme. The farmers were convinced about improving water productivity of Haveli fields by introducing Singhara crop in *kharif* besides wheat in *rabi*. Dr. S.S.Tomar Director Research Services, Dr. N.K. Seth, Dean College of Agricultural Engineering were present on this occasion.

Plate 6.5 Farmers participating in Krishak Sangosthi

6.4.3 Techniques for restructuring in command area

The scientists of the centre along with extension unit of JNKVV, comprising an agronomist and entomologist visited the command area and studied the problems and demographic situations. On the basis of the suggestion of the team, a farmers meeting was organised in the command area of Jamuniya minor. Cleaning of Khulri minor was discussed with the farmers and officials.

Plate 6.6 Farmers discussing the problems with scientists

6.4.4 Radio talks, lectures, workshop

- Er. R, N. Shrivastava delivered a radio talk on All India Radio on Efficient Utilization of Irrigation Pumps in Farmers' fields.
- The scientists of the centre participated in Kisan Melas, Khet Pathshala, farmers' training, trainings of field officers of state government and NGO's etc. organized by JNKVV, State Govt. of Madhya Pradesh, National Research Center, for Weed Science (ICAR), Jabalpur.
- Attended Workshop and Review Meeting at Directorate of Research Services, JNKVV, Jabalpur for 8th – 9th June 2009 and presented the work of the GWU project.
- Attended and presented the project work in Review Meeting at CAE, Jabalpur 23rd May 2009.
- Attended workshop on improving productivity of selected irrigation and drainage assets in five basin under MPWSRP 25-26 June 2009 held at CAE, JNKVV, Jabalpur.
- Attended 'Chief Scientists' meet at MPUAT, Udaipur 27-29 April, 2009.

6.4.5 Trainings conducted

- Agriculture Diversification & Intensification for 5 days
- Production Package of Practices for Medicinal & Aromatic Crops for 5days
- Extension Techniques for Enhancing Water Use Efficiency in Agriculture for 5 days
- Storage of Agriculture Produce for 5 days
- Use of RS and GIS in Water Resources Management in Command Areas for 5 days

6.4.6 Lectures delivered

Soil conservation techniques	Dr. M.K. Awashti
Singhara cultivation - a diversification agriculture	Er. R.N. Shrivastava
Water harvesting & crop intensification	Dr. M.K. Awasthi
Field visit Medicinal Plant- Sohad, Barkheda	Er. R.N. Shrivastava
Improved irrigation practices	Dr. R.K. Nema
Irrigation system for orchards	Dr. R.K. Nema
Concept of RS and its application in agriculture	Dr. R.K. Nema
Satellite, sensor and resolution	Dr. M.K. Awasthi
Remote sensing data acquisition	Dr. R.K. Nema
Hands on exercise with hand held spectro radio meter	Dr. R.K. Nema & Er. R.N. Shrivastava
Hands on exercise with GPS for ground truth	Dr. M.K.Awasthi
Irrigation water measurement devices for calculating water efficiency	Dr R.K. Nema & Er. R.N. Shrivastava
Concepts of water use efficiency, its current status in command areas	Dr. R.K. Nema
Field visit to visualize the status of water use efficiency	Dr. R.K. Nema & Dr. M.K. Awasthi
PRA in village to diagnose the present situation	Er. R.N. Shrivastava
Conjunctive use in command areas	Prof. Y.K. Tiwari
Performance indicators of water use efficiencies	Dr. R.K. Nema

6.5 Transfer of Technology to Farmers (Coimbatore Centre)

6.5.1 Farmers' trainings conducted

Following training programmes were organised for farmers and trainers under "Scaling up of Water Productivity in Agriculture for Livelihoods through Teaching cum Demonstration to the Trainers and Farmers" by the coimbatore centre:

1. Training on "Water Management" to the farmers from 18.06.2009 to 24.06.2009 was held at Annur village, Annur block, Coimbatore district. About 50 farmers including 31 woman farmers from various places of Coimbatore district attended the training and water management practices were explained. Field visits to drip irrigation farms in and around Annur block and irrigation cafeteria, WTC were arranged for practical exposure.

Plate 6.7 Farmers discussing with scientists

2. Training on "Water Management" to the trainers from 13.07.2009 to 26.07.2009 was held at WTC, TNAU, Coimbatore. About 25 trainers from Agriculture, Horticulture, Agricultural Engineering Department and NGOs attended the

training and resource persons from line departments like Agriculture, Horticulture, Agricultural Engineering, Fisheries, DRDA and NGOs were invited for guest lectures. Field visits to ARS, Bhavanisagar and WTC Irrigation Cafeteria were also arranged for practical exposure.

3. Training on "Water Management" to the farmers from 27.08.2009 to 02.09.2009 was held at Allapalayam village of Annur block, Coimbatore district. About 50 farmers including 16 woman farmers from various places of the selected village attended the training and water management practices were explained and demonstrated to them. Field visits to drip irrigation farms in and around Annur block and Irrigation Cafeteria, WTC were arranged for practical exposure.

4. Training on "Water Management" to the farmers from 16.12.2009 to 22.12.2009 was held at Seeliyur village of Karamadai block, Coimbatore district. About 50 farmers including 20 woman farmers from various places of the selected village attended the training and water management practices were explained and demonstrated to them. Field visits to drip irrigation trials at ARS, Bhavanisagar and Irrigation Cafeteria, WTC were arranged for practical exposure.

5. Training on "Water Management" to the farmers from 22.02.2010 to 28.02.2010 was held at Dayanur village of Karamadai block, Coimbatore district. About 50 farmers including 12 woman farmers from various places of the selected village attended the training and water management practices were explained and demonstrated to them. Field visit to drip irrigation trials at ARS, Bhavanisagar was arranged for practical exposure. Demonstration on acid treatment for removal of salts in the drip pipes was also made in the farmers' field. A mobile unit exclusively designed for demonstration of drip components by Jain irrigation system was brought to the Dayanur village and demonstrated by experts.

Plate 6.8 Demonstration on acid treatment to remove salts in drip pipes

Plate 6.9 Demonstration of drip components by Jain irrigation

Plate 6.10 Demonstration on Vermicompost technique to the farmers

6.5.2 Workshop attended

The scientists of the Coimbatore centre (Dr.C.Mayilswami, Professor (SWCE), Chief scientist; Er.A.Valliammai, Soil and Water Conservation

Engineer; Dr.K.M.Sellamuthu, Soil Scientist) attended the Chief Scientists' Meet of the All India Coordinated Research Project (AICRP) on Groundwater Utilization (GWU) at MPUAT, Udaipur, Rajasthan during 27-29, April 2009.

The scientists of the groundwater project also attended the Annual Research Meet 2009 (Projects not covered under crops) held at Tamil Nadu Agricultural University, Coimbatore during 21-22, May 2009.

Dr.C.Mayilswami, Officer in-charge, ICAR-AICRP (GWU) attended the 6th annual meeting of the Asia Oceania Geosciences Society (AOGS) held at Suntec city convention centre, Singapore from 11th August to 15th August 2009.

Dr.C.Mayilswami, Officer in-charge, ICAR-AICRP (GWU) attended the Indo US workshop on "Emerging Issues in Water Management for Sustainable Agriculture in South Asia Region" held at Udhagamandalam during December 10-12, 2009 jointly organized by Central Soil & Water Conservation Research & Training Institute, Udhagamandalam and Michigan State University, East Lansing, MI, USA.

Dr.C.Mayilswami, Officer in-charge, ICAR-AICRP (GWU) attended the workshop on "Water Resources Management" held at Salem during March 01-02, 2010 jointly organized by Central Ground Water Board, Ministry of Water Resources, Government of India, South Eastern Coastal Region, Chennai and Sona College of Technology, Salem.

6.6 Transfer of Technology to Farmers (Udaipur Centre)

The Chief Scientists' Meet of the All India Coordinated Research Project (AICRP) on Groundwater Utilization (GWU) was held at Maharana Pratap University of Agriculture and Technology (MPUAT), Udaipur, Rajasthan during 27-29, April 2009.

Plate 6.11 Hon'ble DDG (NRM) and Director (DWM) released the publications

6.6.1 Training organized

Organized 5 days training programme (20th-24th, Feb. 2010) sponsored by Sadguru Water and Development Foundation on "Water Management for the Progressive Farmers of Jhalawar District, Rajasthan".

6.6.2 Human Resources Development

- **International Fellowship**

Dr. P.K. Singh, Associate Professor and PI received Fulbright Fellowship of Visiting Lecturer from USEFI and visited Florida International University, Miami from 15th September 2009 to 15th January 2010.

- **International Training**

Dr. Deepesh Machiwal participated in International Workshop on Capacity Development for Farm Management Strategies to Improve Crop-Water Productivity using AquaCrop from 14.09.2009 to 18.09.2009 at China Agricultural University, Beijing, China.

- **National Conference / Seminar**

The following staff members attended the national training programmes / seminars / conferences to improve their skills and understanding in the respective fields.

Dr. P. K. Singh attended the National Seminar on "Conservation of Lakes and Water Resources: Management Strategies" organized by Deptt. of Environment, Govt. of Rajasthan during 19-20 Feb., 2010 at CTAE, Udaipur.

Dr. K.K. Yadav attended i) **Platinum Jubilee Symposium** on "Soil Science in Meeting the Challenges to Food Security and Environmental Quality" at **IARI, New Delhi, from 22-25 Dec.,2009 and ii)**National Seminar on "Conservation of Lakes and Water Resources : Management Strategies" organized by Deptt. of Environment, Govt. of Rajasthan during 19-20 Feb., 2010 at CTAE, Udaipur.

Dr. Deepesh Machiwal attended i) National Workshop on "Water Scenario, Efficient Use and Management in Rajasthan" Organized by Central Ground Water Board, Jaipur during March 13-14, 2009 and ii) National Seminar on "Conservation of Lakes and Water Resources : Management Strategies" organized by Deptt. of Environment, Govt. of Rajasthan during 19-20 Feb., 2010 at CTAE, Udaipur.

6.6.3 TV/Radio Talks Delivered

Dr. P.K. Singh delivered a radio talk on the topic **"भू–जल पुर्नभरण का वैज्ञानिक पहलू"** on dated 28th August, 2009 from AIR, Udaipur

6.7 Transfer of Technology to Farmers (Pusa Centre)

6.7.1 Farmers' trainings

Training cum awareness programmes on scaling up of water productivity in agriculture, were organized at various places of the state. The fourth 7 days training programme was organized for 50 farmers of Darbhanga district during 27th May to 3rd June, 2009 at RAU Pusa. The fifth programme was attended by 55 progressive farmers of Muzaffarpur district during 22-28, June, 2009 at Kisan Ghar RAU, Pusa. The sixth training was attended by over 54 farmers of Madhubani district during 22-28, June, 2009 at Ikh Bhavan, RAU, Pusa. In these training programmes, the scientists of RAU, experts of NGOs and Officers of Agriculture Department, Govt. of Bihar delivered lectures and shared their experiences. Demonstrations and field visits on various aspects were also organized. Various scientific approaches for making best use of scarce water resources were discussed interactively. The problems and queries of farmers in respect of ground water and water quality were addressed appropriately. Farmers were made acquainted with various schemes implemented by the governments in support of farming community and new technologies available for enhancing the agricultural production with limited water use. Vice-Chancellor, Director Research, Director of Extension, Dean cum Principal, District authorities also addressed the participating farmers. Dr. S.K. Jain, Senior Scientist & Principal Investigator, other scientists and staffs of the GWU scheme were actively involved in organizing these programmes. .

6.7.2 Participation in agri-expo - 2009

A Kisan Mela was organized by the Rajendra Agricultural University during 5-7th Feb, 2010. A stall was arranged by the scientists and technical staffs of the GWU scheme to increase the awareness in safe exploration and utilization of ground water. The farmers were educated on the various aspects like care and maintenance of diesel pumping systems. Farmers were made aware of the merits of Raingun irrigation systems and their queries about the availability and Government's schemes for promotion of such technology were explained. Farmers were also acquainted with various quality parameters, their importance, health hazards due to various pollutants, causes of ground water contamination and their remedies in relation to human health and better sustainable crop production, through live and pictorial presentation.

Plate 6.12 Scientists interacting with farmers

6.7.3. Seminar/ Symposium/ Conference attended

1. Dr. S. K. Jain participated in the ISAE Annual Convention and Symposium held at B.A.U., Kanke, Ranchi during 15-17, February, 2009.

2. Dr. S.K. Jain participated in Seminar cum Workshop organized by Agril. Deptt., Govt. of Bihar at Patna during 23-24 July, 2009.

6.8 Transfer of Technology to Farmers (Raipur Centre)

During the farmers' training, soil and water testing kits were shown to the farmers and importance of testing of soil and water was explained to them during the programme. Special presentations related to groundwater use and artificial groundwater recharging were shown by the scientists. Appropriate solutions were suggested to various problems of the farmers. Field visit was also arranged during this programme. Pamphlets related to groundwater recharging and its optimum utilization using precise irrigation technologies were distributed to the participating farmers.

Plate 6.13 Farmers interacting with the scientist during the lectures

6.9 Transfer of Technology to Farmers (Junagadh Centre)

6.9.1 Participation in *Krushi mahostav* and *melas*/ farmers' trainings

Krishi-Mahostav was organized by Government of Gujarat from 19/05/2009 to 05/06/2009. During *'Krishi-Mahostav'* scientists along with the staff of line department, Bank, forest, health and NGO's participated in various Seminars at each Taluka of Saurashtra. The lectures delivered by the scientists in seminars updated the scientific information, knowledge and skill of farmers, artisans, fisherman and entrepreneurs of agro-based industries.

Plate 6.14 Demostration of technologies to farmers during state level Krushi mela

The scientists of AICRP have delivered about twelve lectures in various farmers' training programmes/ days organized by different departments of the university during the year.

AICRP Scientists actively participated in a Seminar on *"Jal samapati angenee jaagruti maahitee vitarana ane gyana bhaageedaaree angeno parisanvaad"* organized by Guajarat Water Resources Dev. Corpn. - Gandhinagar at CAET, JAU- Junagadh inaugurated by Dr. N. C. Patel, Hon. Vice Chancellor, JAU- Junagadh on 30-09-2009. Geo resistivity method demonstration was arranged for farmers during parisanvaad.

6.9.2 Seminar organized under *Krushimahotsav* - 2009

A Seminar on 'Application of Drip Irrigation System in Row Crops' was organized under mega event *Krushimahotsav*-2009 by AICRP on Groundwater Utilization, Junagadh. The Chief Guest Dr. Ashwini Kumar, Director, Directorate of Water Management (ICAR)-Bhubaneswar delivered the key note address on "Drip irrigation status in india". Dr. N. C. Patel, Principal and Dean, College of Agril. Engg. &Tech., JAU- Junagadh presided over the function. Other distinguished speakers were Prof. R. B. Maravia, Exec. Director(Agri.), Sardar Sarovar Narmada Nigam Ltd., Gandhinagar, Dr. N. K. Gontia., HOD, Dept. of Soil & Water Engg., JAU, Junagadh, Dr. H. D. Rank, Research Scientist(Agril. Engg.),JAU, Junagadh, Shri

Kalaria, OSD, Gujarat Green Revolution company Ltd, Vadodara and Krushi Rushi, Habibabhai, from village Mangrol. Vote of thanks presented by Er. P. B. Vekariya, Asstt. Prof. Mr. P. G. Vadher, Asst. Prof., Ku. Poonam, Steno, Shri P. V. Vora, Sr. clerk, and Ku. Preeti Jayswal helped in successfully organizing the seminar. Many farmers attended the seminar and got benefited.

6.9.3 Training acquired by staff

Er. P. B. Vekariya, Assistant Professor attended "Climate Change" at Saradar Patel Institute of Public Administration, Ahmadabad, from 8th to 11th June - 2009.

Mr. P. G. Vadher, Assistant Professor attended "Scaling up Water Productivity in Agriculture for Livelihood" from 18th September to 01st October 2009 at Water Technology Centre, Indian Agricultural Research Institute, New delhi-110012.

6.9.4 Participation of staff in professional events

Dr. N. K. Gontia, Research Engineer and Professor & Head attended i) Annual Scientists' Meet of AICRP,GWU at CTAE-Udaipur during April 27-29,09 ii) Seminar on Global Warming, organized by ISPL – Ahmadabad on 7-08-2009. iii) International Conference on Food Security and Environment Sustainability. (FSES -2009). At IIT –Kharagpur during 17th – 20th Dec.-2009 and presented two Papers.

6.9.5 Visits of special guests

Dr. Mangala Rai Hon. DG, ICAR Visited , AICRP, GWU and SWE Deptt., on 9th April-09. He was accompanied by Dr. R.P.S. Alhavat, the then Hon. V.C. NAU-Navsari. Hon. DG ,ICAR appreciated the research & extension activities carried out by the centre.

Dr. Ashwini Kumar, worthy Director, DWM (ICAR) Bhubaneswar. visited coastal experimental site of AICRP-Khapta farm of JAU Porbandar on 27/05/2009 and gave his opinion.

Dr. M. M. Pandey, Hon. DDG, ICAR- New Delhi visited the AICRP,GWU centre and SWE Deptt. on 10/09/2009 and praised the facilities developed.

7

LIST OF PUBLICATIONS DURING 2009-10

7.1 Publications of Ludhiana Centre

7.1.1 International/ National Journal/ Proceeding papers

Aggarwal Rajan, Kaushal, M.P., Kaur, Samanpreet and Singh, Bhupinder. 2009. Water Resource Management for Sustainable Agriculture in Punjab, India. Water Science and Technology-WST 60 (11):2905-2911.

Aggarwal Rajan, Kaur, Samanpreet and Pamela Miglani. 2009. Blockwise assessment of water resources in Jalandhar district of Indian Punjab. Journal of Soil and Water Conservation 8 (3): 66-70.

Aggarwal Rajan, Kaur, Samanpreet and Pamela Miglani. 2009. Blockwise assesment of water resources in Hoshiarpur district of Punjab. Indian Journal of Soil Conservation.37 (2): 106-111.

Aggarwal Rajan and Kaur, Samanpreet. 2009. Energy conservation in agricultural pump sets of Punjab- By people's participation. Proceedings of IIIrd World Aqua Congress, New Delhi: 8-14.

Kaur, Samanpreet, Aggarwal, Rajan and Soni, Ashwani.2009. Assessment of long term water table behavior for the state of Punjab using GIS. Proceedings of IIIrd World Aqua Congress, New Delhi: 167-178.

Garg, S, Bhardwaj, A, Sharda, R., Kaushal, M.P., Biwalkar, N. and Thaman, S. 2009 Effect of precision land leveling on water application efficiency and wheat yield. Proceedings of 9th Agricultural Science Congress under Technological and Institutional Innovations for Enhancing Agricultural Income organised by NAAS at SKAUST, Srinagar June 22-24, 2009 pp.96.

Sharda, R., Kaushal, M.P.,Siag, Mukesh, Garg, S. and Thaman, S. 2009. Rain water harvesting and linkages with micro-irrigation. Proceedings of 9th Agricultural Science Congress under Technological and Institutional Innovations for Enhancing Agricultural Income organised by NAAS at SKAUST, Srinagar June 22-24, 2009 pp.19.

Biwalkar, N., Sharda, R., Kaushal, M.P., Garg, S., Sharma, S.C., Rana, D.S. and Thaman, S. 2009. Rainwater harvesting for livelihood support under rainfed area of Punjab. Proceedings of 9th Agricultural Science Congress under Technological and Institutional Innovations for Enhancing Agricultural Income organised by NAAS at SKAUST, Srinagar June 22-24, 2009 pp.174.

7.1.2 Extension/ Popular Articles

Aggarwal, Rajan, Singh, K.J. and Kaur, Samanpreet. 2009. Tubewell laye filter di sahi choan karo. Moderen kheti: 26-27 (01/01/2009).

Kaur, Samanpreet, Aggarwal, Rajan and.Singh, K.J. 2009. Kheti vitch paani di suchagi vartoan. Moderen kheti: 38-39 (15/01/2009).

Sandhu K S and Aggarwal, Rajan.2009. Sustaining productivity in crops and cropping system. Progressive farming 46 (4):3-4.

Sandhu K S and Aggarwal, Rajan.2009. Efficient irrigation techniques for judicious water use. Progressive farming 46 (4):17-18.

Aggarwal, Rajan and Kaur, Samanpreet.2009. How to detect and remove harmful gases from tube-well. Progressive farming 46 (7):17.

7.1.3 Course Compendium

Sidhu B S, Sekhon, K S, Singh, Avtar, Brar, K S and Aggarwal, Rajan. 2009. Sustenance of ground water resources for higher crop and water productivity. Indian Council of Agricultural Research, PAU, Ludhiana. pp: 202.

7.1.4 Chapters in Course Compendium

Aggarwal , Rajan 2009. Ground water recharge for sustainable agricultutre. Chapter included in

Course Compendium on Sustenance of ground water resources for higher crop and water productivity. Indian Council of Agricultural Research, PAU, Ludhiana. pp: 1-6.

Aggarwal , Rajan 2009. Selection, installation and efficient use of agricultural pumpsets. Chapter included in Course Compendium on Sustenance of ground water resources for higher crop and water productivity. Indian Council of Agricultural Research, PAU, Ludhiana. pp: 182-183.

7.2 Publications of Pantnagar Centre

7.2.1 International/ National Journal/ Proceeding papers

Kadam Satish, Kumar, Shiv, Kumar, Yogendra and Sharma, H.C. 2009. Application of Principal component analysis to study the effect of fertilizer factory effluent and Aril river water on the quality of water of unconfined aquifer of nearby area. International Journal of water resources and environmental management.Vol.1 No.1, pp27-38

Kumar Shiv and Kumar, Yogendra. 2009. Water table fluctuations in an unconfined aquifer with horizontal heterogeneity. ISH Journal of Hydraulic Engineering, special issue,Vol 15, No.3.pp 75-86

Shakya, S.K., Singh, S.R., Anjaneyulu, B. and Vashisht, A.K. (2009). Design of a low-cost bamboo well. Ground Water, 47 (2): 310-313.

Gupta Akanksha, Pal, M.S. and Sharma, H.C. 2009. Temporal land use pattern in Maniyar watershed of Uttarakhand using GIS and Remote Sensing. Pantnagar Journal of Research (In Press).

Chandra, Harish and Sharma, H.C. 2009. Crop water requirement and surface water supply and ground water balance for conjunctive use in canal command area, presented in the National Seminar on Recent Advances in Hydrology for Water Resources Development and Management held from January, 21 to 22 at Water Resources Engineering and Management Institute, Maharaja Sayajirao University of Baroda, Samiala Vadodara,

Chandra, Harish and Sharma, H.C. 2009. Ground water potential in district Udham Singh Nagar of Uttarakhand, presented in the National Seminar on Recent Advances in Hydrology for Water Resources Development and Management held from January, 21 to 22. at Water Resources Engineering and Management Institute, Maharaja Sayajirao University of Baroda, Samiala Vadodara.

Kumar, Shiv, Kumar, Yogendra, Saini, Deepak and Kumar, Munish. 2009. Study of Hydraulic and soil properties for humid(TARAI) region of Uttarakhand. Proceedings (on CD) of XXVII annual convention of Association of Hydrologist of India & National Seminar on " Recent advances in Hydrology for water resources Development and management" held at Water resources Engineering and Management Institute Samiala, Vadodra, Gujrat doring 21st -22nd January 2009.

7.3 Publications of Rahuri Centre

7.3.1 International/ National Journal/ Proceeding papers

Dahiwalkar S. D., Kadam, S. A. and Gorantiwar, S. D. 2009. Studies on effect of municipal waste water on ground water quality. Souvenir of State level Seminar on, "Soil management for food Security", organized by Rahuri Chapter, ISSS, Dept. of SSAC, MPKV, Rahuri at Solapur during February 26-27, 2009. Pp.134-135.

Kadam S. A., Gorantiwar, S. D. Gadge, S. B. Shinde T. A. and Wagh, Y. R. 2010. Performance Characteristics of Mini-sprinkler - A Case Study. Souvenir23rd National Convention of Agricultural Engineers on, "Agricultural Mechanization through Entrepreneurial Development", held at Dr. A. S. College of Agril. Engg., MPKV, Rahuri during 6th and 7th February, 2010.

Dahiwalkar S. D., Kadam, S. A. and Gorantiwar, S. D. 2010. Performance evaluation of filtration unit for artificial groundwater recharge. Souvenir23rd National Convention of Agricultural Engineers on, "Agricultural Mechanization through Entrepreneurial Development", held at Dr. A. S. College of

Agril. Engg., MPKV, Rahuri during 6th and 7th February, 2010.

Dahiwalkar S. D. and Gorantiwar, S. D. 2010. Artificial ground water recharge through filtration technique. Souvenir of International Conference on Food Security and Environmental Sustainability, FSES-2009 held at Agril. And Food Engineering Dept., IIT, Khargpur during December 17-19, 2009

Dahiwalkar S. D., Gorantiwar, S. D. and Singh, R. P. 2010. Development of water and land allocation model for sustainable irrigated agriculture in command of mula irrigation project. Souvenir of National Workshop on, "Water and Land Productivity Enhancement for Sustainable Irrigated Agriculture", organized by Acharya N. G. Ranga Agril. University, Hydrabad at Tirupati during March 9-10, 2010.

7.4 Publications of Jabalpur Centre

7.4.1 Chapters in training manuals / Extension / Popular Articles

Awasthi M.K., Upadhyay V.V. 2009. "Agricultural Diversification & Intensification", A training manual published for officers level training during 21-25 Dec, 2009.

Awasthi M.K.,Tiwari A.B. 2010. "Production package of practices for medicinal & aromatic crops.", A training manual published for officers level training during 4-8 Jan. 2010.

Nema R.K., Awasthi M.K., Sahu M.L. 2010. "Extension Techniques for Enhancing Water use Efficiency in Agriculture", A training manual published for officers level training during 1-5 Feb. 2010.

Tiwari Y.K., Jain D.K. and Pandey, Sheela 2010. "Storage of Agriculture Produce", A training manual published for officers level training during 15-19 Feb. 2010.

Nema R.K., Awasthi M.K., Sharma S.K. 2010. "Use of RS and GIS in water resources management in command area", A training manual published for officers level training during 2-6 Feb. 2010.

Nema R.K., Shrivastava R.N., Awasthi M.K., and Tiwari Y.K. 2010. Efficient water lifting devices for irrigation. A research bulletin published under G.W.U. Project, College of Agricultural Engineering, J.N.KV.V., Jabalpur.

Nema R.K., Awasthi M.K., Tiwari Y.K and Shrivastava R.N. 2010. "Ground Water Pollution in Mandya Pradesh". A research bulletin published by G.W.U. Project, College of Agricultural Engineering, J.N.KV.V., Jabalpur.

Nema R.K., Awasthi M.K., Tiwari Y.K and Shrivastava R.N., 2010. पानी की खेती : हवेली पद्धति, An extension folder published by G.W.U. Project, College of Agricultural Engineering, J.N.KV.V., Jabalpur.

Nema R.K., Awasthi M.K., Tiwari Y.K and Shrivastava R.N., (2010). हवेली खेतों में सिंघाड़ा फसल से अतिरिक्त आय, An extension folder published by G.W.U. Project, College of Agricultural Engineering, J.N.KV.V., Jabalpur.

Nema R.K., Awasthi M.K., Tiwari Y.K and Shrivastava R.N., (2010).निस्तार नालों से फसल सिंचाई, An extension folder published by G.W.U. Project, College of Agricultural Engineering, J.N.KV.V., Jabalpur.

Nema R.K., Awasthi M.K., Tiwari Y.K and Shrivastava R.N., (2010). कृत्रिम पानी सोख्ता, An extension folder published by G.W.U. Project, College of Agricultural Engineering, J.N.KV.V., Jabalpur.

Nema R.K., Awasthi M.K., Tiwari Y.K and Shrivastava R.N., (2010).फब्बारा सिंचाई, An extension folder published by G.W.U. Project, College of Agricultural Engineering, J.N.KV.V., Jabalpur.

Nema R.K., Awasthi M.K., Tiwari Y.K and Shrivastava R.N., (2010).ड्रिप सिंचाई, An extension folder published by G.W.U. Project, College of Agricultural Engineering, J.N.KV.V., Jabalpur.

Nema R.K., Awasthi M.K., Tiwari Y.K and Shrivastava R.N., (2010). "A manual on submersible pumps. User's manual published by G.W.U. Project, College of Agricultural Engineering, J.N.KV.V., Jabalpur.

Nema R.K., Awasthi M.K., Tiwari Y.K and Shrivastava R.N., (2010). "Diversified Agriculture in water-logged areas". A bulletin published by G.W.U. Project, College of Agricultural Engineering, J.N.KV.V., Jabalpur.

Nema R.K., Awasthi M.K., Tiwari Y.K and Shrivastava R.N., (2010) "नहर–जल का कुशल उपयोग" An extension bulletin for farmers published by G.W.U. Project, College of Agricultural Engineering, J.N.KV.V., Jabalpur.

Nema R.K., Awasthi M.K., Tiwari Y.K and Shrivastava R.N., (2010). " कमाण्ड क्षेत्र में नलकूप व नहर का संयुक्त उपयोग कैसे करें " An extension bulletin for farmers published by G.W.U. Project, College of Agricultural Engineering, J.N.KV.V., Jabalpur.

Nema R.K., Awasthi M.K., Tiwari Y.K & Shrivastava R.N., (2010). " कुछ सरल रिचार्ज तकनीकें " An extension bulletin for farmers published by G.W.U. Project, College of Agricultural Engineering, J.N.KV.V., Jabalpur.

Nema R.K., Awasthi M.K., Tiwari Y.K and Shrivastava R.N., (2010). " दक्ष स्प्रिंकलर सिंचाई " An extension bulletin for farmers published by G.W.U. Project, College of Agricultural Engineering, J.N.KV.V., Jabalpur.

7.5 Publications of Coimbatore Centre

7.5.1 National and International Proceeding papers

Sellamuthu, K.M.., C. Mayilswami, A. Valliammai and S. Chellamuthu. "Effect of textile and dye industry pollution on groundwater quality of Noyil River basin, Tamil Nadu, India". A paper presented in 6th annual meeting of the Asia Oceania Geosciences Society (AOGS) held at Suntec city convention centre, Singapore from 11th August to 15th August 2009.

Valliammai, A., C. Mayilswami, K.M. Sellamuthu and S. Chellamuthu. "Impact Evaluation of Artificial Recharge Structure (Recharge Shaft) in Hard rock Regions of Tamil Nadu, India". A paper presented in 6th annual meeting of the Asia Oceania Geosciences Society (AOGS) held at Suntec city convention centre, Singapore from 11th August to 15th August 2009.

Chellamuthu, S. and C. Mayilswami. "Water management through micro-irrigation system in Tamil Nadu – An Overview". A paper presented in Indo – US workshop on "Emerging issues in Water Management for Sustainable Agriculture in South Asia Region" held at Udhagamandalam during December 10-12, 2009.

Chellamuthu, S. and C. Mayilswami. "Increasing crop productivity – more crop per drop of water". A paper presented in the workshop on "Water resources management" held at Salem during March 01-02, 2010.

7.5.2 Bulletin (Tamil)

Palanisami, K.P., S.Chellamuthu, R.Ranganathan, C.Mayilswami, D.Sureshkumar, S.Senthilnathan and N.Ajjan. "Kaalanilai maarupattin karanamagha, inthiya velanmayil yerpattuulla paathipukkal". Farmers training guide, 2010

7.6. Publications of Udaipur Centre

7.6.1 International/National Journal / Proceeding Papers

Yadav, K.K and Singh, P.K. 2009. Heavy metal contamination of agricultural lands and groundwater through urban effluent in vicinity of Ahar river. Ecology, Environment and Conservation. 15 (4): 1-5.

Machiwal, D. and Singh, P.K. 2009. Determination of aquifer parameters in hard-rock aquifer of Ahar River basin, Udaipur, Rajasthan. Workshop on Water Scenario, Efficient Use and Management in Rajasthan, Jaipur, India, March 13-14, 2009.

Yadav, K.K. 2009. Groundwater pollution due to urban effluent through Ahar river in Udaipur, Rajasthan. Presented in Platinum Jubilee Symposium on "Soil Science in Meeting the Challenges to Food Security and Environmental Quality" held at IARI, New Delhi, from 22-25 Dec., 2009.

7.6.2 Books Published

Mahnot, S.C. and Singh, P.K. (2010). Bhu avam Jal Sanrakshan, Rohan Publishers, Udaipur, pp. 130.

Machiwal, D., Singh, P.K. and Yadav, K.K. (2010). Determination of hydraulic properties and delineation of groundwater potential zones in hard rock aquifers, published by MPUAT, Udaipur.

7.6.3 Book Chapters

Selvi, V., Machiwal, D., Shaheen, F.A. and Sharma, B.R. (2009). Groundwater resources and the impact of groundwater sharing institutions: Insights from Indian Punjab. In: Mukherji, A., Villholth, K.G., Sharma, B.R. and J. Wang (Editors), Groundwater Governance in the Indo-Gangetic and Yellow River Basins – Realities and Challenges, CRC Press, p. 328.

Krishnan, S., Islam, A., Machiwal, D., Sena, D.R. and Villholth, K.G. (2009). Using the living wisdom of well drillers to construct digital groundwater data bases across Indo-Gangetic basin. In: Mukherji, A., Villholth, K.G., Sharma, B.R. and J. Wang (Editors), Groundwater Governance in the Indo-Gangetic and Yellow River Basins – Realities and Challenges, CRC Press, p. 328.

7.6.4 Popular Articles

Singh, P.K. and Yadav, K.K. (May, 2009). Multiple use of rainwater harvested through plastic lined farm pond – A success story. Indian Farming, pp 8-11

Yadav, K.K., Machiwal, D. and Singh, P.K. (June, 2009). Bhoo Jal Punarbharan ki Vidhiyan. Rajasthan Kheti Pratap. pp 13 - 15 & 23.

Singh, P.K., Yadav, K.K. and Machiwal, D. (June, 2009). Krishi bhumi par mirda avum jal sanrakshan va sangrahan. Rajasthan Kheti Pratap. pp 8-12.

7.7 Publications of Pusa Centre

7.7.1 International/National Journal / Proceeding Papers

Jain, S. K.; Singh, A.K. and Thakur A.K. 2008. Assessment of quality of gound water pollution arising from various sources. Journal of Indian Water Resources. 28 (3): 9-13.

Singh, A.K., Jain, S. K. and Chandra R. 2009. Studies on impact of municipal, Industrial & Agrochemical pollutants on quality of ground water. Indian Society of Water Management (communicated).

Chandra, R., Singh A.K. and Jain, S.K. 2009. Yantrik Bidhiyon Duara Varsa Jal Prabhandan. Adhunik Kisan. 38(3): 3-5.

Singh A.K. 2009. Varsasrit kheti me Bhumi or Jal Prabhandan. Adhuniik Kisan. 38 (3): 17-20.

Singh, A.K., Jain, S.K. and Chandra, R. 2009. Bhujal Pradushan. Adhunik Kisan 37(5): 40-41.

R. Chandra, S.K. Jain, and A.K. Singh. Ground water resources of Bihar. Published in proceedings of Conference on Food and Environmental Security through Resource Conservation in Central India: Challenges and Opportunities, held at 16-18 September, 2009, Agra, Uttar Pradesh.

S.K. Jain, R. Chandra and A.K. Singh. Study on Water Recharge of Muzaffarpur District, Published in proceeding of Conference on Food and Environmental Security through Resource Conservation in Central India: Challenges and Opportunities held at 16-18 September, 2009, Agra, Uttar Pradesh.

A.K. Singh, R. Chandra and S.K. Jain, and. Studies on the Assessment of Ground Water Quality Parameters of various Sources. Published in proceeding of Conference on Food and Environmental Security through Resource Conservation in Central India: Challenges and Opportunities held at 16-18 September, 2009, Agra, Uttar Pradesh.

7.8 Publications of Raipur Centre

7.8.1 International/National Journal / Proceeding Papers

Tripathi M.P., Agrawal N., Dwivedy S.K. and Verma M.K. 2009. Development of Effective Management Plan for the Critical Sub-Watersheds of Arang Watershed in Chhattisgarh. In Proceedings of International Conference on “Water, Environment, Energy and Society” (WEES-2009) held at New Delhi from 12-19 January 2009, P: 1823-1830.

Tripathi M.P., Jogdand S.V., Pandey V.K. and Patel S.R. 2009. Renewable Energy Sources for Agricultural Development in Chhattisgarh. In Proceedings of 24th National Convention on “Energy Security through Renewable Energy Sources” held at Raipur from 17 -18 January 2009, P: 51-52.

Tripathi M.P., Katre P.and Dheeraj Kumar. 2009. Groundwater Flow and Mass Transport Modelling for Multi Layer Aquifer System of

Small Agricultural Watersheds in Chhattisgarh. In Proceedings of Workshop on "Ground Water Scenario and Quality in Chhattisgarh" held at Raipur from 4- 5 March 2009, P: 9-16.

Jadhao V.G. and Tripathi M.P. 2009. Evaluation of the SWAT Model for Predicting the Daily Surface Runoff and Sediment Yield from a Small Watershed. International Journal of Agricultural Engineering. Muzaffarnagar (U.P.), Vol. 2 (1), P: 39-45.

Jadhao V.G., Bornare D.T. and Tripathi M.P. 2009. Identification and Prioritization of Critical Sub-watersheds Using SWAT Model. International Journal of Agricultural Engineering. Muzaffarnagar (U.P.), Vol. 2 (1), P: 113-123.

Tripathi M.P., Dheeraj Kumar and Katre P. 2009. Groundwater Assessment of a Small Agricultural Watershed Using Visual MODFLOW. In Proceedings of Regional Conference on "Food and Environmental Security through Resource Conservation in Central India Challenges and Opportunities (FESCO – 2009)" held at CSWCRTI, Research Center, Agra from 16-18 September 2009, P: 7.

Jadhao A.K., Jadhao V.G. and Tripathi M.P. 2009. Estimation of Surface Runoff from Agricultural Watershed Using Remote Sensing and GIS Technique. International Journal of Agricultural Engineering, Muzaffarnagar (U.P.), Vol. 2 (2) P: 254-258.

Jadhao V.G., Jadhao A.K. and Tripathi M.P. 2009. Estimation of Monthlu Surface Runoff and Sediment Yield from a Small Watershed by Using Simulation Technique. International Journal of Agricultural Engineering, Muzaffarnagar (U.P.), Vol. 2 (2) P: 278-284.

Jadhao A.K. and Tripathi M.P. 2009. Prediction of Runoff for Small Watershed using GIUH_CAL Model and GIS Approach in Chhattisgarh. International Journal of Agricultural Engineering, Muzaffarnagar (U.P.), Vol. 2 (2) P: 310-314.

Tripathi M.P. and Katre P. 2010. Groundwater Recharge due to Check Dams and Percolation Ponds. In Proceedings of 44th Annual Convention & Symposium of ISAE, held at IARI, New Delhi from 28-30, January 2010, P: 3.1.

Agrawal N., Verma M. K. and Tripathi M. P. 2010. Hydrological Modelling of Arang Watershed Using Weather Generator in the SWAT Model. In Proceedings of 3rd International Conference on "Hydrology and Watershed Management" held at Hyderabad from 3-6 February 2010, P: 193-201.

7.9 Publications of Junagadh Centre

7.9.1 International/National Journal / Proceeding Papers

Gontia N.K. and Tiwari K.N. 2009. Estimation of spatially & temporally distributed crop coefficient & evapotranspiration of wheat in on irrigation command using remote sensing & GIS water resources management, Springer Publication (in press)

P. G. Vadher and Gontia N.K., 2009, Rain water harvesting in coastal aquifers. International conference on food security and environment sustainability. Deptt. of Agril. & Food Engg. , IIT Kharagpur, 17th to 20th Jan.-2009.

Gontia N.K., and K. N. Tiwari ,2009, Evapotranspiration estimation in an irrigation command using remote sensing and GIS. International conference on food security and environment sustainability. Deptt. of Agril. & Food Engg. , IIT, Kharagpur, 17th to 20th Jan.-2009.

P. G. Vadher and Gontia N.K., 2009, Impact of watershed development on quality of ground water in coastal area of saurashtra. A proc. Of 43rd annual Convention ISAE hold at B.A.U. Ranch. Feb.- 15-17, 2009.

7.9.2 Leaflet in local language for farmers

P. B. Vekariya, N.K. Gontia and P.G. vadher: "Bhugarbhjal reechaarjmaa bori bandhanee agatyataa" in Gujarati language

P. B. Vekariya, N.K. Gontia and P.G. vadher: "Daxin paschima Saurashtra maa bhugarbh-starnee pareesthiti", in Gujarati language

ANNEXURE - I

STAFF POSITION DURING 2009-10

Project Coordinating Unit, DWM, BHUBANESWAR

1. Dr. Ashwani Kumar, Director & Project Coordinator
2. Dr. M.J. Kaledhonkar, Principal Scientist
3. Dr. (Mrs.) Mousumi Raychaudhuri, Senior Scientist

I. P.A.U., LUDHIANA

1. Dr. Rajan Aggarwal, Res. Engr & I/C
2. Dr. Sunil Garg, Res. Engr.
3. Er. Samanpreet Kaur, Asstt. Res. Engr.
4. Mr. Harpal Singh, Electrician
5. Mr. Darshan Singh, Mechanic
6. Mr. Parmjit Singh, Mechanic
7. Mr. Tarseem Lal, Sr. Scale steno
8. Mr. Talwinder Singh, Clerk-cum-Store Keeper
9. Mr. Nachattar Pal, Tracer/ Jr. Drafts man
10. Mr. Harjeet Singh, Driver
11. Mrs. Parminder Kaur, Messenger

II. G.B.P.U.A.T., PANTNAGAR

1. Dr. H. C. Sharma, Professor & I/C
2. Dr. Yogendra Kumar, Professor
3. Dr. Harish Chandra, S.R.O.
4. Dr. A.K. Vashisht, JRO/ Asst. Design Engr.
5. Mr. Janardan Singh, Tech. Asstt.
6. Mr. Ashok Kumar, Field Asst.
7. Mr. M. C. Chimwal, Accounts Clerk
8. Mr. Ramu, Survey Mate

III. M.P.K.V., RAHURI

1. Dr. S.D. Dahiwalkar, Associate Professor & I/C
2. Er. S.A. Kadam, Assistant Professor
3. Er. K.G. Pawar, Jr. Research Asstt. (AE)
4. Er. V.N. Male, Jr. Research Asstt. (AE)
5. Mr. E.K. Kadam, Agril. Asstt.
6. Mr. S.D. Kulthe, Clerk-cum-Storekeeper
7. Mr. B. S. Pawar, Messenger Peon

IV. J.N.K.V.V., JABALPUR

1. Dr. R. K. Nema, Irrigation Engineer & I/C
2. Dr. M. K. Awasthi, Junior Scientist
3. Er. Y. K. Tiwari, Junior Scientist
4. Er. R. N. Shrivastava, Tech. Assistant
5. Er. P. K. Sharma, Technical Assistant (Upto Aug 2009)
6. Mr. G. P. Yadav, FEO
7. Mr. T. N. Singh, FEO
8. Mr. S.C. Bagdare, Sr. Mechanic
9. Mr. Amit Shukla, Junior Clerk
10. Mr. Mansingh Yadav, Driver (Upto Jan 2010)
11. Mr. Balwant, Messenger

V. W.T.C, T.N.A.U., COIMBATORE

1. Dr. C. Mayilswami, Professor & I/C
2. Er. A. Valliammai, Asstt. Professor (SWCE)
3. Dr. K.M. Sellamuthu, Asstt. Professor (Soil science)
4. Mr. G. Thiyagarajan, Field Technician
5. Mr. G. Dhanalakshmi, Field Assistant
6. Mr. G. Anandakumar, Field Assistant
7. Mr. N. Krishnaveni, Jr. Clerk
8. Mr. G. Vanitha, Jr. Steno
9. Mr. K. Nagarajan, Messenger

VI. M.P.U.A.T., UDAIPUR

1. Dr. P.K. Singh, Associate Professor & I/C
2. Dr. K.K. Yadav, Asstt. Professor (Soil science)
3. Er. Deepesh Machiwal, Asstt. Professor (SWCE)
4. Mr. Jeet Singh, Field Technician
5. Mr. Sombir Singh, Agril. Supervisor
6. Mr. J.S. Sharma, Agril. Supervisor
7. Mr. M.S. Solanki, clerk
8. Mr. Gunjan Sharma, Steno
9. Mr. Dhulji, Class-IV

VII. R.A.U., PUSA, SAMASTIPUR

1. Dr. S.K. Jain, Associate Professor & I/C
2. Dr. A.K. Singh, Asstt. Professor (Soil Chemistry)
3. Er. Ravish Chandra, Asstt. Professor (Agril. Engineering)
4. Mr. Awadhesh Kumar, Field Asstt.
5. Mr. Vikash Kumar, Field Asstt.
6. Mr. Ravindra Kumar Ray, Computer operator

VIII. I.G.A.U., RAIPUR

1. Dr. M.P. Tripathi, Assoc. Professor & I/C
2. Er. P. Katre, Asstt. Professor
3. Shri. L. K. Ramteke,
4. Mr. Jacob George, Asstt. Gr. II-Steno
5. Mrs. Nirmala Yadav, Messenger

IX. J.A.U., JUNAGADH

1. Dr. N.K. Gontia, Professor & I/C
2. Dr. P.G. Vadher, Asstt. Professor
3. Prof. P.B. Vekaria, Asstt. Professor
4. Miss P.J. Patel, Steno Grade-III
5. Mr. G.N. Paghadar, Jr. Clerk
6. Mr. Y.H. Hala, Technician/Mechanic
7. Mr. M.G. Patolia, Messenger

Location and Jurisdiction Map of AICRP centres on Groundwater Utilization

समन्वय इकाई, ए आई सी आर पि, भूजल उपयोग

जल प्रबंधन निदेशालय

(भारतीय कृषि अनुसंधान परिषद)

चन्द्रशेखरपुर, भुवनेश्वर - ७५१ ०२३, उड़ीसा, भारत

Coordinating Unit, AICRP on Groundwater Utilization

Directorate of Water Management

(Indian Council of Agricultural Research)

Chandrasekharpur, Bhubaneswar - 751 023, Orissa, India

फोन / Phone : 91-674-2300060, 2300010, 2301815, फेक्स / Fax : 91-674-2301651

इ-मेल / E-mail : aicrpgwu@rediffmail.com, aicrpgwu@gmail.com,

वेबसाइट / Website : www.wtcer.ernet.in