वार्षिक प्रतिवेदन
ANNUAL REPORT
2017-2018

सिंचाई जल प्रबंधन पर
अखिल भारतीय समन्वित अनुसंधान परियोजना

All India Coordinated Research Project on Irrigation Water Management

वार्षिक प्रतिवेदन
Annual Report
2017-18

सिंचाई जल प्रबंधन पर
अखिल भारतीय समन्वित अनुसंधान परियोजना
All India Coordinated Research Project on Irrigation Water Managemnt

भाकृअनुप - भारतीय जल प्रबंधन संस्थान
भुवनेश्वर, ओडिशा, भारत

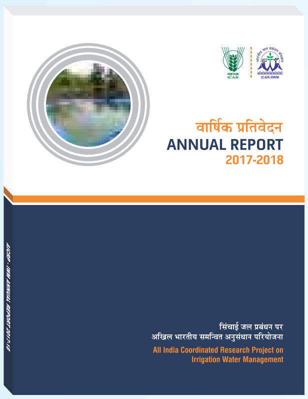
ICAR - Indian Institute of Water Management
(An ISO 9001:2008 Certified Organization)
Bhubaneswar-751023, Odisha, India

AICRP-IWM Annual Report 2017-18

Published by
Dr. S.K. Ambast
Director, ICAR-IIWM, Bhubaneswar

Compiled and Edited by
Dr. P. Nanda
Dr. S. Mohanty
Dr. O.P. Verma
P. Dasgupta

Hindi Translation
Dr. O.P. Verma
Mr. K.K. Sharma



***Citation*:**
AICRP-IWM 2018. Annual Report 2017-18. ICAR-Indian Institute of Water Management, Bhubaneswar, India, 96p.

Printed by
Print-Tech Offset Pvt. Ltd.
F-66/1 & F-66/2, Chandaka Industrial Area,
P.O.: KIIT, Bhubaneswar-751024. Odisha.

PREFACE

The All India Coordinated Research Project on Irrigation Water Management (AICRP on IWM) scheme has been functioning in twenty six centres of the country under five research themes. The scientists have been engaged in carrying out research on improving water use efficiency in different crops and cropping sequence under different sources of irrigation in different agro climatic conditions of the country. Significant achievements have been made during the current year. I am privileged to present the achievements of the centres of All India Coordinated Research Project on Irrigation Water Management (AICRP-IWM) for the year 2017-18. The on station and on farm research endeavours of the scientists resulted in replicable water management technologies that would help in improving irrigation application efficiency in canal commands, groundwater recharge, improved water use efficiency and water productivity under pressurized irrigation and save water and fertilizer inputs. The on station and on farm research output would not only improve water productivity but also enhance farmers' income and livelihoods. The scientists also contributed to preparation of district irrigation plans in different parts of India. Some of the AICRP centres also carried out capacity building exercises for different stakeholders and implemented tribal sub plan schemes for improving livelihoods of tribal people at different palaces. Some of the pilot interventions contributed to rainwater harvesting and groundwater recharge in rainfed areas of the country.

I express my gratitude to Dr. T. Mohapatra, Secretary DARE and Director General ICAR, Govt. of India for his guidance, critical inputs, constant support and encouragement for smooth running of the scheme. I sincerely express the gratitude to Dr. K. Alagusundaram, Deputy Director General (NRM) and Dr. S.K. Chaudhari, Assistant Director General (S&WM), ICAR for their valuable suggestions and timely cooperation during the report period. I thank the research scientists of AICRP-IWM schemes working at different locations for their untiring efforts for improving irrigation water management scenario in the country. Their sincere efforts resulted in tangible outputs in irrigation water management which could go a long way in improving farmer's inome and water productivity. I appreciate the team work of Dr. Prabhakar Nanda, Principal Scientist, Dr. S. Mohanty, Principal Scientist, Dr. O.P. Verma, Scientist, ICAR-IIWM and Pragna Dasgupta, Research Associate, AICRP-IWM, ICAR-IIWM for compiling the research outcomes of the centres and editing the annual report. I also thank Shri K.K. Sharma, Technical Assistant for Hindi translation of executive summary of the report.

Bhubaneswar

(S.K. Ambast)
Director, ICAR-IIWM

CONTENTS

कार्यकारी सारांश

विषय 1: सतही जल एवं भूजल की उपलब्धता एवं गुणवत्ता का आकलन

श्रीगंगानगर केंद्र पर गंग नहर कमांड की जेड (Z) डिस्ट्रीब्यूटरी के आउटलेट 20 जेड (Z) के तहत कुल खेती योग्य कमांड क्षेत्र 304 हेक्टेयर था। रबी मौसम 2016–17 और खरीफ मौसम 2017 के दौरान फसल क्षेत्र क्रमशः 260 हेक्टेयर और 261 हेक्टेयर था और सापेक्ष जल की आपूर्ति 0.42 और 0.88 थी जो दोनों मौसम के दौरान कम जल की आपूर्ति को दर्शा रही थी। इसलिये, जल मांग के साथ जल की आपूर्ति को मिलाने के लिये गेहूँ और अमेरिकन कपास के तहत आने वाले कुछ क्षेत्रों को कम जल की आवश्यकता वाली फसलों के द्वारा प्रतिस्थापित करने की आवश्यकता है।

लुधियाना केंद्र पर पहले से विकसित डीसीजन सपोर्ट प्रणाली के ऊपर एक उन्नत विशेषज्ञ प्रणाली का विकास किया गया। यह प्रणाली भौगोलिक सूचना पद्धति का उपयोग कर पंजाब राज्य हेतु भौगोलिक सूचना के आधार पर सब्मर्सीबल पंप सेट के उचित चुनाव के साथ घुमावदार तार व्यास, तार लंबाई, बाजार में उपलब्ध पंप, जनरेटर क्षमता, अम्मीटर दर, वॉल्ट मीटर दर, कैपेसिटर दर और पॉली विनाइल क्लोराइड (पीवीसी) पाइप व्यास जैसे संबन्धित घटकों का आवश्यक विवरण प्रदान करती है।

राहुरी केंद्र पर वर्ष 2008–09 में मुसलवाड़ी लघु सिंचाई परियोजना की जल वितरण क्षमता को उसके आयतन के आधार पर आउटलेट और खेत के स्तर पर आकलित किया गया और इस सिंचाई परियोजना ने आउटलेट एवं खेत दोनों स्तर पर अच्छी क्षमता को प्रदर्शित किया। मुसलवाड़ी लघु सिंचाई परियोजना की पर्याप्ता खरीफ, रबी और ग्रीष्मकालीन मौसम में क्रमशः 0.10, 0.48 और 0.26 थी जो फसल की जल आवश्यकता के अनुसार जल की अनिकासी की ओर संकेत करती है।

जूनागढ़ केंद्र पर सौराष्ट्र की अजी नदी बेसिन में संभावित जल संसाधनों का निधारण स्वाट (SWAT) मॉडल के उपयोग से किया गया। यहाँ मृदा की बनावट चिकनी (56.1%) प्रकार की थी एवं कृषि भूमि 69.9% थी और इसका ढ़लान 4% (67.0%) तक था। वर्ष 1970–2005 की अवधि से वर्ष 2006–2070 तक की अवधि के दौरान दैनिक न्यूनतम तापमान की गर्मी की प्रवृति में वार्षिक, ग्रीष्मकालीन और मानसून मौसम हेतु क्रमशः 0.027 से 0.040° C/वर्ष, 0.031 से 0.044° C/वर्ष और 0.011 से 0.043° C/वर्ष की वृद्धि हुयी जबकि सर्दी मौसम में 0.046 से 0.032° C/वर्ष की कमी हुई। वर्ष 1970–2005 से वर्ष 2006–2070 तक दैनिक अधिकत्तम तापमान की गर्म प्रवृति में वार्षिक, ग्रीष्मकालीन और मानसून मौसम हेतु क्रमशः 0.027 से 0.025° C/वर्ष, 0.028 से 0.021° C/वर्ष, 0.023 से 0.022° C/वर्ष की कमी हुई जबकि सर्दी के मौसम में 0.033 से 0.34व C/वर्ष की वृद्धि हुई। वार्षिक आधार पर वर्ष 1970–2005, वर्ष 2006–2040 और वर्ष 2041–2071 की अवधि के दौरान औसत रेफ्रेंस वाष्पोत्सर्जन में वृद्धि क्रमशः 1964 मिमी, 1996 मिमी और 2010 मिमी के रूप में दर्ज हुई तथा सर्दी के मौसम में यह वृद्धि 438 मिमी, 458 मिमी और 475 मिमी के रूप में थी। ग्रीष्मकालीन मौसम के दौरान इसमें 700 मिमी, 698 मिमी और 698 मिमी और मानसून के मौसम के दौरान 826 मिमी 839 मिमी और 837 मिमी तक की वृद्धि हुई। वार्षिक रूप से रेफ्रेंस वाष्पोत्सर्जन में 57 मिमी/ शताब्दी की वृद्धि हुई। अजी बेसिन में वर्ष 1951–2005, वर्ष 2006–2040 और वर्ष 2041–2070 की अवधि के दौरान वार्षिक औसत वर्षा को क्रमशः 572 मिमी, 392 मिमी और 430 मिमी के रूप में स्थिर पाया गया। वर्ष 1970–2005, वर्ष 2006–2040 और वर्ष 2041–2070 अवधि के दौरान मानसून मौसम में क्रमशः 261 मिमी, 187 मिमी और 182 मिमी के रूप में वर्षा अपवाह था जो कि स्थिर प्रवृति को दर्शाता है। वर्ष 1970–2005, 2006–2040 और 2041–2070 तक की अवधि के लिये मानसून के मौसम के दौरान भूजल पुनःभरण क्रमशः 42 मिमी, 21 मिमी और 20 मिमी था जो स्थिर प्रवृति को दर्शाता है। जलवायु परिवर्तन के प्रभाव के कारण अतीत की तुलना में भविष्य में सर्दी, ग्रीष्मकालीन और मानसून मौसम के दौरान जल की आवश्यकता क्रमशः 6.4%, –0.3% और 1.5% घट/बढ़ सकती है। अत्यधिक वर्षा (100 वर्ष की अवधि) की घटनाओं में भविष्य में 39% तक की वृद्धि होगी। इसी प्रकार, भविष्य में वर्षा अपवाह में कमी होगी। लेकिन वर्षा के अपवाह की अत्यधिक घटना (100 वर्ष की अवधि) में 87.5% तक की वृद्धि होगी। फसल वाष्पोत्सर्जन और भूजल पुनःभरण की अत्यधिकता क्रमशः –5.7% और –5.8% तक घट सकती है।

उदयपुर केंद्र पर ऊपरी बेराच नदी घाटी का कुल ग्रहण क्षेत्र 11001 वर्ग किलोमीटर है और इस सम्पूर्ण क्षेत्र में ऊबड़–खाबड़ स्थलाकृति है जिससे वर्षा के अपवाह का वेग बहुत अधिक है। इस क्षेत्र में भूजल के मूल्यांकन के लिये कुल 95 कुओं की पहचान की गई और जीपीएस की सहायता से इनके स्थान को निर्धारित किया गया। वर्ष 2016 और 2017 के लिये मानसून से पूर्व एवं बाद के जल स्तर के आँकड़ों का उपयोग कर जल स्तर मानचित्र तैयार किये गये। कुल 12 पंपिंग परीक्षणों का उपयोग कर जलवाही स्तर के मापदंडों का निधारण किया गया। घाटी में मृदा, ढ़लान एवं स्थलाकृति की ऊंचाई जैसे विषयक नक्शे तैयार किये गये। यहाँ कृत्रिम भूजल पुनःभरण के लिये अनुकूल क्षेत्र 2192 वर्ग किलोमीटर था जो चंदेरसिया, गंडोली, सांगवा, शामभोपुरा, बेरण, नौवा, मावली, अकोड्रा, भूतपुरा आदि गाँवों को शामिल करते हुये कुल अध्ययन क्षेत्र का केवल 20% भाग ही है।

उदयपुर केंद्र पर ही राजस्थान के चितौड़गड़ जिले हेतु भूजल की गुणवता का निर्धारण किया गया। यह जिला 7 × 7 वर्ग किमी के ग्रिडों में विभाजित था और यहाँ पर जीपीएस तकनीक का उपयोग करके प्रत्येक ग्रिड से एक कुंए को चुना गया। वर्ष 2017 के दौरान मानसून पूर्व और मानसून के पश्चात कुल 134 भूजल के नमूनों को एकत्रित

किया गया। मानसून मौसम के पश्चात की अवधि में टीडीएस की मात्रा में 80 मिलीग्राम/किग्रा (रावतभाता ब्लॉक) से 1890 मिलीग्राम/किग्रा (कपासन ब्लॉक) तक वृद्धि पाई गई। मानसून पूर्व की अवधि में भूजल की पीएच गंगरार ब्लॉक में 6.2 से डूंगला ब्लॉक में 9.1 तक थी। मानसून के बाद की अवधि के दौरान पीएच निम्बाहेरा ब्लॉक में 6–8 से डूंगला ब्लॉक में 8.4 तक थी। मानसून के पूर्व की अवधि के दौरान विद्युत चालकता रावतभाता ब्लॉक में 0.30 डेसी सिमन्स/मीटर से कपासन ब्लॉक में 930 डेसी सिमन्स/मीटर तक थी।

जबलपुर केंद्र पर विजुअल मोडफ्लो मॉडल का उपयोग करके जलवाही स्तर प्रणाली की द्वि स्तरीय भूजल मॉडलिंग की गई। इस मॉडल को वर्ष 2000 से 2010 तक के आंकड़ों के साथ अंशांकित किया गया और वर्ष 2011 से 2015 तक के आंकड़ों से इसको सत्यापित किया गया था। जल स्तर के पूर्वानुमान परिणाम ने पहले से ही दर्ज जल स्तर के परिणाम के साथ अच्छी तरह सहसंबंध दर्शाया। अंशाकन एवं सत्यापन पर सहसंबंध गुणांक क्रमशः 0.99 और 0.99 थे। इस अध्ययन क्षेत्र में भूजल पुनःभरण 75–175 मिमी के बीच था व विद्युत चालकता 0.00013 मीटर/सेकंड थी तथा परिसीमित जलवाही स्तर की पारगम्य क्षमता की रेंज 17 से 3000 वर्ग मीटर/दिन थी। अस्थायी स्थितियों एवं स्थिर अवस्था में दर्ज एवं सिमुलेटेड जल स्तरों बीच सहसंबंध गुणांक 0.99 के साथ एक अच्छा संबंध था। इस अध्ययन क्षेत्र में असीमित जलवाही स्तर (जलवाही I–परत की मोटाई 1.8 से 20 मीटर, अंशाकित गुणांकः विद्युत चालकता 0.00013 मीटर/सेकंड, विशेष उपज 0.05 से 0.16, भूजल पुनःभरण 106 से 290 मिमी/वर्ष) में भूजल प्रवाह पूर्व से पश्चिम की ओर था। तथापि परिसीमित जलवाही स्तर में भूजल प्रवाह की समग्र दिशा पूर्व से पश्चिम दिशा की ओर गतिशील थी (जलवाही स्तर–II स्तर की मोटाई 20 से 80 मीटर, अंशांकित गुणांकः भंडारण गुणांक 0.0001)।

कोयम्बटूर केंद्र पर अमरावती नदी घाटी के विकास के लिये जल उपलब्धता की मात्रा को जानने हेतु भूजल संतुलन का मूल्यांकन किया गया। वर्ष 1971 से 2014 तक अमरावती घाटी में वर्षा ने –2.49 के क्यू मूल्य के साथ एक घटती प्रवृति को प्रदर्शित किया। परिवर्तनशीलता गुणांक 19.7 से 44.5% के बीच था। दक्षिणी–पश्चिमी मानसून के दौरान घाटी के भूजल स्तर का उत्तार–छड़ाव 0.2 से 3.1 मिमी था और उत्तरी–पूर्वी मानसून के दौरान यह 0.4 से 6.6 मिमी के बीच था। इस घाटी में 33 ब्लॉकों में से 16 ब्लॉक अतिदोहित (≥ 100%), 2 ब्लॉक संवेदनशील (90–100%), 12 ब्लॉक अर्ध संवेदनशील (70–90%) और 3 ब्लॉक सुरक्षित (< 70%) श्रेणी के अंतर्गत पाये गये। यहाँ पर वर्ष 1971 से वर्ष 2014 तक मानसून मौसम के दौरान कुल भूजल पुनःभरण 27% से 12.8% तक पाया गया। यहाँ लगभग 72% क्षेत्र अर्थात वेल्लाकोविल, मुलानूर, धारापुरम, मदथुकुलम, गुडीमंगलम, वेदासन्दूर, दक्षिण पोल्लाची और अरावाकुरिची ब्लॉकों के भागों को बहुत बढ़िया भूजल पुनःभरण क्षेत्रों के रूप में चिन्हित किया गया। वाटरशेड क्षेत्रों में प्रभावी योजना और भूजल संसाधनों के प्रबंधन के लिये वर्षा, पूर्वगामी वर्षा और पूर्वगामी भूजल स्तर के आधार पर विकसित रिग्रेसन मॉडल को प्रेक्षण कुंए में अच्छी तरह से भूजल स्तर के उचित आकलन हेतु अपनाया जा सकता है।

कोयम्बटूर केंद्र पर लोवर भवानी परियोजना कमांड क्षेत्र की कुगलूर डिस्ट्रीब्यूटरी में जीआईएस तकनीक की सहायता से मृदा उर्वरता स्तर और जल गुणवत्ता का आकलन किया गया। यहाँ पर बल्क डेन्सिटी और पार्टिकल डेन्सिटी क्रमशः 1.1 से 1.6 मेगाग्राम/घनमीटर और 2. 0 से 2.8 मेगाग्राम/घनमीटर के बीच पायी गई। यहाँ मृदा की बनावट मुख्यतया रेतीली चिकनी दोमट प्रकार की थी और उसके बाद रेतीली दोमट प्रकार की थी। मृदा उर्वरता के स्तर ने बताया कि मृदा की पीएच और विद्युत चालकता सामान्य है। नाइट्रोजन, फोस्फोरस एवं पोटासियम की उपलब्धता क्रमशः कम से मध्य व मध्य से अधिक तथा मध्य से उच्च थी। सिंचाई जल के विश्लेषण से पता चला कि सभी गाँवों में जल की पीएच और विद्युत चालकता सामान्य थी। क्लोराइड की मात्रा से स्पष्ट हुआ कि जल के नमूने अच्छी स्थिति में है। जल के नमूनों में अवशिष्ट सोडियम कार्बोनेट < 1.0 मिली ईक्विवेलेंट/लीटर था जो यह संकेत देता है कि सिंचाई जल की गुणवत्ता उत्कृष्ट है। कुल घुलनशील ठोस 306 से 462 पीपीएम के बीच था।

विषय 2: सतही एवं दबाव सिंचाई प्रणालियों का डिजाइन, विकास एवं रिफाइनमेंट

परभाणी केंद्र पर मक्का की फसल में ड्रिप सिंचाई प्रणाली द्वारा 1.0 PE के स्तर से सिंचाई करने पर काफी अधिक दाना और चारे की पैदावार प्राप्त हुई और शुद्ध लाभ भी अधिक प्राप्त हुआ। ड्रिप प्रणाली के माध्यम से उर्वर सिंचन स्तर यानि 100% उर्वरकों (150: 75: 75 किलो/हेक्टेयर NPK) की सुझाई गई मात्रा के प्रयोग से दाना उपज, चारा उपज, जल उपयोग दक्षता और शुद्ध लाभ में उल्लेखनीय वृद्धि हुई जो कि ड्रिप के माध्यम से 75% सुझाई गई उर्वरकों की मात्रा के प्रयोग की तुलना में अधिक थी। मक्का की फसल में अधिक पैदावार और शुद्ध लाभ प्राप्त करने के लिये एक दिन के बाद एक दिन पर ड्रिप सिंचाई प्रणाली द्वारा 0.8 PE के सिंचाई स्तर पर सिंचाई करने का सुझाव दिया जाता है। इसी प्रकार, मक्का की फसल में ड्रिप फर्टिगेशन के तहत 112.5: 56.2: 56.2 किग्रा/हे NPK उर्वरकों की मात्रा में से नाइट्रोजन को 12.5% की दर से 8 बराबर स्प्लिट खुराकों में 10 दिनों के अंतराल पर बुआई के 10 से 80 दिनों तक जबकि फोस्फोरस एवं पोटासियम को 2 बराबर स्प्लिट खुराकों मे 50% बुवाई के समय पर और शेष 50% को बुआई के 30 दिनों बाद प्रयोग करने की सिफारिश दी जाती है।

बेलवातगी केंद्र पर खरीफ के मौसम में सूरजमुखी की फसल को ड्रिप सिंचाई प्रणाली के तहत 1.0 ET की सिंचाई के साथ उगाया गया जिससे किसानों की पारंपरिक बाढ़ सिंचाई विधि (1.85 टन/हे) की तुलना में 2.43 टन/हे की अधिक दाना पैदावार प्राप्त हुई। ड्रिप सिंचाई प्रणाली में बाढ़ सिंचाई की बजाय कुल जल की बचत 28.44% हुई। रबी मौसम की फसलों जैसे गेहूँ, उड़द और मूँगफली ने भी किसानों की पद्धति की तुलना में ड्रिप के तहत बेहतर प्रदर्शन दिखाया। गेहूँ, उड़द और मूँगफली की फसलों में सिंचाई की सामान्य विधि की तुलना में ड्रिप सिंचाई से 0.53 ,0.63 और 0.74 टन/हे की अधिक पैदावार प्राप्त हुई। सूरजमुखी–मूँगफली फसल पद्धति के साथ सूरजमुखी समतुल्य उपज (5.95 टन/हे) अधिक थी जिससे ₹

1,37,075 का शुद्ध लाभ प्राप्त हुआ और 2.92 का लाभःलागत अनुपात प्राप्त हुआ। मालाप्रभा कमांड क्षेत्र के अंतर्गत मूंगफली के बाद ड्रिप सिंचाई के साथ सूरजमुखी की फसल को उगाना अन्य फसल पद्धतियों की तुलना में अधिक लाभदायक साबित हुआ। इस फसल पद्धति का वहाँ के क्षेत्र में उगाने के लिये सुझाव दिया जा सकता है।

चलाकुड़ी केंद्र पर एक हस्त और शक्ति संचालित एजीटेटर को विकसित किया गया और इसका परीक्षण भी किया गया। खाद के घोल की तत्व सामग्री, छनित और अवशेष का विश्लेषण किया गया और इसको उर्वर सिंचन के लिये अच्छा पाया गया। उर्वर सिंचन के लिये वर्मीकम्पोस्ट घोल को वर्मीकम्पोस्ट और जल के मिश्रण के 1: 5 के अनुपात के साथ तैयार किया गया इसके बाद 10 मिनट तक इसका एजीटेसन किया गया और बाद में 6 घंटे तक ऐसे ही सेट होने के लिये छोड़ दिया। उर्वर सिंचन के लिये गोबर की खाद के घोल को 5 मिनट तक एजीटेसन और 5 घंटे तक ऐसे ही सेट करने के बाद तैयार किया जा सकता है। हाथ से संचालित एजीटेटर जैविक खाद बनाने में कारगर है जबकि बड़े पैमाने पर खेती के लिये बिजली संचालित एजीटेटर को जैविक खाद इकाई में उपयोग में लिया जा सकता है।

फैजाबाद केंद्र पर ड्रिप फर्टिगेशन यानि 60% PE के स्तर पर सिंचाई एवं 100% नाइट्रोजन उर्वरक के प्रयोग के साथ टमाटर की अधिक उपज (34.13 टन/हे) प्राप्त हुई जिससे अन्य उपचारों की बजाय अधिकतम शुद्ध लाभ ₹ 2,94,700/क्विंटल और 7.33 का लाभःलागत अनुपात प्राप्त हुआ।

फैजाबाद केंद्र पर ही जायद मौसम की भिंडी की फसल में 100% नाइट्रोजन उर्वरक के प्रयोग के साथ 80% PE के सिंचाई स्तर से ड्रिप फर्टिगेशन द्वारा ड्रिप और सतही सिंचाई के अन्य उपचारों की तुलना में 75% N के फर्टिगेशन उपचार को छोड़कर अधिक फली उपज (7.23 टन/हे) प्राप्त हुई। इस उपचार से 31.03 किग्रा/हे–मिमी की जल उपयोग दक्षता के साथ लगभग 50.11% सिंचाई जल की बचत हुई। नाइट्रोजन की खुराक (100% और 75%) ने ड्रिप सिंचाई के तहत भिंडी की पैदावार को काफी अधिक प्रभावित नहीं किया। हालांकि, सतही सिंचाई के तहत इनका महत्वपूर्ण प्रभाव पड़ा। ड्रिप फर्टिगेसन उपचार (100% PE पर सिंचाई +100% N का प्रयोग) को ही अधिकतम शुद्ध लाभ ₹ 37060 प्रति हेक्टेयर के साथ सबसे किफायती पाया गया।

श्रीगंगानगर केंद्र पर सिंचाई और उर्वर सिंचन के स्तरों का ग्रीष्मकालीन स्क्वैश की पैदावार पर औसत प्रभाव पड़ा। ग्रीष्मकालीन स्क्वैश की सबसे अधिक उपज (37.05 टन/हे) 1.0 ETc के सिंचाई स्तर के साथ प्राप्त हुई जो 0.6 ETc एवं 0.8 ETc के सिंचाई स्तरों से प्राप्त उपज से काफी अधिक थी। उर्वर सिंचन के उपचारों यानि 60%, 80% और 100% उर्वरकों की सुझाई गई मात्रा के प्रयोग से उपज में काफी वृद्धि हुई जो बाढ़ सतही सिंचाई के सभी उपचारों की तुलना में अधिक थी। सतही सिंचाई के सभी उपचारों से समान उपज प्राप्त हुई। सिंचाई और उर्वर सिंचन का परस्पर प्रभाव भी महत्वपूर्ण नहीं पाया गया। बाढ़ सिंचाई पद्धति की तुलना में ड्रिप सिंचाई से 53.8 से 70% तक जल की बचत प्राप्त हुई।

विषय 3: वर्षा जल का प्रबंधन और भूजल पुनःभरण की तकनीकों का विकास एवं मूल्यांकन

जूनागढ़ केंद्र पर दो भूजल पुनःभरण तकनीकों अथार्थ कुंआ पुनःभरण और कनेक्टर कुंआ पुनःभरण को इस क्षेत्र के लिये वर्ष 2017 के मानसून मौसम की अवधि के दौरान मूल्यांकित किया गया। मानसून अवधि में कुंये के माध्यम से कुल 2895 घनमीटर भूजल जल का पुनःभरण हुआ। वार्षिक आधार पर अधिकतम वर्षा अपवाह के परिणाम के साथ अधिकतम, न्यूनतम, औसत एवं वर्षा अपवाह की 15 वर्ष की प्रतिलाभ अवधि हेतु भूजल पुनःभरण क्रमशः 40040, 0, 9899 और 19584 घनमीटर था। भूजल पुनःभरण की लागत कुंआ पुनःभरण की संरचना के 15 वर्ष प्रभावी जीवन की दर से ₹ 2.66/घनमीटर थी। कनेक्टर कुंये के साथ 40333 घनमीटर भूजल का पुनःभरण था। इस विधि में नलकूप की लागत को शामिल कर और नलकूप की लागत को छोड़ कर भूजल पुनःभरण की लागत क्रमशः ₹ 0.51/घनमीटर और ₹ 0.32/घनमीटर थी।

जूनागढ़ केंद्र पर फिल्टर में बालू स्तर की मोटाई के साथ फिल्टर की छनाई दक्षता में वृद्धि हुई। बालू स्तर की 10 सेमी, 15 सेमी और 20 सेमी की मोटाई के साथ छनाई दक्षता क्रमशः 63%, 85% और 89% प्राप्त हुई। छनाई दक्षता एवं बालू के स्तरों के बीच रेखिक (Y= –0. 36×2+13.4×–35) संबंध स्थापित किया गया जहाँ Y=छनाई दक्षता (%), X=बालू स्तर की मोटाई (सेंटीमीटर) है। ज्योंही, बालू स्तर की मोटाई में वृद्धि हुई, पुनःभरण बहाव की दर घट गई। बालू स्तर की 10 सेमी, 15 सेमी और 20 सेमी की मोटाई के साथ पुनःभरण बहाव की दर क्रमशः 63%, 85% और 89% प्राप्त हुई। बहाव की दर और बालू की मोटाई के बीच संबंध रेखिक मॉडल (Y= –4.7038×+127.59) के तौर पर स्थापित किया गया, जहाँ Y= पुनःभरण बहाव की दर (%), X=बालू स्तर की मोटाई (सेंटीमीटर) है। इस मॉडल ने R^2=0.99 प्रदर्शित किया।

पूसा समस्तीपुर केंद्र पर भी एक फिल्टर का निर्माण किया गया और कृत्रिम भूजल पुनःभरण हेतु अनेक फिल्टर संयोजनों के साथ इसका परीक्षण किया गया। कंकड़, बालू, और चारकोल से बने फिल्टर संयोजन–6 के साथ अधिकतम पुनःभरण दर पाई गई। रंगीले कंकड़, सफेद कंकड़ और बालू से बने फिल्टर संयोजन–7 में कुल निलंबित ठोस की मात्रा न्यूनतम थी लेकिन उसकी पुनःभरण दर भी न्यूनतम थी। अपवाहित वर्षा जल का औसत मैलापन (टरबीडिटी) 410 एनटीयू था। अधिक मैलेपन को फिल्टर संयोजन–7 के साथ 81.7% तक कम किया गया। विश्लेषण से पता चला कि फिल्टर संयोजन–6 से एक तो अधिकतम पुनःभरण दर प्राप्त हुई और दूसरी ओर न्यूनतम मैलापन भी प्राप्त हुआ जिसकी वजह से यह फिल्टर संयोजन अपनाने एवं कार्यान्वयन के लिये बहुत ही अच्छा विकल्प है।

राहुरी केंद्र द्वारा भूजल पुनःभरण पर सीमेंट नाला बंड के प्रभाव का अध्ययन किया गया। अहमदनगर तालुका के बड़गाँव टंडली में सीमेंट नाला बंड की श्रेणियों का चुनाव किया गया। नदी के बहाव के नीचे की ओर कुओं का मानचित्र बनाया गया और इन सभी कुओं के जल स्तर पर आँकड़े दर्ज किये गये। वर्ष 2017 में इन सीमेंट नाला बंडों के

कमांड क्षेत्र में भूजल भंडार के आयतन में 20–55 हेक्टेयर–मीटर की वृद्धि देखी गई। बड़गाँव टंडली में सीमेंट नाला बंडों का प्रभाव 459.3 मीटर की दूरी तक पाया गया।

राहुरी केंद्र पर खेत में कुंए के पुनःभरण हेतु एक चार स्तरीय फिल्टर के साथ इस फिल्टर तकनीक के सफल प्रदर्शन पर एक परीक्षण किया गया। इसके लिये पाँच फिल्टर पदार्थों जैसे 24–28 मिमी आकार की ईंटे (BF–1), 0.6–2.0 मिमी के आकार की बालू (SG–1), 9.5–15.5 मिमी ग्रेड के नुकीले कंकड़ (AG–1) और 20–40 मिमी के मटर के आकार के कंकड़ (PG–1) आदि का उपयोग किया गया। इस फिल्टर की कुल मोटाई 100 सेमी (25 सेमी प्रत्येक परत) थी जिसका कमांड क्षेत्र के तीन अन्य स्थानों पर भी परीक्षण किया गया। वहाँ, इनकी छनाई दक्षता करीब 84.49% तक पाई गई जिसको वर्ष 2017 के वर्षा के मौसम की अवधि में कुल 1571525 लीटर की पुनःभरण क्षमता के साथ भूजल पुनःभरण हेतु सफलतापूर्वक अपनाया जा सकता है।

जबलपुर केंद्र पर ऊपरी नर्मदा घाटी में भूजल प्रणाली को वर्गीकृत किया गया और उससे नरसिंहपुर जिले में विभिन्न फसलों के क्षेत्र के अंतर्गत भौगोलिक (स्थानिक) और लौकिक (अस्थायी) अंतर का अध्ययन किया गया। वर्ष 2006 और 2015 में जनवरी और फरवरी के महीनों की अवधि के दौरान रिकॉर्ड किये गये उपग्रह आधारित आँकड़ों से फसल नक्शे तैयार किये गये जो यह बताते हैं कि गेहूँ की फसल के क्षेत्र में 109% तक की वृद्धि हुई और चने की फसल के क्षेत्र में 36% तक कमी हुई। वर्ष 2006 की अवधि में गन्ना की फसल वाले क्षेत्र में 25555 हेक्टेयर से वर्ष 2015 में 54997 हेक्टेयर तक की वृद्धि हुई। विजुअल मोड फ्लो मॉडल का उपयोग करके इस अध्ययन क्षेत्र यानी 513300 हेक्टेयर हेतु भूजल बहाव प्रणाली को विकसित किया गया। वर्ष 2000 से वर्ष 2010 तक के लिये मॉडल के सत्यापन के बाद असीमित जलवाही एवं सीमित जलवाही की हाइड्रोलिक चालकता 0. 00107 मीटर/सेकंड एवं 0.0005 मीटर/सेकंड प्राप्त हुई। इस मॉडल को वर्ष 2011 से 2015 तक हाइड्रोलिक हैड के आँकड़ों के साथ प्रमाणित किया गया। यदि भूजल के उपयोग की दर समान रहती है तो हाइड्रोलिक हैड के वर्ष 2025 में 334.14 से 330.41 तक कम होने की स्थिति में भी इस मॉडल की सहायता से हाइड्रोलिक हैड का पूर्वानुमान आसानी से लगाया जा सकता है। यदि गन्ना की तरह अधिक जल की माँग वाली फसलों के तहत क्षेत्र में वृद्धि जारी रहती है तो मानसून पूर्व की अवधि के दौरान भूजल का हाइड्रोलिक हैड गोटेगाँव ब्लॉक में 5.26 मीटर, नरसिंहपुर ब्लॉक में 3.9 मीटर, करेली ब्लॉक में 3.04 मीटर, छावरपथा ब्लॉक में 4.39 मीटर, छिछली ब्लॉक में 5.18 मीटर और साइखेड़ा ब्लॉक में 0.60 मीटर की गहराई तक जा सकता है। अगर वर्तमान दर पर गेहूँ की फसल में सिंचाई भी बढ़ जाती है तो इसी समान दर से कमी में वृद्धि होगी।

रायपुर केंद्र पर मोर्फोमेट्रिक विश्लेषण पर आधारित जलग्रहण क्षेत्र (वाटरशेड) की प्राथमिकता ने बताया कि WS1, WS2, WS6, WS9, WS12, WS14, WS19 और WS20 आदि जलग्रहण क्षेत्र अधिक प्राथमिकता वाले क्षेत्र में आते हैं और यह जलग्रहण क्षेत्र मृदा अपरदन के प्रति अधिक संवेदनशील श्रेणी के अंतर्गत आते हैं। श्योनाथ सब बेसिन में स्थलीय बहाव एवं चैनल बहाव के लिये मैनिंग्स मूल्य क्रमशः 0.132 और 0.024 था। यथार्थ और जनरेटेड दैनिक वर्षा और तापमान दोनों का उपयोग कर मासिक आधार पर श्योनाथ उपघाटी से निकली नदी के निर्वहन और इसमें मौजूद तलछट सांद्रता का आर्क–स्वाट मॉडल ने सटीक रूप से अनुकरण किया। रायपुर जिले के लिये कृत्रिम भूजल की पुनःभरण योजना को मल्टी क्राइटेरिया इवेल्यूएसन/वेटेड ओवरले टेक्निक का उपयोग करके विकसित किया जा रहा है।

कोयम्बटूर केंद्र पर अमरावती घाटी के 33 ब्लॉकों में से 16 ब्लॉक अति–दोहित (≥ 100%) श्रेणी, 2 ब्लॉक संवेदनशील श्रेणी (90–100%), 12 ब्लॉक अर्ध संवेदनशील श्रेणी (70–90%) और केवल 3 ब्लॉक सुरक्षित (ढ70%) श्रेणी के अंतर्गत आते हैं। इस घाटी में वर्ष 1971 से वर्ष 2014 तक के दौरान कुल मानसून पुनःभरण 27 से 12. 80% तक परिवर्तित हुआ। घाटी के करीब 72% क्षेत्र अच्छे पुनःभरण क्षेत्रों में सहयोग करते हैं। इस घाटी के ब्लॉकों के कुछ भाग जैसे वेल्लाकोविल, मूलानूर, धारापुरम, माडाथुकुलम, गुडीमंगलम, वेडासन्दूर, पोल्लाची दक्षिण और अरावाकुरिची आदि की बहुत अच्छे भूजल पुनःभरण क्षेत्रों के तौर पर पहचान की गई। रिग्रेसन मॉडल का विकास किया गया जिसको वाटरशेड में भूजल संसाधनों की प्रभावी योजना एवं इनके प्रबंधन के लिये वर्षा, पूर्वगामी वर्षा एवं पूर्वगामी भूजल स्तर के आधार पर प्रेक्षण कुओं के भूजल स्तर के उचित आकलन के लिये अपनाया जा सकता है।

कोयम्बटूर केंद्र पर कपास–मक्का आधारित अंतःफसल प्रणाली के तहत कपास की फसल में उपसतह ड्रिप सिंचाई प्रणाली से उर्वरकों की सुझाई गई मात्रा (125% (150: 75: 75 किलोग्राम NPK/हेक्टेयर) के प्रयोग के साथ 100% PE के स्तर पर सिंचाई करने से अधिक पैदावार हुई तथा मक्का की फसल में 100% PE के स्तर पर सिंचाई करने व उर्वरकों की सुझायई गई 100% मात्रा (250: 75: 75 किलोग्राम छच्ज्ञ/हेक्टेयर) के प्रयोग से अधिक उपज और आर्थिक लाभ प्राप्त हुआ। परंपरागत सिंचाई की तुलना में उर्वर सिंचन से 23% तक जल की बचत हुई। उप–सतही ड्रिप फर्टिगेसन के माध्यम से कपास– मक्का फसल चक्र में उड़द की अंतःखेती बहुत ही फायदेमंद साबित हुई।

विषय 4 मृदा–जल–पौधे वातावरण के संबंध पर आधारभूत अध्ययन

मॉरेना केंद्र पर रबी धान की फसल में, धान की पैदावार का प्रदर्शन 40 सेमी के मेड़ की ऊँचाई एवं 30 सेमी के मेड़ की ऊँचाई के साथ समान प्राप्त हुआ। इन दोनों ऊँचाई वाले मेड़ों के धान के खेतों से 10 सेमी और 20 सेमी ऊँचाई वाले मेड़ों के खेतों की अपेक्षा धान की फसल में अधिक दाना संख्या/पेनीकल, दाना उपज और पुआल उपज प्राप्त हुई। इसके बाद रबी के मौसम में रबी फसलों (बॅक व्हीट एवं लेथाइरस) की उपज में भी समान प्रभाव प्राप्त हुआ लेकिन 30 सेमी के मेड़ की ऊँचाई वाले खेतों से ₹ 60823 का शुद्ध लाभ अधिक प्राप्त हुआ और 2.93 का अधिक लाभःलागत अनुपात भी प्राप्त हुआ।

मॉरेना केंद्र पर ही अन्य बुआई की विधियों की तुलना में टर्बो हॅप्पी सीडर के द्वारा एवं 100% अवशेष समावेश के माध्यम से फसल की बुआई से बाजरा की फसल में अधिक दाना उपज (4.69 टन/हे) प्राप्त हुई तथा अधिक शुद्ध लाभ (₹ 41337/हे) व लाभःलागत अनुपात (3.

05) प्राप्त हुआ और जल उत्पादकता (1.47 किग्रा/घनमीटर) भी अधिक प्राप्त हुई। अंत–सस्य उपायों की स्थिति में ट्रैक्टर चालित रिज फरो मेकर+ खरपतवारनाशियों के प्रयोग के फलस्वरूप 4.58 टन/हे की काफी अधिक उपज एवं 3.59 के अधिक लाभ:लागत अनुपात के साथ ₹ 56.170/हे की अधिक शुद्ध आय प्राप्त हुई तथा 1.30 किग्रा/घनमीटर के रूप में अधिक जल उत्पादकता भी प्राप्त हुई।

कोटा केंद्र पर जब लहसुन की फसल में 100% PE के स्तर पर सिंचाई की गई तो 16.01 टन/हे की अधिकतम लहसुन उपज की प्राप्ति हुई। इसके बाद 75% PE के सिंचाई स्तर के साथ 14.17 टन/हे की उपज प्राप्त हुई। इसी प्रकार जब इस फसल में उर्वरकों की सुझाई गई 100% मात्रा (120:40:100 किलोग्राम NPK) का प्रयोग किया गया तो अधिकतम उपज (16.3 टन/हे) प्राप्त हुई और यह उर्वरकों की सुझाई गई 75% मात्रा के प्रयोग से प्राप्त उपज (15.4 टन/हे) से सांख्यकी रूप से समान थी।

नवसारी केंद्र पर गन्ने की फसल को गड्ढों के विभिन्न व्यास एवं दूरी के साथ उगाया गया। गड्ढे से गड्ढे की 1.75 मीटर × 1.75 मीटर की दूरी एवं गड्ढे के 60 सेमी व्यास के साथ गन्ने की बुआई से अधिकतम शुद्ध लाभ प्राप्त हुआ। गड्ढों के दोनों उपचार की स्थिति में मुख्य फसल की अपेक्षा तीन वर्षों की रेटून फसलों से सकारात्मक शुद्ध लाभ प्राप्त हुआ जबकि नियंत्रण उपचार (युग्मित पंक्ति रोपण) की स्थिति में यह केवल दो रेटून फसलों तक ही सकारात्मक था।

नवसारी केंद्र पर 8 से 9 वर्ष पुराने आम के बगीचे में जब ड्रिप सिंचाई पद्धति द्वारा चार एचडीपीई/पीवीसी (75 मिमी व्यास) पाइपों के माध्यम से 40 सेमी की मृदा की गहराई पर सीधे प्रत्यक्ष रूप से सिंचाई जल को प्रयोग किया गया तो अधिक शुद्ध लाभ प्राप्त हुआ। सिंचाई जल का प्रयोग ऑनलाइन ड्रिप्पर पर लगी स्पघेट्टी ट्यूब (4 मिमी व्यास) के माध्यम से आम के तने से लगभग 1.5 मी की दूरी पर सभी चार स्थलों पर किया गया।

पावरखेड़ा केंद्र पर चने की फसल की 15 नवम्बर एवं 30 नवम्बर को बुआई की गई तो क्रमशः 2.95 टन/हे और 2.79 टन/हे की संतोषजनक उपज प्राप्त हुई। लेकिन 15 दिसम्बर को बुवाई करने से फसल की उपज (2.12 टन/हे) में अत्यधिक कमी हुई। चने की फसल में पत्ती और फली निर्माण अवस्थाओं पर दो सिंचाइयां 2.81 टन/हे की उपज के साथ अत्यधिक लाभप्रद साबित हुई। यदि केवल एक सिंचाई की उपलब्धता है तो इस स्थिति में इसको फली निर्माण अवस्था (2.56 टन/हे) पर प्रयोग किया जाना चाहिये। चने की फसल की नवंबर में बुआई से अधिकतम शुद्ध लाभ (₹ 65.621/हे) एवं लाभ :लागत अनुपात (2.75) प्राप्त हुआ और जल उपयोग क्षमता (127 किग्रा/हे–सेमी) भी अधिकतम प्राप्त हुई। तीन और दो सिंचाइयों के तहत शुद्ध लाभ लगभग समान (₹ 61.081 और ₹ 60506/हे) था लेकिन दो सिंचाइयों के तहत लाभ:लागत (2.60) अधिकतम था और जल उपयोग क्षमता (112 किग्रा/हे–सेमी) भी अधिकतम थी।

पावरखेड़ा केंद्र पर ही गैहूँ (किस्म– जेडब्ल्यू 1203) की फसल में जीरो जुताई के तहत 1.2 आईडबल्यू/सीपीई के सिंचाई स्तर के साथ सिंचाई से 4.57 टन/हे की अधिकतम पैदावार प्राप्त हुई जो संख्यातमक दृष्टि से 1.0 आईडबल्यू/सीपीई के सिंचाई स्तर से प्राप्त पैदावार (4.39 टन/हे) के समान थी। जल उपयोग दक्षता (165 किग्रा/हे–सेमी), 0.8 आईडबल्यू/सीपीई के सिंचाई स्तर के साथ अधिकतम प्राप्त हुई लेकिन शुद्ध मौद्रिक लाभ (₹ 26299/हे) और लाभ:लागत अनुपात (1.62) वस्तुतः 1–2 आईडबल्यू/सीपीई के सिंचाई स्तर के साथ अधिकतम था और उसके बाद 1.0 आईडबल्यू/सीपीई के सिंचाई अनुपात के स्तर (₹ 24524/हे और 1. 59) से प्राप्त हुआ।

बिलासपुर केंद्र द्वारा किये गये तीन साल के प्रयोग से पता चला कि धान की फसल में खेत से जल सूखने के तीन बाद सिंचाई करने से 6. 92 टन/हे की अधिकतम दाना पैदावार प्राप्त हुई और ₹ 77696/हे का अधिकतम शुद्ध लाभ प्राप्त हुआ। खेत में 20 सेमी × 20 सेमी की पौधों से पौधों की दूरी पर धान की बुआई से 7.06 टन/हे की अधिकतम पैदावार हुई और ₹ 7696/हे का शुद्ध लाभ प्राप्त हुआ तथा 106.82 किग्रा/हे–सेमी की जल उपयोग दक्षता प्राप्त हुई।

पालमपुर केंद्र पर 1% तरल जैव उर्वरक (E 100) के साथ संवृद्ध तरल खाद के साथ नाइट्रोजन की सुझाई गई मात्रा के विभिन्न अनुपात के प्रतिस्थापन और बुआई के समय (बेसल) फास्फोरस व पोटाशियम की अनुशंसित मात्रा के प्रयोग से ड्रिप सिंचित प्याज की फसल में 0.6 PE के स्तर और भिंडी की फसल में 0.8 PE के स्तर पर सिंचाई से उपज और आर्थिक लाभ में काफी वृद्धि हुई। इन फसलों में गोबर की खाद या इसके बिना सुझाई गई नाइट्रोजन का रासायनिक उर्वरक के माध्यम से प्रयोग और सतह सिंचाई विधि द्वारा 5 सेमी की गहराई की सिंचाई करने से बहुत कम उपज प्राप्त हुई और लाभ भी कम प्राप्त हुआ।

विषय 5: सतही और भूजल के संयोजी उपयोग हेतु प्रबंधन रणनीतियों को विकसित करना

कोयंबटूर केंद्र पर लोअर भवनी परियोजना (स्ठच) के कमांड क्षेत्र में सतही और भूजल के संयोजी उपयोग के वर्तमान पैटर्न का आकलन किया गया। गन्ने, केला, सिंचित धान तथा सिंचित व वर्षा आधारित मूंगफली जैसी प्रमुख फसलों पर विचार किया गया। यह देखा गया कि नहरी कमांड के मुख्य छोर पर संयोजी उपयोग बहुत कम होता है लेकिन कमांड के अंतिम छोर पर संयोजी उपयोग की उपयोगिता बढ़ जाती है। धान और मूँगफली जैसी फसलें पूरी तरह से नहर के पानी की आपूर्ति पर निर्भर रहती हैं। इस अध्ययन क्षेत्र में लगभग 75% से अधिक किसानों के पास कुंए एवं नलकूप (1 या 2) हैं ताकि वे गर्मियों के मौसम के दौरान वार्षिक फसलों को सिंचाई दे सकें। कुल 75% किसानों में से 60% किसान नलकूपों से पंप की सहायता से कुओं/सतही टैंकों में जल को भरते हैं ताकि इनसे जल को पंप करके खेतों की सिंचाई की जा सके। इस प्रकार नहर के मुख्य वॉटरकॉर्स में कम जल पहुँचाकर और अंतिम छोर के आउटलेट्स में पुनः जल प्रवाह को बढ़ाकर कमांड क्षेत्र में माइनर सिंचाई के लिये नहरी और भूजल का सन्योजी प्रबंधन किया जा सकता है।

बठिंडा केंद्र पर नहर के जल (CW) और ट्यूबवेल के जल (TW) (सेलाइन सोडिक; आरएससी– 6.4 मिली इक्विवेलेंट/लीटर;

ईसी–2.2 डेसी साइमंस/मीटर; कम लवणता उच्च एसएआर) के विभिन्न अनुपातों के संयोजनों के साथ सिंचाईयों ने यूकेलिप्टस के पौधों की ऊंचाई, तने की मोटाई, लकड़ी और ईंधन की लकड़ी पर महत्वपूर्ण प्रभाव नहीं पड़ा। अलग–अलग उपचारों (CW, CW & TW और 2CW–1TW) में से सभी का प्रभाव पोपलर के पेड़ों की ऊँचाई, तने की मोटाई, लकड़ी और ईंधन की लकड़ी पर बराबर था। केवल नहर के जल के उपचार से डैक के पेड़ में अधिकतम ऊंचाई, लकड़ी और ईंधन की लकड़ी पाई गई जो सांख्यिकीय रूप से 2CW–1TW के बराबर थी, लेकिन TW और 2CW–1TW के साथ सिंचाई की तुलना में काफी अधिक थी। पंजाब राज्य के अर्ध–शुष्क क्षेत्र की कैल्केरियस मृदा में लवणीय सोडिक जल की सिंचाई के तहत इन वृक्षों की प्रजातियों के बीच यूकेलिप्टस से अधिक जल उत्पादकता एवं आर्थिक आय प्राप्त हुई उसके बाद डैक से और सबसे कम पोपलर के पेड़ों से प्राप्त हुई।

बिलासपुर केंद्र पर खरीफ धान की किस्म MTU–1010 ने ट्यूबवेल के जल से सिंचाई की तुलना में 100% डेयरी के जल से सिंचाई के साथ अधिकतम दाना उपज (4.21 टन/हे) और पुआल की पैदावार (5.52 टन/हे) प्राप्त हुई। अन्य उपचारों की तुलना में 75% सुझाई गई उर्वरकों की मात्रा + नील हरित शैवाल के पोषक तत्व प्रबंधन के साथ अधिकतम दाना उपज (4.41 टन/हे) प्राप्त हुई। रबी के मौसम के दौरान गेहूँ की फसल की HD–2932 किस्म ने ट्यूबवेल के जल से सिंचाई की तुलना में 100% डेयरी के जल से सिंचाई के साथ 3.76 टन/हे की काफी अधिक दाना उपज प्राप्त हुई और 4.27 टन/हे की पुआल की पैदावार हुई। विभिन्न उर्वरक स्तरों के बीच 75% सुझाई गई उर्वरकों की मात्रा + नील हरित शैवाल के प्रयोग से 3.95 टन/हे की अधिकतम उपज प्राप्त हुई।

EXECUTIVE SUMMARY

Theme 1: Assessment of availability and quality of surface water and groundwater

At Sriganganagar, under 20 Z outlet of Z distributory in Gang canal command, total CCA was 304 hectares. The cropped area during *Rabi* 2016-17 and *Kharif* 2017 was 280 and 261 ha, and relative water supply was 0.42 and 0.88, respectively indicating deficit water supplies during both the seasons. There is need to replace some of the area under wheat and American cotton (*Gossypium hirsutum*) with low water requiring crops to match the water supply with crop demand.

At Ludhiana, an upgraded expert system was developed over the previously developed decision support system as it provides the required details of associated components such as winding wire diameter, wire length, available pump in the market, generator capacity, ammeter rating, voltmeter rating, capacitor rating and Polyvinyl Chloride (PVC) pipe diameter along with appropriate selection of submersible pump set based on the spatial information for the Punjab using Geographical Information System (GIS).

At Rahuri, water delivery performance of Musalwadi minor irrigation project estimated on volume basis at the outlet and farm level for the year 2008-2009 showed good performance of the project at both outlet and farm. The adequacy of Musalwadi minor irrigation project is 0.10, 0.48 and 0.26 for *kharif*, *rabi* and summer seasons, respectively indicating non release of water as per crop water requirement.

At Junagadh, assessment of potential water resources of Aji river basin of Shaurashtra was done using SWAT Model. Soil texture was clay (56.1%), agricultural land was 69.9% and slope up to 4% (67.0%). The warming trend of daily minimum temperature from 1970-2005 and 2006-2070 for annual, summer and monsoon season increased from 0.027 to 0.040°C/year, 0.031 to 0.044°C/year and 0.011 to 0.043°C/year, respectively while decreased for the winter season from 0.046 to 0.032°C/year. The warming trend of daily maximum temperature from 1970-2005 and 2006-2070 for the annual, summer and monsoon season decreased from 0.027 to 0.025°C/year, 0.028 to 0.021°C/year, 0.023 to 0.022°C/year, while increased for winter from 0.033 to 0.34°C/year. The average reference evapotranspiration reached 1964 mm, 1996 mm, and 2010 mm in annual, 438 mm, 458 mm and 475 mm in winter, 700 mm, 698 mm and 698 mm in summer, and 826 mm, 839 mm and 837 mm in monsoon during the periods 1970-2005, 2006-2040 and 2041-2070, respectively. The reference evapotranspiration increased by 57 mm/century annually. The average annual rainfall of 572 mm, 392 mm and 430 mm in the Aji basin during 1951-2005, 2006-2040 and 2041-2070, respectively was stable. The monsoon seasonal runoff was 261 mm, 187 mm and 182 mm, respectively during 1970-2005, 2006-2040 and 2041-2070 that showed a stable trend. Groundwater recharge during monsoon was 42 mm, 21 mm and 20 mm for periods 1970-2005, 2006-2040 and 2041-2070, respectively indicating stable trend. Crop water requirements during winter, summer and monsoon seasons may increase/decrease by 6.4%, -0.3% and 1.5% during winter, summer and monsoon seasons, respectively in the future as compared to the past, due to climate change impacts. Extreme rainfall (100 year return period) events may increase in the future by 39%. Similarly, runoff may decrease in future but the extreme event (100 year return period) of runoff may increase by 87.5%. The extremity (100 year return period) in crop evapotranspiration and groundwater recharge may decrease by -5.7% and -5.8%, respectively.

At Udaipur, the gross catchment area of the upper Berach river basin is 1101 km^2 and the entire area is having undulating topography in which the velocity of runoff is high. For groundwater monitoring, 95 wells were identified and their GPS locations were recorded. Water table maps were prepared using pre and post monsoon water table data for 2016 and 2017. Aquifer parameters were determined using 12 pumping tests. Thematic maps for soil, slope and topographic elevation were prepared for the basin. The area favourable for artificial recharge is 219.2 km^2, which contributes only 20% of the total study area including villages of Chandersia, Gandoli, Sangwa, Shambhopura, Beran, Nauwa, Mavli, Akodra, Bhutpura, etc.

At Udaipur, assessment of groundwater quality was done for Chittorgarh district of Rajasthan. The district was divided into 7 km x 7 km square grids and one open dug well was selected randomly from each grid using GPS. Total 134 groundwater samples were collected in pre monsoon season and post monsoon season of 2017. In post monsoon season, TDS varied from 80 mg/kg in Rawatbhata block to 1890 mg/kg in Kapasan block. Groundwater pH varied from 6.2 in Gangrar block to 9.1 in Dungla block during pre monsoon. During post monsoon, pH varied from 6.8 in Nimbahera block to 8.4 in Dungla block. Electrical conductivity varied from 0.30 dS/m in Rawatbhata block to 9.30 dS/m in Kapasan block during pre monsoon.

At Jabalpur, two-layer groundwater modeling of soil aquifer system was done using Visual MODFLOW. Calibration was done with data from year 2000 to 2010 and validation from 2011-2015. The predicted results of water level matched well with the observed water level. Correlation coefficients at calibration and validation were 0.993 and 0.992, respectively. Recharge of the study area ranged from 75-175 mm, hydraulic conductivity was 0.00013 m/s, transmissivity of confined aquifer ranged from 17 to 3000 m^2/day. There was good agreement between observed and simulated water levels in steady state as well as transient conditions with correlation coefficient 0.99. Groundwater flow in unconfined aquifer (Aquifer-I: Layer thickness 1.8 to 20 m, Calibrated parameters: Hydraulic conductivity 0.00013 m/s, specific yield 0.05 to 0.16, Recharge 106 to 290 mm/year) is from east to west in the study area. However, the overall direction of groundwater flow in the confined aquifer (Aquifer-II: Layer thickness 20 to 80 m, Calibrated parameters: storage coefficient 0.0001) is also moving from east to west direction.

At Coimbatore, groundwater balance was assessed to quantify water availability for development in Amaravathy basin. Rainfall in Amaravathy basin from 1971 to 2014 showed an non-significant decreasing trend with Q value of -2.49. Coefficient of variability varied from 19.67 to 44.49%. Fluctuation of groundwater level in the basin varied from 0.2 to 3.1 m during south-west monsoon, and 0.4 to 6.6 m during north-east monsoon. Out of 33 blocks in the basin, 16 blocks are overexploited (⩾100%), 2 blocks are critical (90-100%), 12 blocks are semi-critical (70-90%) and 3 blocks are safe (< 70%). Total monsoon recharge from 1971 to 2014 varied from 27 to 12.80%. About 72% area i.e. parts of the blocks such as Vellakovil, Mulanur, Dharapuram, Madathukulam, Gudimangalam, Vedasandur, south Pollachi and Aravakurichi were identified as 'very good' groundwater recharge areas. Regression model developed may be adopted for reasonable estimation of groundwater table at the observation well based on rainfall, antecedent rainfall and antecedent groundwater table for effective planning and management of groundwater resources of the watershed.

At Coimbatore, soil fertility status and water quality in Kugalur distributory of Lower Bhavani Project command area were assessed with GIS. Bulk density and particle density ranged from 1.1 to 1.6 Mg/m^3 and 2.0 to 2.8 Mg/m^3, respectively. Soil texture is mostly sandy clay loam followed by sandy loam texture. Soil fertility status showed that pH and EC are normal. Available N, P and K were low to medium, low to medium, and medium to high, respectively. Irrigation water analysis showed that pH and EC are normal in all the villages. Chloride content implied that water samples are in good condition. Residual Sodium Carbonate in water samples was <1.0 meq/l, which indicated that quality of irrigation water is excellent. Total Soluble Solid ranged from 306 to 462 ppm.

Theme 2: Design, development and refinement of surface and pressurized irrigation systems

At Parbhani, drip irrigation at 1.0 PE recorded significantly higher grain and stover yields and net return of maize was comparable with irrigation at 0.8 PE w.r.t. grain yield. Significantly higher grain yield, stover yield, WUE and net return of maize was observed in fertigation level at 100% RDF (150:75:75 NPK kg/ha) through drip and was comparable with 75% RDF through drip w.r.t. both grain and stover yield. It is recommended to schedule drip irrigation at 0.8 PE on alternate day for higher grain yield and net monetary return of maize. Similarly, drip fertigation with 112.5:56.2:56.2 NPK kg/ha to maize with N in 8 equal splits @ 12.5% at an interval of 10 days from 10 to 80 DAS, while P and K in 2 equal splits of 50% at sowing and 30 DAS is recommended.

At Belavatagi, sunflower grown with drip irrigation at 1.0 ETo during *kharif* season recorded significantly higher grain yield of 2.43 t/ha in pooled data compared to farmers' method of giving flood irrigation at critical stages (1.85 t/ha). Total water saving was 28.44% over flood irrigation. The following *Rabi* crops like wheat, bengal gram and groundnut also performed better under drip as compared to farmers' method. The wheat, bengal gram and groundnut recorded 0.53, 0.63 and 0.74 t/ha higher yields than normal method of irrigation. Sunflower equivalent yield was higher with sunflower-groundnut cropping system with 5.95 t/ha which gave net return of ₹1,37,075 and B:C ratio of 2.92. In Malaprabha command area, growing sunflower with drip irrigation followed by groundnut is more profitable compared to other cropping systems. The cropping system is recommended for package of pracitces.

At Chalakudy, a hand and power operated agitator was developed and tested. The nutrient content of manure solution, filtrate and residue were analyzed and found good for fertigation. Vermicompost solution can be prepared for fertigation by mixing vermicompost and water in the ratio of 1:5 followed by agitation for 10 minutes and settling for 6 hours. Cowdung solution can be prepared for fertigation by agitation for 5 minutes followed by settling for 5 minutes. The hand operated agitator is effective in agitating organic manure, whereas the power operated agitator can be introduced in organic fertigation unit for large scale cultivation.

At Faizabad, drip fertigation at 60% PE with 100% N recorded significantly higher yield (34.13 t/ha) of tomato with maximum net return of ₹ 2,94,700 per quintal and B:C ratio of 7.33 over other treatments. Drip fertigation at 80% PE with 100% N recorded significantly higher yield (7.23 t/ha) of *zaid* okra over other treatments of drip and surface irrigation except its 75% N fertigation treatment. This treatment saved about 50.11% irrigation water with WUE of 31.03 kg/ha-mm. Nitrogen doses (100% and 75%) did not affect the okra yield significantly under drip irrigation. However, it has significant effect under surface irrigation. Drip irrigation treatment (60% of PE + 100% N application) was found most economical with maximum net return of Rs. 37060 per hectare.

At Sriganganagar, mean effect of irrigation and fertigation schedules on yield of summer squash was significant. Highest yield of summer squash was recorded at 1.0 ETc (37.05 t/ha), significantly higher than the yield obtained with irrigations at 0.6 ETc and 0.8 ETc. With fertigation treatments, yield at 60% RD, 80% and 100% RD significantly increased over that of flood surface irrigation (control), with all treatments giving significantly similar yield. The interaction effect of irrigation and fertigation was also non-significant. Water saving with drip irrigation ranged from 53.8 to 70.0% compared to flood irrigation method.

Theme 3: Development and evaluation of groundwater recharge technologies, and management of rainwater

At Junagadh, two groundwater-recharging techniques *viz.*, open well recharging and connector well recharging were evaluated during monsoon season of 2017 for Junagadh region. During the monsoons, 2895 m^3 was recharged through open well. With annual extreme runoff event, groundwater recharge was 40040 m^3, 0 m^3, 9899 m^3 and 19584 m^3 for maximum, minimum, average and 15 year return period of runoff, respectively. Cost of groundwater recharge was ₹ 2.66/m^3 @ 15 years effective life of open well recharge structure. There was positive recharge of 40333 m^3 with the connector well. Cost of groundwater recharge was ₹ 0.51/m^3 and ₹ 0.32/m^3 on including and excluding tubewell cost, respectively.

At Junagadh, filtration efficiency increased with thickness of sand bed. With 10 cm, 15 cm and 20 cm thickness of sand bed, filtration efficiency was 63%, 85% and 89%, respectively. Relation between filtration efficiency and thickness of bed was established as a linear model: $y = -0.36x^2 + 13.4x - 35$, where y=Filtration efficiency, x=Thickness of sand bed in centimetre. Recharge flow rate decreased as thickness of sand bed increased. With 10 cm, 15 cm and 20 cm thickness of sand bed, recharge flow rate was 63%, 85% and 89%, respectively. Relation between flow rate and thickness of bed was established as a linear model: $y = -4.7038x + 127.59$, where y=Recharge flow rate, %, x=Thickness of sand bed in centimetre. The model showed $R^2 = 0.99$.

At Pusa, a filter was fabricated and tested with various filter combinations for artificial recharge. Filter combination-6 consisting of gravel, sand and charcoal had highest recharge rate and 2nd lowest TSS value. Total suspended solid (TSS) was lowest after passing through the filter combination-7 consisting of coloured gravel, white gravel and sand, but the recharge rate was lowest. Average turbidity of the runoff water was 410 NTU. Maximum turbidity was reduced by 81.7% with filter combination-7. The analysis revealed that filter combination-6 showing highest recharge rate and 2nd lowest turbidity is the best for adoption and implementation.

At Rahuri, impact of cement nala bund (CNB) on groundwater recharge was studied. A series of cement nala bunds at Vadgaon Tandali, Ahmednagar was selected. The wells downstream of these structures were mapped and the observations on water levels in these wells were recorded. The volume of groundwater storage in the command of these CNB for the year 2017 showed an increase of 20.55 ha-m. The influence of cement nala bund at Vadgaon Tandali was found upto a distance of 459.3 m.

At Rahuri, hydraulic performance of filter technology was tested with a four layer filter for bore well recharge in farm/field. The filter materials were brick flakes (BF-I) of size 24.28 mm, sand (SG-I) of size 0.6-2.0 mm, angular gravel (AG-I) of grade 9.5-15.5 mm and pea gravel (PG-I) of size 20-24 mm. The filter having total thickness of 100 cm (25 cm/layer) tested at three different locations in the command showed filtration efficiency of about 84.49%, which can be considered as satisfactory performance with recharge capacity of 1511525 litres during the rainy season of 2017.

At Jabalpur, groundwater system in the upper Narmada basin was characterized by studying the spatial and temporal variation of area under different crops in Narsinghpur District. Crop maps prepared for the years 2006 and 2015 based on satellite data captured during the month of January and February indicated area under wheat increased by 109% and area under gram reduced by 36%. Area under sugarcane crop incresead from 25555 ha during 2006 to 54997 ha in 2015. Groundwater flow system was developed in the study area of 513300 ha by Visual MODFLOW. Hydraulic conductivity (K) obtained after calibration of model for 2000 to 2010 is 0.00107 m/s for unconfined aquifer and 0.0005 m/s for confined aquifer. Model was validated with hydraulic head data from year 2011 to 2015. The model forcasted hydraulic head to further deplete from 334.14 m to 330.41 m in 2025 if rate of groundwater use remains same. Groundwater heads during pre-monsoon period may go deeper by 5.26 m in Gotegaon block, 3.91 m in Narsinghpur block, 3.04 m in Kareli block, 4.39 m in Chawarpatha block, 5.18 in Chichli block and 0.60 m in Saikheda block if area under high water consuming crop like sugarcane continues to increase. Also, if irrigation to wheat is increased at a present rate, depletion will increase.

At Raipur, prioritization of watershed based on morphometric analysis revealed that the watersheds WS1, WS2, WS6, WS9, WS12, WS14, WS19 and WS20 fall in the high priority and indicated as the high soil erosion susceptible watersheds. Manning's 'n' values for overland flow and channel flow are 0.132 and 0.024, respectively for the Seonath sub-basin. Arc-SWAT model accurately simulated stream discharge and sediment concentration from the Seonath sub-basin on monthly basis using both observed and generated daily rainfall and temperature. Artificial groundwater recharging plan for Raipur district was developed using Multi Criteria Evaluation/ Weighted Overlay technique.

At Coimbatore, out of the 33 blocks in Amaravathi basin, 16 blocks fell under the category of overexploited (⩾ 100%), two blocks under critical (90-100%), 12 blocks under semi-critical category (70-90%) and only three blocks under safe category (<70%). Total monsoon recharge during 1971 to 2014 varied from 27 to 12.80% in the basin. About 72% of the basin areas contribute to good recharge areas. Parts of the blocks such as Vellakovil, Mulanur, Dharapuram, Madathukulam, Gudimangalam, Vedasandur, Pollachi south and Aravakurichi in the basin were identified as very good groundwater recharge areas. Regression model was developed, that may be adopted for reasonable estimation of groundwater table at observation well based on the rainfall, antecedent rainfall and antecedent groundwater table for effective planning and management of groundwater resources of the watershed.

At Coimbatore, subsurface drip irrigation at 100% PE with 125% RDF (150:75:75 kg NPK/ha) for cotton and 100% PE irrigation regime with 100% RDF (250:75:75 kg NPK) for maize gave higher yield and economic benefits in cotton-maize based intercropping system. The fertigation schedule saved water up 23% compared to conventional irrigation. Intercropping of blackgram under cotton – maize sequence proved beneficial through subsurface drip fertigation.

Theme 4: Basic studies on soil-plant–water-environment relationship

At Jorhat, performance of rice crop with bund height of 40 cm was at par with bund height of 30 cm recording significantly higher number of grains/panicle, grain yield and straw yield of rice than 10 and 20 cm high bunds. The yield of subsequent *rabi* crops (linseed, buckwheat and Lathyrus) followed similar trend. However, bund height of 30 cm recorded highest net return of ₹ 60,823 and B:C ratio of 2.93.

At Morena, pearlmillet grain yield (4.69 t/ha), net return (₹ 41,337/ha), B:C ratio (3.05) and water productivity (1.47 kg/m^3) were significantly higher under 100% RRSHS (Residue retention through sowing of crop by turbo happy seeder) sowing method compared to other sowing methods. In case of intercultural operations, tractor operated ridge furrow maker + weedicide application resulted in significantly higher yield of 4.58 t/ha, net income of ₹ 56,170/ha, B:C ratio of 3.59 and water productivity of 1.30 kg/m^3.

At Kota, maximum and significantly higher garlic yield of 16.01 t/ha was obtained when irrigation was applied at 100% PE followed by 14.17 t/ha with irrigation at 75% PE. Similarly, 100% of recommended dose of fertilizer (NPK 120:40:100) produced the maximum garlic yield (16.31 t/ha) but was at par with the yield (15.41 t/ha) obtained with 75% of recommended dose.

At Navsari, sugarcane crop grown under different pit diameters and pit spacings showed highest net profit with treatment D_2S_2 (60 cm pit diameter with 1.75 x 1.75 m pit spacing) which was followed by D_1S_2 (45 cm pit diameter with 1.75 x 1.75 m pit spacing). Increase in net profit over plant crop was positive up to three ratoon crops in case of both the pit treatments. Whereas, it was positive only up to two ratoon crops in case of control treatment (paired row planting).

At Navsari, higher net profit from 8 to 9 years old mango plantation was obtained when drip irrigation was applied directly through four vertically inserted HDPE/PVC pipe (75 mm diameter) into the soil at 40 cm depth below ground level on all the four sides around 1.5 m away from mango trunk through spaghetti tube (4 mm diameter) fitted on online dripper.

At Powarkheda, sowing of chickpea (gram) on 15th November and 30th November gave satisfactory yields of 2.95 t/ha and 2.79 t/ha, respectively. But sowing on 15th December (2.12 t/ha) resulted in drastic reduction in yield. Two irrigations i.e. at branching and pod formation stages of gram proved to be most beneficial with yield of 2.81 t/ha. In case of availability of only one irrigation, it should be applied at pod formation stage (2.56 t/ha). Net monetary return (₹ 65,621/ha), B:C ratio (2.75) and WUE (127 kg/ha-cm) were maximum under 15th November sowing. Net monetary return under 3 irrigations and 2 irrigations were nearly equal (₹ 61,081 and ₹ 60,506/ha) but the B:C ratio of 2.60 and WUE of 112 kg/ha-cm under 2 irrigations was higher under two irrigations.

At Powarkheda, wheat crop (JW 1203) under zero tillage gave highest yield of 4.57 t/ha with irrigation at 1.2 IW/CPE, which was statistically similar to yield (4.39 t/ha) with irrigation at 1.0 IW/CPE. Water use efficiency was higher (165 kg/ha-cm) with 0.8 IW/CPE but net monetary return (₹ 26,299/ha) and B:C ratio (1.62) were substantially higher with 1.2 IW/CPE closely followed by 1.0 IW/CPE ratio (₹ 24524/ha and 1.59).

At Bilaspur, three years of experiment showed that irrigation at 3DADPW recorded highest rice grain yield of 6.92 t/ha and maximum net return of ₹ 77,634/ha. Also, plant spacing of 20 cm x 20 cm gave higher yield of 7.06 t/ha, net return of ₹ 77,696/ha and WUE of 106.82 kg/ha-cm.

At Palampur, substitution of different proportion of recommended dose of nitrogen with various locally prepared liquid manure enriched with 1% liquid biofertilizer (E100) and recommended dose of phosphorus and potassium as basal application resulted in significantly higher yield and economics with drip irrigated green onion at 0.6 PE and okra at 0.8 PE, than crop fertilized with recommended nitrogen through chemical fertilizer with or without recommended FYM and 5 cm surface irrigation.

Theme 5: To evolve management strategies for conjunctive use of surface and groundwater

At Coimbatore, present pattern of conjunctive use of surface water and groundwater was assessed in Lower Bhavani Project (LBP) command area. Major crops like sugarcane, banana, irrigated wet crop paddy and irrigated dry crop groundnut were considered. It was observed that conjunctive use is very low at the head reaches and increases towards the tail reaches. Paddy and groundnut completely depends on canal water supply. More than 75% of the farmers having open wells in the study area are having borewells (one or two) so that they can give irrigation to annual crops during summer. Out of the 75% farmers, 60% of them pump out water from borewells in to open wells/surface level tanks and give irrigation to fields by pumping water from open wells/diverting water from surface level tanks. Canal and groundwater could be managed conjunctively for minor irrigation in the command area by delivering less water to canal head-end watercourses and redirect flows to tail-end outlets; water distribution equity is restored in the canal and/or reverse inequity is established.

At Bathinda, conjunctive use of different proportions of canal water (CW) and tubewell water (TW) (saline sodic; RSC: 6.4 meq/l; EC: 2.2 dS/m; low salinity high SAR; saline-sodic) irrigations had non-significant effect on girth, height, timber and fuel wood in case of *Eucalyptus*. Among different treatments, the height, girth, timber and fuel wood of Poplar trees were at par among CW, CW-TW and 2CW-1TW treatments. In case of Dek, maximum height, timber and fuel wood was found in CW treatment, which was statistically at par with 2CW-1TW but significantly higher than irrigation with TW and 2TW-1CW. Among these tree species, water productivity and economic returns were higher with *Eucalyptus* followed by Dek and least in Poplar under saline sodic water irrigation in calcareous soil of semi-arid region in Punjab.

At Bilaspur, *Kharif* rice var. MTU-1010 produced highest grain yield (4.21 t/ha) and straw yield (5.52 t/ha) with 100% dairy water irrigation than tubewell water irrigation. Nutrient management with 75% RDF + BGA recorded highest grain yield (4.41 t/ha)compared to other treatments. Following wheat crop var. HD-2932 during *rabi* season gave significantly higher grain yield of 3.76 t/ha and straw yield of 4.27 t/ha under irrigation with 100% dairy surface water than tubewell water irrigation. Among different fertility levels, application of 75% RDF + BGA resulted in significantly higher grain yield of 3.95 t/ha.

INTRODUCTION

All Indian Coordinated Research Project on Water Management (WM) and All India Coordinated Research Project on Groundwater Utilisation (GWU) were merged to be rechristened as All India Coordinated Research Project on Irrigation Water Management (AICRP-IWM) during the XII Plan. AICRP-IWM is operating in 26 centres under various agro-ecological regions of the country. There are multiple centres under Tamil Nadu Agricultural University (Bhavanisagar, Madurai, Coimbatore), Jawaharlal Nehru Krishi Viswa Vidyalaya (Powarkheda and Jabalpur) and Punjab Agricultural University (Ludhiana and Bathinda).

Revised mandates of AICRP on Irrigation Water Management after merger of AICRP on WM and AICRP on GWU

1. Assessment of surface water and groundwater availability and quality at regional level and to evolve management strategies using Decision Support Systems (DSS) for matching water supply and demand in agricultural production systems
2. Design, development and refinement of surface and pressurized irrigation systems including small landholders' systems for enhancing water use efficiency and water productivity for different agro-ecosystems
3. Management of rainwater for judicious use and to develop and evaluate groundwater recharge technologies for augmenting groundwater availability under different hydro-geological conditions
4. Basic studies on soil-plant-water-environment relationship under changing scenarios of irrigation water management
5. To evolve management strategies for conjunctive use of surface water and groundwater resources for sustainable crop production

List of existing centres and their controlling institutions under AICRP on Irrigation Water Management (Table 1)

Table 1. Centres and their controlling universities

S.No.	Location of Centre	Controlling University/ICAR Institute
1	Almora	VPKAS, Almora
2	Bathinda, Ludhiana	PAU, Ludhiana
3	Belavatagi	UAS, Dharwad
4	Bhavanisagar, Madurai, Coimbatore	TNAU, Coimbatore
5	Bilaspur, Raipur	IGKVV, Raipur
6	Chalakudy	KAU, Thrissur
7	Chiplima	OUAT, Bhubaneswar
8	Dapoli	DBSKKV, Dapoli
9	Faizabad	NDUAT, Faizabad
10	Hisar	CCSHAU, Hisar
11	Jammu	SKUAST, Jammu
12	Jorhat	AAU, Jorhat
13	Junagadh	JAU, Junagadh
14	Gayeshpur	BCKVV, Mohanpur
15	Kota	AU, Kota
16	Morena	RVSKVV, Gwalior
17	Navsari	NAU, Navsari
18	Palampur	CSKHPKVV, Palampur
19	Pantnagar	GBPUAT, Pantnagar
20	Parbhani	VNMKV, Parbhani
21	Powarkheda, Jabalpur	JNKVV, Jabalpur
22	Pusa	Dr.RPCAU, Pusa
23	Rahuri	MPKV, Rahuri
24	Shillong	ICAR Research Complex for NEH region
25	Sriganganagar	SKRAU, Bikaner
26	Udaipur	MPUAT, Udaipur

Irrigation Commands under AICRP on Irrigation Water Management

The locations of the centres of AICRP on Irrigation Water Management catering to different irrigation commands and agro-ecological regions of the country are given in Table 2.

Table 2. Distribution of the centres of AICRP on Irrigation Water Management across the Agro-ecological Subregions (AESRs) of India and irrigation commands represented by the centres.

ECOSYSTEM	AER Description	AESR	Description of AESR	Irrigation region	Centre	Controlling organization
ARID ECOSYSTEM	1 Western Himalayas, cold arid eco-region	1.1	Eastern aspects of Ladakh Plateau, cold, hyper-arid ecosub-region (ESR) with shallow skeletal soils, very low AWC and LGP < 60 days	-	-	-
		1.2	Western Aspects of Ladakh plateau and North Kashmir Himalayas, cold to cool, typic–arid ESR with shallow, loamy-skeletal soils, low AWC and LGP 60-90 days	-	-	-
	2 Western plain, Kachchh and parts of Kathiawar Peninsula, hot arid eco-region	2.1	Marusthali, hot hyper-arid ESR with shallow and deep sandy desert soils, very low AWC and LGP <60 days	IGNP Bhakra	Sriganganagar Bathinda	SKRAU, Bikaner PAU, Ludhiana
		2.2	Kachchh Peninsula (The Great Rann of Kachchh as inclusion), hot hyper-arid ESR with deep loamy saline and Alkali soils, low AWC and LGP < 60 days	-	-	-
		2.3	Rajasthan Bagar, North Gujarat plain and South-western Punjab plain, hot typic-arid ESR with deep, loamy desert soils (inclusion of saline phase), low AWC and LGP 60-90 days	Bhakra	Hisar	CCSHAU, Hisar
		2.4	South Kachchh and north Kathiawar peninsula, hot arid ESR with deep loamy saline and alkali soils, low AWC and LGP 60-90 days	-	-	-
	3 Karnataka plateau (Rayalseema as inclusion), hot arid ESR with deep loamy and clayey mixed red and black soils, low to medium AWC and LGP 60-90 days	-	-	-	-	-
SEMIARID ECOSYSTEM	4 Northern plain (and Central Highlands including Aravallis, hot semi-arid eco-region	4.1	North Punjab plain, Ganga-Yamuna Doab and Rajasthan upland, hot semi-arid ESR with deep loamy alluvium-derived soils (occasional saline and sodic phases), medium AWC and LGP 90-120 days	-	Ludhiana	PAU, Ludhiana
		4.2	North Gujarat plain (inclusion of Aravalii range and east Rajasthan uplands), hot dry semi-arid ESR with deep loamy grey brown and alluvium derived soils, medium AWC and LGP 90-120 days	-	Udaipur	MPUAT, Udaipur
		4.3	Ganga-Yamuna Doab, Rohilkhand and Avadah plain, hot moist semi-arid ESR with deep, loamy alluvium-derived soils (sodic phase inclusion), medium to high AWC and LGP 120-150 days	-	-	-

		4.4	Madhya Bharat Plateau and Bundelkhand uplands, hot, moist semi-arid ESR with deep loamy and clayey mixed red and black soils, medium to high AWC and LGP 120-150 days	Chambal	Morena	RVSKVV, Gwalior
	5 Central Highlands (Malwa) Gujarat plain and Kathiawar Peninsula, semi-arid eco-region	5.1	Central Kathiawar Peninsula, hot dry Semi-arid ESR with shallow and medium loamy to clayey black soils (deep black soils as inclusion), medium AWC and LGP 90-120 days	-	Junagadh	JAU, Junagadh
		5.2	Madhya Bharat plateau, Western Malwa plateau, eastern Gujarat plain, Vindhyan and Satpura range and Narmada valley hot moist semi-arid ESR with medium and deep, clayey black soils (shallow black soils as inclusions), medium to high AWC and LGP 120-150 days	Chambal	Kota	AU, Kota
		5.3	Coastal Kathiwar Peninsula, hot moist semi-arid ESR with deep loamy coastal alluvium-derived soils (saline phases inclusion), low to medium AWC and LGP 120-150 days	-	-	-
	6 Deccan plateau, hot semi-arid eco-region	6.1	South-western Maharashtra and North Karnataka Plateau, hot dry semi-arid ESR with shallow and medium loamy black soils (deep clayey black soils as inclusion) medium to high AWC and LGP 90-120 days	-	-	-
		6.2	Central and western Maharashtra plateau and north Karnataka plateau and north western Telangana plateau, hot moist semi-arid ESR with shallow and medium loamy to clayey black soils (medium and deep clayey black soils as inclusion) medium to high AWC and LGP 120-150 days	Jayakwadi Mula	Parbhani Rahuri	VNMKV, Parbhani MPKV, Rahuri
		6.3	Eastern Maharashtra plateau, hot moist semi-arid ESR with medium and deep clayey black soils (shallow loamy, to clayey black soils as inclusion), medium to high AWC and LGP 120-150 days	-	-	-
		6.4	Moderately to gently sloping North Sahyadris and western Karnataka plateau, hot dry sub-humid ESR with shallow and medium loamy and clayey black soils (deep clayey black soils as inclusion), medium to high AWC and LGP 150-180 days	Malaprabh a	Belavatagi	UAS, Dharwad
	7 Deccan plateau (Telengana) and Eastern Ghats, hot semi-arid eco-region	7.1	South Telengana Plateau (Rayalsema) and Eastern Ghat, hot dry semi-arid ESR with deep loamy to clayey mixed red and black soils, medium AWC and LGP 90-120 days	-	-	-
		7.2	North Telangana plateau, hot moist semi-arid ESR with deep loamy and clayey mixed red and black soils, medium to very high AWC and LGP 120-150 days	-	-	-
		7.3	Eastern ghat (south), hot moist semi-arid/dry subhumid ESR with medium to deep loamy to clayey mixed red and black soils, medium AWC and LGP 150-180 days	-	-	-

	8 Eastern Ghats and Tamil Nadu uplands and Deccan (Karnataka) plateau, hot semi-arid eco-region	8.1	Tamil Nadu uplands and leeward flanks of south Sahyadris, hot dry semi-arid eco-subregion with moderately deep to deep, loamy to clayey, mixed red and black soils medium AWC and LGP 90-120 days	Periyar Vaigai Periyar Vaigai	Coimbatore Madurai	TNAU, Coimbatore TNAU, Coimbatore
		8.2	Central Karnataka Plateau, hot moist semi-arid ESR with medium to deep red loamy soils, low AWC and LGP 120-150 days	-	-	-
		8.3	Tamil Nadu uplands and plains, hot moist and ESR with deep red loamy soils, low AWC and LGP 120-150 days	Lower Bhavani	Bhavanisagar	TNAU, Coimbatore
SUBHUMID ECOSYSTEM	9 Northern plain, hot subhumid (dry) eco-region	9.1	Punjab and Rohilkhand plains, hot dry/moist subhumid transitional ESR with deep, loamy to clayey alluvium-derived (inclusion of saline and sodic phases) soils medium AWC and LGP 120-150 days	-	-	-
		9.2	Rohilkhand, Avadh and south Bihar plains, hot dry subhumid ESR with deep loamy alluvium-derived soils, medium to high AWC and LGP 150-180 days	Sharda Sahayak	Faizabad	NDUA&T, Faizabad
	10 Central Highlands (Malwa and Bundelkhand), hot subhumid (dry) eco-region	10.1	Malwa plateau, Vidnyan scarpland and Narmada valley, hot dry subhumid ESR with medium and deep clayey black soils (shallow loamy black soils as inclusion), high AWC and LGP 150-180 days	- Tawa	Jabalpur Powarkheda	JNKVV, Jabalpur JNKVV, Jabalpur
		10.2	Satpura and Eastern Maharashtra plateau, hot dry subhumid ESR with shallow and medium loamy to clayey black soils (deep clayey black soils as inclusion), medium to high AWC and LGP 150-180 days	-	-	-
		10.3	Vidhyan Scarpland and Baghelkhand plateau, hot dry subhumid ESR with deep loamy to clayey mixed red andblack soils, medium to high AWC and LGP 150-180	-	-	-
		10.4	Satpura range and Wainganga valley, hot moist subhumid ESR with shallow to deep loamy to clayey mixed red and black soils, low to medium AWC and LGP 180-210 days	-	-	-
	11 Moderately to gently sloping Chhattisgarh/ Mahanadi basin, hot moist/ dry subhumid transitional ESR with deep loamy to clayey red and yellow soils, medium AWC and LGP 150-180 days	-	-	Hasdeo Bango -	Bilaspur Raipur	IGKVV, Raipur IGKVV, Raipur
	12 Eastern plateau (Chhotanagpur) and Eastern Ghats, hot subhumid eco-region	12.1	Garjat Hills, Dandakaranya and Eastern Ghats, hot moist subhumid ESR with deep loamy red and lateritic soils, low to medium AWC and LGP 180-210 days	Hirakud	Chiplima	OUAT, Bhubaneswar

		12.2	Eastern Ghats, hot moist subhumid ESR with medium to deep loamy red and lateritic soils, medium AWC and LGP 180-210 days	-	-	-
	13 Eastern plain, hot subhumid (moist) eco-region	13.1	North Bihar and Avadh plains, hot dry to moist subhumid ESR with deep, loamy alluvium derived soils, low to medium AWC and LGP 180-210 days	Gandak	Pusa	RAU, Samastipur
		13.2	Foothills of central Himalayas, warm to hot moist subhumid ESR with deep loamy to clayey Tarai soils, high AWC and LGP 180-210 days	-	-	-
	14 Western Himalayas, warm subhumid (to humid with	14.1	South Kashmir and Punjab Himalayas, cold and warm dry semi-arid/dry subhumid ESR with shallow to medium deep loamy brown forest and Podzolic soils, low to	-	-	-
		14.2	South Kashmir and Kumaun Himalayas, warm moist to dry subhumid transitional ESR with medium to deep loamy to clayey brown forest and podzolic soils, medium	Yamuna Ravi and Tawi	Almora Jammu	VPKAS, Almora SKUAST, Jammu
		14.3	Punjab Himalayas warm humid to perhumid transitional ESR with shallow to medium deep loamy brown forest and podzolic soils, low to medium AWC and LGP 270-300 + days	-	Palampur	HPKVV, Palampur
		14.4	Kumaun Himalayas, warm humid to perhumid transitional ESR with shallow to medium deep loamy red and yellow soils, low AWC and LGP 270-300 + days	-	-	-
		14.5	Foothills of Kumaun Himalayas (subdued), warm humid/perhumid ESR with medium to deep, loamy Tarai sols, medium AWC and LGP 270-300 + days	-	Pantnagar	GBPUAT, Pantnagar
HUMID-PERHUMID ECOSYSTEM	15 Assam and Bengal plains, hot subhumid to humid (inclusion of perhumid) eco-region	15.1	Bengal basin and North Bihar plain, hot moist subhumid ESR with deep loamy to clayey alluvium derived soils, medium to high AWC and LGP 210-240 days	Damodar Valley Corporation (DVC)	Gayeshpur	BCKVV, Mohanpur
		15.2	Middle Brahmaputra plain, hot humid ESR with deep, loamy to clayey alluvium derived soils, medium AWC and LGP 240-270 days	-	-	-
		15.3	Teesta, lower Brahmaputra plain and Barak valley, hot moist humid to perhumid ESR with deep, loamy to clayey alluvium-derived soils, medium AWC and LGP 270-300 days	-	-	-
		15.4	Upper Brahmaputra plain, warm to hot perhumid ESR with moderately deep to deep loamy, alluvium derived soils, medium AWC and LGP > 300 days	Jamuna	Jorhat	AAU, Jorhat
	16 Eastern Himalayas, warm perhumid eco-region	16.1	Foot-hills of Eastern Himalayas (Bhutan foot hills) warm to hot perhumid ESR with shallow to medium, loam-skeletal to loamy Tarai soils, low to medium AWC and LGP 270-300 days	-	-	-

		16.2	Darjeeling and Sikkim Himalayas, warm perhumid ESR with shallow to medium deep loamy brown and Red Hill soils, low to medium AWC and LGP > 300 days	-	-	-
		16.3	Arunanchal Pradesh (subdued Eastern Himalayas), warm to hot perhumid ESR with deep, loamy to clayey red loamy soils, low to medium AWC and PGP > 300 days	-	-	-
	17 North-eastern hills (Purvachal), warm perhumid eco-region	17.1	Meghalaya plateau and Nagaland hill, warm to hot moist humid to perhumid ESR with medium to deep loamy to clayey red and lateritic soils, medium AWC and LGP 270-300 + days	Umiam	Shillong	ICAR Complex for NEH Region, Shillong
		17.2	Purvachal (Eastern range), warm to hot perhumid ESR with medium to deep loamy red and yellow soils, low to medium AWC and LGP > 300 days	-	-	-
COASTAL ECOSYSTEM	18 Eastern Coastal plain, hot subhumid to semi-arid eco-region	18.1	South Tamil Nadu plains (Coastal), hot dry semi-arid ESR with deep, loamy to clayey, alkaline coastal and deltaic alluvium-derived soils, medium AWC and LGP 90-120 days	-	-	-
		18.2	North Tamil Nadu Plains (Coastal), hot moist semi-arid ESR with deep, clayey and cracking coastal and deltaic alluvium-derived soils, high AWC and LGP 120-150 days	-	-	-
		18.3	Andhra plain, hot dry subhumid ESR with deep, clayey coastal and deltaic alluvium derived soils, low to medium AWC and LGP 150-180 days	-	-	-
		18.4	Utkal plain and east Godavari delta, hot dry subhumid ESR with deep, loamy to clayey coastal and deltaic alluvium-derived soils, medium AWC and LGP 180-210 days	-	-	-
		18.5	Gangetic delta, hot moist subhumid to humid ESR with deep, loamy to clayey coastal and deltaic alluvium-derived soils, medium AWC and LGP 240-270 days	-	-	-
	19 Western Ghats and coastal plain, hot humid-perhumid eco-region	19.1	North Sahyadris and Konkan coast, hot humid ESR with medium to deep loamy to clayey mixed red and black soils, medium to high AWC and LGP 210-240 days	Ukai-Kakrapar	Navsari	NAU, Navsari
		19.2	Central and south Sahyadris, hot moist subhumid to humid transitional ESR with deep, loamy to clayey red and lateritic soils, low to medium AWC and LGP 210-270 days	Chalakudy -	Chalakudy Dapoli	KAU, Thrissur DBSKKV, Dapoli
		19.3	Konkan, Karnataka and Kerala coastal plain, hot humid to perhumid transitional ESR with deep, clayey to loamy, acidic, coastal alluvium-derived soils, low AWC and LGP 240-270 days	-	-	-
ISLAND ECOSYSTEM	20 Islands of Andaman-Nicobar and Lakshadweep, hot humid to perhumid island eco-region	20.1	Andaman-Nicobar group of islands, hot perhumid ESR with shallow to medium deep, loamy to clayey red and yellow and red loamy soils, low to medium AWC and LGP > 300 days	-	-	-
		20.2	Level Lakshadweep and group of islands hot humid ESR with shallow to medium deep loamy to sandy black, sandy and littoral soils, low to medium AWC and LGP 240-270 days	-	-	-

Locality Characteristics of AICRP on Irrigation Water Management Centres

Locality characteristics in terms of soil, water table, annual rainfall, source of irrigation, etc. for each AICRP centre are given in Table 3.

Table 3. Locality characteristics of AICRP centres in irrigation commands

Name of centre	Soil type	Depth of water table (m)	Annual rainfall (mm)	Source of irrigation
Belavatagi	Sandy loam to clay	Very deep	556	Canal
Bhavanisagar	Red sandy loam to clay loam	3-10 m	702	Canal
Bilaspur	Sandy loam to clay	> 2 m	1249	Canal
Chalakudy	Loamy sand to sandy loam, slightly acidic	> 2 m	3146	Canal
Chiplima	Sandy loam to sandy clay loam	0.2-5 m	1349	Canal
Faizabad	Silty loam to silty clay loam	3-4 m	1163	Canal Tubewell
Hisar	Loamy sand to sandy loam	0.4-1 m	430	Canal Tubewell
Jammu	Sandy loam to silty loam	> 4 m	1175	Canal
Jorhat	Sandy loam to sandy clay loam, slightly acidic	0-15 m	1985	Canal Tubewell
Bathinda	Loamy sand to sandy loam	1.0-4 m	400	Canal Tubewell
Kota	Clay loam to clay	0.7-2 m	777	Canal
Madurai	Sandy loam to clay loam	0.5-2 m	858	Canal
Gayeshpur	Sandy loam to clay loam	0.2-2 m	1315	Canal Tubewell
Morena	Sandy loam to sandy clay loam	5-15 m	875	Canal Tubewell
Navsari	Clayey	1-5 m	1418	Canal
Pantnagar	Sandy loam to clay loam	0.5-3 m	1370	Canal Tubewell
Parbhani	Medium to deep black clayey	> 3 m	879	Canal
Powarkheda	Clay loam to clayey	1-5 m	1285	Canal
Pusa	Sandy loam	2-6 m	1200	Canal Tubewell
Rahuri	Deep black clayey	2-5 m	523	Canal
Sriganganagar	Loam to silty clay loam	> 10 m	276	Canal Tubewell

Theme 1

Assessment of surface water and groundwater availability and quality at regional level and to evolve management strategies using decision support system (DSS) for matching water supply and demand in agricultural production systems

1.1. Sriganganagar (AESR 2.1)

1.1.1. Assessment of water use efficiency and its improvement through introduction of technological interventions at selected outlet in Gang canal command area

20 Z outlet of Z distributory in Gang canal command was selected to estimate area under crops, crop water requirement and demand-supply scenario of canal water. Total command area under the 20 Z outlet was 304 ha. Total cropped area during *Rabi* 2016-17 and *Kharif* 2017 was 280 and 261 ha (Table 1.1.1), respectively with irrigation intensity of 148.7%. There were only six water reservoirs in the outlet command, out of which only 2.0 ha (Kinnow orchard) was under drip irrigation. During Rabi 2016-17 and Kharif 2017, 5120.03 ha-cm and 5560.46 ha-cm canal water (excluding rainfall) was released against crop water requirements of 12321.5 ha-cm and 13751 ha-cm, respectively. Canal water diverted during Rabi 2016-17 and *Kharif* 2017 was 5120.03 ha-cm and 5560.46 ha-cm, respectively. Water available at field was 5120.03 ha-cm during *rabi* and 3446.37 ha-cm during kharif. Irrigation water requirement of crops during the seasons were 12321.5 ha-cm and 13751 ha-cm (Table 1.1.1). Water supply was deficit in both the seasons with relative water supply (RWS) of 0.42 and 0.88 during rabi and kharif, respectively (Table 1.1.1).

Table 1.1.1. Irrigation water requirement (IWR) and relative water supply (RWS) to crops in Gang canal command area

Rabi 2016-17										
Parameter	**Wheat**	**Mustard**	**Barley**	**Gram**	**Fodder**	**Vegetable**	**-**	**-**	**Total**	**RWS**
Area (ha)	78	147	50	-	5	-	-	-	280	0.42
IWR (ha-cm)	4212	2200	5659.5	-	250	-	-	-	12322	
***Kharif* 2017**										
Parameter	**American Cotton**	**Desi Cotton**	**Bajra**	**Cluster bean**	**Mung bean**	**Sugarcane**	**Fodder**	**Orchard**	**Total**	**RWS**
Area (ha)	25	0	1	205	2	17	5	6	261	0.88
IWR (ha-cm)	1900	0	41	7790	55	3400	205	360	13751	

American cotton- *Gossypium hirsutum* L.; Desi cotton- *Gossypium arboreum* L.

1.1.2. Assessment of water availability at distributary level and to devise intervention for matching water supply and demand for maximization of production

Khetawali distributary (KWD) of IGNP command was selected for the study on water supply and demand scenario. The distributary has 16 outlets in KWD system, 6 outlets in Khetawali minor (KWM) system and 2 outlets in Amarpura minor (ARM) system. The design discharge of KWD system, KWM and APM were 74.64, 17.05 and 4.0 cusec, respectively. During 2016-17, flow in KWD, KWM and APM systems was 72 cusec, 14.9 cusec and 2.5 cusec, respectively. The flow was almost constant during *rabi* and *kharif* seasons. During *rabi* 2016-17, canal ran for 60 days from October 2016 to March 2017. Wheat crop covered maximum area in the command area and utilized most of the canal water. Average RWS (0.42) was low during *rabi* season. During *kharif* 2016, canal water was supplied for 62 days and total water release was 109227.29 ha-cm. American cotton occupied maximum area during *kharif*. Average RWS (0.80) during *kharif* season also showed deficit irrigation (Table 1.1.2). Thus, it was suggested to replace part of the area under wheat with mustard or barley during *rabi* and some parts of American cotton (*Gossypium hirsutum*) with low water requiring crops like guar and moong during *kharif* in order to match canal water supply with irrigation water requirement in the KWD, KWM and ARM systems.

Table 1.1.2. Area and irrigation water requirement of crops and relative water supply (RWS) under Khetawali distributary system

System#	Area (ha)	Irrigation water requirement (ha-cm)	Canal water diverted (ha-cm)	Water available at field (ha-cm)	Effective rainfall (ha-cm)	Total water supply (ha-cm)	RWS
Rabi 2016-17							
KWD	2641	130169.5	77374.98	47957.01	6866.6	54823.61	0.42
KWM	765	39165	20878.20	13433.03	1989	15422.03	0.39
APM	115	5347	3633.57	2270.98	299	2569.98	0.48
Kharif 2017							
KWD	2591	173518	82830.70	51338.47	74361.70	125700.17	0.72
KWM	718	51519	22603.98	14543.40	20606.60	35150.00	0.68
APM	90	5063	3792.61	2370.38	2583.00	4953.38	0.98

#KWD-Khetawali distributary (16 outlets), KWM-Khetawali minor (6 outlets), APM-Amarpura minor (2 outlets)

1.2. Ludhiana (AESR 4.1)

1.2.1. Upgradation of Decision Support System for estimating pumping energy requirements

An expert system is developed to estimate specifications of a submersible pump set and its allied components. This expert system is advanced than the previously developed decision support system by the centre. It provides details of associated components like winding wire diameter, wire length, available pump in the market, generator capacity, ammeter rating, voltmeter rating, capacitor rating and PVC pipe diameter along with appropriate selection of submersible pump set based on spatial information of Punjab using Geographical Information System (GIS). This system is developed for two types of users, the administrator and the end-user. A standalone application is also developed for end-user, where decisions are made based on stored information in the system. The second option in view menu is expert system. When user selects expert system, a window appears as shown in Fig. 1.2.1. This screen demands some required fields and some non-required fields. After providing all the information, a click on the calculate button shows results like present depth, depth for design, average rise/fall of selected village, discharge required, power (hp) required, wire diameter and its length, PVC pipe diameter, available pump, generator capacity, voltmeter rating, ammeter rating and capacitor rating. The expert system may help the farming community to estimate the configuration required for their submersible pumping system.

Fig. 1.2.1. Expert system form with inputs

1.3. Rahuri (AESR 6.2)

1.3.1. Assessment of performance of irrigation project

The Musalwadi minor irrigation project was selected to assess its performance in terms of equity, adequacy and excess. The canal is 6.7 km long with design discharge of 18 cusec and covers a command area of 762 ha (4 villages). It has 12 outlets covering 840.9 ha. Net irrigated area during *kharif*, summer (*zaid*) and *rabi* seasons was 336.38 ha each. Rotation-wise water released during *zaid*, *kharif* and *rabi* was 324680, 509820 and 978430 m^3 against crop water requirement of 3044922.7, 1567064.1 and 3866423.6 m^3, respectively. The crop-wise equity was estimated on volume basis using different methods like Christiansen coefficient, Inter-quartile ratio, Modified inter-quartile ratio, Coefficient of variance and Theil's index for *kharif* season, *rabi* season and summer season. The crop-wise and rotation-wise values of adequacy and excess for irrigation system were estimated for *kharif*, *rabi* and summer seasons for each rotation.

The overall results of the performance indicators for Musalwadi minor irrigation for *kharif*, *rabi* and summer season are presented in Table 1.3.1. The values of equity estimated using different methods indicated good performance of the project at the outlet and farm levels. The adequacy of Musalwadi minor irrigation project was 0.10, 0.48 and 0.26 for kharif, *rabi* and summer seasons, respectively thereby indicating non release of water as per crop water requirement.

Table 1.3.1. Performance indicators of the Musalwadi minor irrigation project

Formula	Kharif		Rabi		Summer	
	Volume		Volume		Volume	
	Outlet	Farm	Outlet	Farm	Outlet	Farm
Christianson coefficient	0.97	1	0.97	1	0.97	1
Inter-quartile ratio	0.96	1	0.96	1	0.96	1
Modified inter-quartile ratio	0.94	1	0.94	1	0.94	1
Coefficient of variance	0.064	0	0.064	0	0.064	0
Theil's index	-0.032	-5.84	-0.032	-5.93	-0.032	-6.21
Adequacy	0.10		0.48		0.26	
Excess	0.00		0.01		0.00	

1.4. Junagadh (AESR 5.1)

1.4.1. Assessment of potential water resources of Aji river basin using SWAT Model

The study was carried out in Aji river basin which is the most important river of Shaurashtra having length of 164 km and catchment area of 2130 km^2. Various thematic maps of the river basin like soil map, land use map, drainage map and slope map were obtained using remote sensing and GIS. The soil map showed that maxmum area in the basin is covered by clayey soil (56.13%). Coarse textured soil was not found in the Aji basin, which shows that the basin is having higher runoff potential and lower groundwater recharge. The land use map showed maximum area under agricultural land (69.91%) followed by deciduous forest (14.74%), evergreen forest (4.54%), water (3.17%), mixed forest (2.6%), residential rural area with low population density (2.55%), mixed wetland (0.98%), pasture land (0.86%), urban area with high population density (0.62%) and barren land (0.03%). Maximum area in the basin is under agriculture. This indicates good scope for *in situ* soil and water conservation practices in the agricultural land through various agronomic measures like contour faming, farming across the slope, bunding along the rows of crops, etc.

SWAT model was used to analyze possibilities of soil and water conservation practices in the basin. Calibration of the model was done for a 12-year period and validation was done for a 7-year period. Comparison of observed and simulated runoff for the calibration and validation periods is shown in Fig. 1.4.1a and 1.4.1b, respectively. During calibration, the computed runoff data matched well with the observed data with R^2 of 0.97. During validation, SWAT computed runoff matched well with observed runoff (R^2=0.76). This indicated that the simulated runoff was comparable to the observed runoff in the Aji basin.

The SWAT model was also used to estimate groundwater recharge in the basin. Trends of decadal average of groundwater recharge during the monsoon season are depicted in Fig. 1.4.2 from the year 1970 to 2070. The groundwater recharge during monsoon season was found to be 42 mm, 21 mm and 20 mm during periods 1970-2005, 2006-2040 and 2041-2070, respectively.

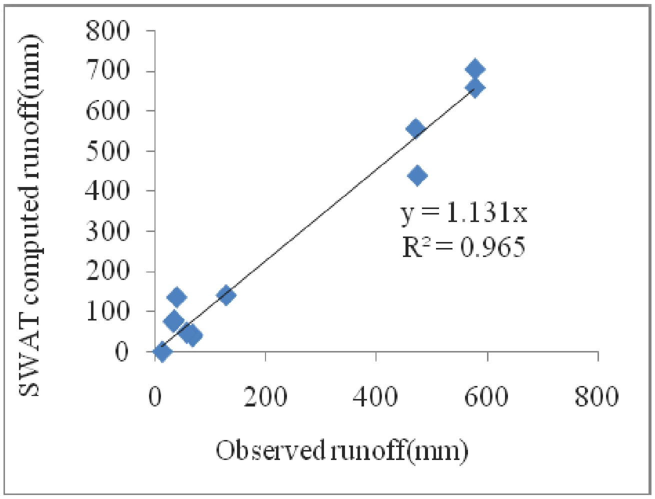


Fig. 1.4.1a. Comparison of observed and SWAT computed runoff from Aji basin during calibration period

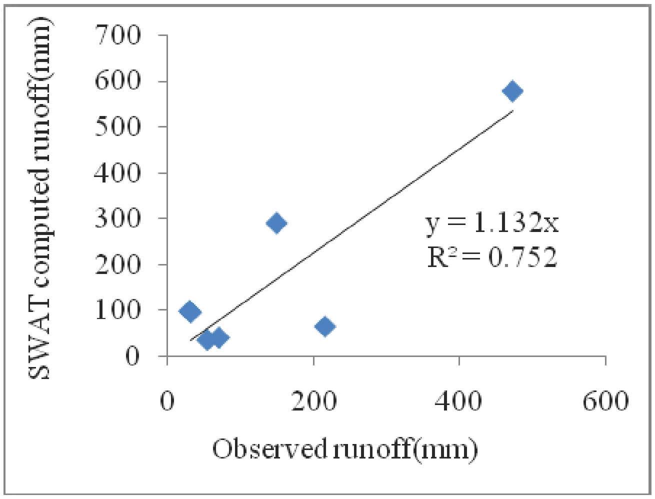


Fig. 1.4.1b. Comparison of observed and SWAT computed runoff from Aji basin during validation period

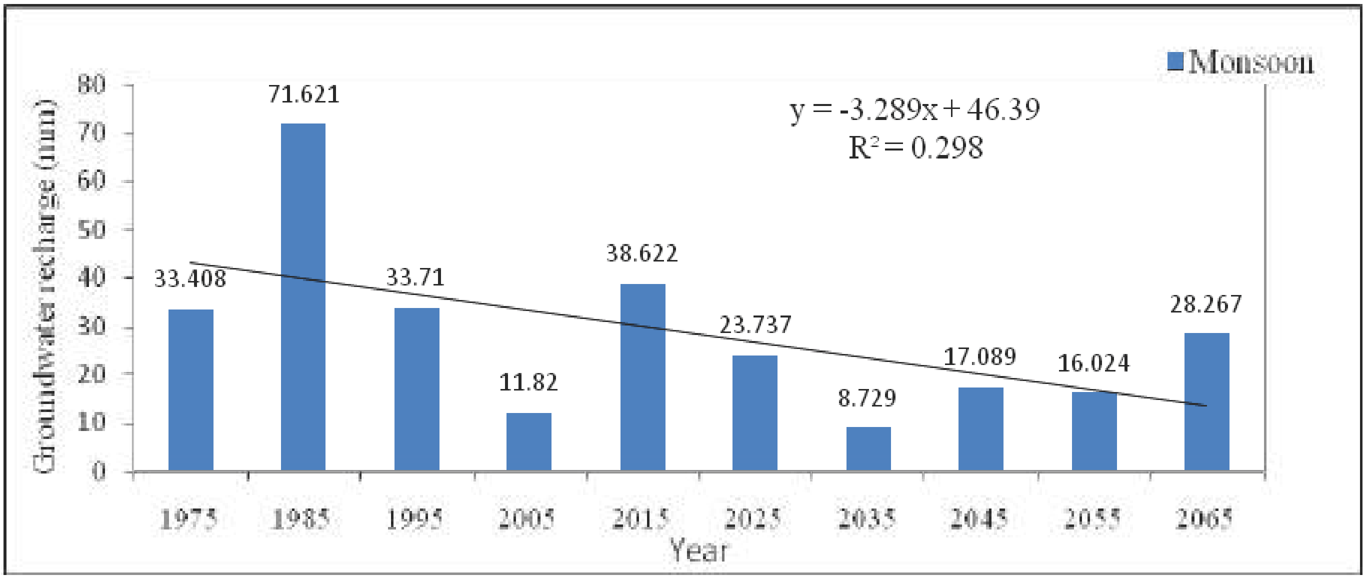


Fig. 1.4.2. The variation and trend of groundwater recharge during monsoon season for the period 1970-2070 in Aji Basin

1.5. Udaipur (AESR 4.2)

1.5.1. Delineation of Groundwater Potential Zones of upper Berach river basin of Udaipur district

Groundwater potential map of the study area, i.e. Upper Berach river basin of Udaipur district (Fig. 1.5.1a) revealed four distinct zones representing 'good', 'moderate', 'poor' and 'very poor' groundwater potential in the area. The 'good' groundwater potential zone mainly encompassed valley fill and buried pediment areas around the lake. It demarcated the areas where the terrains were most suitable for groundwater storage and also indicated the availability of groundwater. The area covered by 'good' groundwater potential zone was about 15.89 per cent and covered Sangwa, Chandersia, Lakshmapura, Bhatewar, Mavli, Phachar, Sardarpura and Ranakoi villages. The southern portion and some small patches of northeastern region of the study area have 'moderate' groundwater potential covering 37.41 per cent area. This zone included Dabok, Gudli, Debari, Khemokhera, Nuroda, Palana kalan, Mandesar, Vallabhnagar, Nauwa, Gudli, Radiya kheri, Karanpur and Ghasa villages. About 32.47 per cent area showed 'poor' groundwater potential zone including villages Sihara, Bichhadi, Majhera, Godach, Khera Bhansol, Rithujana, Mangthala, Mogana-1, Uthnol, Palana khurd and Depar. In study area, 14.23 per cent area showed very poor groundwater potential and included villages of Bilota, Lega magra, Rama, Chirwa-1, Dholi magri. The various classes of groundwater potential zones along with their corresponding areas are shown in Table 1.5.1.

Table 1.5.1. Groundwater potential zone classes and area

Class	Area (km^2)	Area (%)
Good	174.14	15.89
Moderate	409.98	37.41
Poor	355.89	32.47
Very poor	155.98	14.23

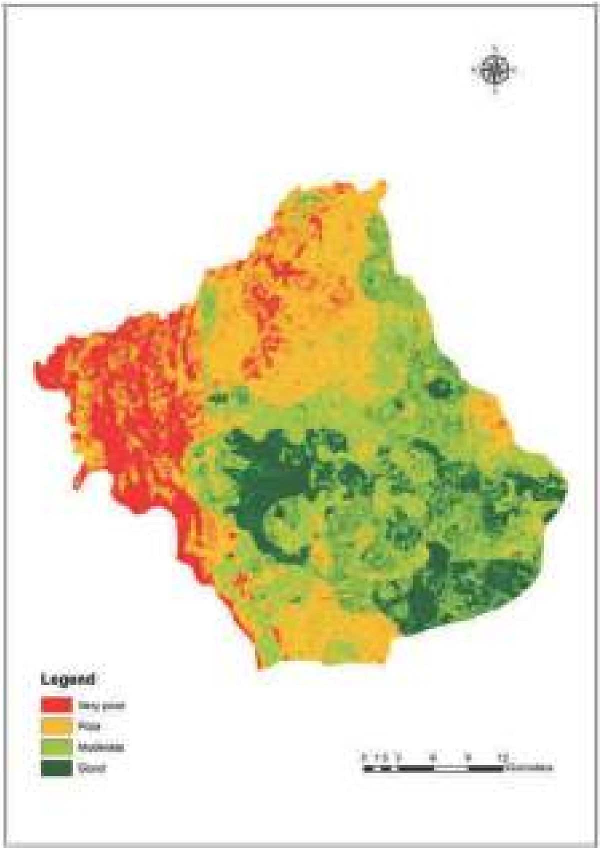


Fig. 1.5.1a. Groundwater potential zones of Upper Berach basin

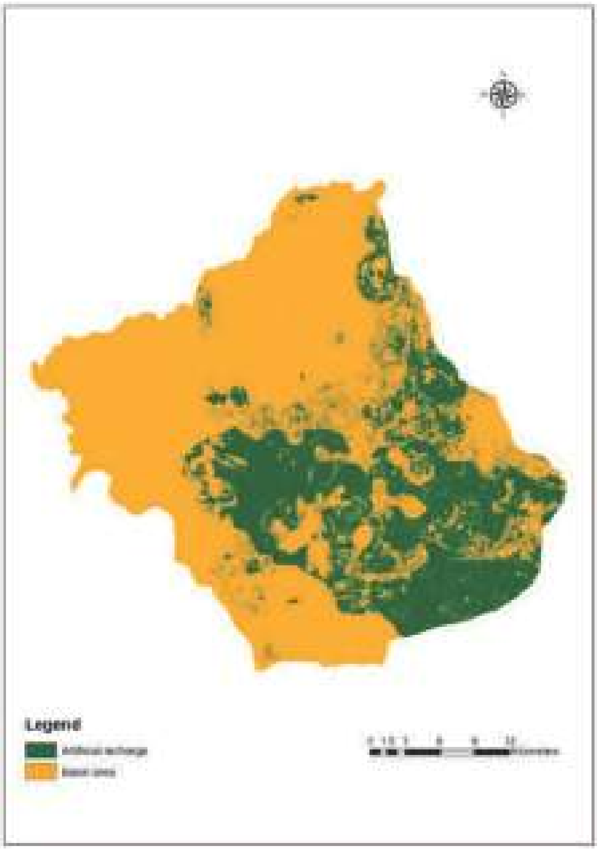


Fig. 1.5.1b. Favorable artificial recharge zones of Upper Berach basin

The favourable artificial groundwater recharge zone for the study area (Fig. 1.5.1b) was delineated using RS&GIS technique. Green color in the map indicates favourable zone for artificial recharge. Such areas were found in the southern part of the basin including Chandersia, Gandoli, Sangwa, Shambhopura, Beran, Nauwa, Mavli, Akodra and Bhutpura villages and some other scattered portions of the catchment. For artificial recharge, suitable recharge structures such as percolation ponds, check dams and earthen dams were recommended for construction. The area that is favourable for artificial recharge is 219.2 km^2, which contributes only 20% of the total study area.

1.5.2. Assessment of groundwater quality of Chittorgarh district of Rajasthan

A study was conducted for analysis of groundwater quality and suggesting suitable crops in Chittorgarh district of Rajasthan. The district was divided into 7 km × 7 km square grids. From each grid one open dug well was randomly selected. The locations of wells were recorded with the help of global positioning system (GPS) and were given a particular identity. Groundwater samples were collected and brought to laboratory for analysis. Total 134 groundwater samples were collected during pre monsoon season (first fortnight of June 2017) and post monsoon season (November and December 2017). Different parameters analysed during pre and post monsoon periods are presented in Table 1.5.2.

The cationic composition of groundwater of Chittorgarh district showed that magnesium is the dominant one in groundwater followed by calcium among the divalent cations. Among monovalent cations, sodium is dominant in pre and post monsoon periods in the district. The anionic composition of groundwater varied with both seasons as well as locations. In general, post monsoon groundwater contains less anions compared to pre monsoon season. Chloride was dominant anion in groundwater in both the seasons followed by bicarbonate, sulphate and carbonate ions. It was revealed that problem of sodicity is not prevailing in the district and that groundwater had the problem of medium RSC only.

Table 1.5.2. Physical, chemical properties of groundwater in Chittorgarh district of Rajasthan. Pre and Post denotes pre monsoon and post monsoon periods

Block	Statistical Parameter	Depth of well (m)	Water Level (m)		TDS (ppm)		pH		EC (dS/m)		SAR		RSC (meq/l)	
			Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Bari Sadri	Minimum	11.0	7.7	5.6	109	92	7.3	7.2	0.40	0.23	0.38	0.22	0.00	0.00
	Maximum	25.7	23.0	20.8	1030	829	8.5	8.3	2.70	1.85	1.93	1.83	1.80	1.60
Dungla	Minimum	7.0	6.5	4.3	406	327	6.8	7.1	0.80	0.72	0.63	0.41	0.00	0.00
	Maximum	26.2	20.9	18.7	1730	1220	9.1	8.4	3.50	2.80	5.06	3.38	2.40	1.40
Nimbahera	Minimum	11.0	7.2	5.3	195	162	6.2	6.8	0.45	0.40	0.13	0.14	0.00	0.00
	Maximum	20.0	18.0	15.7	1380	1090	8.1	7.8	3.00	2.74	2.90	2.75	0.40	0.80
Bhadesar	Minimum	9.0	3.0	0.8	251	207	6.9	7.0	0.60	0.40	0.12	0.14	0.00	0.00
	Maximum	26.7	22.2	20.1	711	575	7.8	7.6	1.60	1.54	1.96	1.94	0.60	0.60
Chittorgarh	Minimum	8.0	4.2	2.2	130	110	6.7	7.0	0.50	0.33	0.28	0.16	0.00	0.00
	Maximum	23.0	16.2	14.1	678	548	8.2	7.8	1.50	1.25	2.30	2.19	2.00	1.60
Begun	Minimum	10.0	5.6	3.5	129	104	6.5	7.1	0.40	0.32	0.38	0.40	0.00	0.00
	Maximum	22.0	16.2	12.5	1060	820	7.8	7.7	2.40	2.00	2.55	2.12	1.00	1.00
Gangrar	Minimum	9.0	5.8	3.7	154	133	6.2	7.1	0.40	0.30	0.36	0.39	0.00	0.00
	Maximum	25.0	19.0	16.1	1050	820	7.7	7.6	2.40	1.84	3.59	2.61	2.40	2.00
Kapasan	Minimum	9.0	3.0	0.9	310	258	6.8	7.1	0.60	0.44	0.25	0.29	0.00	0.00
	Maximum	30.2	25.0	23.1	2920	1890	8.5	7.9	9.30	4.50	5.07	4.50	2.40	2.60
Rashmi	Minimum	8.5	5.0	3.1	254	205	6.8	7.1	0.40	0.42	0.11	0.12	0.00	0.00
	Maximum	27.0	23.3	21.2	1880	1560	8.0	7.7	5.20	3.50	2.97	2.61	2.20	1.80
Rawatbhata	Minimum	7.0	4.6	1.7	84	80	6.5	7.1	0.30	0.20	0.25	0.16	0.00	0.00
	Maximum	22.0	14.7	12.3	635	513	8.2	7.9	1.30	1.12	2.63	2.11	2.20	1.20
Overall District	Minimum	7.0	3.0	0.8	84	80	6.2	6.8	0.30	0.20	0.11	0.12	0.00	0.00
	Maximum	30.2	25.0	23.1	2920	1890	9.1	8.4	9.30	4.50	5.07	4.50	2.40	2.60

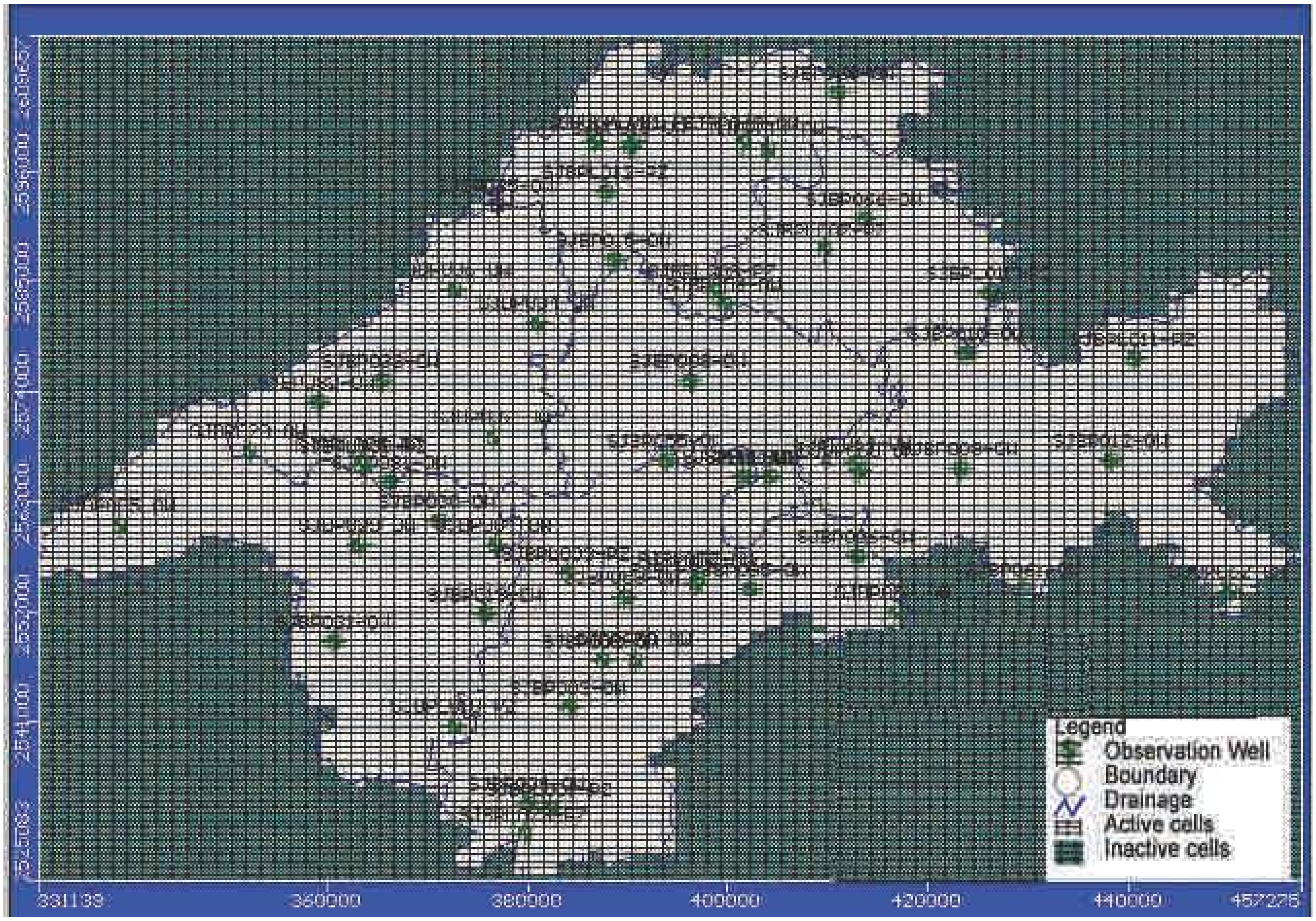
1.7. Jabalpur (AESR 10.1)

1.7.1. Using SWAT for recharge computation and application in MODFLOW to generate groundwater flow

The study was carried out in the Narmada river basin. The spatial recharge information generated by SWAT for 16-year period (2000-2015) was used to predict groundwater behavior of the study area using visual MODFLOW. The hydrological response units generated by SWAT model were scaled and adjusted for seven blocks in the study area to check groundwater status and dynamics. This may help in efficient management of groundwater and policy planning.

Based on the analysis of lithology data, a two-layer groundwater flow model of soil aquifer system was developed using Visual MODFLOW. The first layer mostly consisted of 15-20 m alluvium zone underlain by 20-80 m thick basalt, alluvium and fracture zone. The top layer represented alluvium portion in the system typically designated as unconfined layer. The second layer represented basalt and fractured zone and assumed to have semi confined to confined conditions with variable T and S. Inputs like hydraulic conductivity and specific yield were assigned to the model. Transmissivity of the layers was estimated by multiplying thickness of the aquifer with the hydraulic conductivity. The parameters like initial condition, boundary condition, recharge estimated from SWAT, pumping schedule, etc. were assigned to the model. The model set up using Visual MODFLOW is shown in Fig.1.7.1.

Fig. 1.7.1. Model set up in the study area



The calibration and validation results of developed Visual MODFLOW model showed good agreement between observed and simulated water levels in steady state as well as transient conditions with correlation coefficient of 0.99. The groundwater flow in the unconfined aquifer (Aquifer-I: layer thickness 1.8 to 20 m, Calibrated parameters: hydraulic conductivity 0.00013 m/s, specific yield 0.05 to 0.16, recharge 106 to 290 mm/year) is from east to west in the entire portion of the study area. However, the overall direction of groundwater flow in the confined aquifer for Aquifer-2 (Layer thickness 20 to 80 m; Calibrated parameters: storage coefficient 0.0001) is also moving from east to west direction.

1.8. Chalakudy (AESR 19.2)

1.8.1. Survey and intervention studies in Left Bank Canal of Chalakudy river diversion scheme

The entire left bank canal (LBC) system of Chalakudy river diversion scheme (Fig. 1.8.1) was selected for the study. Canal system was tracked, land use map was prepared, ground truth data of the area was obtained, major crops (nutmeg, banana, tapioca, vegetables and paddy) were identified and crop water requirement was computed, information on rotation-wise supply system and number of days of supply were obtained from four sections of LBC namely, Chalakudy, Koratty, Karukutty and Angamaly. Total release for the entire irrigation season was about 73990 million litres and total branch-wise water demand was 13622.38 million litres. Seepage losses at the head reach accounted for inadequacy of water to meet the demand. The released water at the head reach was five times more than the actual demand. Even though the release from the starting point was higher than the water requirement (Table 1.8.1), water deficit was observed in most of the branches. Supply based on demand and proper management can improve efficiency of irrigation in the command. Illegal draining of water from spouts for water diversion also caused loss of large amount of water. In several places water had been diverted through spouts from main canal and they operated for the entire irrigation season. Proper control of this misuse can reduce great amount of water loss. From the details of total release from the weir it is clear that the supply is enough to meet the demand, but the issues in the supply system are improper management of canals, losses from main canals due to breaks in canals, improper diversion of water through the spouts, unscientific supply system without considering the water demand, etc. Availability of water in the CRDS depends on release from the hydroelectric projects situated upstream and hence the control is not with the Department of Irrigation. But proper communication between the departments and intelligent management can help overcome the present gaps in water demand and supply. Rainfall variability due to climate change creates a precarious situation in terms of water availability. If the water deficit continues for more years, then cropping patterns of the region may have to be changed especially when paddy and nutmeg are the major crops.

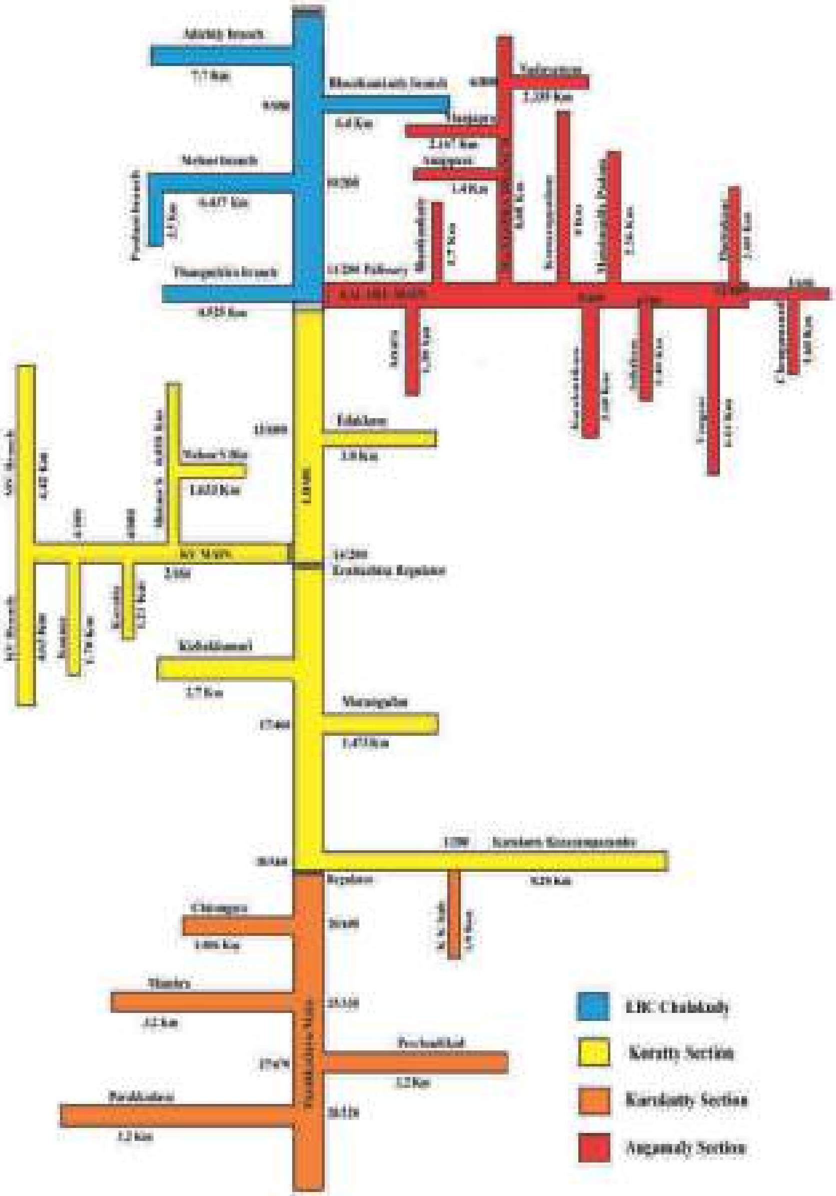


Fig. 1.8.1. Lower Bank Canal system under different sections

Table 1.8.1. Irrigation water requirement in different branches of the Left Bank Canal of Chalakudy river

Week (1/12/16 to 31/5/17)	Irrigation water requirement (million litres) in different branches of the Left Bank Canal of Chalakudy river										
	Adichily	Bhoohamkutty	Meloor poolani	Poolani	Thanguchira	Kizhakkumuri	Chirangara	Meloor South	Koratty	Konoor	K.V.
1	6.23	1.59	7.39	3.60	8.95	3.60	1.78	10.04	2.77	0.87	6.04
2	7.01	1.73	8.27	4.03	10.00	3.95	1.95	11.23	3.03	0.98	6.61
3	18.56	3.97	20.82	10.14	25.19	9.95	4.91	28.28	7.65	3.44	16.69
4	23.67	4.98	26.34	12.83	31.88	12.71	6.27	35.79	9.76	4.61	21.31
5	25.58	4.78	27.90	13.59	33.77	12.68	6.26	37.91	9.74	4.99	21.27
6	27.01	4.63	29.08	14.17	35.18	12.67	6.25	39.50	9.73	5.27	21.24
7	27.01	4.63	29.08	14.17	35.18	12.67	6.25	39.50	9.73	5.27	21.24
8	27.01	4.63	29.08	14.17	35.18	12.67	6.25	39.50	9.73	5.27	21.24
9	27.96	3.02	28.25	13.76	34.18	9.68	4.78	38.38	7.44	5.47	16.23
10	33.67	4.93	34.02	16.57	41.16	11.80	5.83	46.22	9.07	6.66	19.79
11	33.67	4.93	34.02	16.57	41.16	11.80	5.83	46.22	9.07	6.66	19.79
12	33.67	4.93	34.02	16.57	41.16	11.80	5.83	46.22	9.07	6.66	19.79
13	34.15	5.09	34.51	16.81	41.75	12.10	5.97	46.88	9.30	6.83	20.29
14	9.50	1.46	9.60	4.68	11.62	3.27	1.61	13.05	2.51	1.84	5.48
15	36.61	5.99	36.99	18.02	44.76	13.74	6.78	50.25	10.55	7.76	23.03
16	12.93	2.03	13.06	6.36	15.80	4.59	2.26	17.74	3.52	2.59	7.69
17	30.73	5.01	31.05	15.13	37.57	11.47	5.66	42.18	8.81	6.47	19.23
18	39.06	6.89	39.46	19.22	47.75	14.64	7.23	53.61	11.25	8.27	24.55
19	34.58	6.16	34.94	17.02	42.27	13.11	6.47	47.46	10.07	7.40	21.99
20	37.17	6.68	37.55	18.29	45.44	14.01	6.91	51.02	10.76	7.91	23.49
21	27.23	4.69	27.51	13.40	33.29	10.58	5.22	37.37	8.12	5.97	17.73
22	31.59	5.19	31.92	15.55	38.62	12.01	5.93	43.36	9.23	6.78	20.14
23	15.96	2.35	16.13	7.86	19.52	6.21	3.07	21.91	4.77	3.51	10.41
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	15.96	2.35	16.13	7.86	19.52	6.21	3.07	21.91	4.77	3.51	10.41
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**616.54**	**102.63**	**637.10**	**310.38**	**770.90**	**247.93**	**122.38**	**865.55**	**190.46**	**124.97**	**415.70**

1.9. Bathinda (AESR 2.1)

1.9.1. Matching and reconciliation water supply with crop water demands in consideration of crop diversification and water application

Balluana minor of the Behman distributory of Bathinda branch was selected to evaluate irrigation system performance and to work out intervention for improvement of the irrigation system and its management. Canal water was monitored and month wise opening and duration of water flow from November, 2016 to October, 2017 was recorded. Canal running days varied from 0 to 31 days in different months with the highest in the month of May, 2017 and the lowest in December, 2016 and January, 2017.

During *Rabi* 2016-17, total rainfall received was 148.4 mm and wheat was the main crop at all the nine outlets. The variation in total effective rainfall and calculated water requirement and relative water supply (RWS) for different *rabi* crops in the cultivable command area (CCA) are presented in Table 1.9.1 and 1.9.2. Relative water supply (RWS) below one indicated that there is need to replace large part of the area under wheat with barley, gram and raya, which require less water in order to match the water supply with water requirement during *rabi* season at both the outlets.

During *Kharif* 2015, total rainfall received was 399.6 mm and cotton was the main crop at all the outlets. The variation in total effective rainfall and calculated water requirement and RWS for different *Kharif* crops in the cultivable command area (CCA) are presented in Table 1.9.2 and 1.9.3. RWS below one indicated decreasing supply of water or possibility of replacing high water requirement crops with low water consuming crops like cotton, guar and bajra.

Table 1.9.1. Crop-wise area (ha) and water requirement (ha-cm) during *Rabi* 2016-17

Outlet No.	Wheat		*Raya*/Chickpea		Barley		Vegetable		Orchard		Fodder & others		Total	
	Area	Water	Area	Water	Area	Water	Area	Water	Area	Water	Area	Water	Area	Water
3758/R	607.8	30389.5	2.1	79.7	1.0	44.3	5.3	317.1	2.8	168.3	41.7	2499.7	660.62	33498.7
14025/L	555.4	27770.2	1.5	56.8	0.9	41.4	1.4	82.3	2.6	156.7	41.1	2463.5	602.86	30570.8
14040/R	534.8	26740.2	1.4	54.7	0.9	39.8	1.3	79.2	2.5	150.9	39.5	2372.1	580.50	29436.9
18163/R	530.7	26532.9	1.4	54.3	0.9	39.5	1.3	78.6	2.5	149.7	39.2	2353.7	576.00	29208.7
20170/L	780.3	39012.8	2.0	76.1	1.3	58.6	3.6	215.9	23.6	1413.5	43.5	2609.3	854.21	43386.2
25000/L	643.7	32184.8	1.8	70.3	0	0.0	3.2	194.8	34.9	2094.2	33.7	2021.2	717.36	36565.4
26630/L	714.1	35705.4	2.0	78.0	0	0.0	3.6	216.1	38.7	2323.3	37.4	2242.3	795.83	40565.2
35977/TL	735.9	36796.8	7.3	280.5	0	0.0	1.8	106.1	19.9	1194.0	38.6	2314.2	803.46	40691.6
35977/TR	482.1	24104.8	4.0	154.7	0.5	21.0	0.9	53.5	10.3	618.5	22.9	1373.2	520.68	26325.8

Table 1.9.2. Relative water supply (RWS) during *Rabi* 2016-17 and *Kharif* 2017

Outlet No.	CCA (ha)		Canalwater diverted (ha-cm)		Effective rainfall (ha-cm)		Total water supply (ha-cm)		Water requirement (ha-cm)		RWS	
	Rabi	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*
3758/R	660.62	660.62	7322.6	7422.9	1988.5	22342.2	9311.1	29765.1	33498.7	70865.0	0.28	0.42
14025/L	602.86	602.86	6572.5	6662.5	1814.6	20388.7	8387.1	27051.2	30570.8	66209.5	0.27	0.41
14040/R	580.5	580.5	6322.4	6409.0	1747.3	19632.5	8069.7	26041.6	29436.9	63753.8	0.27	0.41
18163/R	576	576	6286.7	6372.8	1733.8	19480.3	8020.5	25853.2	29208.7	63259.6	0.28	0.41
20170/L	854.21	854.21	9287.2	9414.4	2571.2	28889.4	11858.4	38303.8	43386.2	92091.1	0.27	0.42
25000/L	717.36	717.36	7787.0	7893.6	2159.3	24261.1	9946.2	32154.7	36565.4	70864.3	0.27	0.45
26630/L	795.83	795.83	8644.2	8762.7	2395.4	26915.0	11039.7	35677.6	40565.2	78616.0	0.27	0.45
35977/TL	803.46	803.46	8751.4	8871.3	2418.4	27173.0	11169.8	36044.3	40691.6	72499.6	0.27	0.50
35977/TR	520.68	520.68	5679.5	5757.3	1567.2	17609.4	7246.7	23366.7	26325.8	50454.0	0.28	0.46
Total			66653.5	67566.6	18395.7	206691.6	85049.2	274258.2	310249.3	628612.8	0.27	0.44

Table 1.9.3. Crop-wise area (ha), water requirement (ha-cm) in *Kharif* 2017

Outlet No.	Cotton		Rice		Guar / Moong		Vegetable		Orchard		Fodder and others		Total	
	Area	Water	Area	Water	Area	Water	Area	Water	Area	Water	Area	Water	Area	Water
3758/R	218.4	16601.8	352.2	49308.1	29.6	1330.2	10.0	600.9	1.7	103.1	48.7	2920.8	660.6	70865.0
14025/L	227.4	17280.7	332.3	46519.7	12.2	548.6	5.4	323.0	1.8	106.3	23.9	1431.1	603.0	66209.5
14040/R	218.9	16639.8	320.0	44794.3	11.7	528.2	5.2	311.0	1.7	102.4	23.0	1378.1	580.5	63753.8
18163/R	217.2	16510.8	317.5	44447.1	11.6	524.1	5.1	308.6	1.7	101.6	22.8	1367.4	575.9	63259.6
20170/L	309.4	23512.3	453.2	63441.8	24.3	1091.9	9.0	539.7	19.3	1156.5	39.1	2348.8	854.3	92091.1
25000/L	371.7	28246.1	275.7	38591.6	11.7	528.4	3.5	210.1	29.7	1780.0	25.1	1508.1	717.4	70864.3
26630/L	412.3	31335.9	305.8	42813.0	13.0	586.2	3.9	233.1	32.9	1974.7	27.9	1673.0	795.8	78616.0
35977/TL	520.0	39518.9	203.8	28535.8	22.3	1001.8	7.0	418.6	17.4	1043.4	33.0	1981.1	803.5	72499.6
35977/TR	292.5	22230.7	183.9	25747.2	12.0	538.9	3.5	211.4	8.7	521.0	20.1	1204.7	520.7	50454.0

1.10. Coimbatore (AESR 8.1)

1.10.1. Groundwater balance study to assess the quantity of water available for development in the Amaravathy basin

Amaravathi river is one among the main tributaries of the river Cauvery and is surrounded by four districts *viz.*, Coimbatore, Dindigul, Karur and Tirupur in Tamil Nadu. In the districts, 26 blocks are over-exploited, two blocks are critical, 18 blocks are semi-critical and six blocks are under safe category. Groundwater fluctuations in and around the study area with varying rainfall were analyzed using GIS for every four year from 1991 to 2010 using spatial interpolation technique (Fig. 1.10.1). Through the year of 2003-2006, Palani, Kodaikanal, Oddanchatram, Reddiyarchatram blocks showed an increase in groundwater table in the range of 0.77 m to 2.38 m below ground level. Western and south-western part of the study area recorded increase in groundwater table whereas eastern and north-eastern parts recorded decrease in groundwater table (-0.07 m to 3.84 m BGL). During the period 2007-10, fluctuation of groundwater table varied from -2.20 m to 1.62 m below ground level (BGL). It was observed that the fluctuation of groundwater table was changing every four-year interval. This was mainly due to increase in population, urbanization and industrialization in the region and spatial variation of rainfall.

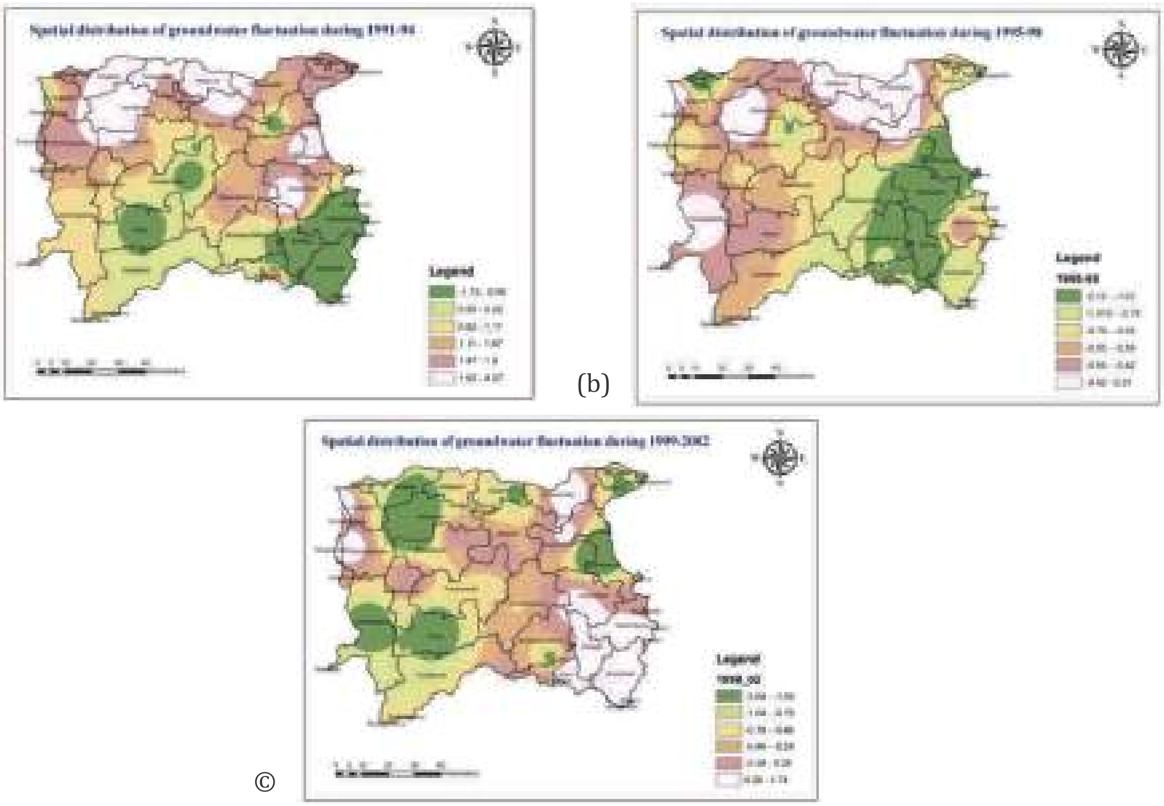
Recharge estimation by water table fluctuation method

Groundwater level fluctuation in Amaravathi basin varied from 0.2 to 3.1 m due to SW monsoon, while it was from 0.4 to 6.6 m during NE monsoon. Total monsoon recharge during 1971 to 2014 varied from 1.27% to 12.80% with an average of 4.01% in the basin (Fig. 1.10.2).

To ensure judicious use of groundwater, groundwater resources were assessed and thematic maps of geology, geomorphology, soil, lineament density, drainage density, rainfall and land use were prepared for the area. The multi influencing factors for groundwater recharge zones namely geology, slope, land-use/land-cover, geomorphology, drainage, soil and lineament density were examined and assigned an appropriate weight and are shown in Table 1.10.1.

After successful integration of all the thematic maps, groundwater recharge zones map (Fig. 1.10.3) was obtained with classification of 'very high' recharge zone (1847.21 km^2), 'high' recharge zone (5228.01 km^2), 'moderate' recharge zone (939.0 km^2) and 'poor' recharge zone (0.02 km^2). The high recharge areas correspond to alluvial plains, areas with lineaments, which coincide with the gentle slope (0-5 per cent). Thus almost 72 per cent of the region has good groundwater potential that indicates the possibility for the storage of water.

Aquifer response to rainfall showed that water level records of the observation wells in Amaravathinagar showed a wide variation ranging from 1.10 m to 11.16 m BGL. Average groundwater recharge calculated by using water level fluctuation method was 10.13 per cent due to SW monsoon and 2.60 per cent due to NE monsoon.



(a) (b) ©

Fig. 1.10.1. Spatial distribution of groundwater table fluctuation during (a) 1991-94, (b) 1995-98 and (c) 1999-2002

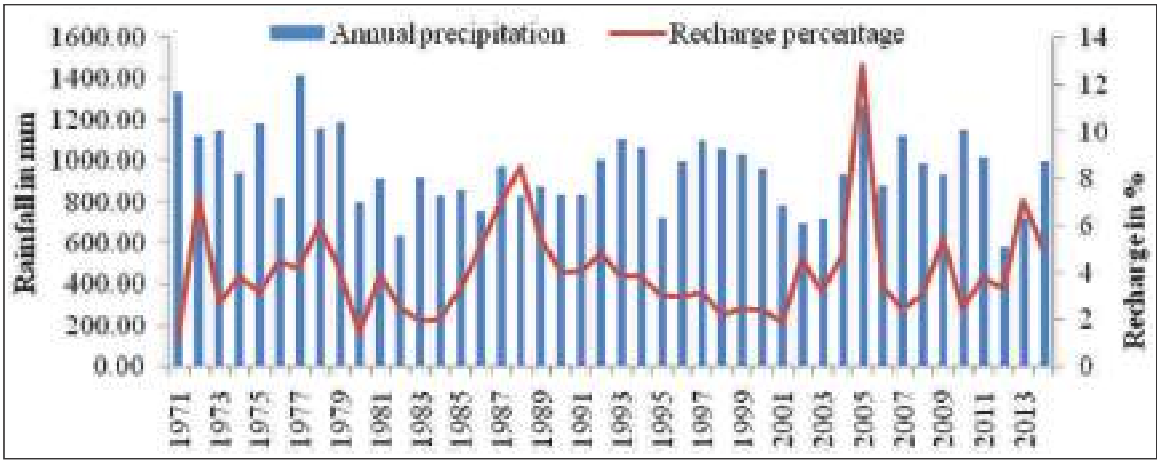


Fig. 1.10.2. Recharge estimation by water table fluctuation method

Table 1.10.1. Weighted factors influencing the recharge zones

S.N.	Factor	Class	Ranking (In words)	Ranking (In numbers)	Weightage (%)
1	Land use land cover class	Agriculture	Very good	1	24
		Wetlands	Very good	1	
		Water bodies	Very good	1	
		Forest	Good	2	
		Wastelands	Low	3	
		Built-up	Poor	4	
2	Geological class	Sand and silt	Very good	1	23
		Hornblende-biotite gneiss	Moderate	2	
		Garnet-sillimanite gneiss	Moderate-Poor	3	
		Charnockite	Poor	4	
		Granite (Gr1)	Poor-nil	4	
3	Lineament density class (km/km^2)	Good (> 0.40)	Poor	4	12
		Moderate good (0.14 to 0.40)	Moderate	3	
		Moderate poor (0.01to 0.14)	Good	2	
		Poor to nil(0)	Very good	1	
4	Geomorp-hologic class	Pediplain Weathered/ buried	Good	1	11
		Flood Plain	Very good -Good	1	
		Water Body Mask	Moderate -Good	2	
		Bazada	Moderate -Poor	3	
		Pediment - Inselberg Complex	Poor	4	
		Denudational and Residual hills	Poor-nil	4	
5	Slope class (%)	0 to 5	Good	1	15
		5 to 10	Moderate	2	
		10 to 15	Low	3	
		15 to 35	Very poor	4	
		35 to 50	Very poor	4	
6	Drainage density class (km/km^2)	0-0.18	Very good	1	9
		0.18-0.48	Good	1	
		0.48-0.68	Moderate	2	
		0.68-1.39	Moderate	2	
7	Soil class	Sand (Soil group A)	Very good	1	6
		Sandy loam (Soil group A)	Very good	1	
		Loamy sand (Soil group A)	Very good	1	
		Loam (Soil group A)	Very good	1	
		Sandy clay loam (Soil group C)	Low	3	
		Sandy clay (Soil group D)	Poor	4	
		Clay loam (Soil group D)	Poor	4	
		Clay (Soil group D)	Poor	4	

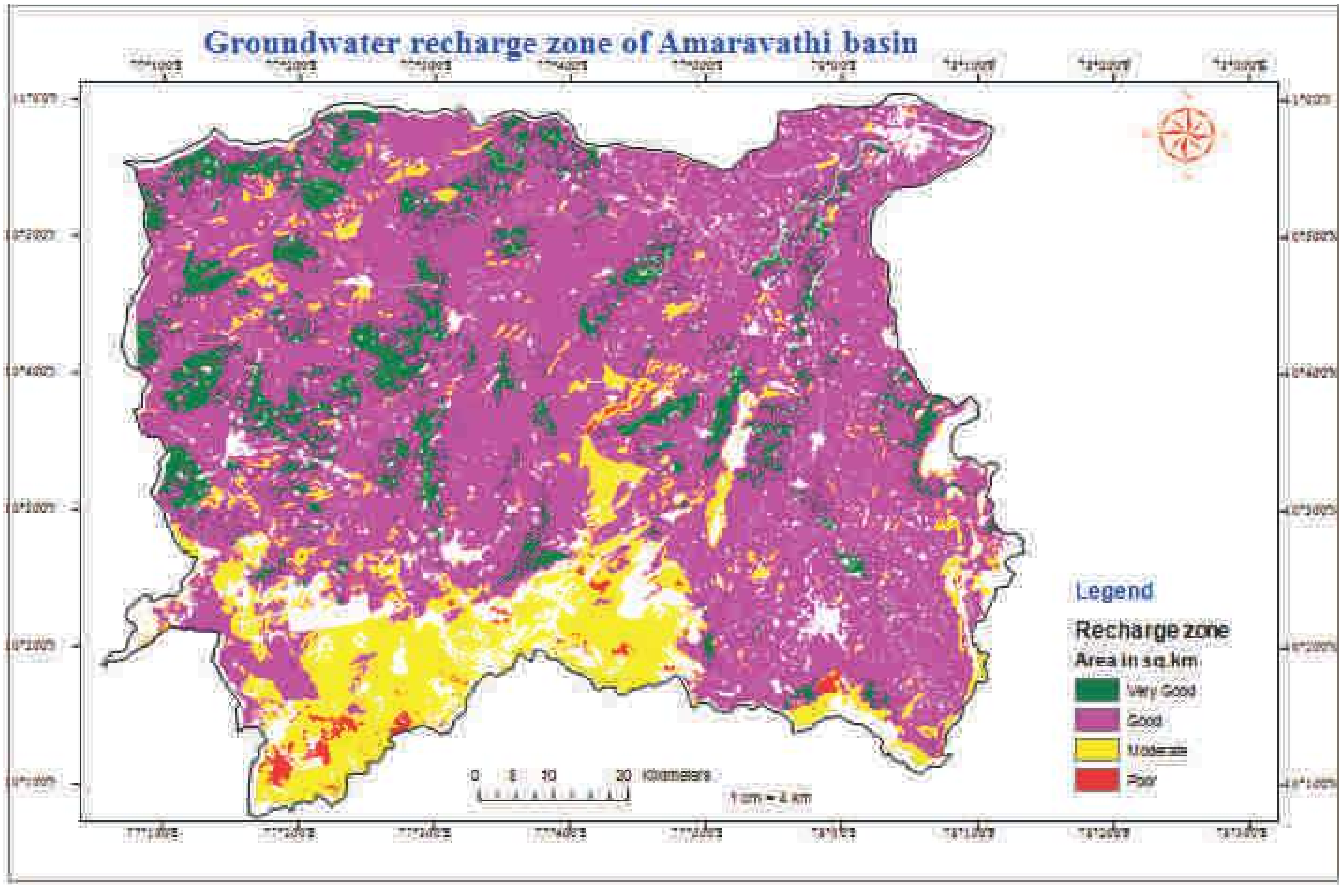


Fig. 1.10.3. Groundwater recharge map of the study area

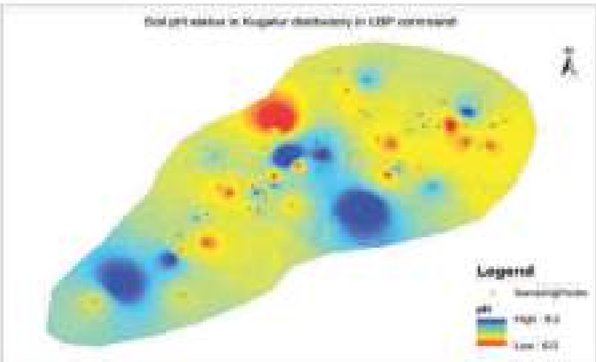
Recommendations for further development/ management of water resources of the basin:

- More than 50 per cent of the annual rainfall is received during the monsoon. It is recommended to recharge the groundwater artificially by constructing/digging percolation ponds wherever feasible in the basin. Where feasible runoff water can also be directly allowed into the bore/dug wells after filtration. If 50 per cent rainfall is conserved, water demand for 2025 can be met and depletion will reduce.
- Educational and awareness programmes on negative externalities of groundwater overdraft as well as the benefits of water conservation should be intensified in all levels including schools so that the future generation will be aware of the importance of water conservation and management.
- In order to prevent the overexploitation of groundwater and to reduce well density, spacing norms for different types of wells as per NABARD should be strictly enforced i.e. gaps between two open wells is 150 m; between two less deep tubewells is 175m; between two filter points is 175 m; between two very deep tubewells is 600 m; between open wells and less deep tubewells is 362.5 m; between open well and medium deep tubewell is 375 m
- Further, new borewells should be banned particularly in overexploited and critical blocks where over exploitation has been already experienced. Hence, to sustain the groundwater developments in the basin as well as in the State, regulatory instruments and procedure in controlling the overexploitation should be made compulsory.
- The integration of farm technologies with the natural boundary of the drainage area for the optimum development of land, water, plant and all other resources is necessary to meet the basic needs of people in a sustained manner. It is important to intensify watershed development activities especially in overexploited and critical blocks on priority basis so that well failure will be minimized.

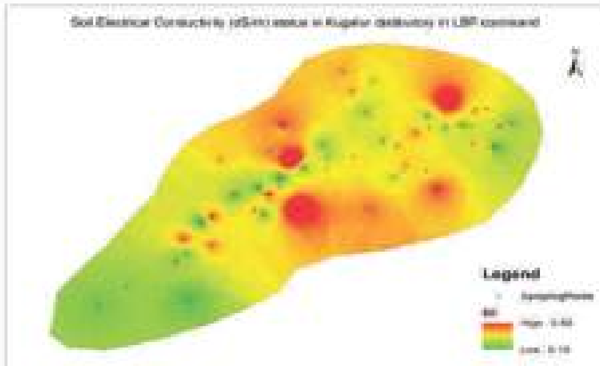
1.10.2. Assessment of soil fertility status and water quality in the Kugalur distributory of Lower Bhavani Project Command through GIS technique

Soil fertility status and water quality status of Kugalur distributory of Lower Bhavani Project command area were assessed with 65 samples of surface soil (0-15 cm) collected from a grid size of 0.5 km x 0.5 km. It was observed that soil texture was mostly sandy clay loam, some soils having sandy loam texture. TSS ranged from 306 to 462 ppm. Fertility mapping was done for soil fertility parameters viz., pH, EC, organic carbon and available nitrogen, available phosphorus, available potassium, iron, zinc, copper and manganese using GIS (Fig. 1.10.4).

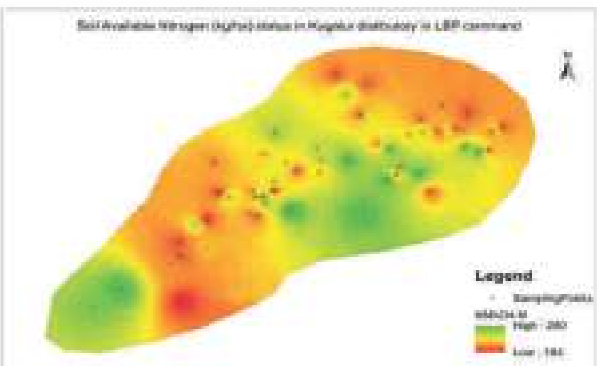
Soil fertility maps showed that pH and EC ranged from 6.8 to 8.2 dS/m and 0.10 to 0.59 dS/m, respectively, which showed that they are normal in the villages. The available nitrogen content (164 - 280 kg/ha) is low to medium in the villages of the study area. Available phosphorus and potassium content ranged from 8.0 (low) to 16.5 kg/ha (medium) and 203 (medium) to 530 kg/ha (high), respectively. Organic carbon (0.12 – 0.36 per cent) was low in all the villages in the study area. Micronutrient status showed that available zinc, iron, manganese and copper contents ranged from 0.17-1.52 ppm, 2.2-8.8 ppm, 2.75-5.70 ppm and 0.41-1.54 ppm, respectively. This implied that zinc content was below critical level, iron and copper contents were below critical level in most of the soil samples, while in some samples it was above the critical level. Manganese was above the critical level in all the samples. Chloride ion ranged from 0.8-3.5 me/l, which implied that water samples are in good condition. Calcium and magnesium contents ranged from 2.4-1.6 me/l and 9.6-8.2 me/l, respectively. Carbonate and bicarbonate ions ranged from 0.80-1.6 ppm and 3.2-4.4 ppm, respectively. Residual sodium carbonate (RSC) values of the water samples were <1.0 me/l which indicated that the quality of irrigation water was excellent. Soil physical properties *viz.*, bulk density and particle density ranged from 1.1-1.6 Mg/m^3 and 2.0-2.8 Mg/m^3, respectively.



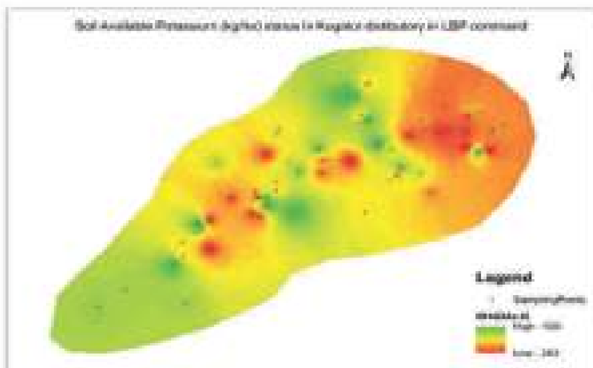
Soil pH



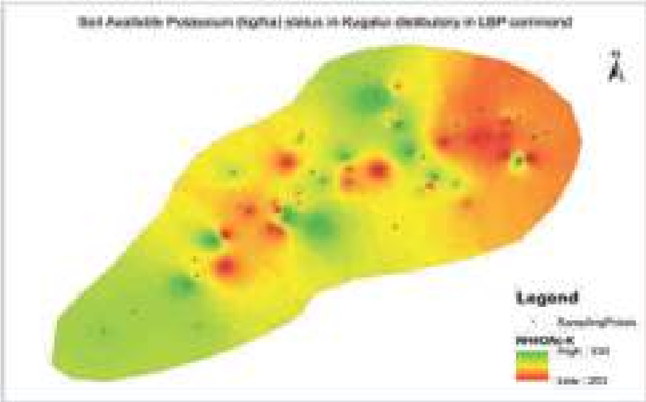
Soil EC



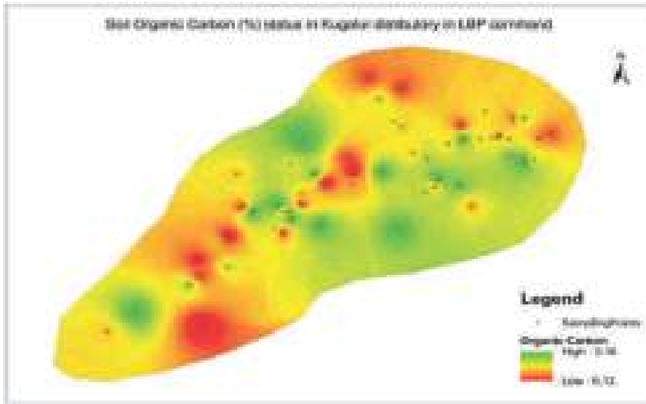
Available nitrogen



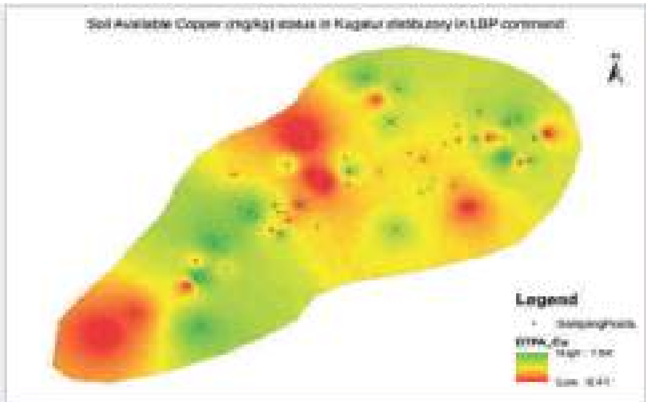
Available phosphorus



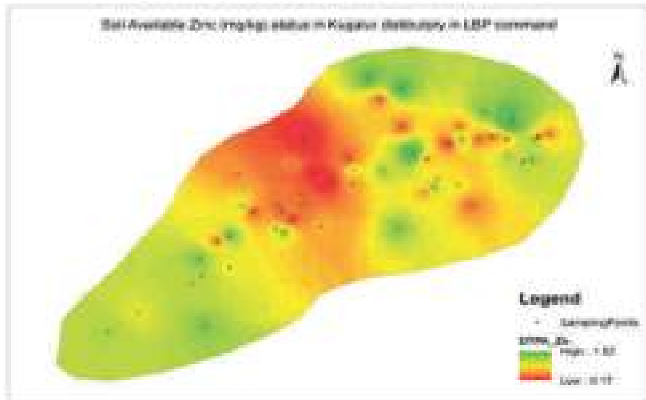
Available potassium



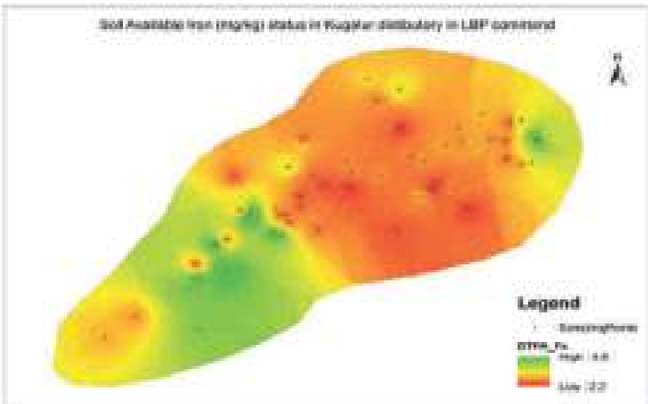
Soil Organic Carbon



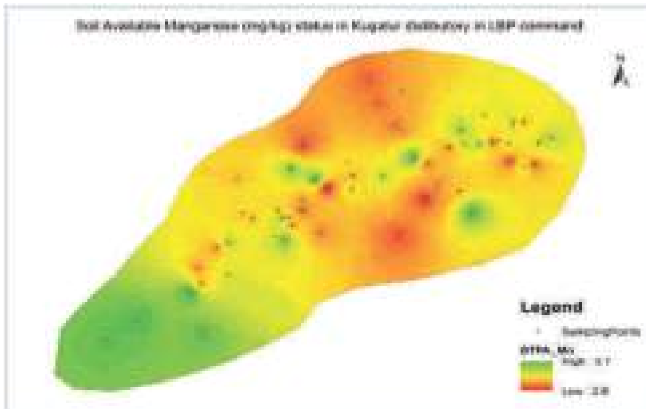
Soil available copper



Soil available zinc



Soil available iron



Soil available manganese

Fig. 1.10.4. Mapping of soil fertility status in Kugalur distributory of LBP Command

Theme 2

Design, development and refinement of surface and pressurized irrigation systems including small holders' systems for enhancing water use efficiency and water productivity for different agro-ecosystems

2.1. Parbhani (AESR 6.2)

2.1.1. Response of maize hybrid to drip irrigation and fertigation levels in post kharif season

Drip irrigation at 1.0 PE recorded significantly higher grain yield, stover yield, net monetary return (NMR) of maize and were comparable with irrigation at 0.8 PE in respect of grain yield. Significantly higher grain, stover yield and gross monetary return of maize was observed in fertigation level 100% RDF (150:75:75 NPK kg/ha) through drip and was comparable with 75% RDF through drip in respect of both grain and stover yield. The application of 100% RDF (150:75:75 NPK kg/ha) through drip recorded significantly higher GMR and was comparable with 75 % RDF through drip. The maximum WUE was noticed in 100% RDF (150:75:75 NPK kg/ha) followed by 75% RDF through drip. It was recommended to schedule drip irrigation on alternate days or at 80% CPE through inline lateral laid at 120 cm apart for paired rows (45x30-75 cm) and drip fertigation of 113:57:57 NPK kg/ha, N in 8 equal splits @12.5% at an interval of 10 days from 10 to 80 days after sowing, while P and K in 2 equal splits at sowing and 30 days after sowing for higher grain yield and net monetary return of kharif maize (Table 2.1.1).

Table 2.1.1. Pooled performance of maize hybrid under drip irrigation scheduling and fertigation (Pooled 2015-16 to 2017-18)

Treatment	Irrigation water (mm)	Yield (t/ha)	WUE (kg/ha-mm)	Net monetary return (₹/ha)	B:C ratio
Irrigation level					
I_1: Irrigation at 1.0 PE	359.3	85.76	31.68	112131	2.60
I_2: Irrigation at 0.8 PE	287.4	81.35	33.18	103081	2.48
I_3: Irrigation at 0.6 PE	215.6	75.71	27.64	91066	2.31
$CD_{0.05}$	-	5.41	-	10140	-
Fertigation level					
F_1: 100% RDF (150:75:75 NPK) through drip	287.4	88.67	23.29	108882	2.42
F_2: 75% RDF through drip	287.4	85.84	26.44	109435	2.56
F_3: 50% RDF through drip	287.4	73.14	29.38	90852	2.44
F_4: 100% RDF through soil	287.4	76.10	30.89	99168	2.43
$CD_{0.05}$	-	6.10	-	11632	-
$CD_{0.05}$ (I x F)	-	NS	-	NS	-

Mean rainfall (2014 to 2017)=458.3 mm; NS-Non-significant

2.2. Palampur (AESR 14.3)

2.2.1. Effect of drip irrigation and fertigation levels on yield and quality of strawberry in an acid Alfisol

The study was conducted to evaluate the effect of irrigation depth and NPK fertigation through gravity fed drip irrigation system on strawberry crop. Results showed that drip irrigation levels of 0.6 PE, 0.8 PE and 1.0 PE and NK fertigation levels of 50% RDF, 75% RDF and 100% RDF were studied for strawberry crop under protected condition (Plate 2.2.1). Recommended dose of fertilizer (RDF) and surface irrigation of 5 cm water depth as per package of practices was taken as control. In fertigation treatments, 25% N and K along with 100% P was applied as basal and 75% N and K was applied through fertigation through urea and water soluble fertilizer. Observations on main effects and interaction effects on yield are shown in Table 2.2.1 and 2.2.2. Interaction effects of irrigation and fertigation levels were significant with respect to marketable yield of strawberry. Drip irrigation at 0.8 PE with 100% NK fertigation had significantly higher marketable yield compared to drip at 0.8 PE with 75% NK fertigation during 2015-16. However, during 2016-17, the drip irrigation at 1.0 PE with 100% NK fertigation had significantly higher marketable yield compared to drip at 1.0 PE with 50% NK fertigation. Interaction effect of treatments showed that there are both fertilizer (25% NK) and water (40%) savings when strawberry crop was irrigated with 0.6 PE and fertigated with 75% NK as compared to crop irrigated with 1.0 PE and fertigated with 100% NK under protected conditions (Table 2.2.1 and 2.2.2). It was concluded that under protected conditions, drip irrigated strawberry crop should be irrigated with 0.6 PE and fertigated with 75-100% of recommended NK.

Table 2.2.1. Performance of potato under drip fertigation in acid Alfisol

Treatment	Marketable yield (g/m^2)	Water use efficiency (g/m^2-mm)		B:C ratio		
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Drip irrigation level (depth)						
0.6 PE	328.9	275.2	0.92	0.73	3.5	3.2
0.8 PE	320.6	292.7	0.67	0.60	3.4	3.1
1.0 PE	323.9	303.3	0.55	0.51	3.4	3.2
CD (P=0.5)	NS	15.7	0.07	0.05	-	
NK fertigation level						
50% RDF	245.7	228.4	0.54	0.47	2.4	2.6
75% RDF	345.6	315.7	0.77	0.65	4.1	3.7
100% RDF	382.0	327.1	0.84	0.68	4.2	3.6
CD (P=0.5)	13.9	15.7	0.04	0.05	-	
Control vs Other						
Control	373.2	354.7	0.58	0.60	4.2	4.1
Others	324.4	290.4	0.71	0.62	4.0	4.0
CD (P=0.5)	20.8	23.2	0.04	0.06	-	

Table 2.2.2. Interaction effect of irrigation and NK fertigation levels on marketable yield (g/m^2) of strawberry

NK fertigation level	2015-16			2016-17		
	0.6 PE	0.8 PE	1.0 PE	0.6 PE	0.8 PE	1.0 PE
50% RDF	239.1	254.4	243.7	212.4	232.1	240.8
75% RDF	371.7	312.4	352.6	302.4	317.2	327.4
100% RDF	375.8	394.9	375.2	310.7	328.9	341.8
CD (P=0.5)	28.6			21.7		

Plate 2.2.1. Strawberry cultivation under protected conditions

2.3. Belavatagi (AESR 6.4)

2.3.1. Evaluation of irrigation levels to sunflower based cropping systems under pressurized (drip) method of irrigation

Sunflower during kharif season followed by rabi season crops like wheat, bengal gram and groundnut were grown under drip irrigation for two years. Sunflower grown with drip at 1.0 ETo recorded significantly higher grain yield of 2.43 t/ha in two years compared to farmers' method of irrigation by flood at critical stages (1.85 t/ha). There was total saving of water to the extent of 28.44% over flood method. The rabi crops like wheat, bengal gram and groundnut also performed better under drip compared to farmers' method, with 0.53, 0.63 and 0.74 t/ha higher yield than normal method of irrigation. The sunflower equivalent yield was higher with sunflower-groundnut cropping system with 5.95 t/ha which recorded net return of ₹ 1,37,075 and B:C ratio of 2.92 (Table 2.3.1). In Malaprabha command area, growing sunflower followed by groundnut is more profitable with drip irrigation compared to other cropping systems. The results are included in package of practices of UAS Dharwad and recommended to farmers.

Table 2.3.1. Performance of *kharif* sunflower and *rabi* crops grown in drip irrigation in Sunflower-based cropping system in Malaprabha command area

Treatment	Water applied (Drip+Rain) (mm)	*Kharif* sunflower (SF) yield (t/ha)	*Rabi* crop	Yield of *rabi* crops (t/ha)	SF equivalent yield (t/ha)	Net return from the cropping system (₹/ha)	B:C ratio
Sunflower grown with irrigation at 1.0 ET_o	790	2.43	Bengal gram	2.44	5.06	128396	3.63
	948		Wheat	3.28	4.19	95409	2.86
	996		Groundnut	2.68	5.95	137075	2.92
Sunflower grown with irrigation at 0.8 ET_o	730	2.17	Bengal gram	2.21	4.86	121485	3.49
	890		Wheat	3.01	4.11	92426	2.80
	938		Groundnut	2.33	5.54	122712	2.72
Farmers' practice	875	1.85	Bengal gram	1.92	4.42	105942	3.17
	1105		Wheat	2.65	3.79	81256	2.59
	1164		Groundnut	1.94	4.89	99706	2.40
CD at 5 %	-	0.13	-	-	-	-	-

2.4. Raipur (AER 11)

2.4.1. Development and evaluation of energy efficient gravity operated drip irrigation system

The experiment was set up to design a low cost drip irrigation system to evaluate energy efficient ways for lifting water to storage tank and irrigate kitchen garden for growing vegetables. The experimental setup of gravity drip irrigation system (Fig. 2.4.1) comprises of a 750 litre LDPE water tank, structure to support LDPE water tank and piping, valves and drip lines. HDPE sub-main pipes (63 mm) have been used at the base of the reservoir for operating the system and provide connections of lateral pipe through grommet take off (GTO). Lateral pipes have also been equipped with a lateral filter followed by a lateral valve. Filtered water emits through inline emitter, which can be controlled by a lateral valve. Drip irrigation system having a lateral size of 16 mm of 20 m length with 1.3 lph emitters (inline) at 30 cm spacing was used in the experimental setup. Ten laterals from the sub main line with 67 emission devices in each line have been used. Out of the 10 lateral lines, 5 lines with only 4 emitters each (total emitters = 20) have been chosen randomly as representative for observation of discharge and hydraulic performance evaluation. Irrigation water was supplied for 10 minutes from an elevated water tank at a height of 3.55 m and filtered through a lateral filter screen. The flow rate or discharge of emitter was collected in plastic container directly and then measured in measuring cylinder. Discharge of emitters with respect to test time was converted into discharge in litre per hour.

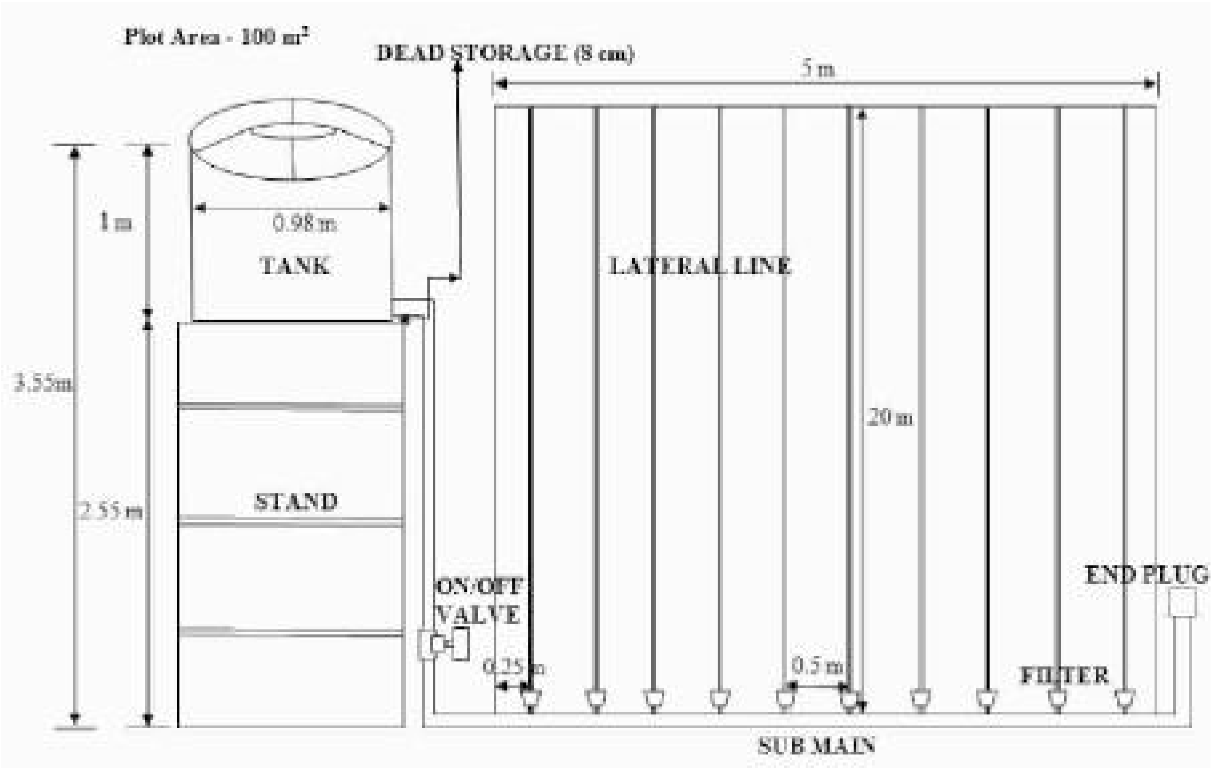


Fig. 2.4.1. Experimental setup of gravity fed drip system of irrigation.

2.5. Chalakudy (AESR 19.2)

2.5.1. Development and testing of Organic Fertigation Unit with power operated agitator

A hand operated agitator was developed and tested (Plate 2.5.1a). Process of mixing organic manure thoroughly with water needs agitation in order to improve nutrient content of supernatant and filtrate. This may also reduce the dilution of organic solution and help in getting a concentrated organic filtrate which can be injected into the irrigation line through ventury/injector pump as in the case of inorganic fertigation. So mechanical agitation with power operated agitator fixed in the mixing chamber of organic fertigation unit was necessary. A power operated agitator was fabricated and tested for its performance (Plate 2.5.1b). Performance of this agitator was evaluated for various mixing proportion of manure and water, duration of agitation and settling time. The nutrient content of manure solution, filtrate and residue were analyzed and found good for fertigation (Table 2.5.1). Vermicompost solution for fertigation can be prepared by mixing vermicompost and water in a ratio of 1:5 followed by agitation for 10 minutes and settling for 6 hours (Table 2.5.2). In the case of cowdung, nutrient content decreases with settling time. Agitation time does not have any effect on nutrient content in the cowdung solution. Thus the hand operated agitator developed and tested is effective in agitating organic manure. A power operated agitator can be introduced in organic fertigation unit for large scale cultivation.

Plate 2.5.1 (a). Hand operated agitator

(b) Power operated agitator

Table 2.5.2. Effect of treatments on nutrient content of vermicompost

Concentration	Duration of agitation (min)	Settling time (hour)	pH	Phosphorous (%)	Potassium (%)
1:10	5	0	7.42	0.0038	0.0086
		6	7.39	0.0054	0.0213
		12	7.26	0.0042	0.0196
		24	7.24	0.0028	0.0120
	10	0	7.61	0.0073	0.0258
		6	7.56	0.0036	0.0202
		12	7.58	0.0047	0.0253
		24	7.52	0.0040	0.0240
	15	0	6.73	0.0044	0.0149
		6	6.27	0.0037	0.0190
		12	6.57	0.0046	0.0253
		24	6.82	0.0044	0.0266
1:5	5	0	7.10	0.0121	0.0243
		6	7.18	0.0165	0.0354
		12	7.20	0.0051	0.0272
		24	7.36	0.0046	0.0612
	10	0	7.14	0.0074	0.0659
		6	7.32	0.1170	0.0769
		12	7.28	0.3191	0.0600
		24	7.21	0.0028	0.0379
	15	0	7.14	0.0070	0.0362
		6	6.94	0.0026	0.0231
		12	7.09	0.0031	0.0310
		24	7.06	0.0021	0.0247
1:2	5	0	7.45	0.0500	0.0787
		6	6.78	0.0030	0.0314
		12	7.15	0.0038	0.0679
		24	7.34	0.0032	0.0436
	10	0	7.15	0.0038	0.0406
		6	7.21	0.0044	0.0376
		12	7.34	0.1280	0.0390
		24	7.16	0.1604	0.0819
	15	0	7.30	0.0262	0.1462
		6	6.96	0.0098	0.144
		12	7.15	0.0072	0.136
		24	6.94	0.0044	0.0946

Table 2.5.1. Nutrient content in manure solution (10 minutes agitation) obtained from hand operated agitator in comparison with manual mixing

Nutrient	Cowdung solution (1:30)	Cowdung filtrate (1:30)	Cowdung residue (1:30)	Cowdung solution (1:30)	Cowdung filtrate (1:20)	Cowdung residue (1:20)	Cowdung solution (1:10)	Cowdung filtrate (1:10)	Cowdung residue (1:10)	Cowdung solution (1:30), manual mixing	Cowdung filtrate (1:30) manual mixing	Cowdung residue (1:30)	Percentage increase due to agitation	Percentage increase due to agitation
K (ppm)	74.2	46.0	107.4	164.6	117.7	49.9	302.5	207.7	343.5	31.5	21.4	98.2	136.0	115.0
P (ppm)	248.4	245.3	254.7	321.1	285.9	303.1	344.5	396.1	532.0	100.0	100.0	279.2	148.0	145.0
Ca (ppm)	113.9	41.2	39.0	135.2	111.0	77.7	137.9	151.0	264.2	101.2	10.0	292.1	12.5	310.0
Mg (ppm)	141.1	129.8	136.4	140.7	136.6	140.3	141.1	141.8	142.0	15.8	9.7	46.2	793.0	1234.0

2.6. Faizabad (AESR 9.2)

2.6.1. Evaluation of drip irrigation with surface irrigation in tomato

Three years of experimentation showed that drip irrigation applied at 80%, 60% and 40% PE saved 53.33, 64.99 and 76.70% water compared to surface irrigation (0.8 IW/CPE) in hydrid tomato (Hybrid-SHS) crop. The crop yielded highest (34.13 t/ha) with irrigation at 60% PE with 100% N, with WUE of 229.38 kg/ha-mm among other drip and surface irrigation treatments (Table 2.6.1). The treatment combination also fetched highest net return of ₹ 2,94,700/ha and benefit-cost ratio of 7.33. Thus drip fertigation at 60% PE and 100% N every 3rd day was recommended for improvement in yield efficiency and economical viability of irrigation system for hybrid tomato cultivation.

Table 2.6.1. Performance of hybrid tomato crop under drip fertigation during three years of experimentation

Treatment	Yield (t/ha)	Water applied (mm)	WUE (kg/ha-mm)	Water saved (%)	Net income (₹/ha)	B:C ratio
I_1- 0.8 IW/CPE with 100%N	26.60	425.0	62.6	-	226780	6.79
I_2- 0.8 IW/CPE with 75% N	23.94	425.0	56.3	-	200750	6.20
I_3- Drip irrigation @ 80% PE with 100% N	32.66	198.3	164.7	53.3	279940	7.00
I_4- Drip irrigation @ 80% PE with 75% N	31.40	198.3	158.3	53.3	267810	6.80
I_5- Drip irrigation @ 60% PE with 100% N	34.13	148.8	229.4	65.0	294780	7.33
I_6- Drip irrigation @ 60% PE with 75% N	32.92	148.8	221.2	65.0	283180	7.16
I_7- Drip irrigation @ 40% PE with 100% N	28.69	99.0	289.8	76.7	240510	6.18
I_8- Drip irrigation @ 40% PE with 75% N	26.91	99.0	271.8	76.7	223260	5.87
$CD_{0.05}$	1.68	-	-	-	-	-

2.6.2. Evaluation of drip irrigation with surface irrigation system in *zaid* okra

Two years of experimentation showed that drip irrigation applied at 80% and 60% of PE saved 50.11 and 62.53% water compared to surface irrigation (1.0 IW/CPE) in zaid okra (Ankur) crop. The crop yielded highest (7.23 t/ha) with irrigation at 80% PE with 100% N, with WUE of 31.03 kg/ha-mm among other drip and surface irrigation treatments (Table 2.6.2). The treatment combination also fetched highest net return of ₹ 37,060/ha and benefit-cost ratio of 2.05. Thus drip fertigation at 60% PE and 100% N every 3rd day was recommended for improvement in yield efficiency and economical viability of irrigation system for hybrid tomato cultivation. The surface irrigation at 0.8 IW/CPE treatment with 100% dose of nitrogen obtained the lowest net return of ₹ 17540/ha with benefit cost ratio of 1.58. Nitrogen doses (100% and 75%) did not have significant effect on the yield of okra under drip irrigation. Thus it was recommended to grow zaid okra with fertigation @ 80% PE and 100% dose of nitrogen to obtain high yield and remuneration.

Table 2.6.2. Performance of *zaid* okra crop under drip fertgation during three years of experimentation

Treatment	Yield (t/ha)	Water applied (mm)	WUE (kg/ha-mm)	Water saved (%)	Net income (₹/ha)	B:C ratio
I_1- 0.8 IW/CPE with 100% N	4.80	375	12.81	19.05	17540	1.58
I_2- 1.0 IW/CPE with 100% N	5.23	467	11.20	-	20790	1.66
I_3- Drip irrigation @ 80% PE with 100% N	7.23	233	31.03	50.11	37060	2.05
I_4- Drip irrigation @ 80% PE with 75% N	6.77	233	29.05	50.11	32980	1.95
I_5- Drip irrigation @ 60% PE with 100% N	5.89	175	33.68	62.53	23940	1.68
I_6- Drip irrigation @ 60% PE with 75% N	5.52	175	31.57	62.53	20790	1.60
CD at 5%	0.71	-	-	-	-	-

2.7. Coimbatore (AESR 8.1)

2.7.1. Techno economic evaluation of raingun irrigation on the yield of ragi

Two years of experiment was carried out to evaluate suitability of raingun for ragi, pressure requirements under raingun and evaluate water consumption through raingun for ragi crop. The results of the two year study revealed that the growth, yield attributes and yield of CO (Ra) 14 were influenced by raingun irrigation (Table 2.7.1). Based on the experimentation of raingun studies the following conclusions were drawn.

- Raingun irrigation scheduled at 75% PE recorded significantly higher growth and yield attributes than other irrigation regimes using raingun and surface irrigation.
- Irrigation with raingun at 75% PE recorded the highest water productivity of 6.56 kg/ha-mm with 23% water saving compared to that of surface irrigation at IW/CPE ratio of 0.75 which recorded a water productivity of 3.95 kg/ha-mm.

Table 2.7.1. Performance of ragi crop under raingun irrigation

Treatment	Plant height (cm)	No. of tillers	1000 grain weight (g)	Total water used (mm)	Water saving (%)
Irrigation through raingun at 75% PE	96.1	7.9	3.05	460	22.97
Irrigation through raingun at 60% PE	86.4	6.9	2.40	435	27.15
Irrigation through raingun at 45% PE	74.6	5.8	1.85	406	32.02
Surface irrigation at 0.75 IW/CPE	87.2	7.0	2.45	597	-
CD (P=0.05)	9.69	0.70	0.21	-	-

2.7.2. Sub-surface drip irrigation on cotton and maize sequence

The experiment was conducted to evaluate performance of cotton and maize in the cotton-maize cropping sequence, along with intercrops of cowpea, blackgram and clusterbean. Sowing was taken up over the raised bed under which sub-surface irrigation laterals were raised. Two irrigation regimes, three fertigation levels and three intercropping systems were evaluated. With regard to the irrigation levels and intercropping systems, growth parameters performed were statistically similar (Table 2.7.2). Among the fertigation levels, application of 125% RDF showed significantly highest seed cotton yield of 2.99 t/ha, followed by 100% RDF and 75% RDF. No significant variation was observed to main crop of cotton due to intercropping. Higher net income was realized with irrigation at 100% PE compared to 75% PE across the fertigation levels and intercropping systems (Table 2.7.2). Among the intercropping systems, cotton + blackgram recorded higher B:C ratio. Among the different combinations, net income of ₹ 1,20,443/ha and B:C ratio of 2.98 was registered under 100% PE irrigation regime with 125% RDF. The treatment combination registered water use efficiency of 6.91 kg/ha-mm and water productivity of ₹ 310.9/ha-mm (Table 2.7.4). There were water savings of 38% and 24% with irrigation levels of 75% PE and 100% PE, respectively compared to surface irrigation. The intercrop of blackgram with cotton is recommended for getting higher yield and income with irrigation regime of 100% PE + 125% RDF.

Table 2.7.2. Performance of monocrop of cotton and intercrops under different levels of fertigation

Interaction effect	Cotton equivalent yield (t/ha)			Water use efficiency (kg/ha-mm)			Net income (₹/ha)	B:C ratio
	2016	2017	Pooled	2016	2017	Pooled		
$I_1F_1C_1$	2.46	2.36	2.41	4.48	4.93	4.70	58657	2.18
$I_1F_1C_2$	2.44	2.66	2.55	4.45	5.57	5.01	59712	2.09
$I_1F_1C_3$	2.81	3.13	2.97	5.14	6.54	5.84	78802	2.44
$I_1F_1C_4$	2.49	2.72	2.61	4.54	5.70	5.12	61549	2.11
$I_1F_2C_1$	2.68	2.62	2.65	4.89	5.48	5.19	68045	2.33
$I_1F_2C_2$	2.64	2.94	2.79	4.82	6.16	5.49	69080	2.22
$I_1F_2C_3$	3.04	3.43	3.24	5.55	7.18	6.36	89250	2.58
$I_1F_2C_4$	2.72	2.95	2.83	4.96	6.17	5.57	70264	2.23
$I_1F_3C_1$	2.98	2.87	2.92	5.43	6.00	5.71	78708	2.49
$I_1F_3C_2$	2.94	3.36	3.15	5.37	7.03	6.20	83763	2.44
$I_1F_3C_3$	3.34	3.76	3.55	6.09	7.86	6.97	101588	2.75
$I_1F_3C_4$	3.04	3.31	3.18	5.56	6.92	6.24	84554	2.45
$I_2F_1C_1$	2.61	2.47	2.54	3.89	4.23	4.06	63960	2.27
$I_2F_1C_2$	2.60	2.81	2.70	3.87	4.82	4.34	65820	2.18
$I_2F_1C_3$	2.97	3.26	3.12	4.42	5.60	5.01	84605	2.52
$I_2F_1C_4$	2.65	2.87	2.76	3.96	4.92	4.44	67776	2.20
$I_2F_2C_1$	2.81	2.76	2.79	4.19	4.73	4.46	73392	2.41
$I_2F_2C_2$	2.80	3.14	2.97	4.18	5.39	4.79	76497	2.33
$I_2F_2C_3$	3.23	3.61	3.42	4.81	6.18	5.50	96532	2.68
$I_2F_2C_4$	2.93	3.22	3.08	4.37	5.53	4.95	80501	2.39
$I_2F_3C_1$	3.23	3.19	3.21	4.81	5.47	5.14	90873	2.70
$I_2F_3C_2$	3.25	3.59	3.42	4.85	6.16	5.50	95098	2.62
$I_2F_3C_3$	3.69	4.03	3.86	5.5	6.91	6.20	114981	2.96
$I_2F_3C_4$	3.46	3.64	3.55	5.15	6.24	5.69	100410	2.70
Control	2.08	2.11	2.10	2.48	2.60	2.54	49677	2.18

I_1 – 75 % PE; I_2 – 100 % PE; F_1 – 75 % RDF; F_2 – 100 % RDF; F_3 – 125 % RDF; C_1- Cotton; C_2 -Cotton + Cowpea; C_3-Cotton+Blackgram; C_4-Cotton+Clusterbean

Maize hybrid var. COMH-6 was raised as a component crop under the system study of cotton based intercropping and sown in a similar way as cotton. Grain yield of maize was significantly influenced by irrigation regimes. Highest grain yield of 7.01 t/ha was observed with 100% PE and lowest grain yield of 6.39 t/ha with 75% PE. Among the fertigation levels, grain yield of 6.97 t/ha was highest with 125% RDF, which was statistically similar to grain yield of 6.71 t/ha with 100% RDF (Table 2.7.3). The lowest grain yield of 6.42 t/ha was recorded in 75% RDF which was at par with 100% RDF. Grain yield of maize crop was not significantly influenced by growing intercrops. Among the irrigation regimes, higher crop equivalent of maize (CEY) were realized in 100% PE compared to 75% PE. With increasing fertigation levels, crop equivalent of maize also increased. Among the intercrops, highest crop equivalent of maize was registered in maize+blackgram intercropping compared to maize+cowpea, maize+cluster bean intercropping (Table 2.7.4). Among the different combinations, 100% PE + 125% RDF with blackgram intercropping ($I_2F_3C_3$) registered highest crop equivalent of maize (9.19 t/ha).

Table 2.7.3. Performance of monocrop of maize and intercrops under different levels of fertigation

Treatment	Maize equivalent yield (t/ha)			Water use efficiency (kg/ha-mm)			Net income (₹/ha)			B:C ratio		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
$I_1F_1C_1$	6.32	6.27	6.32	17.8	17.7	17.7	50032	44775	47052	2.04	1.91	1.97
$I_1F_1C_2$	6.58	6.73	6.58	18.5	19.0	18.7	51896	44750	47972	2.03	1.80	1.91
$I_1F_1C_3$	6.86	7.31	6.86	19.3	21.0	20.0	55540	56700	54654	2.09	2.03	2.06
$I_1F_1C_4$	6.61	6.85	6.61	18.6	19.3	19.0	51577	46585	48730	2.01	1.83	1.92
$I_1F_2C_1$	6.65	6.53	6.65	18.7	18.4	18.6	53144	46530	49826	2.06	1.90	1.98
$I_1F_2C_2$	6.87	7.11	6.87	19.3	20.0	19.7	54522	48140	51320	2.04	1.82	1.93
$I_1F_2C_3$	7.19	7.68	7.19	20.2	22.1	20.9	58805	60240	58231	2.11	2.05	2.08
$I_1F_2C_4$	6.91	7.30	6.91	19.4	20.6	20.0	54202	50985	52582	2.02	1.87	1.95
$I_1F_3C_1$	6.92	6.73	6.92	19.4	19.0	19.2	55234	47261	51579	2.05	1.88	1.96
$I_1F_3C_2$	7.23	7.49	7.23	20.3	21.1	20.7	57812	51576	55025	2.06	1.85	1.95
$I_1F_3C_3$	7.50	8.12	7.50	21.1	23.4	22.0	61367	64886	62038	2.12	2.09	2.10
$I_1F_3C_4$	7.25	7.81	7.25	20.4	22.0	21.2	57495	56356	57257	2.04	1.93	1.98
$I_2F_1C_1$	6.65	6.87	6.65	14.6	15.0	14.8	54791	53415	53542	2.13	2.08	2.10
$I_2F_1C_2$	6.90	7.43	6.90	15.2	16.3	15.7	56656	54855	55194	2.12	1.97	2.04
$I_2F_1C_3$	7.34	8.26	7.34	16.1	18.5	17.1	62700	71040	64929	2.23	2.28	2.25
$I_2F_1C_4$	7.00	7.69	7.00	15.4	16.8	16.1	57249	58795	57461	2.12	2.04	2.08
$I_2F_2C_1$	6.98	7.18	6.98	15.3	15.7	15.5	57988	55860	56703	2.15	2.08	2.11
$I_2F_2C_2$	7.22	7.94	7.22	15.9	17.4	16.6	59577	60325	59730	2.13	2.03	2.08
$I_2F_2C_3$	7.74	8.74	7.74	17	19.5	18.1	66820	76200	69814	2.26	2.32	2.29
$I_2F_2C_4$	7.42	8.17	7.42	16.3	17.9	17.1	61722	63780	62530	2.16	2.08	2.12
$I_2F_3C_1$	7.19	7.48	7.19	15.8	16.4	16.1	59087	58211	58770	2.12	2.08	2.10
$I_2F_3C_2$	7.49	8.35	7.49	16.5	18.3	17.4	61579	64171	62996	2.12	2.05	2.09
$I_2F_3C_3$	7.87	8.97	7.87	17.3	20.1	18.5	66784	77786	70796	2.21	2.30	2.25
$I_2F_3C_4$	7.62	8.46	7.62	16.7	18.5	17.6	62662	65916	64410	2.13	2.08	2.10
Control	5.68	5.66	5.68	10.4	9.5	9.9	46892	43035	—	2.13	2.03	2.08

I_1 – 75 % PE; I_2 – 100 % PE; F_1 – 75 % RDF; F_2 – 100 % RDF; F_3 – 125 % RDF; C_1- Maize; C_2 -Maize+Cowpea; C_3-Maize+Blackgram; C_4-Maize+Clusterbean

Table 2.7.4. Cotton equivalent yield of the cotton-maize based intercropping system

Treatment	Cotton equivalent yield of the system (t/ha/2 yrs)	Cost of cultivation (₹/ha/2 yrs)	Net income (₹/ha/2 yrs)	B:C ratio	WUE (kg/ha-mm)	WP (₹/ha-mm)
$I_1F_1C_1$	9.01	196726	208679	2.06	10.4	466.5
$I_1F_1C_2$	9.54	216526	212649	1.98	11.0	493.9
$I_1F_1C_3$	10.66	215726	264154	2.22	12.3	552.2
$I_1F_1C_4$	9.70	218583	217807	2.00	11.2	502.2
$I_1F_2C_1$	9.69	204096	232074	2.14	11.2	501.9
$I_1F_2C_2$	10.25	223896	237154	2.06	11.8	530.6
$I_1F_2C_3$	11.43	223096	291334	2.31	13.2	592.0
$I_1F_2C_4$	10.40	225953	242102	2.07	12.0	538.6
$I_1F_3C_1$	10.39	211684	256001	2.21	12.0	538.2
$I_1F_3C_2$	11.21	231484	272996	2.18	12.9	580.5
$I_1F_3C_3$	12.30	230684	322721	2.40	14.2	636.8
$I_1F_3C_4$	11.37	232791	279024	2.20	10.6	589.0

$I_2F_1C_1$	9.59	198806	232534	2.17	8.9	400.5
$I_2F_1C_2$	10.18	218606	239524	2.10	9.5	425.4
$I_2F_1C_3$	11.43	217806	296614	2.36	10.6	477.6
$I_2F_1C_4$	10.42	220663	248007	2.12	9.7	435.2
$I_2F_2C_1$	10.29	206176	256814	2.25	9.6	429.9
$I_2F_2C_2$	11.00	225976	269144	2.19	10.2	459.7
$I_2F_2C_3$	12.32	225176	329334	2.46	11.4	514.9
$I_2F_2C_4$	11.35	228033	282762	2.24	10.5	474.3
$I_2F_3C_1$	11.31	213763	295052	2.38	10.5	472.4
$I_2F_3C_2$	12.12	233563	311967	2.34	11.3	506.5
$I_2F_3C_3$	13.34	232763	367362	2.58	12.4	557.2
$I_2F_3C_4$	12.45	234870	325480	2.39	11.6	520.3
Control	7.97	167940	190710	2.14	5.7	255.8

It was concluded that in cotton based intercropping system, cotton+blackgram would be the ideal intercropping followed by cotton+cluster bean intercropping. To get higher yield (3.86 t/ha cotton equivalent yield) and income (gross income ₹ 173718/ha, net income ₹ 114981/ha, and B: C ratio of 2.96) in cotton based intercropping, cotton + blackgram intercropping irrigated at 100% PE irrigation regime with 125 % RDF (150:75:75 kg NPK/ha) would be the ideal practice which saves water up to 24 per cent. In maize based intercropping system, maize + blackgram intercropping would be the best system. To get higher yield (7.74 t/ha maize equivalent yield) and economical benefits (gross income ₹ 126915/ha, net income, ₹ 69814/ha, B: C ratio 2.29) in the system, 100% PE irrigation regime with 100 % RDF (250:75:75 Kg NPK) would be the ideal which saves water up to 23 per cent.

2.8. Sriganganagar (AESR 2.1)

2.8.1. Studies on drip irrigation and fertigation schedule for summer squash (*Cucurbita pepo* L.) under low tunnel

The experiment was conducted to assess the suitability of summer squash in cotton-vegetable cropping sequence in drip system under low tunnel. Irrigation schedules 0.6 ETc (29.94 t/ha), 0.8 ETc (33.49 t/ha), 1.0 ETc (37.05 t/ha) showed significantly higher yields of summer squash (var. Chand) compared to flood irrigation (20.93 t/ha) (Table 2.8.1). Fertigation schedules had significant effect on yield of summer squash, with highest yield under 100% RD in 10 splits at 10 days interval (35.06 t/ha) statistically similar to yield under 80% RD in 10 splits at 10 days interval (34.02 t/ha). The interaction effect of irrigation and fertigation was non-significant. The maximum fruit yield of summer squash was recorded when the crop was irrigated at 1.0 ETc with 100% RD of fertilizers. Water used under drip irrigation schedules of 0.6 ETc, 0.8 ETc and 1.0 ETc were 218.32 mm, 270.24 mm and 325.19 mm against 660.0 mm with surface irrigation, thereby saving 70.0%, 62.1% and 53.8% than surface irrigation.

Table 2.8.1. Performance of summer squash under drip fertigation during 2017

Treatment	Irrigation applied (mm)	WUE (kg/ha-mm)	Yield (t/ha)
Irrigation schedule			
0.6 ETc	198.32	137.15	29.94
0.8 ETc	250.24	123.93	33.49
1.0 ETc	305.19	113.96	37.06
Flood irrigation	660.0	30.77	20.93
CD at 5%	-	-	3.66
CD at 5% (drip vs flood)	-	-	5.17
Fertigation schedule			
60% RD	-	-	31.42
80% RD	-	-	34.02
100% RD	-	-	35.06
CD at 5%	-	-	3.66

Rainfall=20 mm

Theme 3

Management of rainwater for judicious use and to develop and evaluate groundwater recharge technologies for augmenting availability under different hydro-ecological conditions

3.1. Junagadh (AESR 5.1)

3.1.1. Evaluation of groundwater recharge techniques for Junagadh region

Two groundwater recharging techniques namely openwell and connector well recharging techniques were evaluated during monsoon season of 2017 for Junagadh region. Filter materials used for open well recharge had thickness as shown in Table 3.1.1. During monsoon season of 2017, total runoff volume of 6476 m^3 was generated from catchment area of open well recharge structure, out of which 2895 m^3 was recharged through open well and 3581 m^3 escaped towards downstream side of the filter. Annual extreme runoff event wise groundwater recharge was 40040, 0, 9899 and 19584 m^3 for maximum, minimum, average and 15 year return period of runoff, respectively and cost of groundwater recharge was Rs. 2.66 per m^3 for 15 years effective life of open well recharge structure in Junagadh region.

Table 3.1.1. Depth and size of filter materials used for open well recharge

Layer	Material	Size of material (mm)	Estimated thickness (cm)	Thickness used in the filter (cm)
1	Fine sand	Size 0.5 mm to 1.0 mm	20.00	20.0
2	Coarse sand	Diameter of coarse sand 2 to 3 mm	4.78	5.0
3	Gravel	Diameter of gravel 8 to 12 mm	12.00	20.0
4	Pebbles	Diameter of pebbles 30 to 40 mm	18.53	20.0
5	Supporting stones	Diameter of supporting stones 80 to 120 mm	24.00	25.0

Connector well recharging technique was designed to recharge deep aquifers by spillover water of check dam. Connector well recharge structure is made of recharge bore well, two spillways i.e. inlet spillway and outlet spillway, pre filter, main filter, outlet tank, inlet pipe line, outlet pipe line and connecting pipe between filter and tubewell (Plate 3.1.1, 3.1.2 and 3.1.3). When spillover water starts flowing, part of spillover water that flows through inflow pipeline from check dam diverts to pre filter and then flow passes through the inlet spillway (broad crested weir). After the flow passes over main filter where sediments filtration take place and clean water from the bottom of the main filter diverts to recharge borewell and excess flow bypasses through outlet spillway to downstream side of dam through outlet pipeline. Under connector well recharging technique during monsoon season of 2017, recharge of 40333 m^3 was observed and cost of groundwater recharge was Rs.0.51 and Rs.0.32 per m^3 including and excluding tubewell cost, respectively in Junagadh region.

Plate 3.1.1. Execution of connector well system

Plate. 3.1.2. Functioning filter during runoff event

Plate. 3.1.3. Collection of water samples of recharge

3.1.2. Development of online screen-gravel filter for groundwater recharge

Development and evaluation of an online screen filter was done. Existing design criteria of traditional filter was taken into account to work out specification of online screen-gravel filter for groundwater recharge. The concept of screen-gravel filter is shown in Fig. 3.1.2. Between top and bottom composite screen sections of macro and fine screens, only single sand layer is kept and sediment water is allowed to pass from top to bottom and excess water is guided towards downstream side. Plate 3.1.4 shows some views of the on-line filter.

The filter was evaluated with three different thickness of sand bed, i.e. 10 cm, 15 cm and 20 cm. Filtration efficiency increased with thickness of sand bed, which was established as a linear model. It was 63%, 85% and 89% with sand bed thickness of 10 cm, 15 cm and 20 cm, respectively. Recharge flow rate decreased with increase in sand bed thickness, which was also established as a linear model. The recharge flow rate was 80%, 57% and 33% with sand bed thickness of 10 cm, 15 cm and 20 cm respectively.

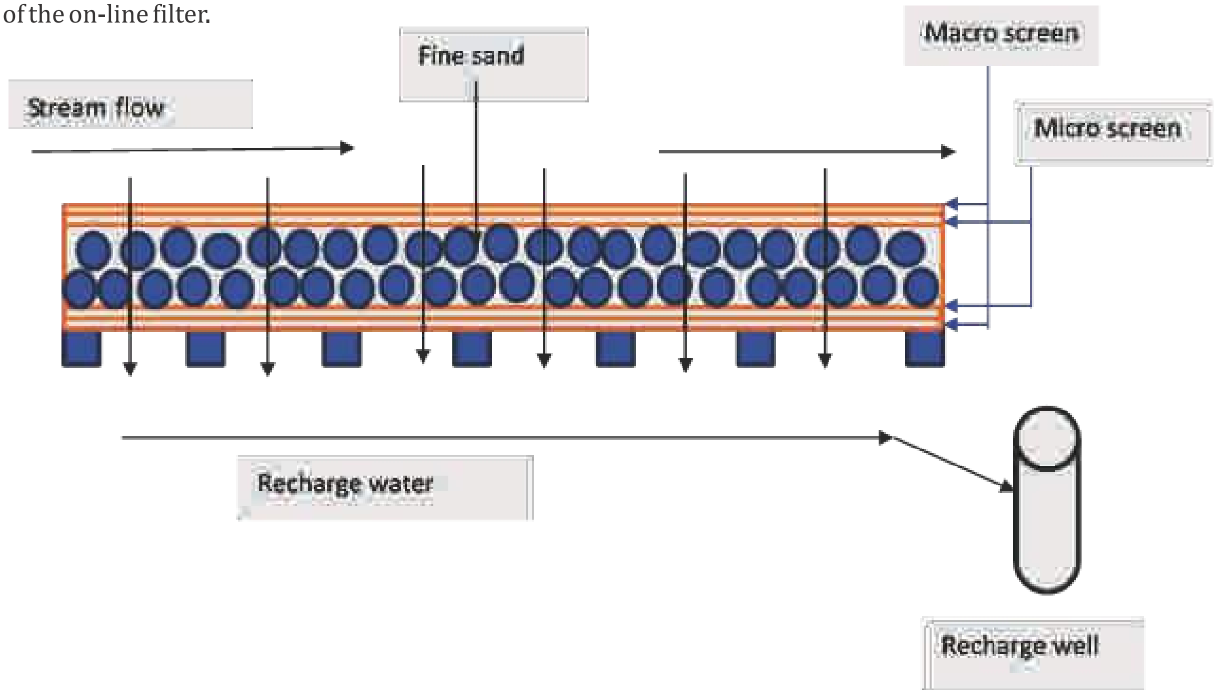


Fig. 3.1.2. Conceptual detail of online screen–gravel filter

Plate 3.1.4. View of the online screen-gravel filter

3.2. Ludhiana (AESR 4.1)

3.2.1. Modelling groundwater recharge through abandoned wells under constant head conditions

Two abandoned wells were selected and cleaned up for recharging groundwater recharge at constant head. Abandoned well of diameter 1.88 m and depth 8.31 m at Site 1 was at the research farm of Soil Science department (Fig. 3.2.1). The lined water channel to carry canal water was at a distance of 3 m from the abandoned well and flow was diverted from canal water channel to the dug well by gravity. At the top, the abandoned well was covered with iron grills for its safety. The observation well was installed at 6 m distance from the abandoned well to monitor the groundwater depth as well as groundwater quality. At Site 2, which was also in the farm of Soil Science department, the abandoned well was at a distance of 10 m from canal water channel. The well was of 1.82 m diameter and 7.36 m depth (Fig. 3.2.2). The water table depth in these wells was 25.31 m at Site 1 and 24.27 m at Site 2 from the surface. Canal water was diverted into the recharge well and a flow control valve was used to maintain constant head conditions in the abandoned well. A flow meter was installed at the inlet section to monitor the recharge rate at different time intervals. At Site 1, depth of well was 8.31 m and a constant head of 7.4 m was maintained. Similarly at Site 2, depth of well was 7.36 m and a constant head of 6.36 m was maintained. It was observed that the recharge rate decreased from 8.96 l/s to 7.79 l/s at Site 1 and from 4.2 l/s to 3.96 l/s at Site 2.

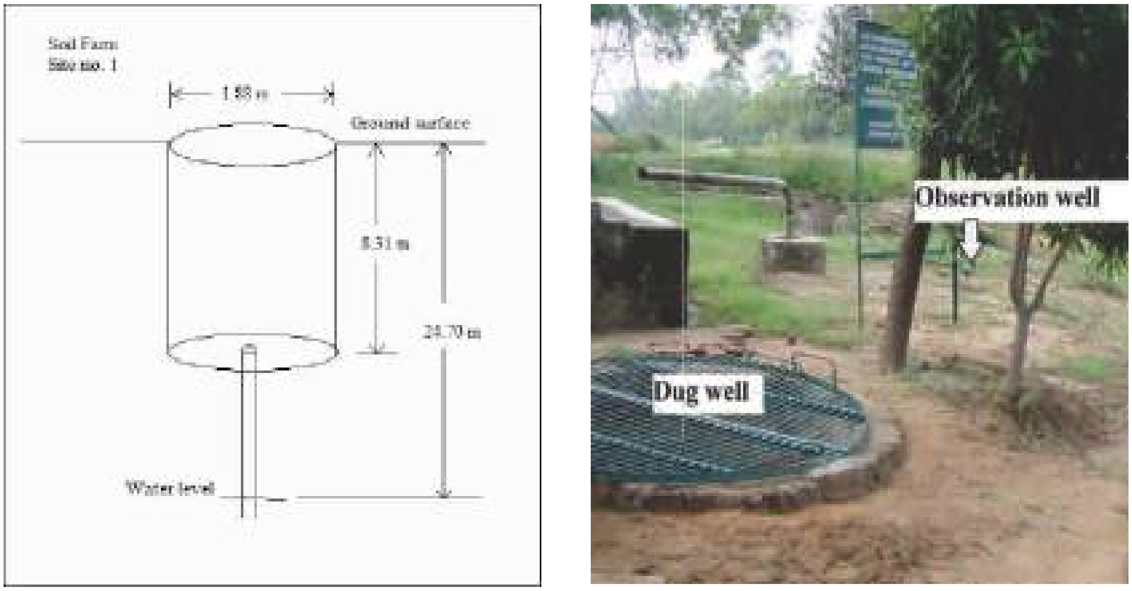


Fig. 3.2.1. Abandoned well with dimensions at Site 1.

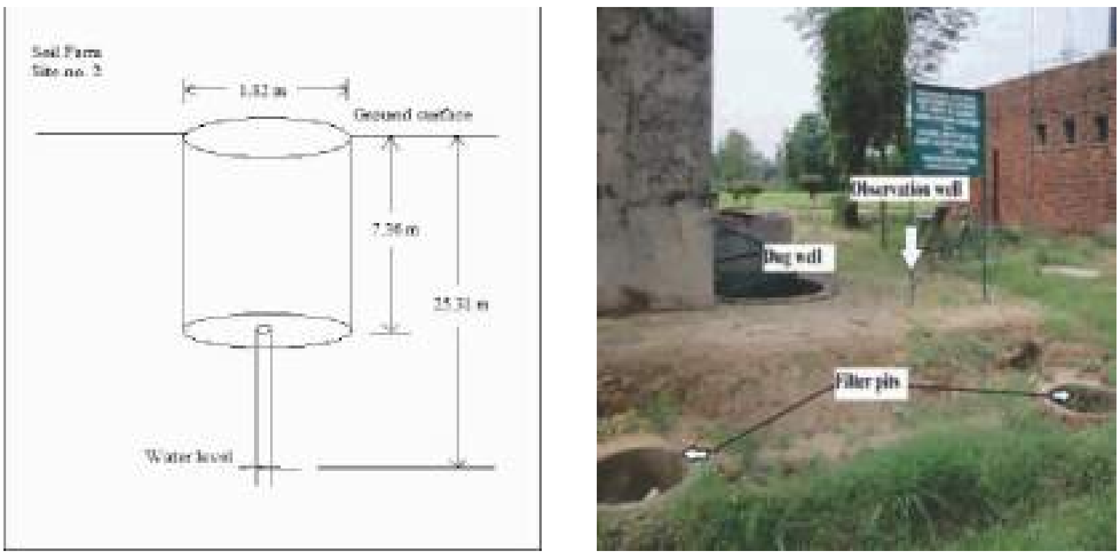


Fig. 3.2.2. Abandoned well with dimensions at Site 2.

3.3. Pusa (AESR 13.1)

3.3.1. Design and evaluation of drainage cum recharge structure under North Bihar condition

The study was undertaken with a view to evaluate drainage-cum-recharge structure under North Bihar condition (Plate 3.3.1). The filter assembly was tested with various filter combinations by measuring recharge rate using volumetric method. Samples of runoff water (water carrying sediment from agricultural fields) were collected from the source before passing through the recharge filter and after passing through the recharge filters with various filter combinations. Recharge rates and total suspended solids (TSS) values after passing through the filter are presented in Fig. 3.3.1. Concentration of TSS of runoff water varied from 1200 to 1340 mg/l with an average value of 1270 mg/l. The analysis revealed that Filter combination 6 consisting of gravel, sand and charcoal was having highest recharge rate and 2nd lowest TSS value. Filter combination 6 was found to be most promising in terms of recharge rate and TSS. The TSS was lowest after passing through the Filter combination 7 consisting of coloured gravel, white gravel and sand, but the recharge rate was also the lowest.

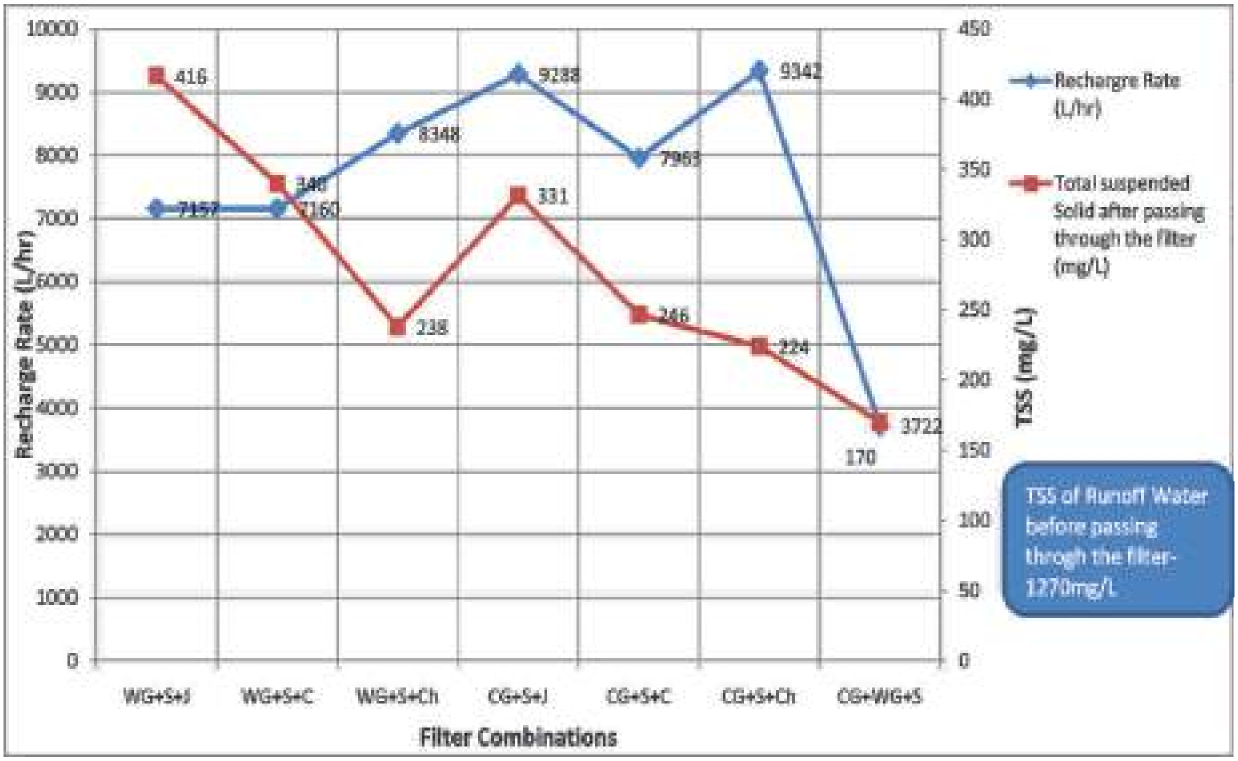


Fig. 3.3.1. Recharge rate and TSS after passing through different filter combination using runoff water

Plate 3.3.1. Filter assembly testing under field condition using runoff water

3.4. Rahuri (AESR 6.2)

3.4.1. Impact of cement nala bund on groundwater recharge

A series of cement nala bunds (bunds constructed across the nala to hold maximum runoff water, so that upstream area gets flooded temporarily for some weeks and groundwater recharge is done) were selected at Vadgaon Tandali, Ahmednagar for the study. Open wells were selected in the downstream side of the cement nala bunds to record the groundwater levels at an interval of 15 days. The monthly observation of water levels in these wells were recorded before and after monsoon during the year 2017 to know the influence of cement nala bund on groundwater recharge and develop a model for studying the influence of cement nala bund on groundwater recharge. Groundwater draft was estimated and using this value along with the change in groundwater level data, monthwise groundwater recharge was estimated (Table 3.4.1). There was a recharge of 51.44 ha-m, draft of 30.89 ha-m with net change in groundwater of 20.55 ha-m during May 2017 to November 2017. The distance upto which the canal nala bund influences the recharge into the well was estimated by developing a relationship between the water level fluctuations in all the wells from May 2017 to November 2017 and distances of respective wells from the canal nala bund.

Table 3.4.1. Net change in groundwater storage due to series of cement nala bund

Period	Change in groundwater storage (ha-m)		
	Recharge	Draft	Net Change
June-2017	1.62	1.61	0.01
July-2017	0.37	5.16	-4.79
August-2017	0.70	1.32	-0.62
September-2017	13.25	2.63	10.63
October-2017	34.76	0.49	34.27
November-2017	0.75	19.7	-18.95
Total	**51.44**	**30.89**	**20.55**

3.4.2. Performance evaluation of filter technology for artificial groundwater recharge through bore well on the farm/field

The study was conducted to test the performance of a four-layer filter in terms of filtration efficiency for purifying the water before injecting into the bore well on agricultural fields. Different grades and thickness of filter materials like brick flakes, sand and gravel were tested for the constant suspended load concentration of 200 NTU and varying suspended load taking into consideration filtration under low hydraulic head independently and in combination of single layer, two layers, three layers and four layers with varying layer thickness in the laboratory model. The effect of filter materials on filtration was studied by recording the observations on inlet head, outlet head, velocity of flow, time of filtration and filtration efficiency. The four layer filter comprising of brick flakes (BF-I) of size 24.28 mm, sand (SG-I) of size 0.6-2.0 mm, angular gravel (AG-I) of grade 9.5-15.5 mm and pea gravel (PG-I) of size 20-24 mm with thickness of 25 cm/layer and total thickness of 100 cm performed better in terms of filtration efficiency (92.3%) and average discharge (1.156 lps) amongst all filters (Fig. 3.4.2). Two sites were selected for evaluating the filter in farmers' field. The filter had filtration efficiency ranging from 81.2 to 90.0% at Site I. At Site II, it showed filtration efficiency ranging from 79.2 to 87.4%. Recharged water varied from 82.8 m^3 to 385.3 m^3 at Site I and 68.8 to 320.0 m^3 at Site II. Overall filtration efficiency of the filter was 84.5%, which was considered to be satisfactory performance of the filter at farm/field. Average recharge volume was 1511 m^3 during the rainy season of 2017.

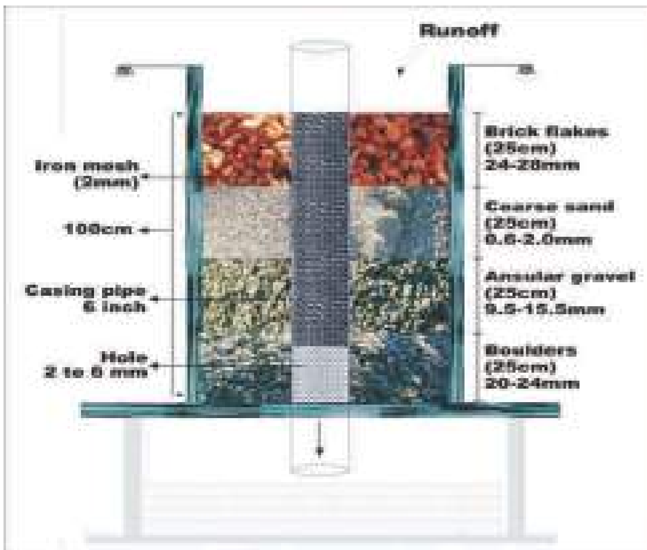


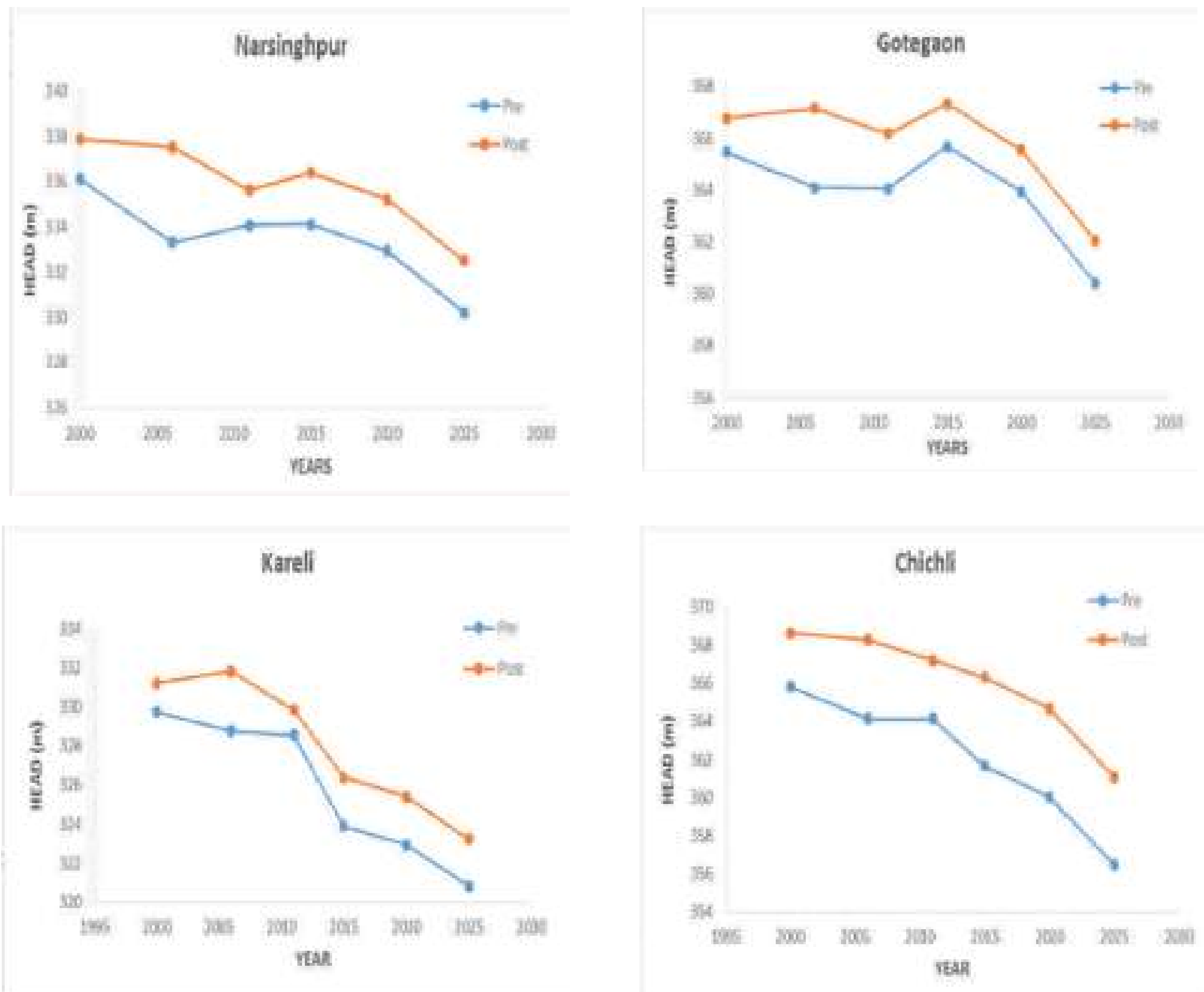
Fig. 3.4.2. Four layer filter for groundwater recharge through borewell

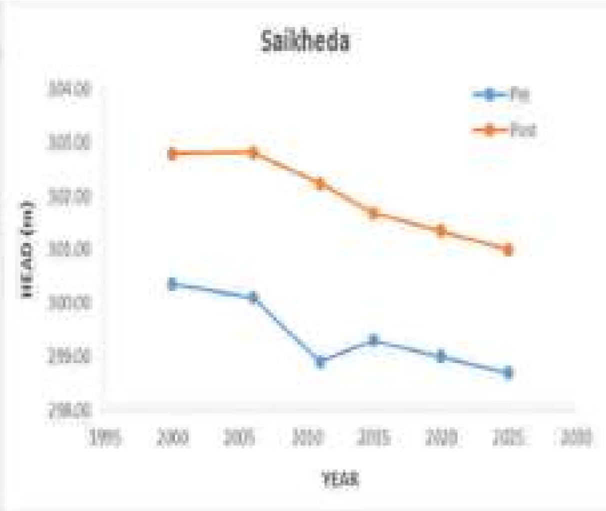
3.5. Jabalpur (AESR 10.1)

3.5.1. Evaluation of groundwater recharge technologies for upper Narmada basin – Narsinghpur district

Upper Narmada basin was selected to study spatial and temporal variation of area under different crops in six blocks namely Saikhera, Babai Chichli, Chawarpatha, Kareli, Narsinghpur and Gotegaon of Narsinghpur district in Upper Narmada basin and to model groundwater flow system using Visual MODFLOW to study the impact of changing crop scenario on groundwater level.

Crop maps prepared for the year 2006 and 2015 based on satellite data captured during the month of January and February indicated an increase of 109% area under wheat with reduction of 36% area under chickpea. Area under sugarcane crop increased from 25555 ha during 2006 to 54997 ha during 2015. The spread is more (12115 ha) in Chichli block of Narsinghpur district, which is a part of Upper Narmada basin. Groundwater flow system in the study area of 513300 ha has been developed using groundwater model Visual MODFLOW. The values of hydraulic conductivity (K) after calibration of model from year 2000 to 2010 are 0.00107 m/s for unconfined aquifer and 0.0005 m/s for confined aquifer. The calibration was acceptable with correlation coefficient (r) of 0.86 to 0.97 between observed and predicted hydraulic heads during pre and post monsoon season. Validation was done with the hydraulic head data from year 2011 to 2015, with 'r' value 0.90 to 0.96. Considering the trend of increase in groundwater withdrawal, model was used to forecast the hydraulic heads in the study area for the year 2020 and 2025 (Fig. 3.5.1). It was found that hydraulic head may further deplete from 334.14 to 330.41 m in the year 2025, if rate of groundwater use continues to be the same. Groundwater heads during pre-monsoon period may go deeper by 5.26 m in Gotegaon block, 3.91 m in Narsinghpur block, 3.04 m in Kareli block, 4.39 m in Chawarpatha block, 5.18 in Chichli block and 0.60 m in Saikheda block if high water consuming crop like sugarcane continue to increase in areal extent. If irrigation to wheat is increased at a present rate, the depletion will further increase.





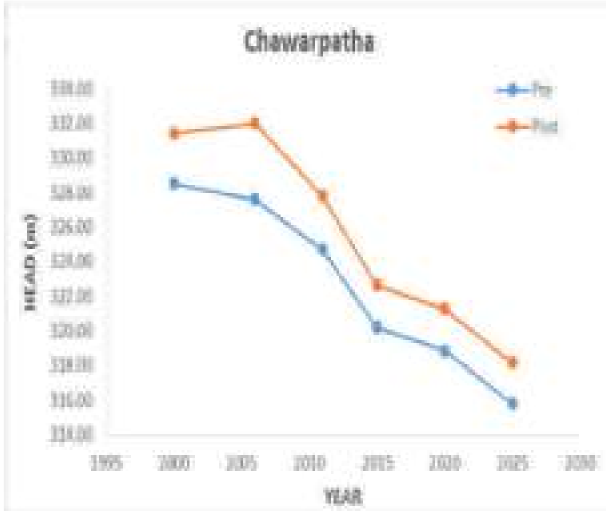


Fig. 3.5.1. Predicted scenario of hydraulic head of groundwater in six blocks of Narsinghpur district under 10% and 30% pumpage conditions

3.6. Raipur (AER 11)

3.6.1. Surface and Groundwater modelling for developing management plan for critical watershed of Seonath Sub basin

1. Prioritization of watershed based on morphometric analysis revealed that the watersheds, WS1, WS2, WS6, WS9, WS12, WS14, WS19 and WS20 fall in the high priority and indicated as the high soil erosion susceptible watersheds.
2. Manning's 'n' values for overland flow and channel flow are 0.132 and 0.024, respectively for the Seonath sub-basin.
3. Sensitivity analysis of the model input parameters shows that the stream discharge/flow rate and sediment concentration are more sensitive to Soil Conservation Service (SCS) Curve Number (CN) followed by Manning roughness coefficient for overland flow (OV_N), Surface runoff lag time (SURLAG) and Support practice factor (USLE_P).
4. The Arc-SWAT model accurately simulates stream discharge and sediment concentration from the Seonath sub-basin on monthly basis using both observed and generated daily rainfall and temperature (maximum and minimum).
5. Nutrient losses including NO_3-N and total-P can be simulated satisfactory by the SWAT model for the monsoon season (Fig. 3.6.2).
6. The Arc-SWAT model can successfully be used for identifying critical watersheds for the management purpose. The model can be used for planning and management of the Seonath sub-basin on long-term basis using generated rainfall.
7. The visual MODFLOW model can estimate groundwater potential satisfactorily for the critical watershed (WS 9).
8. The visual MODFLOW model can be used for evaluating the density of tubewells in the critical watershed (WS9).
9. The filter strip and stone/soil bunds measures are recommended because these measures reduce the total sediment yield by 27.8%. 34.7%, respectively.
10. Total 120, 70, 34 and 16 number of suitable recharge structures namely storage tank, percolation tank, stop dam and check dam, respectively are recommended in the low groundwater potential area of critical watershed (Fig. 3.6.1).
11. The physical factors like gentle slope and shallow water table are the major factors supporting the chances of getting shallow aquifer contaminated in critical watershed.
12. The high vulnerability index is attributed to the presence of shallow water bodies and high aquifer yield in the critical watershed.

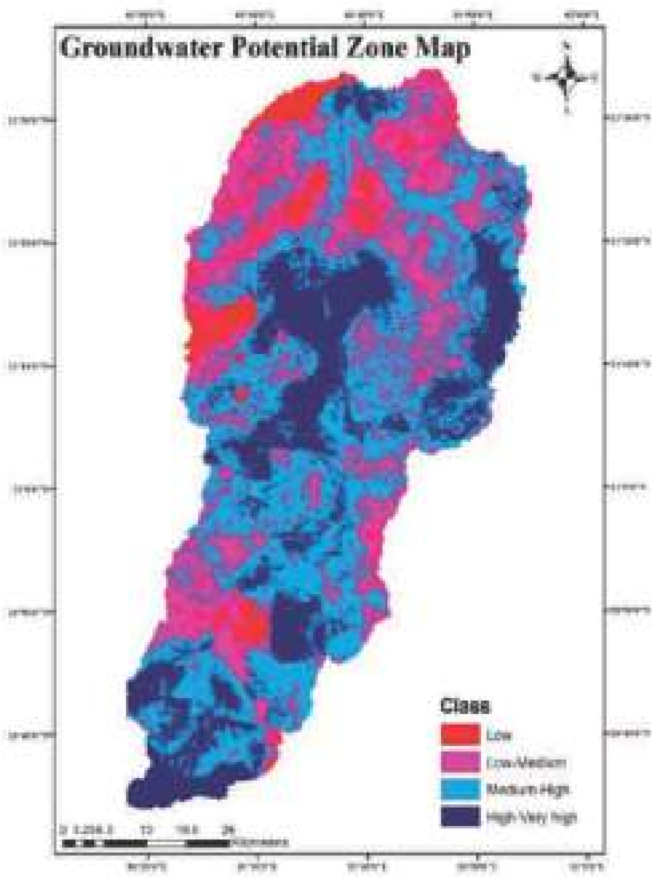


Fig. 3.6.1. Groundwater potential zone map of critical watershed

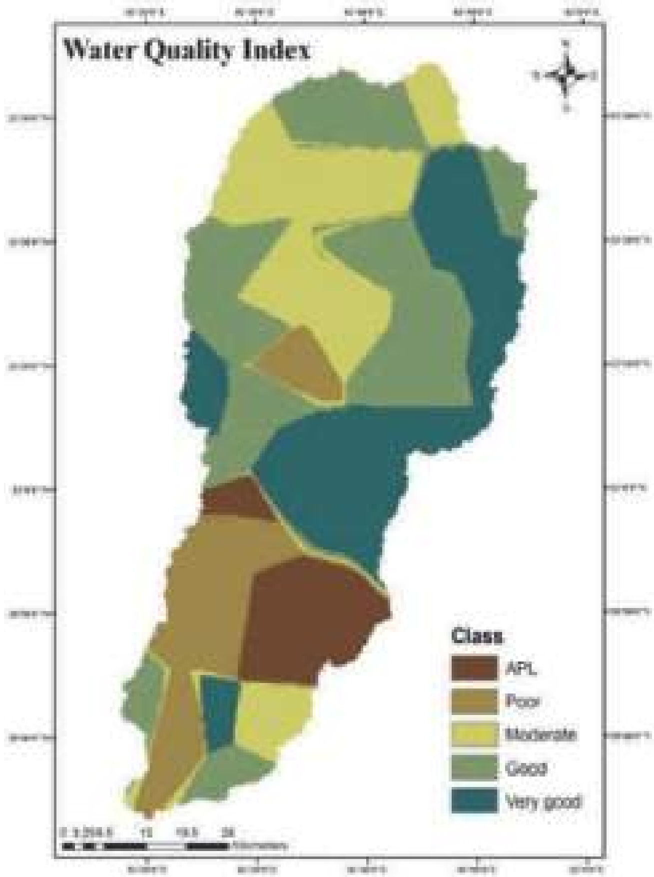


Fig. 3.6.2. Groundwater quality index map of critical watershed

Theme 4

Basic studies on soil-plant–water-environment relationship under changing scenarios of irrigation water management

4.1. Jorhat (AESR 15.4)

4.1.1. Water saving irrigation via partial root drying (PRD) and deficit irrigation on growth and yield of potato

Tuber yields of <25 g, 50-75 g and >75 g and total tuber yield of potato recorded under full irrigation (I_1) were significantly higher than partial root drying (I_3) and deficit irrigation (I_2). Pooled data of 3 years also revealed that total tuber yield recorded under full irrigation (I_1) was significantly higher than partial root drying (I_3) and deficit irrigation (I_2). Three irritations at stolonization, tuberization and tuber development recorded significantly higher tuber yield than two irrigations at stolonization and tuberization and one irrigation at stolonization. Pooled data of 3 years also revealed similar results. The data on total water use and water productivity of potato is presented in Table 4.1.1. It was observed that the amount of irrigation as well as total water used by the crop increased with the increasing levels of irrigation regimes. Among the irrigation regimes, highest amount of irrigation (1200 m^3) and total water use (1776 m^3) were recorded under full irrigation treatment (I_1). Among the irrigation schedules, S_3 required maximum irrigation water (1200 m^3/ha) and water use (1767 m^3/ha). Among the irrigation regimes, I_3 recorded the highest water productivity (15.21 kg/m^3) followed by I_2 (13.44 m^3/ha) and I_1 (12.76 m^3/ha). Among the irrigation schedules, S_2 recorded the highest water productivity (14.32 kg/m^3) followed by S_3 (13.67 kg/m^3) and S_1 (12.96 kg/m^3). Among the irrigation regimes, I_3 recorded the highest gross and net return and B:C ratio followed by I_2 and I_1 (Table 4.1.1). Among the irrigation schedules, S_2 recorded highest net return and B:C ratio followed by I_2 and I_1. Thus under limited water supply, partial root drying may be practiced. It may be concluded that in potato, three irrigations at stolonization, tuberization and tuber development recorded the highest tuber yield and economic benefit. Every furrow irrigation resulted in higher tuber yield than alternate furrow and partial root drying. Partial root drying recorded higher water use efficiency than each furrow and alternate furrow irrigation.

Table 4.1.1. Performance of potato under partial root drying and deficit irrigation

Treatment	Potato tuber yield (t/ha)	Irrigation (m^3/ha)	Total water used (m^3/ha)	Water productivity (kg/m^3)	Net return (₹/ha)	B:C ratio
Irrigation regime						
I_1	22.67	1200	1776	12.76	97760	2.10
I_2	17.32	600	1289	13.44	60860	1.69
I_3	19.82	600	1303	15.21	76260	1.86
Irrigation schedule*						
S_1	15.12	400	1167	12.96	47760	1.54
S_2	20.53	800	1434	14.32	82760	1.94
S_3	24.16	1200	1767	13.67	104360	2.17
Treatment vs. Control						
Treatment	-	-	-	-	78360	1.89
Control	13.06	0	1168	15.05	30860	1.35

*S_1: Irrigation at stolonization; S_2: Irrigation at stolonization and tuberization; S_3: Irrigation at stolonization, tuberization and tuber development

4.1.2. Optimizing dyke height for rainwater conservation in rice field and its effect on performance of relay crops in medium land situation

Different bund height significantly influenced the growth, yield attributes and yield of rabi crops. Bund height of 40 cm being at par with 30 cm recorded significantly higher plant height and seed and stover yields of linseed than 10 and 20 cm high bunds. However, in case of capsules/plant, 20 cm bund height also showed statistical parity with 40 cm bund height. Number of primary branch/plant, number of seeds/capsule and test weight were not significantly influenced by bund height. In buckwheat, bund height of 40 cm being at par with 30 cm recorded significantly higher plant height, number of seeds/plant and seed and stover yields of linseed than 10 and 20 cm bund height. Similar trend was observed in case of seed and stover yields of Lathyrus. Grain yield of the cropping system expressed in rice equivalent yield revealed that bund height of 40 cm being at par with 30 cm recorded significantly higher rice equivalent yield. Among the relay crops, inclusion of linseed with rice recorded significantly higher rice equivalent grain yield compared to lathyrus and buckwheat. The pooled data also revealed similar trends (Table 4.1.2). Runoff loss was highest under 10 cm bund. No runoff loss was observed under 30 and 40 cm bunds. As such, 30 and 40 cm bunds recorded higher water use and water use efficiency than 10 and 20 cm bunds. The highest WUE (66.78 kg/ha-cm) was observed under 30 cm bund. This treatment also recorded the highest rainwater use efficiency (66.14 kg/ha-cm). The highest WUE of the system was observed under 30 cm bund (61.13 kg/ha-cm) (Table 4.1.2). It was followed by 40 cm bund (59.89 kg/ha-cm). Among the cropping systems, rice-linseed cropping system recorded the highest WUE (62.84 kg/ha-cm). Bund height of 30 cm recorded the highest net return (Rs.60823). This treatment also recorded the highest B:C ratio (2.93). Among the relay crops, inclusion of linseed in the system recorded the highest net return (Rs 64828) and B:C ratio (3.14). It was concluded that bund height of 30 cm recorded the highest yield of kharif rice and system equivalent yield, highest water use efficiency, rainwater use efficiency and net returns. Thus it was recommended that for rainfed kharif rice, height of bund should be 30 cm to retain rainwater for higher yield of rice as well as to conserve residual moisture for higher yield of succeeding relay crops.

Table 4.1.2. Effect of bund height and relay crops on performance of rice

Treatment	Pooled yield (t/ha)	WUE of the system (kg/ha-cm)	Net return (₹/ha)	B:C ratio
Bund height				
10 cm	5.04	52.93	46053	2.56
20 cm	5.23	54.63	47903	2.57
30 cm	6.16	61.13	60823	2.93
40 cm	5.99	59.89	57683	2.80
CD (P=0.05)	0.30	-	-	-
Relay crops				
Lathyrus	5.41	54.09	47301	2.40
Linseed	6.34	63.41	64828	3.14
Buckwheat	5.07	50.68	46866	2.61
CD (P=0.05)	0.26	-	-	-

4.1.3. Determination of water requirement and crop coefficient of summer sesame and potato through weighing type lysimeter

Summer sesame: The experiment showed that actual ET of summer sesame was 221.5 mm during the crop growing period. In the early period, crop coefficient (K_c) was 0.91. It increased to 1.20 during 41-50 DAS, and then came down gradually to 0.85 during the time of crop harvest (Table 4.1.3).

Potato: Crop coefficient was lowest in the early crop growth period (0.65 during 0-10 DAS). Crop coefficient gradually increased and reached peak during 56-65 DAS (1.24) and then decreased. Actual ET for the crop growth period is 128.7 mm (Table 4.1.3).

Table 4.1.3. Actual Evapotranspiration, Pan Evaporation and Penman Monteith Reference ET during crop growing season of summer sesame and potato

From	Actual ET	Pan Evaporation	PM reference ET	K_c
Summer sesame				
0-10 DAS	16.0	23.5	20.2	0.79
11-20 DAS	21.1	30.1	23.2	0.91
21-30 DAS	26.7	29.6	25.9	1.03
31-40 DAS	30.5	31.1	26.1	1.17
41-50 DAS	31.2	29.1	26.0	1.20
51-60 DAS	33.0	37.3	28.0	1.18
61-70DAS	31.3	31.8	29.8	1.05
71-80 DAS	22.3	27.1	23.7	0.94
81-83 DAS	9.4	7.9	11.1	0.85
Potato				
1-10 DAS	10.6	18.5	16.3	0.65
11-20 DAS	11.1	17.1	15.4	0.72
21-30 DAS	11.9	15.4	13.8	0.86
31-40 DAS	13.8	13.1	13.6	1.01
41-50 DAS	16.6	16.4	14.6	1.14
51-60 DAS	18.2	15.0	14.9	1.22
61-70 DAS	19.5	16.8	16.0	1.22
71-80 DAS	18.9	19.4	16.9	1.12
80-85 DAS	8.1	9.4	8.7	0.93

4.1.4. Irrigation and fertilizer management in late sown toria (*Brassica campestris* var. toria) grown after sali rice

Different levels of irrigation influenced plant height, total branches/plant, number of siliquae/plant, siliqua length, number of seeds/siliqua and seed yield of rapeseed significantly. Test weight was not influenced by the irrigation treatments. Two irrigations of 6 cm each were applied- one at pre-flowering (25 DAS) and another at siliqua formation (50 DAS) [I_3] being at par with one irrigation at siliqua formation stage [I_2] recorded significantly total branches/plant and seed yield. However, there had not been any significant difference among I_1, I_2 and I_3 with respect to plant height, number of siliquae/plant, siliqua length and number of seeds/siliqua. Pooled data of 3 years revealed that two irrigations at pre-flowering and post flowering stage recorded significantly highest seed yield.

Different levels of fertilizers influenced plant height, total branches/plant, number of siliquae/plant, siliqua length and seed yield of rapeseed significantly during 2016-17. Fertilizer levels did not have significant effect on test weight and number of seeds/siliqua. Application of 75-50-50 N-P_2O_5-K_2O kg/ha being at par with 60-40-40 N-P_2O_5-K_2O kg/ha recorded significantly higher plant height, total branches/plant, number of siliquae/plant, siliqua length and seed yield than 45-30-30 N-P_2O_5-K_2O kg/ha. Pooled data of 3 years revealed that application of 75-50-50 N-P_2O_5-K_2O kg/ha being at par with 60-40-40 N-P_2O_5-K_2O kg/ha recorded significantly highest seed yield. The amount of irrigation as well as total water used by the crop increased with the increasing levels of irrigation regimes. Thus, the highest amount of irrigation (12.0 cm) and total water use (23.1 cm) were recorded under irrigations at pre-flowering (25 DAS) and siliqua formation stage (50 DAS). Rainfed crop recorded the lowest water used (15.6 cm). Highest water use efficiency was also observed under irrigations at pre-flowering stage (49.4 kg/ha-cm) followed 6 cm irrigation at siliqua formation stage (48.0 cm). Lowest water use efficiency was observed under two irrigations, one each at pre-flowering and pod formation stage (41.9 kg/ha-cm). Economic analysis revealed that two irrigations at pre-flowering and post-flowering stages recorded the highest net return (₹ 9956.90) and B:C ratio (1.48) (Table 4.1.4). Among the fertilizer levels, 60-40-40 N-P_2O_5-K_2O kg/ha recorded the highest B:C ratio (1.42).

Conclusion:

- In late sown toria, two irrigations at pre flowering and post flowering stage recorded the highest yield attributes and yield
- Two irrigations also recorded the highest gross and net return

Recommendation:

In late sown toria, two irrigations of 6 cm depth should be applied at pre-flowering and siliqua formation stage.

Table 4.1.4. Effect of irrigation and fertilizer management in late sown toria

Treatment	Seed yield (t/ha)	IW (cm)	Total water used (cm)	Field WUE (kg/ha-cm)	Net return (₹/ha)	B:C
Irrigation regime						
I_0 = Rainfed	0.65	0	15.6	43.9	4182.32	1.22
I_1 = 6 cm irrigation at pre flowering stage (25 DAS)	0.81	6.0	19.4	47.0	8686.78	1.44
I_2 = 6 cm irrigation at siliqua formation stage (50 DAS)	0.80	6.0	18.3	48.0	8292.63	1.42
I_3 = 6 cm irrigation at 25 DAS and 50 DAS	0.87	12.0	23.1	41.2	9956.90	1.48
CD (P=0.05)	0.06	-	-	-	-	-
Fertilizer management (N-P_2O_5-K_2O kg/ha)						
F_1 = 45-30-30	0.71	-	-	-	6568.31	1.35
F_2 = 60-40-40	0.80	-	-	-	8324.90	1.42
F_3 = 75-50-50	0.84	-	-	-	8445.76	1.40
CD (P=0.05)	0.05	-	-	-	-	-
Interaction	NS	-	-	NS	NS	NS

4.2. Morena (AESR 4.4)

4.2.1. Effect of irrigation scheduling and residue management through sowing methods on pearl millet–wheat cropping system on growth, yield and water productivity in alluvial soils

Wheat var. RVW 4106 sown with 'Turbo Happy Seeder' (Plate 4.2.1) with 100% residue retention of *kharif* crop resulted in significantly higher grain yield of 4.81 t/ha and WP of 1.47 kg/m^3 compared to yield and WP obtained with conventional tillage (CT) and zero tillage (ZT) (Table 4.2.1). Among irrigation levels, significantly higher grain yield of 4.78 t/ha was obtained with five irrigations at five critical growth stages of wheat over three and four irrigtaions. Total water use was minimum with 100% RRSHS (Table 4.2.1), with 10.69% water saving than with CT. Physiochemical properties of soil such as EC, pH and OC remained unchanged after harvest of wheat. Availability of N, P, K and S in soil were significantly influenced by residue retention, with maximum availability under 100% RRSHS.

For the succeeding crop i.e. *kharif* pearlmillet (hybrid), 100% RRSHS and weed management with tractor operated ridge furrow maker + weedicide addition showed significantly higher yields of 4.69 and 4.83 t/ha, WPs of 1.27 and 1.30 kg/m^3, net returns of ₹ 43652/ha and ₹ 56170/ha, benefit-cost ratios of 3.64 and 3.59 with minimum water use of 3698 and 3722 m^3/ha, respectively among all treatments (Table 4.2.2).

Recommendations:

Pearlmillet: Pearlmillet crop establishment with happy seeder and intercultural operations through tractor operated ridge furrow maker with weedicide addition is recommended for getting higher yield, economic benefit, water productivity and improved soil health in alluvial soil.

Wheat: Wheat crop establishment with happy seeder, residue retention of *kharif* crop and five irrigations at critical stages are recommended for getting higher yield, economic benefit, water productivity and improved soil health in alluvial plains.

Table 4.2.1. Effect of residue management through sowing method and irrigation level on performance of wheat under pearl millet-wheat cropping sequence

Treatment	Grain yield (t/ha)	Net return (₹/ha)	B:C ratio	Total water use (m^3/ha)	Water productivity (kg/m^3)	Available nutrient (kg/ha)			
						N	P	K	S
Sowing method*									
CT	3.92	48072	2.68	3833	1.05	164	10.1	180	17.5
ZT	4.23	56494	3.18	3521	1.23	177	10.7	182	18.0
25% RRSHS	4.55	58673	3.14	3446	1.32	183	10.9	190	19.2
50% RRSHS	4.68	58566	3.03	3225	1.42	209	11.3	195	20.9
100% RRSHS	4.81	57798	2.81	3215	1.47	212	11.5	199	22.1
$CD_{0.05}$	0.11	2650	0.07	155	0.11	10.9	0.76	8.6	1.80
Irrigation level#									
3 Irrigation (CRI, LJ, M)	4.06	49080	2.72	2840	1.43	192	11.0	190	19.8
4 Irrigation (CRI, T, LJ, M)	4.47	55358	2.88	3530	1.26	189	10.8	189	19.5
5 Irrigation (CRI, T, LJ, M, D)	4.78	60465	2.98	3935	1.22	186	10.8	189	19.3
CD (P=0.05)	0.10	-	-	135	-	NS	NS	NS	NS

*CT-Conventional tillage, ZT-Zero tillage, RRSHS-Residue retention sowing through happy seeder; #CRI-Crown root initiation, T-Tillering, LJ-Late jointing, M-Milking, D-Dough stages; WP-Water productivity; Nutrient before crop sowing: N-161, P-10.2, K-181, S-19.3 kg/ha

Table 4.2.2. Effect of sowing method and intercultural operation on performance of pearl millet under pearl millet-wheat cropping sequence

Treatment	Grain yield (t/ha)	Net return ('000 ₹/ha)	B:C ratio	Total water use (m^3/ha)	WP (kg/m^3)
Sowing method					
CT	4.16	43251	2.84	3892	1.07
ZT	4.12	45932	3.27	3800	1.08
25% RRSHS	4.39	46296	3.24	3745	1.17
50% RRSHS	4.52	45640	3.23	3720	1.22
100% RRSHS	4.69	43652	3.64	3698	1.27
$CD_{0.05}$	0.12	1015	0.27	194	0.07
Intercultural operation#					
I_1	3.85	37370	2.56	3876	0.99
I_2	4.59	53999	3.69	3715	1.24
I_3	4.83	56170	3.59	3722	1.30
$CD_{0.05}$	0.34	890	0.21	180	0.05

#I_1-Intercultural operation (IO) through hand weeding, I_2- IO through tractor operated ridgefurrow maker, I_3- Use of weedicide + IO through tractor operated ridge furrow maker

4.3. Kota (AESR 5.2)

4.3.1. Drip fertigation studies on water soluble fertilizers for enhancing water productivity and quality of garlic crop in S-E Rajasthan

Three years of experiment indicated that the *rabi* garlic bulb yield of 16.01 t/ha obtained when drip irrigation was applied at 100% PE is significantly superior to the bulb yield obtained under control (surface irrigation). Similarly, application of 100% of recommended dose of fertilizer (120:40:100) also resulted in significantly higher and maximum garlic bulb yield of 16.31 t/ha, which remained at par with yield (15.41 t/ha) under application of 75% RDF of fertilizer. The interaction effect between irrigation schedule and fertilizer dose showed that maximum WUE of 27.44 kg/ha-mm was recorded with 75% PE and 100% RDF closely followed by 75% PE and 75% RDF (Table 4.3.1).

Table 4.3.1. Effect on irrigation schedule and fertilizer dose performance of garlic crop

Treatment	Garlic yield (t/ha)	Depth of irrigation (mm)	WUE (kg/ha-cm)		
			100% RDF	75% RDF	50% RDF
Irrigation schedule					
100% PE	16.01	588	-	-	-
75% PE	14.17	770	27.44	26.39	22.78
CD (P=0.05)	1.31	-	20.95	20.15	17.4
Fertilizer dose					
100% RDF	16.31	-	-	-	-
75% RDF	15.41	-	-	-	-
50% RDF	13.52	-	-	-	-
CD (P=0.05)	1.80	-	-	-	-
Surface irrigation at 1.2 IW/CPE + Full dose of NPK (120:40:100) as soil application	13.62	820	-	-	-

RDF - Recommended dose of fertilizers

4.4. Navsari (AESR 19.1)

4.4.1. Pit method of planting in sugarcane under drip irrigation

Five years of study showed that pit diameter and pit spacing had significant effect on cane yield (Plate 4.4.1). Significantly higher cane yields of 135.7 t/ha and 137.3 t/ha were observed with pit diameter 60 cm (D_2) during 1st and 2nd ratoon crops, respectively compared to pit diameter 45 cm (D_1), but was at par with pit diameter 75 cm (D_3). Whereas, pit diameter D_2 produced significantly higher cane yields of 120.6 t/ha and 116.9 t/ha over rest of the pit diameter during Ratoon-3 and pooled result, respectively. In case of pit spacing, S_2 (1.75 x 1.75 m) resulted in significantly higher yield of 123.4 t/ha compared to S_3 (2.1 x 2.1 m) (99.1 t/ha). Similar trend was observed with Ratoon-1 and Ratoon-4. Likewise, significantly highest cane yield of 141.9, 126.7 and 123.0 t/ha were recorded under treatment S_2 during Ratoon-2, Ratoon-3 and in pooled results. Interaction effect of pit diameter and pit spacing showed that during Ratoon-2, treatment combination D_2S_2 reported significantly highest yield (151.0 t/ha) over rest of the treatment combinations. Highest net profit of ₹ 2,90,441/ha was reported with treatment D_2S_2 (Table 4.4.3). Net profit over plant crop was positive up to three ratoons in case of both pit treatments. Whereas it is positive up to two ratoon crop only in case of control treatment.

It was recommended that farmers of south Gujarat in heavy rainfall zone should grow sugarcane through pit

Plate 4.4.1. Drip irrigated grown in pits

method. Pit of 60 cm diameter and 40 cm depth should be dug with spacing of 1.75 x 1.75 m by using post hole pit digger. Sixteen two-budded sugarcane sets to be put in pits followed by filling of pits with soil and FYM/biocompost to a depth of 25 cm below and 15 cm above the sets. By adopting this method, three ratoon crops can be taken with higher yield and net profit compared to two ratoon crops with paired row planting (0.6 x1.2 m) under drip irrigation.

Table 4.4.1. Performance of sugarcane under different pit diameter and pit spacing (pooled basis)

Treatment	Cane yield (t/ha)	Water applied (mm)	WUE (kg/ha-mm)
Pit diameter (cm)			
D_1-60 cm	107.8	925	116.5
D_2-75 cm	116.9	925	126.3
D_3-90 cm	112.7	925	121.8
Pit spacing (cm)			
S_1-1.5 x 1.5	115.4	925	124.7
S_2-1.75 x 1.75	123.0	925	132.9
S_3-2.1 x 2.1	99.0	925	107.0
Control	100.0	925	108.0

Table 4.4.2. D x S interaction effect on cane yield in pooled (t/ha)

Treatment	S_1 (1.5 x 1.5 m)	S_2 (1.75 x 1.75 m)	S_3 (2.1 x 2.1m)
D_1: 45 cm	112.5	122.8	88.2
D_2: 60 cm	115.9	127.7	107.2
D_3: 75 cm	117.8	118.5	101.6
Source	**S**	**D**	**S x D**
CD at 5%	3.76	3.76	6.52

Table 4.4.3. Economics of sugarcane under different treatments

Treatment	System cost (₹/ha/year)	Cane yield (t/ha)	Total income (₹/ha)	Net return (₹/ha)
S_2D_1	14514	125	398465	277248
S_2D_2	14514	130	415124	290441
Control	20045	100	319872	215939

Selling price of sugarcane: Rs.3.2/kg

Table 4.4.4. Quality parameters of sugarcane

Treatment	*Pol (%)	Purity (%)	CCS (%)	Fibre (%)	*Pol in cane (%)
Pit diameter (D)					
D_1	17.79	90.04	12.39	14.56	13.43
D_2	17.37	89.35	12.08	14.36	13.19
D_3	17.72	89.70	12.30	14.31	13.40
Pit spacing (S)					
S_1	17.16	89.33	11.95	14.46	13.03
S_2	17.60	89.53	12.22	14.46	13.29
S_3	18.09	90.23	12.63	14.31	13.70
Control	17.95	88.76	12.40	14.55	13.55

*Pol (Polarization measurement) - Sucrose content in juice of sugarcane

4.4.2. Effect of water application in different layers of soil on growth and yield of drip irrigated young mango plantation

The experiment was carried out during the year 2009 to 2017 and initially growth parameters were measured until getting stable yield of mango (2014-15). After getting stable yield of mango, treatment-wise uniform mango trees were selected. In this experiment, 1.5 m away from trunk of mango tree, four HDPE pipes of 75 mm diameter were inserted vertically below ground level (bgl) at different depths (as per treatment). Irrigation water was applied through drip irrigation system directly into these pipes through spaghetti tube of 4 mm diameter fitted on the online dripper (Plate 4.4.2).

Plate 4.4.2. Drip irrigated mango

Pooled analysis showed significantly higher fruit yield of mango (25.4 t/ha) under treatment T_3 (40 cm bgl through drip) compared to rest of the treatments during first year but it remained at par with treatments T_4, T_5 and T_2 (Table 4.4.5). Effect of different treatments did not have significant effect on mango quality. Significantly higher volume of mango fruit (220 ml) was reported with treatment T_4 as compared to rest of treatments, but it remained at par with treatment T_3 (217 ml), T_2 (216 ml) and T_5 (216 ml) (Table 4.4.6). Similar trend was also observed with respect to weight of fresh harvest fruit, weight of ripe fruit and pulp of ripe fruit (Table 4.4.6 and 4.4.7). Maximum acidity was recorded in case of water applied on surface and decreased with increase in the depth of water application. However, in case of pulp peel ratio, reverse trend was observed as compared to acidity of mango fruit (Table 4.4.7). Treatment T_4 registered significantly higher total soluble sugar (21.3%), reducing sugar (2.47%) and non reducing sugar (18.5%) as compared to rest of the treatments. But it remained at par with treatment T_5 in case of total soluble sugar and non reducing sugars, and T_2 and T_3 in case of reducing sugar. Maximum net profit of ₹ 2,53,100/ha was accrued under T_4 i.e. 50 cm bgl followed by treatment T_3 (₹ 2,41,600/ha).

It is concluded that for achieving higher net profit from 8 to 9 year old mango orchard, irrigation water can be applied by drip irrigation system directly in four HDPE/PVC pipe (75 mm diameter) inserted at depth of 40-50 cm bgl on four sides about 1.5 m away from the mango trunk through spaghetti tube (4 mm diameter) fitted on online dripper.

Recommendation for farmers

Farmers of south Gujarat (heavy rainfall zone) having 8 to 9 years old mango plantation at a spacing of 5 m x 5 m are recommended to apply irrigation water after flowering initiation directly into vertically inserted HDPE/PVC pipes (diameter = 75 mm) into the soil at 40 cm depth bgl on four sides 1.5 m away from mango trunk through spaghetti tube (4 mm diameter) fitted on online dripper for getting good quality mango, higher yield, net profit and water use efficiency compared to water applied through surface drip system.

Table 4.4.5. Effect of different treatments on yield of mango fruits

Treatment	Fruit yield (t/ha)	Water applied (mm)	Fruit yield (t/ha)	WUE (kg/ha-mm)	Net profit (₹/ha)
T_1 (Surface)	14.1	598	14.1	23.6	1,79,000
T_2 (30 cm bgl)	16.6	598	16.6	27.8	2,131,00
T_3 (40 cm bgl)	18.5	598	18.5	30.9	2,41,600
T_4 (50 cm bgl)	19.3	598	19.3	32.3	2,53,100
T_5 (60 cm bgl)	18.3	598	18.3	30.1	2,36,500
CD at 5%	1.2	-	-	-	-
-	**CD at 5%**	-	-	-	-
Y	3.9	-	-	-	-
Y x T	2.1	-	-	-	-

Note: Selling price of mango fruit: 17.50 Rs/kg

Table 4.4.6. Effect of water application at different layers on quality parameters of mango fruit

Treatment	Volume of fruit (ml)	Weight of fresh harvested fruit (g)	Weight of ripe fruit (g)	TSS (°B)	Acidity (%)
T_1 (Surface)	198	205	188	18.9	0.44
T_2 (30 cm bgl)	216	228	202	18.9	0.43
T_3 (40 cm bgl)	217	229	200	18.6	0.43
T_4 (50 cm bgl)	220	234	205	18.3	0.41
T_5 (60 cm bgl)	216	230	204	18.3	0.39
CD at 5%	10.7	9.92	9.04	NS	0.021

TSS - Total soluble solids; °B - Brix

Table 4.4.7. Effect of water application at layers on qualities parameters of mango fruit

Treatment	Pulp of ripe fruit (g)	Peel of ripe fruit (g)	Pulp peel ratio	Total sugar (%)	Reducing sugar (%)	Non reducing sugar (%)
T_1 (Surface)	104	34.7	3.07	18.3	2.14	16.4
T_2 (30 cm bgl)	111	35.9	3.13	18.1	2.43	16.0
T_3 (40 cm bgl)	114	35.5	3.28	19.5	2.40	17.2
T_4 (50 cm bgl)	117	36.1	3.30	21.3	2.47	18.5
T_5 (60 cm bgl)	113	34.3	3.40	20.2	2.20	17.4
CD at 5%	6.96	NS	0.238	1.11	0.11	0.89

4.5. Powarkheda (AESR 10.1)

4.5.1. Response of gram (*Cicer aeritinum*) to irrigation levels under late sown condition

Chickpea variety JG 130 was tested for different dates of sowing (15^{th} November, 30^{th} November and 15^{th} December) and number of irrigations at critical growth stages like branching (one irrigation), pod formation (one irrigation), branching + pod formation (two irrigations) and branching + pod formation + grain development (three irrigations) in a split plot design. Results showed that sowing of chickpea on 15^{th} Nov and 30^{th} Nov gave statistically similar yields of 2.95 t/ha and 2.79 t/ha, respectively and significantly lower yield with sowing at 15^{th} Dec (2.12 t/ha). Two irrigations i.e. at branching + pod formation stages proved best treatment with yield of 2.81 t/ha (Table 4.5.1). Additional irrigation at grain development stage had no significant beneficial effect on yield (2.85 t/ha). In case of availability of only one irrigation, it should be applied at pod formation stage (2.56 t/ha). Among the sowing dates, 15^{th} Nov sowing gave net monetary return of ₹ 65,621/ha, B:C ratio of 2.75 and WUE of 127 kg/ha-cm. Among irrigation treatments, highest B:C ratio of 2.60 and WUE of 112 kg/ha-cm was obtained with two irrigations i.e. at branching and pod formation stages.

Table 4.5.1. Performance of chickpea crop to sowing time and number of irrigations

Treatment	Seed yield (t/ha)	NMR (₹/ha)	WUE (kg/ha-cm)	B:C ratio
Date of sowing				
D_1 – 15 Nov.	2.95	65621	127	2.75
D_2 – 30 Nov.	2.79	60161	121	2.60
D_3 – 15 Dec.	2.12	36781	92	1.98
$CD_{0.05}$	0.27	-	-	-
Number of irrigations				
I_1- Branching	2.49	50271	142	-
I_2- Pod formation	2.56	52791	146	-
I_3- Branching + Pod formation	2.81	60506	112	-
I_4- Branching + Pod formation + Grain development	2.85	61081	88	-
$CD_{0.05}$	-	-	-	-

NMR - Net monetary return

4.5.2. Irrigation and fertilizer management in wheat with zero tillage

Two years of experiment showed that grain yield of wheat was significantly affected by irrigation levels (Table 4.5.2). The wheat crop under zero tillage gave the highest seed yield of 4.57 t/ha with irrigation at 1.2 IW/CPE, which was at par to the yield (4.39 t/ha) with 1.0 IW/CPE ratio. Water use efficiency was higher (165 kg/ha-cm) with 0.8 IW/CPE ratio but the net monetary return and B:C ratio were substantially higher with 1.2 IW/CPE (₹ 26299/ha and 1.62) closely followed by 1.0 IW/CPE ratio (₹ 24524/ha and 1.59).

Table 4.5.2. Seed yield, water depth, WUE and economics of wheat under different treatment

Treatment	Seed yield (t/ha)			Depth of water (cm)	WUE (kg/ha-cm)	Net return (₹)	B:C ratio
	2015-16	2016-17	Pooled				
Irrigation level							
I_1 - Irrigation at 0.6 IW/CPE	2.58	4.04	3.30	22.5 (3)	146	9099	1.23
I_2 - Irrigation at 0.8 IW/CPE	3.15	4.26	3.71	22.5 (3)	165	15279	1.38
I_3 - Irrigation at 1.00 IW/CPE	4.09	4.69	4.39	30.0 (4)	146	24524	1.59
I_4 - Irrigation at 1.20 IW/CPE	4.33	4.82	4.57	37.5 (5)	122	26299	1.62
CD at 5%	0.78	0.73	0.55	-	-	-	-
Nitrogen splitting							
N_1 - 50% as basal + 50% at 1st Irrigation	3.59	4.47	4.03	28.1	143	19359	1.47
N_2 - 50% as basal + 25 % at 1st Irrigation + 25 % at 2nd Irrigation	3.53	4.38	3.95	28.1	141	18189	1.44
N_3 - 34% as basal + 33 % at 1st Irrigation + 33 % at 2nd Irrigation	3.49	4.49	3.99	28.1	142	18804	1.45
CD at 5%	NS	NS	NS	-	-	-	-

Market price of wheat – Rs.15/kg; NS: non-significant

4.6. Bilaspur (AER 11)

4.6.1. Effect of different levels of water and spacing on growth and yield of rice under SRI system

Irrigation level significantly affected all the growth and yield attributing characters of rice (var. Karma Mahsuri) under SRI system, except test weight (Plate 4.6.1). Irrigation at 3DADPW (I_2) gave significantly higher plant height (116.3 cm), tiller per metre row length (313), panicle length (27.0 cm) and number of grains per panicle (243) than I_3 and I_4 but followed by I_1 (Table 4.6.1). Among the spacing treatments, S_1 (20 cm x 20 cm) recorded significantly higher number of tillers per metre row length (286), panicle length (26.3 cm) and number of grains per panicle (229) than spacing S_3 (30 cm x 30 cm) followed by spacing S_2 (25 cm x 25 cm). Other parameters like plant height and test weight were non-significant with respect to spacing. Among the irrigation levels, I_2 produced significantly higher grain yield (7.43 t/ha) and straw yield (7.97 t/ha) than I_3 and I_4 but at par with I_1. Under different spacings, S_1 gave significantly higher grain yield (7.42 t/ha) and straw yield (8.40 t/ha) than S_3 but at par with S_2. Water regimes I_2 gave higher net return of ₹ 87544/ha with WUE of 104.44 kg/ha-cm and water saving of 16.44% as compared to I_1. Under different spacings, S_1 gave higher net return of ₹ 86858/ha with 104.35 kg/ha-cm WUE.

On the basis of 3 year of experimentation, irrigation level I_2 recorded maximum rice grain yield (6.92 t/ha) and maximum net return of ₹ 77634/ha. However, higher WUE was gained with treatment I_4. Among the spacing, treatment S_1 (20 cm x 20 cm) gave higher mean yield of rice (7.06 t/ha), net return (₹ 77696/ha) and WUE (106.82 kg/ha-cm).

Table 4.6.1. Performance of rice under varying irrigation levels and plant spacing

Treatment	Plant ht (cm)	Tillers/ meter row	Panicle length (cm)	No. of grains/ panicle	Grain yield (t/ha)	Straw yield (t/ha)	No. of Irrgn.	WEE (kg/ha-cm)	Net profit (₹/ha)	B:C ratio
Irrigation level										
I_1	114.43	277	26.38	224	7.04	7.48	5	82.72	79495	1.93
I_2	116.31	313	27.01	243	7.43	7.97	4	104.44	87544	2.19
I_3	113.30	253	25.85	217	6.34	7.08	3	98.81	70246	1.80
I_4	110.76	238	25.14	197	5.94	6.53	2	103.86	63589	1.65
CD (5%)	3.91	6.9	0.86	5.9	0.68	0.85	-	-	-	-
Plant spacing										
S_1	114.64	286	26.30	229	7.42	8.40	4	104.35	86858	2.10
S_2	113.71	270	26.00	219	6.79	7.18	4	95.44	76712	1.94
S_3	112.75	254	25.99	212	5.84	6.22	4	82.14	62297	1.64
CD (5%)	NS	6.1	0.98	5.1	0.89	0.92	-	-	-	-

I_1: Continuous submergence of 3 to 5 cm ponded water after tillering; I_2: Irrigation at 1 DADPW; I_3: Irrigation at 3 DADPW; I_4: Irrigation at 5 DADPW. Depth of irrigation=7.0 cm. Effective rainfall=43.14 cm. DADPW: Day After Disappearance of Ponded Water; Irrgn: Irrigation

Plate 4.6.1. SRI cultivation

4.6.2. Effect of irrigation levels and crop geometry on *rabi* pigeonpea in unbunded clay soil of Chhattisgarh plains under drip

The experiment showed that grain and stover yields of *rabi* pigeonpea were significantly influenced by irrigation levels and spacing (Table 4.6.2). Treatment I_1 (80% PE) produced significantly higher grain (2.26 t/ha) and stover yield (4.07 t/ha) as compared to I_3 and I_4 irrigation levels, however grain yield was at par with I_2 (60% PE). Treatment I_4 (furrow irrigation) recorded lowest grain and straw yield under study. Spacing S_2 (45 cm x 10 cm) resulted in significantly higher grain yield (2.37 t/ha) and stover yield (3.29 t/ha) in comparison to wider spacing of 60 cm x 10 cm (S_1), but at par with closest spacing of 30 cm x 10 cm (S_3). Water expenses (WE) ranged from 22.92 cm to 54.62 cm. Water expense efficiency (WEE) was maximum (75.69 kg/ha-cm) in I_3, whereas it was minimum (27.90 kg/ha-cm) in I_4 (Furrow irrigation). Further, WEE showed maximum value under S_3 and minimum under S_1. Net return and B:C ratio were maximum with I_1 (80% PE) and minimum with I_4 (Furrow irrigation). Spacing S_2 (45 cm x 10 cm) showed maximum gross, net return and B:C ratio followed by S_3 treatment.

Table 4.6.2. Effect of irrigation level and spacing on performance of *rabi* pigeonpea

Treatment	Grain yield (t/ha)	Stover yield (t/ha)	WEE (kg/ha-cm)	Net return (₹/ha)	B:C ratio
Irrigation level					
I_1 (80%PE)	2.26	4.07	50.00	53087	2.05
I_2 (60%PE)	2.07	3.36	60.68	46507	1.79
I_3 (40%PE)	1.74	2.59	75.69	34852	1.34
I_4 (Furrow irrigation)	1.52	2.16	27.90	27767	1.08
CD (5%)	0.55	0.59	-	-	-
Crop geometry: Plant spacing					
S_1 (60 cm x 10 cm)	1.41	2.88	48.80	23447	0.90
S_2 (45 cm x 10 cm)	2.37	3.29	59.91	57292	2.22
S_3 (30 cm x 10 cm)	1.91	2.96	64.40	40807	1.58
CD (5%)	0.53	0.35	-	-	-

4.7. Jammu (AESR 14.2)

4.7.1. Alternate wetting and drying irrigation regimes management in basmati rice through field water measuring tube device under light texture soil

Three years of experimentation with basmati rice showed that all treatments of alternate wetting and drying irrigation regimes significantly influenced average grain and straw yields of rice (Table 4.7.1). Cultivation with farmers' practice (T_8) resulted in significantly higher grain yield (2.98 t/ha) and straw yield (6.68 t/ha), which was statistically similar with T_1 (Irrigation after 7 cm drop of water level below surface 7 DAT to 10 days prior to harvest) i.e. grain yield of 2.80 t/ha and straw yield of 6.56 t/ha. Maximum average B:C ratio for three years was 1.78 with farmers' practice (T_8) followed by T_1 with B:C ratio of 1.75. Highest WUE (2.06 kg/ha-mm) was recorded under Irrigation after 15 cm drop of water level below surface from 7 DAT to 10 days prior to harvest (T_3), whereas lowest WUE (1.22 kg/ha-mm) was under farmers' practice (T_8). Maximum water saving (50%) was recorded under T_3 treatment over T_8. Therefore, farmers may be recommended to apply irrigation after 7 cm drop of water level below surface 7 DAT to 10 days prior to harvest for obataining maximum economic benefit in light texture soil of Jammu. Water saving with this treatment was 18.73% higher over farmers' practice.

Table 4.7.1. Effect of alternate wetting and drying regime through measuring tube device on grain yield, straw yield and economics of basmati rice

Treatment#	Grain yield (t/ha)			B:C ratio	WUE (kg/ha-mm)			Water saving (%)
	2015	2016	2017		2015	2016	2017	
T_1	3.06	2.96	2.39	1.75	1.43	1.45	1.11	18.73
T_2	2.75	2.79	2.24	1.67	1.67	1.88	1.29	37.57
T_3	2.61	2.67	2.14	1.62	2.02	2.09	1.54	49.25
T_4	2.81	2.82	2.27	1.61	1.41	1.48	1.13	24.01
T_5	2.91	2.85	2.39	1.58	1.17	1.26	0.97	7.94
T_6	2.75	2.77	2.26	1.62	1.48	1.57	1.25	30.40
T_7	2.83	2.85	2.29	1.56	1.20	1.30	0.99	12.43
T_8	3.22	3.15	2.56	1.78	1.21	1.22	0.98	-
CD at 5%	0.30	0.25	0.18	-	-	-	-	-

#$T_{2=}$ Irrigation after 7 cm drop of water level below surface from 7 DAT to 10 days prior to harvest; T_2= Irrigation after 10 cm drop of water level below surface from 7 DAT to 10 days prior to harvest; T_3= Irrigation after 15 cm drop of water level below surface from 7 DAT to 10 days prior to harvest; T_4= Irrigation after 10 cm drop of water up to maximum tillering stage and 7 cm drop of water level below surface up to 10 days prior to harvest; T_5= Irrigation after 10 cm drop of water up to maximum tillering stage and continuous submergence up to 10 days prior to harvest; T_6= Irrigation after 10 cm drop of water up panicle initiation stage and 7 cm drop of water up to 10 days prior to harvest; T_7= Irrigation after 10 cm drop of water up panicle initiation stage and continuous flooding upto 0 days prior to harvest; T_8= Farmers' practice

4.8. Palampur (AESR 14.3)

4.8.1. Effect of liquid manure based drip fertigation on water use and productivity of onion-okra sequence

The experiment was conducted for three years with three treatments of liquid manures *viz.*, banana pseudo stem sap (B), locally prepared liquid manure (L) and locally prepared liquid manure + 1% liquid biofertilizers (E) and three fertility levels (substitution of recommended N) *viz.*, 50% from liquid manure + 50% from chemical fertilizer (urea), 75% from liquid manure + 25% from chemical fertilizer and 100% N from liquid manure. These were tested against control treatment where 100% of recommended N from chemical fertilizers + FYM and weekly surface irrigation of 5 cm was applied. Onion crop raised under drip irrigation (0.6 PE), substitution of 100 per cent of recommended N with locally prepared liquid manure which was enriched with 1 per cent liquid biofertilizer (E100) resulted in significantly higher green onion yield, WUE, gross return, net return and B:C ratio than all other treatments during the three years of experimentation (Table 4.8.1). WUE with this treatment was at par with substitution of 100 per cent of recommended N with locally prepared liquid manure (L100). Succeeding okra crop (Table 4.8.2) raised under drip irrigation (0.8 PE), substitution of 100 per cent of recommended N with locally prepared liquid manure which was enriched with 1 per cent liquid biofertilizer (E100) resulted in significantly higher okra pod yield, WUE, gross return, net return and B:C ratio than all other treatments while remaining at par with substitution of 100 per cent of recommended N with locally prepared liquid manure (L100). It was concluded that onion crop should be irrigated at three day interval with 0.6 CPE and okra crop should be irrigated at two day interval with 0.8 CPE. Both crops should be fertigated with 1.0 CPE and recommended nitrogen with locally prepared liquid manure enriched with 1 per cent liquid biofertilizer (E100) and recommended dose of phosphorus and potassium as basal application.

Table 4.8.1. Performance of onion crop under onion-okra cropping system

Treatment	Green onion yield (t/ha)				Water use efficiency (kg/m^{-3})				Net return (₹/ha)				B:C ratio			
	2014-15	2015-16	2016-17	Mean	2014-15	2015-16	2016-17	Mean	2014-15	2015-16	2016-17	Mean	2014-15	2015-16	2016-17	Mean
B50U50	26.13	28.17	22.80	25.70	11.12	13.29	10.65	11.68	213309	237709	355658	268892	2.13	2.07	3.54	2.58
B75U25	27.70	29.63	26.36	27.89	11.79	13.98	12.31	12.69	232236	255436	427242	304971	2.32	2.45	4.27	3.01
B100	30.67	32.87	28.20	30.58	13.05	15.50	13.17	13.90	267542	293942	464425	341970	2.66	2.63	4.66	3.32
L50U50	27.40	28.40	24.53	26.77	11.66	13.40	11.46	12.17	228509	240509	390258	268425	2.28	2.40	3.88	2.85
L75U25	30.33	31.90	28.66	30.29	12.91	15.05	13.39	13.78	264131	282931	473241	340101	2.64	2.83	4.73	3.40
L100	33.00	34.67	31.60	33.09	14.04	16.35	14.76	15.05	293398	313398	532425	379740	2.87	3.06	5.34	3.76
E50U50	28.13	29.30	28.86	28.76	11.97	13.82	13.48	13.09	237642	251642	476858	322047	2.38	2.52	4.75	3.22
E75U25	31.80	32.93	30.93	31.88	13.53	15.53	14.45	14.50	282214	295814	518641	365556	2.84	2.98	5.19	3.67
E100	35.27	37.03	31.83	34.71	15.01	17.47	14.87	15.78	320853	342053	537025	399977	3.15	3.36	5.39	3.97
RF+FYM	21.77	23.47	22.23	22.49	18.14	11.57	11.00	13.57	157564	177964	330241	221923	1.53	1.92	2.88	2.11
RF	14.47	16.37	16.53	15.79	12.06	9.39	8.18	9.87	73514	96314	229491	133106	0.74	1.46	2.26	1.49
CD (P=0.5)	2.27	2.01	1.97	2.11	1.39	1.40	1.32	1.26	28523	25908	26453	26873	0.35	0.35	0.39	0.36

Table 4.8.2. Performance of okra crop under onion-okra cropping system

Treatment	Okra pod yield (t/ha)			WUE (kg/m^{3})			Net return (₹/ha)			B:C ratio		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
B50U50	5.77	5.65	5.71	1.56	1.53	1.55	75421	73088	74255	1.89	1.83	1.86
B75U25	6.97	6.78	6.88	1.89	1.84	1.87	99653	95920	97787	2.51	2.41	2.46
B100	7.47	7.36	7.42	2.02	2.00	2.01	112886	110753	111820	2.83	3.03	2.93
L50U50	6.83	6.90	6.87	1.85	1.87	1.86	97220	98553	97887	2.46	2.49	2.48
L75U25	7.80	7.85	7.83	2.11	2.13	2.12	116320	117320	116820	2.93	2.95	2.94
L100	8.80	8.94	8.87	2.38	2.42	2.40	136553	139353	137953	3.46	3.53	3.50
E50U50	7.67	7.73	7.70	2.08	2.10	2.09	113421	114688	114055	2.84	2.87	2.86
E75U25	8.47	8.54	8.51	2.29	2.32	2.31	129653	131120	130387	3.27	3.30	3.29
E100	9.73	9.80	9.77	2.64	2.65	2.65	155220	156553	155887	3.93	3.96	3.95
RF+FYM	7.30	7.37	7.34	1.93	2.00	1.97	94969	94969	94969	1.86	1.86	1.86
RF	5.47	5.52	5.50	1.49	1.51	1.50	77702	71769	74736	1.46	1.39	1.43
CD (P=0.5)	0.98	0.92	0.95	0.40	0.37	0.39	19512	18532	19022	0.50	0.40	0.45

4.9. Chalakudy (AESR 19.2)

4.9.1. Partial Rootzone Drying method of irrigation in brinjal

Pooled analysis of three years of experimentation showed that yield of the crop was significantly highest for drip at 75% PE and basin irrigation at 100% PE compared to Partial Rootzone Drying (PRD) method of irrigation. Whereas water use efficiency was highest for PRD compared to other treatments. Mulching of the crop basin increased yield and water use efficiency of the crop. Mulching with paddy straw helped in moisture conservation and thereby resulted in better yield (Table 4.9.1).

Soil moisture content was highest for basin and drip methods of irrigation. Different weather parameters greatly influenced yield of the crop. Higher temperature affected flowering and fruit set. Crop yielded only after the initiation of SW monsoon (delayed by 2 months). There was no higher production of secondary roots and root volume did not increase under PRD conditions. Root volume under drip and PRD was comparable (Table 4.9.3). Root volume was comparable among treatments. Reduced irrigation caused yield reduction under PRD. Soil moisture content was also less under PRD condition (Table 4.9.2). Result of the study for the three years showed that drip irrigation along with mulching resulted in better yield and water use efficiency of the brinjal crop. Mulching with paddy straw benefitted in moisture conservation. In situations where water is a most scarce resource, PRD method of irrigation is the most suited one.

Table 4.9.1. Pooled analysis of three years of experiment on the effect of irrigation methods and mulching of brinjal crop

Irrigation method	Yield (t/ha)	Total water use (ha-cm)	WUE (kg/ha-cm)	Net return (₹/ha)	B:C ratio
Irrigation					
Partial rootzone drying at75% PE	7.31	28.52	259.90	131549.45	0.98
Partial rootzone drying at 100% PE	7.39	38.15	193.80	133085.15	0.99
Drip at 75%PE	9.44	57.23	164.90	169865.88	1.33
Basin irrigation	9.72	76.31	127.35	174924.40	1.23
CD (0.05)	1.18	-	21.39	21307.29	0.16
Mulching					
With mulching	8.77	49.95	196.731	157861.29	1.18
Without mulching	8.16	49.95	176.242	146851.15	1.08
CD (0.05)	NS	NS	15.123	NS	NS

Table 4.9.2. Effect of irrigation methods and mulching on soil moisture content (%)

Factor A* (Irrigation method)	Factor B (Mulching)*		Mean
	Without mulch	With mulch	
PRD 75% PE	9.46	10.71	10.08
PRD 100% PE	9.99	10.71	10.34
Drip 75% PE	12.12	13.01	12.57
Basin 100% PE	12.68	13.44	13.07

*CD (0.05) for Factor A = 0.92, Factor B = 0.65 and A x B = 1.31

Table 4.9.3. Root growth characteristics of brinjal

Treatment	No. of primary roots	No. of secondary roots	No. of tertiary roots	Fresh weight (g)	Dry weight (g)	Root volume (cm^3)
PRD 75% PE	6	23	226	50.4	38.8	75
PRD 100% PE	9	16	209	31.48	31.07	53
Drip 75% PE	6	18	157	39.03	29.93	68
Basin 100% PE	6	23	205	45.52	34.20	60

Theme 5

To evolve management strategies for conjunctive use of surface and groundwater resources for sustainable crop production

5.1. Coimbatore (AESR 8.1)

5.1.1. Conjunctive use of groundwater and canal water in the command area of Lower Bhavani Project

Total cropped areas and fallow areas were collected for three years from 2014 to 2016 to assess the present cropping situation (Table 5.1.1). It was observed that during canal water release, percentage of cropped area was high at the head reaches and decreased towards the tail reaches. During the non release of canal water supply, percentage of fallow increased considerably at head and middle reaches of the distributary.

Table 5.1.1. Cropped and fallow areas in Kugulur distributary

Particular	2014-Odd turn			2014-Even turn		
	Head	Middle	Tail	Head	Middle	Tail
Cropped area (%)	74.52	74.25	56.35	73.49	74.81	67.65
Fallow area (%)	25.48	25.75	43.65	26.51	25.19	32.35
	2015-Odd turn			2015-Even turn		
Cropped area (%)	87.2	79.01	62.21	56.33	64.72	64.46
Fallow area (%)	12.8	20.99	37.79	43.67	35.28	35.54
	2016-Odd turn			2016-Even turn		
Cropped area (%)	62.15	52.14	38.48	53.33	44.83	51.06
Fallow area (%)	37.85	47.86	61.52	46.67	55.17	48.94

Major crops such as sugarcane, banana, groundnut and irrigated wetland paddy were analysed to study the pattern of conjunctive use of surface water and groundwater in the study area (Table 5.1.2 and 5.1.3).

Table 5.1.2. Conjunctive water use for sugarcane during the year 2015

Canal reach	Area irrigated (ha)	Crop water demand (ha-m)	Canal water supply		Groundwater		Conjunctive use	
			ha-m	Percent	ha-m	Percent	ha-m	Per cent
Odd turn sluice command								
Head	20	36.48	26.74	73.30	9.74	26.70	6.82	18.69
Middle	18	32.83	21.93	66.80	10.90	33.20	8.72	26.56
Tail	15	27.36	12.09	44.20	15.27	55.80	9.92	36.27
Even turn sluice command								
Head	18	32.83	-	-	32.83	100.00	-	-
Middle	19	34.66	-	-	34.66	100.00	-	-
Tail	12	21.89	-	-	21.89	100.00	-	-

Table 5.1.3. Conjunctive water use for banana during the year 2015

Canal reach	Area irrigated (ha)	Crop water demand (ha-m)	Canal water supply		Groundwater		Conjunctive use	
			ha-m	Percent	ha-m	Percent	ha-m	Percent
Odd turn sluice command								
Head	18	47.88	38.89	81.23	8.99	18.77	5.30	11.07
Middle	14	37.24	25.99	69.80	11.25	30.20	8.50	22.83
Tail	11	29.26	13.99	47.80	15.27	52.20	10.87	37.17
Even turn sluice command								
Head	17	45.22	-	-	45.22	100.00	-	-
Middle	19	50.54	-	-	50.54	100.00	-	-
Tail	12	31.92	-	-	31.92	100.00	-	-

Annual canal water supply for the year 2015 was 2239.18 ha-m. It has been observed that maximum canal supply of 527.1 ha-m is in September followed by 326.1 ha-m in October (Fig. 5.1.1). There is no canal water supply during May, June and July. Groundwater requirement has also been estimated and it has been observed that maximum groundwater requirement was during May to July. The annual groundwater requirement is 627.82 ha m. When there was supply in the distributary, demand of groundwater was low.

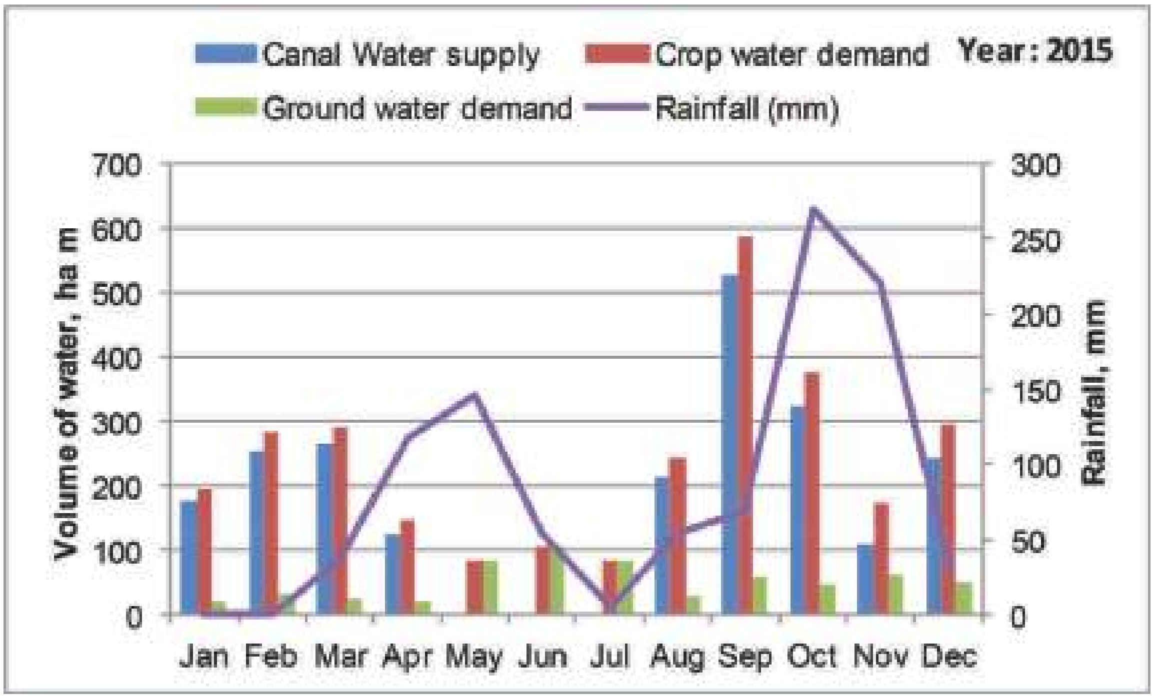


Fig. 5.1.1. Monthly canal water supply, crop water demand and ground water requirement for the selected distributor for the study period of 2015

Gross groundwater draft was 1369.01 ha-m. Net draft was 75% of gross draft. So net draft was 1026.76 ha-m. Stage of groundwater development was 61.5%, that was considered to be 'safe'. From the year 2015, groundwater depth varied between ground level and 8-12 m below ground level (bgl) in head, middle and tail reaches of the distributary. Depth to water level during pre monsoon (Sep 2015) was 8.5 m bgl, while it ranged from 1.0-7.5 m bgl during post monsoon (Jan 2015). During 2016, depth to water level in the distributary varied between ground level and 20-25 m bgl in head, middle and tail reaches of the distributary. Depth to water level during pre monsoon (Sep 2016) was 15-20 m bgl, and 1.0-3.0 m bgl during post monsoon (Jan 2016).

Long-term water level fluctuation at the distributary for the period 1971-2013 was studied with water level data of observation well (Fig. 5.1.2). The study indicated that rise in water level in the distributary was 0.03 - 0.09 m/year and fall in water level was 0.01 - 0.50 m/year.

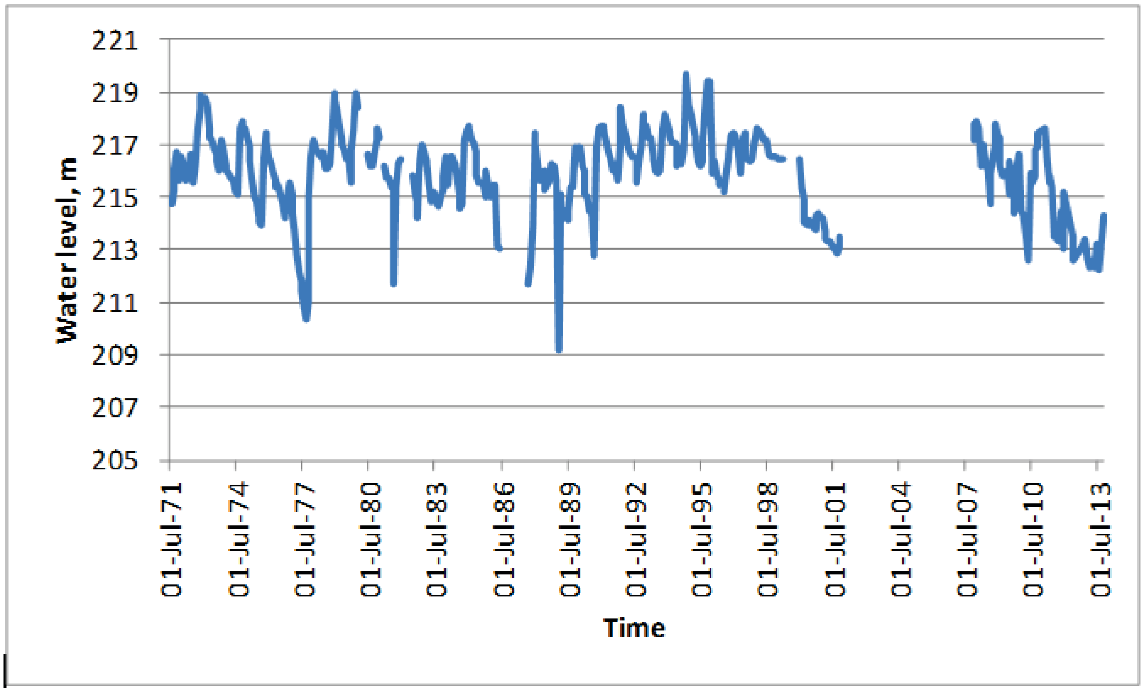


Fig. 5.1.2. Long-term water level fluctuation from 1971 to 2013

Conclusion and Recommendation

Conjunctive use of canal water and groundwater can be managed for minor irrigation command areas using the following strategies:

- Raising waterlogging and salinity problems in Kugulur distributary is easily manageable.
- The canal command was originally designed for wet and dry crops alternately in a calendar year. But farmers are practicing high water consuming cash crops such as sugarcane and banana throughout the year irrespective of low or no flow situation. This practice must be avoided by adopting micro irrigations.
- Deliver less water to canal head end water courses and redirect flows to tail end outlets; water distribution equity is restored in the canal and/or reverse inequity is established.
- Increase surface water supplies to an entire distributary command so that farmers in middle and tail reaches can get an increase over currently sanctioned allocations.
- Periodically skip certain canal rotations to induce farmers especially at head reaches to use groundwater during those periods.
- Groundwater from wells in the command area may be pumped into the canal system to increase water supply. Though the feasibility for this option is very limited, it augments the canal water to lower the water table to prevent waterlogging problems. Community wells may be developed in such waterlogged areas.

- Allow the farmers to manage/develop the available groundwater resources to cultivate crops. It may reduce the dependency on canal water.
- Pipe irrigations for canal water supply may be adopted for tail end farmers.
- On long term options, ratio of surface water to groundwater in conjunctive use in irrigated agriculture may be identified assuming no change in the total volume of irrigation water demand.

5.2. Bathinda (AESR 2.1)

5.2.1. Growth and water use of tree species under different saline sodic water environments

The experiment was conducted to check the suitability of tree species under saline sodic water environments. It was conducted on loamy sand soil (Table 5.2.1) in a randomized block design with three replications with 7 trees per plot. Plantation of *Eucalyptus* (C 413, *Eucalyptus triticornis*), poplar (PL 7, *Populus deltoides*) and dek (local, *Melia azadirach*) was done on 08.09.2010, 27.01.2011 and 23.08.2010, respectively. The 6-year experimental data on growth attributes revealed that irrigation with different proportions of fresh canal water (CW) and tubewell water (TW) having low salinity and high SAR i.e. saline-sodic had non-significant effect on girth, height, timber and fuel wood in case of *Eucalyptus* (Table 5.2.2). Among different treatments, height, girth, timber and fuel wood of poplar trees were at par among CW, CW-TW and 2CW-1TW treatments which were significantly higher than TW and 2TW-1CW treatments (Table 5.2.2). In case of dek, maximum height, timber and fuel wood was found in CW treatment, which was statistically at par with 2CW-1TW but significantly higher than irrigation with TW and 2TW-1CW (Table 5.2.3). Irrigation water applied in 5 years was 169.4 cm for *Eucalyptus*, 163.8 cm for poplar and 144.6 cm for dek. Among the tree species, water productivity and economic returns were higher with *Eucalyptus* followed by dek and least in poplar (Table 5.2.1) under saline sodic irrigation water in calcareous soil of semi-arid region in Punjab. It was concluded that *Eucalyptus* can be successfully grown with saline–sodic water (EC upto 2.4 dS/m; RSC upto 6.5 meq/L) in calcareous loamy sand soil for higher economic returns. Poplar can be grown with alternate irrigation of CW and saline sodic TW whereas dek can be cultivated in rotation of two irrigations with CW followed by one irrigation with saline sodic TW after initial establishment of seedlings with good quality water. Therefore, the light textured calcareous soils and marginal underground waters can be efficiently utilized for growing of *Eucalyptus* which may help in diversification and increasing forest cover to some extent. The poplar and dek can be grown with conjunctive use of saline sodic water with good quality water CW in a coarse textured calcareous soil.

Table 5.2.1. Performance of Eucalyptus under different qualities of water

Treatment	Height (m)	Girth (cm)	Timber wt (t/ha)	WP (kg timber/m^3 water used)	Fuel wood wt (t/ha)	NR (₹/ha/year)	WP (kg wood/m^3 of water)
CW	22.54	71.2	216.9	5.53	81.9	137869	7.62
TW	20.56	65.4	193.8	4.94	71.3	121388	6.76
CW:TW	21.96	70.1	205.0	5.34	78.1	129713	7.22
2CW:1TW	22.41	69.8	209.4	5.23	75.6	132019	7.27
2TW:1CW	20.75	66.7	198.1	5.05	74.4	124706	6.95
CD (5%)	NS	NS	NS	-	NS	-	-

Table 5.2.2. Performance of Poplar under different qualities of water

Treatment	Height (m)	Girth (cm)	Timber wt (t/ha)	WP (kg timber/m^3 water used)	Fuel wood wt (t/ha)	NR (₹/ha/year)	WP (kg wood/m^3 of water)
CW	13.29	50.9	102.3	2.65	31.1	76162	3.45
TW	10.91	39.0	50.5	1.31	17.7	30686	1.76
CW:TW	12.40	47.8	91.1	2.36	23.6	64937	2.97
2CW:1TW	12.94	48.9	96.5	2.50	25.2	69755	3.15
2TW:1CW	11.22	42.1	63.1	1.63	19.2	41261	2.13
CD (5%)	1.34	3.2	15.2	-	4.9	-	-

wt - weight; WP - Water productivity

Table 5.2.3. Performance of Dek under different qualities of water

Treatment	Height (m)	Girth (cm)	Timber wt (t/ha)	WP (kg timber/m^3 water used)	Fuel wood wt (t/ha)	Net return (₹/ha/year)	WP (kg wood/m^3 of water)
CW	12.97	55.5	139.4	3.79	55.4	117788	5.30
TW	9.60	41.8	57.5	1.57	16.4	40450	2.01
CW:TW	11.31	52.0	106.9	2.91	32.3	91944	3.79
2CW:1TW	12.32	53.5	125.6	3.42	40.8	110863	4.53
2TW:1CW	10.79	45.4	76.3	2.08	25.1	63163	2.76
CD (5%)	1.04	3.6	19.8	-	9.9	-	-

wt - weight; WP - Water productivity

Plate 5.2.1. Eucalyptus plantation in Bathinda

5.3. Bilaspur (AER 11)

5.3.1. Effect of value added water and integrated nutrient management on growth and yield of rice-wheat crop sequence under conjunctive water use condition

The yield attributing character of rice i.e. tillers per m^2 and grains per panicles were significantly influenced by different water, whereas, test weight was non significant. Irrigation by dairy ponded water (W_1) recorded significantly higher tillers per m^2 (363.44) and number of grains per panicle (175.8) than W_2 but at par with W_3. Whereas, plant height, test weight and panicle length were found non-significant. Among the nutrient management practices, treatment F_5 (75% RDF + BGA) recorded higher plant height, number of tillers per square metre, test weight, panicle length and grains per panicle than the other nutrient management treatments.

Wheat grown during *rabi* season with conjunctive use of surface water and tubewell water showed significantly higher plant height (95.46 cm), number of grains per panicle (51), grain yield (3.76 t/ha) and straw yield (4.27 t/ha) than irrigation with 100% tubewell water but at par with 50% dairy water + 50% tubewell water. Under different fertility level (residual effect of rice), all the parameters were significant. The grain and straw yields under different sources of fertility i.e. 75% RDF + BGA produced significantly higher grain yield (3.95t/ha), straw yield (4.53 t/ha), plant height (96.29 cm) and number of grains per panicle (53) followed by those with 75% RDF + green manure and 100% RDF (Table 5.3.1).

Table 5.3.1. Performance of rabi wheat and kharif rice influenced by Integrated Nutrient Management and conjunctive use of dairy surface water and tubewell water

Treatment	Wheat		Rice		pH	N (kg/ ha)	P (kg/ ha)	K_2O (kg/ha)	*BD (g/cm^3)
	Grain yield (t/ha)	Straw yield (t/ha)	Grain yield (t/ha)	Straw yield (t/ha)					
W_1: Dairy surface water	3.76	4.25	4.21	5.52	6.83	239.57	11.31	251.85	1.33
W_2: Tubewell water	3.31	4.07	3.80	4.65	6.69	230.83	11.06	247.32	1.33
W_3: Dairy surface water + Tubewell water	3.59	4.22	3.93	4.94	6.75	242.95	11.28	247.30	1.32
CD%	0.50	NS	NS	NS	NS	9.60	NS	NS	NS
F_1: 100% RDF	3.68	4.33	4.07	5.06	6.84	250.89	11.60	255.64	1.33
F_2:75% RDF	3.02	3.79	3.56	4.45	6.67	222.34	10.41	236.08	1.33
F_3: 75% RDF + Green manure	3.85	4.19	3.97	5.22	6.64	243.41	11.54	251.88	1.31
F_4:75% RDF + Brown manure	3.27	4.09	3.77	4.95	6.72	227.02	10.60	246.27	1.32
F_5:75% RDF + BGA	3.95	4.53	4.41	5.48	6.87	245.27	11.95	254.25	1.32
CD%	0.40	0.38	0.67	0.70	NS	13.12	0.53	9.57	NS

*BD - Bulk density

5.4. Rahuri (AESR 6.2)

5.4.1. Conjunctive use planning of surface and groundwater in Musalwadi minor irrigation project under Mula Irrigation Project

Musalwadi minor irrigation project under Mula (major) Irrigation Project was chosen for the study. The study involved the inventory of total water resources in outlet command area, utilization pattern, studying the existing conjunctive utilization strategy and evolving several alternative strategies, development of the concept for conjunctive use of groundwater and surface water in the command area of the irrigation project, development of methodology and model for different chosen outlets for different utilization strategies. Results showed that maximum net benefit obtained was ₹ 1,00,94,226 when irrigations were applied as per the rotations of surface water. Whereas, maximum net benefit obtained was ₹ 1,43,17,437 when the irrigations were applied as per the recommendations by using conjunctive use strategy (surface water + groundwater). Maximum net benefit of ₹ 1,79,35,617 was obtained when four irrigations are applied using surface water and seven irrigations using groundwater as a conjunctive use strategy (Table 5.4.1).

Table 5.4.1. Conjunctive use strategies based on volume (4 surface water irrigations + 7 groundwater irrigations) and net benefits

Strategy Id.	Total area (ha)	Source	Total water required (mm)	*SWR (mm)	**GWR (mm)	Total cost (₹)	Total benefit (₹)	Net benefit (₹)	Aquifer penalty (₹)	Reservoir penalty (₹)	Canal penalty (₹)	Benefit considering penalties (₹)
1	336.34	7GWR + 4SWR	91689.52	27784.52	63905	38681570	55050649.9	16369079.68	0	276850	6937.05	16085292.62
2	336.34	7GWR + 4SWR	100694.25	29658.55	71035.7	38681570	55689042.2	17007471.98	0	280800	6826.19	16719845.78
3	336.34	7GWR + 4SWR	97341.57	27852.97	69488.6	38681570	55787256.4	17105686.18	0	281550	6956.15	16817180.02
4	336.34	7GWR + 4SWR	108766.13	29120.05	79646.08	38681570	56720291.3	18038721.08	0	283700	6861.68	17748159.39
5	336.34	7GWR + 4SWR	118329.75	35185.63	83144.12	38681570	56916719.7	18235149.48	0	293050	6481.68	17935617.79
6	336.34	7GWR + 4SWR	93798.98	29557.7	64241.28	38681570	55787256.4	17105686.18	0	285650	6775.68	16813260.49

*SWR - Surface water required; **GWR - Groundwater required

TECHNOLOGY ASSESSED REFINED AND TRANSFERRED

Technologies assessed and refined by centres of AICRP on IWM under their corresponding agro-ecological regions (AER) and agro-ecological subregions (AESR) are listed below.

AER 2

AESR 2.1: Hot hyper-arid ecosub-region (ESR), shallow and deep sandy desert soils

Bathinda

Cyclic use of saline sodic water and good quality canalwater (1:1) can result in higher green okra yield along with rice mulch @ 6 t/ha in south-west Punjab. This technology has been approved by REC in 23.05.2017 and included in the package of practices.

Sriganganagar

- Drip irrigation at 0.8 ETc was found optimum irrigation schedule for **bitter gourd**. It gave 14.5 % higher fruit yield and saved 52.6 % irrigation water over surface irrigation. This treatment gave net seasonal income worth ₹ 7,51,384 with BC ratio of 3.40. If there is scarcity of irrigation water, then the drip irrigation in bitter gourd at 0.6 ETc has been recommended. This treatment saved 60.7 % irrigation water in comparison to flood irrigation without reduction in fruit yield.
- The application of 180 kg N, 120 kg P_2O_5 and 80 kg K_2O/ha with drip irrigation in 9 equal splits each at an interval of 11 days has been recommended as an optimum fertigation schedule for **tomato**. It gave 24.28% higher fruit and saved 24.18 % irrigation water over surface irrigation. It gave net seasonal income of ₹ 3,39,200 with B:C ratio of 3.40. One can save 40 % of fertilizer without any reduction in fruit yield of tomato with the application of 108 kg N, 72 kg P_2O_5 and 48 kg K_2O/ha with drip irrigation in 9 equal splits each at an interval of 11 days as its yield was at par with 100 percent RD of nutrient with flood irrigation.
- In case of canal closure or some other reason if sowing is not possible in time, then **cotton** seedlings may be raised in plastic bags and transplanted in field up to 30th May with drip irrigation without yield losses. Transplanted cotton crop with drip irrigation on 30th May, 10th June and 20th June gave 15.42, 24.18 and 47.00% higher seed cotton yield over direct sown crop on these dates with drip irrigation, respectively. Transplanted cotton crop with drip irrigation on 30th May gave net seasonal income of ₹ 86,589 per hectare with B:C ratio of 1.95.

AER 4

AESR 4.1: Hot semi-arid ESR, with deep loamy alluvium-derived soils (occasional saline and sodic phases)

Udaipur

Low cost rainwater harvesting-cum-groundwater recharge structures were constructed at Doongri Para, Jhanpa and Punjpur villages of three districts (Udaipur, Banswara and Dungarpur) of Rajasthan having hard rock regions. Groundwater storage capacity of the structures at Doongri Para, Jhanpa and Punjpur was 260 to 3489 m^3, 450 to 8966 m^3 and 1145 m^3, respectively. The structures were utilized to store rainwater and provide life-saving irrigation to *kharif* maize suffering from dry spells on 0.70 ha and 1.1 ha land during 2016 and 2017, respectively, and also *rabi* crops (wheat and chickpea) grown on 7 ha land in the villages. These recharge structures helped in improving socio-economic status of tribal farmers of the region. An additional recharge of about 18518 m^3 and 8626 m^3 has been created in Jhanpa and Doongri pada, respectively. Economic returns due to the structures in terms of agricultural production in Jhanpa and Doongri pada showed benefit:cost ratios of 1.07:1 and 1.96:1, respectively.

AER 5

AESR 5.1: Hot dry semi-arid ESR, shallow and medium loamy to clayey black soils (deep black soils as inclusion)

Junagadh

- Runoff coefficient, mathematical model and nomograph developed for rainfall intensity-duration-frequency relationship is suggested for hydrologic design of flood control and design of water harvesting-cum groundwater recharging structures, etc. for the scientific community/ NGOs/Government sectors working on implementations of projects on flood control and water harvesting-cum-groundwater recharge.
- Under planning for conjunctive use of surface water and groundwater for wheat crop in Junagadh region, 533.94 cu-m of groundwater draft (7.72%) per hectare can be reduced and 123.8 kWh power (4.9%) per hectare can be saved per irrigation given from check dam. It is economical when at least two

irrigations are given from surface source. From second irrigation to wheat crop, the benefit-cost ratio rises by 0.038 with conjunctive use compared to without conjunctive use per irrigation given from check dam. Conjunctive use of water can reduce up to 101 mm of evaporation loss from surface water sources.

- Scientific community/Government/Non-government organizations were suggested that aquifer properties for different talukas of Junagadh district are useful for groundwater recharge/development planning and management as well as simulating groundwater behavior for adopted cropping pattern. It can also be useful for finance institutions for sanctioning loans on groundwater development projects.
- **Suitability of groundwater quality for drip irrigation:** Contour maps of groundwater quality parameters like EC, TDS, pH, Ca, Mg, Na, Fe and Mn, carbonate, bicarbonate, chloride, sulphate, nitrate-nitrogen and water hardness based on groundwater sample analysis of 391 wells in 73 talukas of 11 districts of Saurashtra region during *rabi* season 2012 and 2013 are proposed which can be useful for the farmers for the drip irrigation operation and maintenance. The scientific information along with groundwater quality maps are released for the scientific community.
- **Seawater intrusion impacts on the groundwater quality in South Saurashtra coast:** The groundwater quality parameters *viz.*, EC, pH, Ca, Mg, Na, K, CO_3, HCO_3 and Cl, SAR, ESP and RSC and SAR, RSC, RSBC, SSP, TDS, Puri's Salt index, total hardness, LSI, sodium hazard, potential salinity, permeability index, Mg/Ca, MAR, Kelli's ratio, Ca^{++}/HCO_3^-, Na^+/Cl^-, Mg^{++}/Cl^- and HCO_3^-/Ca^{++} are proposed for the coastal belt area at distances of 5, 10, 15 and 20 km from seacoast during before/after monsoon period. Various criteria are considered for evaluating the quality of irrigation water. The mathematical models relating rainfall and groundwater EC are developed for the scientific communities/line departments of state/central governments/NGOs. The information is also useful for selection of cropping pattern and irrigation water management strategies by the farmers.
- Water harvesting measures were suggested to be the best options for improving groundwater quality in the coastal area. Groundwater quality w.r.t. EC, pH, carbonates, bicarbonates, chlorides, SAR, RSC and soluble sodium percentage has been improved in treated area compared to non-treated area.

Kota

Total 60 field demonstrations were conducted at farmers' field, out of which 18 were at head, 18 at middle and 12 at tail reaches of Manasgaon distributary. Besides these, 6 each of SRI and soybean + maize intercropping demonstrations were also carried out at farmers' field. The project staff advised Govt. officials to promote improved and innovative water management technologies among farmers. The technologies undertaken were:

Crop	Technologies undertaken
Wheat and soybean	Border strip irrigation (5 m x 50 m) with 80% cut-off ratio
Soybean + maize intercropping	Intercropping of soybean + maize (4:2) and irrigation at critical stages *viz.*, flowering and pod development (need based)
Wheat and soybean	Irrigation at critical stages: CRI, tillering, flowering, milking and pod development
Paddy	Irrigation of 7 cm (5±2) depth of irrigation with 1-3 days after disappearance of ponding water
Paddy	System of Rice Intensification (SRI)
Wheat	Conjunctive use of water i.e. cyclic irrigation with canal and brackish water or blending
Coriander	Sprinkler irrigation

AER 6

AESR 6.2: Hot moist semi-arid ESR, shallow and medium loamy to clayey black soils (medium and deep clayey black soils as inclusion)

Parbhani

1. Inline drip irrigation system at alternate day with 1.0 ETc depth of irrigation should be practiced by the farmer for better and quality yields of *rabi* **onion.** For better and quality produce of *rabi* onion, application of 75 kg/ha nitrogen through water soluble fertilizers in drip system with five equal splits at 15, 30, 45, 60 and 75 days after planting should be adopted.
2. For better and quality produce of *rabi* **brinjal,** inline drip irrigation system with one lateral for paired row (0.6 x 0.6 m) is recommended to operate at alternate day with 60% of pan evaporation depth.
3. For increased yield, quality produce and economic return from **turmeric,** it is recommended to apply irrigation of 60 mm when cumulative pan

evaporation reaches 75 mm at 0.8 IW/CPE (the average irrigation interval of different months is June-14, July-16, August and September-18, October-13, November-15, December and January-17, February-13 and March-10 days). For increased yield, quality produce and economic returns from turmeric it is recommended to apply 150:50:50 kg/ha N, P_2O_5 and K_2O respectively as compared to other combinations of fertilizers.

4. For higher yield, gross monetary return, net monetary return and B:C ratio, it is recommended to irrigate ***Bt* cotton** after every two days with 0.5 CPE depth using in line drip irrigation system for paired planting at 60 x 60 -120 cm as sole crop or 180 x 30cm with green gram as intercrop. For higher yield and economic benefits from *Bt* cotton, application of 75:37.5:37.5 kg/ha NPK through water soluble fertilizers in 7, 3 and 4 splits respectively during 7 to 115 days after sowing is recommended.

5. For highest yield and economic benefit, **wheat** crop be irrigated by sprinkler method with 5 cm depth at five critical growth stages (CRI, tillering, late jointing/booting, flowering and milk stage).

6. For higher yield, gross monetary return, net monetary return and B:C ratio of *rabi* **sorghum**, inline drip irrigation system scheduled at 1.0 ETc is recommended for paired row planting of 45x15-75 cm. The recommended fertilizer dose 80:40:40 kg/ha NPK in 3,2 and 3 splits, respectively till 60 days after sowing is recommended.

7. For higher yield, gross and net monetary return, and B:C ratio of *rabi* **okra,** inline drip irrigation system laid at alternate row and scheduled at alternate day with depth of water equal to 40% pan evaporation along with 75% recommended dose of water soluble fertilizers at 75,37.5 and 37.5 kg/ha NPK, respectively in 5,3 and 5 splits from 0 to 75 days after sowing is recommended.

8. For higher yield, gross monetary return, net monetary return and B:C ratio of **sweet orange**, inline drip system forming a loop around the tree canopy is recommended along with application of 75% recommended dose of fertilizers (600:300:300 g/plant NPK) in 12 splits till 240 days after stress withdrawal of *Mrugbahar*.

9. For higher fresh rhizome yield, net monetary return and B:C ratio of **turmeric** planted on 1.5 m wide raised bed with paired row planting (45 x 15 cm), it is recommended to schedule alternate day inline drip irrigation with 80% of cumulative pan evaporation.

   Similarly, drip fertigation with 160:80:80 N, P_2O_5, K_2O kg/ha to **turmeric** with N in 5 equal splits @17.5% at an interval of 30 days from 30 DAP to 150 DAP while sixth dose of N @12.5% at 180 DAP and P_2O_5 and K_2O in 3 splits of 50%, 25% and 25%, respectively at planting, 60 DAP and 120 DAP is recommended.

10. For higher fruit yield and net monetary return of *rabi* **brinjal**, it is recommended to schedule inline drip irrigation at 80% of pan evaporation daily with fertigation of 80:40:40 kg/ha of N: P: K; N in 5 equal splits at an interval of 30 days from transplanting to 120 DAP, and P and K in three splits of 20, 10 and 10 kg/ha, respectively at planting, 30 DAP and 60 DAP.

11. For higher yield and net monetary return from summer **groundnut,** it is recommended to adopt inline drip lateral laid at the centre of broad bed furrow (BBF) having top width of 90 cm and three rows of groundnut planted at 30 cm covered by transparent or black polythene mulch and daily irrigation scheduled at 100% of pan evaporation on medium deep soils of Marathwada region.

12. For higher yield and net monetary return from **watermelon**, inline drip irrigation scheduled at 80% of pan evaporation daily with lateral laid at the centre of broad bed furrow of 90 cm top and crop is sown at 50 cm plant to plant spacing on the bed covered with black polythene mulch of 30 micron is recommended.

13. In **soybean-chickpea cropping system** for higher yield and economic returns from chickpea it is recommended to apply two irrigations of 60mm depth first at flowering and second at pod formation stage through sprinkler irrigation.

AESR 6.4: Hot dry sub-humid ESR with shallow and medium loamy and clayey black soils (deep clayey black soils as inclusion)

Belavatagi

- Proven technology is very much popular in Malaprabha command and farmers are adopting for saving of irrigation water. The AAF technology can be adopted in any region of the country where maize and cotton is growing in Vertisols. This AAF technology saves water, time and labour. This avoids over irrigation in command area and soil salinity.
- Proven technology is very much popular in Malaprabha command and farmers are adopting for saving of water. This 80% cutoff length of boarder strip irrigation technology in narrow spaced crops

viz., **wheat** and **chickpea** crops can be adopted in any region of the country. This proven technology will save water, time and labour. This avoids over irrigation in command area and soil salinity.

- Sprinkler irrigation can be used for giving irrigation to **chickpea** crop and it gives higher yield, net returns and B:C ratio as compared to rainfed crop. Combination of surface irrigation at flowering followed by sprinkler at pod formation is ideal for getting higher grain yield, net returns and B:C ratio in chickpea in northern dry zone of Karnataka.

AER 9

AESR 9.2: Hot dry subhumid ESR, deep loamy alluvium-derived soils

Faizabad

- Multiuse of water by either renovating old ponds or constructing new ponds in the areas where water may be available either through canal and rains for pisiculture and on bunds of pond banana, vegetables and fuel trees may be grown. In such pond command areas, integrated farming system (IFS) including pisiculture, duckery and cropping systems was more profitable compared to the conventional cropping system **Rice-Wheat+Rai**. Benefit-cost ratio of 2.40 was obtained with IFS compared to B:C ratio of 1.60 with Rice–Wheat+Rai. The farmers are very much convinced with this system.
- Improved water management practices in **rice** (7 cm water, 1-3 days after disappearance of ponded water applied with check basins of 10 m x 10 m) should be practiced in place of continuous ponding of water through plot to plot or field to field flood irrigation method.
- Improved water management practices in **wheat** (6 cm water at CRI, late jointing and milking stages by check basin of 10 m x 5 m) should be practiced in place of heavy irrigation through plot to plot or field to field flood irrigation method.
- **Pigeonpea** grown on raised bed in paired rows at 50 cm spacing intercropped with 5 rows of short duration rice (NDR-97) in sunken beds or 3 rows of blackgram (100 cm) on raised beds was more productive and remunerative under poor availability of canalwater at tail end of minor during *kharif* season.
- **Rice-potato-okra** and **maize-potato-okra** were found most remunerative cropping systems under head and tail end of distributory, respectively. Okra crop sown in summer needs more irrigation. It was also observed that okra should be sown on raised beds and 5-6 cm water should be given at 7 days interval after first irrigation (at 20 DAS).
- Application of 75% NPK (RDF) + 25% N through biocompost was found suitable with five irrigations at critical stages in case of **wheat**.
- Drip irrigation @ 80% on wetted surface with 75% N was suitable for irrigation in **aonla** orchard.
- Drip irrigation @ 80% PE with 100% N was suitable for **sugarcane** crop production being high yielding and more remunerative irrigation system.
- Drip irrigation @ 80% of PE with 100% N is more suitable for **marigold** as it gives higher production of marigold flower and more remunerative.
- 7 cm irrigation at 3 DADPW before panicle initiation (PI) and at 1 DADPW from PI to milking stage of scented **rice** with 75% RDF + 25% N through biocompost is high yielding and more remunerative for production of scented rice.
- Drip irrigation @ 80% PE every third day under rice straw mulch (5 t/ha) is high yielding and most remunerative irrigation system for *zaid* **cowpea.**
- 15-25 October is optimum period for planting of *rabi* **maize** with 1.0 IW/CPE moisture regime for getting maximum production and higher net return.
- Irrigation level 0.8 IW/CPE with integrated nutrient supply system (75% RDF + 25% N through biocompost) has been found most suitable for getting higher production and economic return from **broccoli**.
- **Wheat** crop should be sown latest by 25th December and irrigated at 1.0 IW/CPE schedule for high production of wheat under late sown condition.
- Irrigation schedule 7 cm water at 4 DADPW is high yielding and economical for drum seeded **rice** under puddled soil.
- Irrigation schedule 1.0 IW/CPE with raised bed paired row planting of **mentha** on 70 cm beds and 20 cm furrow is high oil yielding and economical for mentha cultivation.
- Fertigation @ 60% of PE with 100% nitrogen application every 3rd day is high yielding, efficient and economical viable irrigation system for tomato crop production.
- Fertigation @ 80% of PE with 100% nitrogen every 3rd day is found high yielding and most remunerative irrigation system for *zaid* **okra.**

AER 11: Hot moist/dry subhumid ESR; deep loamy to clayey red and yellow soils

Bilaspur

- In rice bunded field, **soybean** can be successfully grown with depth of drainage channel 30 cm at a distance of 6 mstrip in clay loam soil in the region.
- Sprinkler irrigation up to vegetative stage with surface irrigation afterwards gave higher grain yield of **wheat** with lower water expanse and maximum net return as compared to border strip method of irrigation.
- **Wheat** gives higher yield with high WEE and net return by providing 5 irrigations and fertilizer dose of 100:60:40 kg/ha under late sown conditions in Chhattisgarh plain.
- **Chickpea** can be grown successfully in residual moisture of paddy fields and subsequent irrigation at 45 days (at start of flowering) and 90 days (at seed filling) enhance the grain yield.
- The IW/CPE ratio 0.8 (or four irrigations 25, 54, 82 and 102 days after sowing) gives higher *rabi* **sunflower** yield with higher water expense efficiency.
- The IW/CPE ratio 0.9 (or 8-9 irrigations) is recommended for summer **groundnut** which gave higher yield with high water expense efficiency.
- Use of sprinkler irrigation gives higher yield of **onion** and **potato** with increase in yield of 26% and 18% with saving of water 42% and 36% over surface irrigation, respectively.
- The IW/CPE ratio 1.0 with 200 kg N/ha is recommended for **maize** which gave higher grain yield with higher water expense efficiency.
- **Brinjal** (var. Mukta Keshi) response better growth and green fruiting with irrigation at 0.8 IW/CPE (about 7 irrigations at an interval of 20-25 days) with application of 200 kg/ha nitrogen in sandy loam soil.
- The drip irrigation (alternate day) at 0.6 PE with Boron @ 2.0 kg/ha gives maximum **tomato** (var. Pusa Ruby) yield with benefit cost ratio of 1.8 while comparing other drip irrigation treatments (irrigation at 1.0, 0.8 and 0.4 PE) and increased 74% yield and 45.45% saving of water over traditional surface (alternate furrow) irrigation.
- The drip irrigation at 80% PE with paired row planting 60 cm is recommended, for **sugarcane** (var. CO-1305), it gives maximum yield with increased in yield 24.8% and 43.3% saving of water over traditional surface irrigation.
- The higher yield of **banana** was recorded under drip at 80% PE with 43.62% increase in yield and 27.63% saving of water as compared to surface irrigation. When compared with the mulch, 20.3% more water saving is observed.
- **Buch** (*Acorus calamus*) recorded higher rhizome yield with high net return with a spacing of 30 cm x 20 cm. The crop consumes 288 cm of water in its cropping period of 10-11 months if irrigation is provided after 1DADPW. Buch can be well adopted in waterlogged areas.
- Higher grain yield (3.94 t/ha) of **wheat** was recorded with application of fertilizer 100:60:40, NPK kg/ha and water expanse of 32.64 cm. The net return was ₹ 37310/ha.
- Higher bulb yield of **onion** (24.06 t/ha) was recorded with irrigation at 60% CPE and application of micronutrient - Zinc 5 kg/ha + Sulphur 20 kg/ha. The technology provide water expanse efficiency of 585.84 kg/ha-cm with net return of ₹ 1,93,565/ha.
- Irrigation at 3DADPW with spacing of 20 cm x 20 cm provided maximum **rice** grain yield (8.84 t/ha) with maximum net return under System of Rice Intensification (SRI).

AER 12

AESR 12.1: Hot moist subhumid ESR; deep loamy red and lateritic soils

Chiplima

Demonstration of water saving through system of rice intensification (SRI) was done at Village- Basantpur, District- Sambalpur for crop variety MTU-1001 during *Rabi* 2016-17. There was increase in yield by 42.32%, number of effective tillers per hill (21.9) by 253%, number of spikelets per panicle (95.7) by 23.9%, filled grains by 16.7% than the conventional method. Test weight of grains obtained by two methods of cultivation was same. SRI method led to 31% water saving and increased water productivity by 105% compared to conventional method. The cost of cultivation per hectare under SRI method was Rs.7,800 higher than conventional method due to lack of experience of labourers in handling SRI method. But yield advantages compensated for the extra cost of cultivation. It is expected that the additional expenditure in SRI could be minimized with experience in its cultivation over years.

Table 1. Relative performance of conventional and SRI method of rice cultivation in farmers' field of Hirakud command

Parameter	SRI	Conventional	Advantage over conventional (%)
Rice variety	MTU-1001	MTU-1001	-
Spacing	25 × 25 cm	20 × 10 cm	-
Nutrient Management	100% RD (80:40:40)	100% RD (80:40:40)	-
Water Management	Maintenance of water in channels	Shallow submergence (5 ± 2 cm)	-
Weed Management	Mechanical weeding thrice	Hand Weeding twice	-
No of hills/ m^2	16	50	-
Average no. of effective tillers/ hill	21.90	6.20	253.23
No. of spikelets/ panicle	95.70	77.20	23.96
Percentage of filled grains	91.00	78.00	16.67
Test weight (g)	23.80	23.80	0.00
Actual grain yield (q/ha)	60.20	42.30	42.32
Cost of cultivation (₹/ha)	36700.00	28900.00	26.99
Irrigation water requirement (cm)	90.00	130.00	-30.77
Water productivity (kg/ha-cm)	66.89	32.54	105.57
B:C	2.39	2.14	12.07

AER 14

AESR 14.2: Warm moist to dry subhumid ESR, medium to deep loamy to clayey brown forest and podzolic soils

Almora

LDPE lined ponds were constructed by harvesting water from rivulets, nala, spring or roof. Sewage, silt or other impurities were removed from the harvested water by constructing sand filter with the help of locally available sand, stones and gravels. Farmers were advised to make multiple use of the water to enhance water productivity. Ponds with covering of locally made blocks are gaining popularity due to low cost, capacity to fully protect ponds and provide better condition for fish cultivation. Space between locally made blocks was filled with mixture of sand and cement to protect the LDPE lining. Pond covered with net further increased suitability for the multiple water use model. LDPE film lined tanks were built and demonstrated at farmers' field. Capacity of 386 m^3 was developed in one farmer's field in three villages of Almora district during 2016-17. It was constructed to harvest water from surface runoff and small streams. Net was used on tanks to prevent wild animal and children damage the tanks. There is increased acceptance of the tanks among farmers.

Jammu

- **Improving management of irrigation canals in Jammu**: Relative water supply of irrigation commands of Jammu is in the range of 0.3 to 0.4. All the irrigation canals of Jammu province having command area to the extent of 1.0 lakh hectare has 40% and 60% deficit irrigation supply during *kharif* and *rabi* seasons, respectively. The recommendations were presented by AICRP on IWM on 17.02.2018 with JK State Water Resource Regulatory Authority, J&K Government. The Chairperson raised the issue with stakeholders like Chief Engineer of RTIC, Chief Engineer I&FC, Jammu along with Director, Agriculture and Director Command Area, Jammu to improve the management of irrigation potential developed and its utilization so that the recommendations of AICRP on IWM/ SKUAST-J are met with for improving productivity and farmer income within rice-wheat sequence.
- Guidelines to scale-up water productivity through modern irrigation technologies through introduction of microirrigation within small and marginal farmer clusters of Jammu province were passed on to the Principal Secretary, Agriculture Production Department, Srinagar, J&K Govt.

- Targeted area of one lakh hectare comprised of small and marginal farm clusters with irrigation on 1.0 ha basis.
- Targeted area of 2.65 lakh ha, Sloping/Kandi belts comprising of small and marginal farm clusters with irrigation on 0.25 to 0.50 ha basis.

➢ **Multiple water use model for waterlogged areas of Jammu region:** Raised beds: Cereal-based cropping system, vegetable/exotic vegetable-based cropping system, floriculture-based cropping system, pulses-based cropping system, horticulture (high density guava); sunken beds: fisheries (Indian major carps like catla, rohu, mrigal and exotic carps like silver carp, grass carp and common carp). The technology helped in enhancing productivity of wetlands, water productivity and income of the farming community. The technology is included in technology document of SKUAST-J for scalability by stakeholders. Results of the study would be applicable to about 20,000 ha of waterlogged areas within different districts of Jammu province and can be scaled up in Kashmir province as well.

- Refinement of technology guidelines for adopting microirrigation system (mini-sprinkler and microdrip) has been forwarded to the Project officer, Soil and Water Management, Command Area Development, Jammu. Ten percent area each of two canal command *viz.*, Pargwal canal command (286 ha) and Ramban cluster canal projects (270 ha) is to be covered under microirrigation for vegetable crops to improve water use efficiency under PMKSY.
- The design of microirrigation system for vegetable crops is refined for plot size of 100 m x 100 m within farmer clusters. Capacity of water storage tank to meet water requirement per half-an-hour/cycle for 4 mm depth of water within 0.25 ha = 10000 l. Pump size with discharge capacity of pump is 7.5 HP having discharge of 470 l/min/7.8 l/s. Component wise details of microirrigation system has been provided for implementation by CAD and Agriculture department, Jammu.

➢ Technology refinement/recommendations on sprinkler method of irrigation for potato crop during RCM, 2016 has been approved for adoption through OFT's. The salient aspects of the recommendations are that in absence of sprinkler irrigation facility with the farmers, the skip furrow method of irrigation may be popularized/adopted. The water productivity (WP) under sprinkler irrigation will increase by 15% and 66.4% over skip furrow method and flood irrigation, respectively. Sprinkler irrigation increased net return by Rs.9000/ha over skip furrow method and Rs.53,500/ha over flood irrigation.

➢ Technologies transferred to Director Planning, Agriculture Production Department on formulation of state water policy- A view of stakeholders thereof through Directorate of Research related to following action plan.
  - Action plan at block and district level to be adopted by state (I&FC) department, Jammu.
  - Action plan at block and district level to be adopted by Agriculture Department/ Command area/ Allied development departments, Jammu.

AESR 14.3: Warm humid to perhumid ESR, shallow to medium deep loamy brown forest and podzolic soils

Palampur

- For better production and economics, onion crop should be irrigated at three day interval with cumulative PE of 0.6% and okra crop should be irrigated at two day interval with cumulative PE of 0.8%. Both crops should be fertigated with 100% of recommended N with locally prepared liquid manure enriched with 1% liquid biofertilizer (E100).
- For higher productivity and profitability, capsicum and tomato crops can be grown through soilless culture under protected conditions. Capsicum and tomato irrigated with 0.8 PE and fertigated with NPK levels of 6.00:3.60:3.00 g/plant and 7.50:4.50:2.50 g/plant, respectively gave yield as much as obtained with irrigation level of 1.2 PE.

AER 17

AESR 17.1: Warm to hot moist humid to perhumid ecosub-region, medium to deep loamy to clayey red and lateritic soils

Shillong

➢ Unpuddled transplanted (4.70 t/ha) and no tilled (3.52 t/ha) **rice** recorded about 199.9% higher yield compared to puddled wet seeded rice. Also, the water use efficiency (195.7%) was significantly higher under unpuddled transplanted rice. The technology was disseminated among farmers.

➢ Intercropping system of **Maize + Groundnut** paired row with residue retention resulted in 28.2% higher yield (4.78 t/ha) as compared to sole maize yield. Yield of succeeding toria was higher under maize + groundnut paired row (residue removal) (1138 kg/ha) as compared to sole Maize.

➢ **Maize** grown under zero tillage recorded highest grain yield (4040 kg/ha) as compared to conventional tillage. Whereas, among the residue management practices, the grain yields of maize (4226 kg/ha) and toria (1391 kg/ha) were highest under maize stalk cover + poultry manure + *Ambrosia* @ 5 t/ha, and 20.7% and 80.5% higher than the yield recorded under the control, in the same order.

- **Turmeric** grown under terrace condition with paddy straw mulching recorded significantly higher rhizome yield (13389 kg/ha) as compared to other treatments. There was an increase of 126% rhizome yield under paddy straw mulching compared to the other treatments.

Coimbatore

The results of water productivity in integrated farming system in western zone of Tamil Nadu revealed that the wetland IFS recorded lower water consumed (20,454 m^3) compared to conventional farming system (29,620 m^3). The higher gross income of ₹ 5,27,825, physical water productivity (3.68 kg/m^3) and economic water productivity (₹ 25.80/m^3) recorded under IFS compared to CFS.

In garden land IFS situation also, lower amount of water was consumed (14249 m^3) compared to conventional farming system (22,925 m^3). The higher gross income of ₹ 5,62,044 was recorded under IFS compared to CFS (₹ 2,16,838). In garden land, the higher physical water productivity (3.05 kg/m^3) and economic water productivity (₹ 39.44/m^3) were recorded. From the results, the IFS recorded higher no of man-days/ha (698 – wetland & 487 – garden land) compared with CFS (368 – wetland & 318 – garden land).

AER 19

AESR 19.1: hot humid ESR, medium to deep loamy to clayey mixed red and black soils

Navsari

- The farmers of heavy rainfall zone of south Gujarat are recommended to go for pit method of sugarcane planting by digging out pits of 60 cm diameter each in spacing 1.75 m x 1.75 m at 40 cm depth by using post hole pit digger. Sixteen two budded sugarcane sets should be put in the pit with filling of soil and FYM/biocompost to a depth of 25 cm below surface and 15 cm above surface. By adopting of this method, three ratoons can be taken with higher yield and net profit as compared to two ratoons with paired row planting (0.6 m x1.2 m) with drip irrigation.

Proposed system details are:

Lateral and dripper spacing : 3.5 m

Size of micro tube fitted on dripper : 4 mm

Dripper discharge: 8 lph

Operating pressure: 1.2 kg/cm^2

Operating frequency: Alternate day

Operating time: October-December: 1 hour and 50 min to 2 hour and 37 min

March-June: 3 hour and 05 min to 6 hour and 08 min.

- The farmers of heavy rainfall zone of south Gujarat having 8 to 9 year old mango plantation at a spacing of 5 m x 5 m are recommended to apply irrigation water after initiation of flowering directly through vertically inserted HDPE/PVC pipe (75 mm diameter) into the soil at different layers i.e. 40 to 50 cm depth below ground level in four sides at 1.5 m away from the mango trunk through spaghetti tube (4 mm diameter) fitted on online dripper through drip system for getting good quality mango fruit with higher yield, net profit and water use efficiency as compared to water applied through surface drip system.

Proposed system details are:

Lateral spacing	:	5 m
Dripper discharge	:	8 lph
No. of drippers per tree	:	4
Operating pressure	:	1.2 kg/cm^2
Operating frequency	:	Alternate day
Operating time	:	Oct. – Nov.: 2 hour to 2 hour and 20 minutes
March – May	:	2 hour and 26 minutes to 5 hour and 30 minutes

- Farmers of heavy rainfall zone of south Gujarat growing summer rice are recommended that the surface irrigation is more economical than drip irrigation due to higher yield and less cost. However, during water scarcity and availability of drip irrigation system, they can adopt the drip system at 60 cm lateral spacing for getting higher water productivity and 41% water saving, once 4 to 5 irrigations of 80 mm depth given by surface method during initially establishment of the crop.

The system details are as under:

Crop spacing: 20x20:40 cm (Paired row)

Lateral spacing: 60 cm

Dripper spacing: 60 cm

Dripper discharge: 8 lph

Operating pressure: 1.20 kg/cm^2

System operating period: twice in week

Operating time: March to May: 1 hour and 50 minutes to 2 hour and 5 minutes

RECOMMENDATIONS

Recommendations by centres of AICRP on Irrigation Water Management (IWM) during 2016-17 and 2017-18 are given with their corresponding agro-ecological subregions (AESRs). Description of AESR is given within brackets.

Sriganganagar (AESR 2.1: Hot hyper-arid ESR, deep loamy saline alkali soils)

- In *Kharif* brinjal, drip irrigation schedule at 0.8 ETc has been recommended when the crop is grown with 30 micron bicolour (gray & black) mulch. This treatment saved 34.1% of irrigation water over surface irrigation and 15.7% irrigation water over drip irrigation scheduled at 1.0 ETc without plastic mulch. It gave 12.2% higher fruit yield of **brinjal** in comparison to surface irrigation. This treatment gave net income of ₹ 7,32,916 with incremental benefit cost ratio of 2.43.
- In *Bt* **cotton**, drip irrigation at 0.8 ETc has been recommended when the crop is grown on raised bed with bicolour plastic mulch. This treatment gave 8.3 per cent higher seed cotton yield and saved 12.6% water in comparison to drip irrigation at 1.0 ETc without plastic mulch. This treatment gave net seasonal income worth ₹ 86,374 with B:C ratio of 1.65.
- For **bitter gourd**, fertigation schedule of 80 kg N, 32 kg P_2O_5 and 32 kg K_2O/ha in 12 splits each at an interval of 11 days has been recommended. This treatment saved 20 per cent fertilizers and gave 11.5 per cent higher yield in comparison to conventional surface irrigation. This treatment gave net seasonal income worth ₹ 7,03,773 with B-C ratio of 3.20.

Bathinda (AESR 2.1: Hot hyper-arid ESR, deep loamy saline alkali soils)

- In light textured soils, alternate use of saline sodic water and good quality canalwater (1:1) in **potato** is recommended to obtain higher marketable tuber yield. Application of rice straw mulch @ 6 t/ha along with cyclic use of CW/TW further improves the potato tuber yield and to maintain soil health. (Approved in 249th REC meeting of PAU held on 22-01-2016)
- **Guar-Wheat** cropping system for higher economic returns, water productivity and maintenance of soil health in semi-arid region of Punjab (Approved in 249th REC meeting of PAU held on 22-01-2016)
- Alternate use of saline sodic water (TW) and good quality canal water (1:1) in okra is recommended to obtain higher green okra yield. Application of rice straw mulch @6 t/ha along with cyclic use of CW/TW further improves the yield and maintains soil health on long term basis in south-west Punjab. Recommendation included in Package of Practices for vegetable crops.

Morena (AESR 4.4: Moist semi-arid ESR, deep loamy and clayey mixed red and black soils)

- **Pigeonpea–Wheat** crop establishment on permanent broad bed with furrow sowing and sub-surface irrigation with inline dripper is recommended for getting higher yield, benefits, improved water productivity and improved soil health.
- **Soybean–Wheat** crop establishment after levelling of land at 0.1% slope through laser leveller on permanent broad bed sowing and furrow irrigation method is recommended for getting higher yield, benefits, improved water productivity and improved soil health of alluvial plains.
- **Pearlmillet**: Pearlmillet crop establishment with happy seeder and intercultural operations through tractor operated ridge furrow maker method with weedicide addition is recommended for getting higher yield, benefits, improved water productivity and improved soil health of alluvial soil.
- **Wheat:** Wheat crop establishment by happy seeder with residue retention of *kharif* crop and five irrigations at critical stages are recommended for getting higher yield, benefits, improved water productivity and improved soil health of alluvial plains.

Junagadh (AESR 5.1: Hot dry semi-arid ESR, shallow and medium loamy to clayey black soils)

- The aquifer properties for different talukas of Junagadh district were recommended for the scientific community/government/non-government organizations. The properties are useful for groundwater recharge/development planning and management as well as simulating groundwater behaviour for adopted cropping pattern in the region. It can also be useful for finance institution for loan sanctions on groundwater development projects.
- **On-stream check dam** is an effective groundwater recharge technique in Junagadh region, which may

result in 0.15 m^3 groundwater recharge/m^2 of catchment area with cost of ₹ 1.02/m^3 considering prevailing cost.

- **Recharge basin** is a cost effective groundwater recharge technique in Junagadh region, which may recharge 0.13 m^3 groundwater/m^2 of catchment area at the cost of ₹ 0.27/m^3 considering prevailing cost.
- Roof water harvesting is an effective groundwater recharge technique in Junagadh region. Out of potential runoff of 0.73/m^2 of roof area, groundwater recharge of 0.22 m^3 may be done through tubewell and remaining 0.51 m^3 may be stored in a sump with a cost of ₹ 34/m^3. The annual roof water runoff coefficient of 0.71 for rooftop is recommended for designing the **roof water harvesting system**.

Parbhani (AESR 6.2: Hot moist semi-arid ESR with shallow and medium loamy to clayey black soils)

- Inline drip irrigation system with one lateral for paired row (0.6 m x 0.6 m) is recommended to operate at alternate day with 60% PE for better and quality produce of *rabi* **brinjal**.
- Irrigation of 60 mm when cumulative pan evaporation reaches 75 mm at 0.8 IW/CPE is recommended for increased yield, quality produce and economic returns from **turmeric** (Average irrigation intervals in different months are: June-14 days, July-16 days, August-18 days, September-18 days, October-13 days, November-15 days, December and January-17 days, February-13 days and March-10 days).
- For increased yield, quality produce and economic returns from **turmeric,** it is recommended to apply 150:50:50 kg/ha N, P_2O_5 and K_2O as compared to other combinations of fertilizers.
- It is recommended to irrigate *Bt* **cotton** after every two days at 0.5 CPE using inline drip irrigation system for paired planting at 60 x 60-120 cm as sole crop or 180 x 30 cm with greengram as intercrop in order to get higher yield, gross monetary returns, net monetary returns and B:C ratio. Also, application of 75:37.5:37.5 kg/ha NPK through water soluble fertilizers in 7, 3 and 4 splits, respectively during 7 to 115 days after sowing is recommended for the crop.
- For higher yields, gross monetary returns, net monetary returns and B:C ratio of *rabi* **sorghum**, inline drip irrigation system scheduled at 1.0 ETc is recommended for paired row planting of 45x15-75 cm. The fertilizer dose at 75:37.5:37.5 kg/ha NPK, respectively in 5, 3 and 5 splits from 0 to 75 days after sowing is recommended.
- For higher yields, gross monetary returns, net monetary returns and B:C ratio of **sweet orange**, inline drip system forming a loop around the tree canopy is recommended along with application of 75% recommended dose of fertilizers (600:300:300 g/plant NPK) in 12 splits till 240 days after stress withdrawal of *Mrugbahar* variety of orange.
- Paired row planting of **turmeric** at 45 x 15 cm spacing on raised beds of 150 cm with alternate day drip irrigation at 0.5 PE is recommended for obtaining higher rhizome yield, economic benefit and water use efficiency. The amount of irrigation water (in litres) for drip system recommended is: 'V' (Irrigation water (litre) per meter length of raised bed = 0.45 x cumulative pan evaporation (mm) of two days from the raised bed.
- To obtain about 54% higher additional income, 14% higher net extra income and 17% higher water use efficiency, summer **chilli** and watermelon may be planted in medium deep soils of western Maharashtra by using 40 mm silver black polythene mulch on raised bed (90 cm) with a spacing of 60 x 45 cm and drip fertigation at 70% ETc and 125% RDF fertigation for chilli-watermelon crops as per the scheduled given below.

Fertigation schedule for chilli

Sl. No.	Crop stage	Days	Period (weeks)	Fertilizers (kg/ha)		
				N	P_2O_5	K_2O
1.	Grand growth and branching	60	6	20.0	10.0	10.0
2.	Flowering	30	4	40.0	20.0	20.0
3.	Fruiting	60	6	40.0	20.0	20.0
			Total	**100.0**	**50.0**	**50.0**

Fertigation schedule for watermelon

Sl. No.	Crop stage	Days	Period (weeks)	Fertilizers (kg/ha)		
				N	P_2O_5	K_2O
1.	Grand growth	15	2	25.0	12.5	12.5
2.	Flowering	30	4	50.0	25.0	25.0
3.	Fruiting	15	2	25.0	12.5	12.5
			Total	**100.0**	**50.0**	**50.0**

- For higher grain yield and net monetary returns of maize, it is recommended to schedule drip irrigation at 80% pan evaporation with alternate day. Similarly drip fertigation with 112.5:56.2:56.2 NPK kg/ha to maize with N in 8 equal splits @12.5% at an interval of 10 days from 10 DAS to 80 DAS while P and K in 2 equal splits of 50% at sowing and 30 DAS is recommended.
- For increased yield, quality produce and economic returns from **turmeric,** it is recommended to apply irrigation of 60 mm when cumulative pan evaporation reaches 75 mm at 0.8 IW/CPE (the average irrigation interval of different months is June-14, July-16, August and September-18, October-13, November-15, December and January-17, February-13 and March-10 days). For increased yield, quality produce and economic returns from **turmeric,** it is recommended to apply 150:50:50 kg/ha N, P_2O_5 and K_2O respectively as compared to other combinations of fertilizers.

Belavatagi (AESR 6.4: Hot dry sub-humid ESR with shallow and medium loamy and clayey black soils (deep clayey black soils as inclusion)

- Eighty percent cutoff length of border strip irrigation that proved to be rewarding for **wheat** and **chickpea** in Malaprabha command is recommended for the study area as well as narrow spaced crops in any region of the country. This proven technology will save water, time and labour. The technology will avoid over-irrigation in command area and check soil salinity.
- Drip fertigation scheduling at 0.6 IW/CPE (4-5 irrigations) along with 125% RDF (150:75:75 $N:P_2O_5:K_2O$ kg/ha) is recommended to save water and fertilizer (wasted by farmers due to broadcasting) and obtain higher yield of *Bt* **cotton** in *Vertisols* of Malaprabha command area.
- Among the pulses, **chickpea** should be sown in the first fortnight of December to obtain higher yield. Its yield level goes on decreasing with delay in sowing. In contrast to chickpea, performance of greengram and cowpea will be better when sown in the 2nd fortnight of December and 1st fortnight of January. Greengram crop irrigated at 0.6 IW/CPE recorded 1.54 t/ha of chickpea equivalent yield, with 22.22% water saving, net return of ₹ 44,485 and B-C ratio of 5.54. The recommendation of growing greengram in the 2nd fortnight of December is recommended for farm trial.

Coimbatore (AESR 8.1: Hot dry semi-arid ESR with moderately deep to deep, loamy to clayey, mixed red and black soils)

- Intercropping of **blackgram** in cotton-maize sequence was found to be best suitable system. Sub-surface drip irrigation at 100% PE with 125% RDF (150:75:75 kg NPK/ha) for cotton and irrigation at 100% PE with 100% RDF (250:75:75 kg NPK/ha) for maize is recommended to get higher yield and economic benefits in the system.
- Sub-surface drip fertigation of "**Chewing cane**" at 0.90 PE and 100% RDF was recommended for higher growth, yield parameters, yield of chewing cane with water saving of about 27%.
- Microirrigation to small **onion** at 60% PE with 100% and 75% RDF in the canal command area of Periyar Vaigai in Tamil Nadu was recommended.
- It is recommended to construct the additional groundwater recharge structures i.e. 5 check dams, 3 percolation ponds and 4 farm ponds of 168.2 ha-m storage volume for harvesting the surface water to meet crop water demand (327.81 ha-m) in a watershed of Amaravathi river basin. Further, it requires ground truthing before implementation.

Faizabad (AESR 9.2: Hot dry subhumid ESR, deep loamy alluvium-derived soils)

- Sowing of **greengram** on raised beds in paired rows along with furrow irrigation at 1.0 IW/CPE or irrigation at 10 days interval is recommended.
- Application of 7 cm irrigation in check basin of 10 m x

10 m size at 1-3 days after disappearance of ponded water is recommended as a high yielding, efficient and water saving irrigation practice and economical for **rice** in canal command of Chandpur distributory.

- Drip fertigation at 60% PE with 100% N every 3rd day is recommended as high yielding, efficient and economical viable irrigation schedule for **tomato** (Hybrid - SHS) cultivation.
- Drip fertigation at 80%PE with 100% N is recommended for *zaid* **okra** for high yield and remuneration.

Powarkheda (AESR 10.1: hot dry subhumid ESR with medium and deep clayey black soils (shallow loamy black soils)

- **Chickpea** should be grown upto 30th November without substantial loss in yield. This can be a good substitute for wheat upto this period. The improved chickpea variety JG 130 should be given two irrigations (at branching & pod formation) for optimum economic returns and higher WUE. If one irrigation is available, it should be given at pod formation stage.
- In deep black soils of Tawa command area, **wheat** crop under zero tillage should be irrigated at 1.0 IW/CPE ratio (i.e. four irrigations) for obtaining optimum seed yield.

Bilaspur (AER 11: Hot moist/dry subhumid transitional ESR with deep loamy to clayey red and yellow soils)

- Irrigation schedule i.e. IW/CPE 0.9 (or 8-9 irrigations) is recommended **for summer groundnut** for higher yield and water expense efficiency.
- Drip irrigation @ 80% PE with paired row planting of 60 cm is recommended for **sugarcane** (var. CO-1305), as it gave higher yield by 24.8% and water saving by 43.3% over traditional surface irrigation.

Chiplima (AESR 12.1: hot moist subhumid ESR with deep loamy red and lateritic soils)

- At Chiplima, cropping pattern obtained under Scenario – II may be adopted for the command area of distributary of Retamunda Branch Canal for *rabi* season for optimal land and water utilization, and generation of requisite employment

Jammu (AESR 14.2: Warm moist to dry subhumid transitional ESR with medium to deep loamy to clayey brown forest and podzolic soil)

- It may be recommended to farmers that irrigation after 7 cm drop of water level below surface from 7 DAT to 10 days prior to harvest is recommended for higher grain yield, straw yield, water saving and benefit-cost ratio of **basmati rice** under light textured soil in comparison to farmers' practice.
- The uptake of microirrigation within 10% of irrigation command of Jammu for **vegetable crops** has been recommended by AICRP on IWM under Draft State Water Policy and Plan in reference to University letter no.: AUJ/PP&MO/2016-17/F-81046-47 dated: 17.01.2017.

Palampur (AESR 14.3: Warm humid to perhumid transitional ESR with shallow to medium deep loamy brown forest and podzolic soils)

- For better production and economics, **onion** crop should be irrigated at three-day interval with cumulative PE of 0.6% and okra crop should be irrigated at two day interval with cumulative PE of 0.8%. Both crops should be fertigated with 100% recommended dose of nitrogen with locally prepared liquid manure enriched with 1% liquid biofertilizer (E100) and recommended doses of phosphorus and potassium as basal application.

Jorhat (AESR 15.4: Warm to hot perhumid ESR with moderately deep to deep loamy, alluvium derived soils)

- In rainfed *kharif* **rice**, height of bund should be 30 cm to retain rainwater for higher yield of rice as well as to conserve residual moisture for higher yield of succeeding relay crops.
- In late sown **toria**, two irrigations of 6 cm depth should be applied at pre-flowering and siliqua formation stage of the crop.

Navsari (AESR 19.1: Hot humid ESR with medium to deep loamy to clayey mixed red and black soils)

- **Chickpea** crop JG 130 can be sown upto 30th November without substantial loss to the seed yield. This can be a good substitute for wheat upto this period. This improved variety of chickpea should be given two irrigations (at branching &pod formation) for optimum yield, economic returns and higher WUE. If only one irrigation is available, it should be given at pod formation stage.
- For achieving higher net profit from 8 to 9 years old **mango** plantation, irrigation water can be applied through drip irrigation system directly in four vertically inserted HDPE/PVC pipe (75 mm diameter) into the soil at 40 cm depth below ground level on all the four sides around 1.5 m away from mango trunk through spaghetti tube (4 mm

PUBLICATIONS

Almora

Panday, S.C., Choudhary, M., Singh, S., Meena, V.S., Mahanta, D., Yadav, R.P., Pattanayak, A., and Bisht, J.K. (2018) Increasing farmer's income and water use efficiency as affected by long-term fertilization under a rainfed and supplementary irrigation in a soybean-wheat cropping system of Indian mid-Himalaya. *Field Crops Research*, 219:214-221.

Choudhary M., Panday S.C., Meena V.S., Singh S., Yadav R.P., Mahanta D., Mondal T., Mishra P.K., Bisht J.K., Pattanayak A. (2018) Long-term effects of organic manure and inorganic fertilization on sustainability and chemical soil quality indicators of soybean-wheat cropping system in the Indian mid-Himalayas. *Agriculture, Ecosystems & Environment*, 257:38-46.

Belavatagi

Aruna K.T., Satish Kumar U., Ayyana Gowdar M.S., Srinivasa Reddy G.V., Shanwad, U.K. (2017) Estimation of crop coefficient (Kc) values for groundnut crop with evaluated crop evapotranspiration at different moisture deficit levels under agro climatic condition of Raichur, Karnataka. *Green Farming*, 8(5):155-158.

Mallikarjuna, B., Maheshwara Babu, U., Satishkumar, G.V., Srinivasa Reddy, S.R., Balanagoudar, Shanwad, U.K. (2017) Identification of groundwater recharge potential zones for Devasugur nala watershed using Remote Sensing and GIS in Raichur district, Karnataka. *International Journal of Scientific & Engineering Research*, 8(5): 997-1007.

Adishesha, K., Janagoudar, B.S., Amaregouda, A., Shanawad, U.K., and Chandranaik, M., (2017) Morphological characters of maize (*Zea mays* L.) genotypes to elevated carbon dioxide and temperature regimes. *International Journal of Pure and Applied Biosciences*, 5(5):163-170. DOI: http://dx.doi.org/10.18782/2320-7051.5477.

Meghashree Meti, Mallikarjun Kenganal, D.S. Aswathanarayana, Gururaj Sunkad and U.K. Shanwad, (2017) Response of Host Resistance in Mungbean Cultivars against Yellow Mosaic Disease Caused by Mungbean Yellow Mosaic Virus (MYMV). *International Journal of Current Microbiology and Applied Sciences*, 6(10): 1559-1565. https://doi.org/10.20546/ijcmas.2017.610.187.

Prasanna S. Pyati, B.M. Chittapur, A.S. Halepyati, U.K. Shanwad, S.N. Bhat and M.R. Umesh, (2017) Realization of Target Yield in Bt Cotton (*Gossypium hirsutum*) with Different Methods of Establishment under Varied Dates of Planting. *International Journal of Current Microbiology and Applied Sciences*, 6(11): 3005-3010. https://doi.org/10.20546/ijcmas.2017.611.351.

Aruna, K.T., Satish Kumar U., Srinivasa Reddy, G.V., Amare Gowda A., Shanwad, U.K. (2017) Water use efficiency, yield and crop coefficient (Kc) of groundnut crop at different water regimes under agroclimatic condition of Raichur, Karnataka, India. *International Journal of Current Microbiology and Applied Sciences*, 6(12):1956-1963. https://doi.org/10.20546/ijcmas.2017. 612.223.

Adishesha, K., Janagoudar, B.S., Amaregouda, A., Shanawad, U.K., Chandranaik, M. (2017) Bio-physical characters of maize (*Zea mays* L.) genotypes to elevated carbon dioxide and temperature regimes, *Agriculture Update*, 5(5):1126-1232. https://doi.org/10.15740/has/au/12.techsear (5)2017/1226-1232.

Bilaspur

Ravishankar, Pandey, D., Kumar, J., Jangre N., Sahu, H. (2018) Simulation of the model for proper *rabi* crops planning: A case study on Nawagarh Distributary of Janjgir branch canal, District-Janjgir-Champa (Chhattisgarh, India). *Trends in Biosciences*, 11(6):887-893.

Ravishankar, Pandey, D., Pali, A.K., Sahu, A.K. (2018) Assessment of demand-supply gap of an irrigated command: A case study on summer rice (*Oryza Sativa L*). *Trends in Biosciences*, 11(6):899-904 pp.

Ravishankar, Pandey D., Sinha J., Sahu G., Singh, K.K. (2018) Calibration and validation of the canal simulation model: A case study on Nawagarh Distributary of Janjgir Branch Canal, District-Janjgir-Champa (Chhattisgarh, India). *Journal of Farmacognosy and Phytochemistry*, 7(2):6-13.

Ravishankar, Pandey, D., Pali, A.K., Sahu, A.K. (2018) A short note on simulation modelling of canal irrigated command area: A case study. *International Journal of Fauna and Biological Studies*, 5(2):14-16.

Chalakudy

Thomas, A.T. Thomas, D., Abraham, M., Thomas, G.C. (2017) Water - weed interactions in aerobic rice. *Journal of Tropical Agriculture*, 55(2):195-199, 2017.

Punnoose, A. Anitha, S. (2017) Biochar on the growth and yield performance of Amaranth (*Amaranthus tricolor* L.). *Trends in Biosciences*, 10(16):2908-2912.

Hisar

Lamba, S., Phogat, V.K., Kumar, N. (2017) Sustainable agriculture for sustaining mankind - A Review of International Literature. *Vegetos-An International Journal of Plant Research*, 30:477-482.

Jammu

Raina, A., Nanda, P.K., Singh, J. (2018) Performance evaluation of Tawi-Lift command. *Environment & Ecology*, 36(1):163-165.

Ahmad, M.A., Gupta, L.M., Gupta, M., Gupta, N.K. (2018) Influence of irrigation schedules on growth, yield and water use efficiency in aloe (*Aloe barbadensis*). *The Indian Journal of Agricultural Sciences*, 88(1):1-16.

Raina, A.K, Bharti, V., Nanda, P.K. (2017) Performance evaluation for up-scaling water productivity of wheat in Ranbir canal command of Jammu. *Environment & Ecology*, 3 (2D):1526-1528.

Kota

Narolia, R.S., Verma, A.K., Singh, P. (2017) Performance of improved water management technology on rice grown in Chambal command area of south-eastern Rajasthan. *Annals of Agricultural Research*, 38(4): 385-390.

Narolia, R.S., Meena, B.S., Meena, H.P., Meena, D.S., Dashora, A., Singh, P. (2017) Evaluation of improved water management practices on soybean grown in Chambal command area of south-eastern Rajasthan. *Soybean Research*, 15(2):01-08.

Meena, H., Meena, P.K.P., Narolia, R.S., Kumhar, B.L. (2017) Grassy weed management in cotton under humid south plain zone of Rajasthan. *Chemical Science Review and Letters*, 6(22):1018-1021.

Meena, H., Meena, P.K.P., Narolia, R.S., Kumhar, B.L. (2017) Response of post emergence herbicide against grassy weed flora in cotton. *International Journal of Pure & Applied Bioscience*, 5(2):137-141.

Morena

Singh, Y.P., Sudhir, S., Nanda, P. Singh, A.K. (2017) Establishment techniques and maturity duration of pigeonpea cultivar impact on yield, water productivity and properties of soil. *Agricultural Research*. (*Accepted*)

Singh, Y.P., Singh, S., Singh, A.K. (2017) On farm abiotic stress management in pigeon pea (*Cajanus cajan*) and its impact on yield, economics and soil properties legume research Print ISSN:0250-5371/Online ISSN:0976-0571.

Tomar, S.S., Singh, A., Dwivedi, A., Sharma, R., Naresh, R.K., Kumar, V., Yadav, A.S., Singh, B.P. (2017) Effect of integrated nutrient management for sustainable production system of maize (*Zea mays* L.) in Indo-gangetic plain zone of India. *International Journal of Chemical Studies*, 5(2):310-316.

Verma, J.K., Singh, R., Tomar, S.S., Vivek, B.P. Dhyani, Kumar, S. (2017) Effect of pre and post emergence application of different doses of Imazethapyr along with other herbicides on nutrient uptake by crop and weeds. *Journal of Plant Development Sciences*, 9(1):23-28.

Yadav, K.K., Singh, S.P., Kumar, A., Dhayni, B.P., Kumar, B.P., Tomar, S.S. (2017) Nutrients availability and yield of wheat under different integrated nutrient management practices in rice-wheat cropping system. *Progressive Agriculture-An International Journal*, 17(1):126-131.

Prasad, K.M., Singh, R.V., Tomar, S.S., Singh. R., Dhayni, B.P., Bhatnagar, S.K., (2017) The effect of fertility levels and different herbicides for effective weeds control in wheat crop. *Progressive Agriculture*, 17:(1)150-154.

Kumar, A., Kumar, M., Tripathi, B.N., Tomar, S.S. (2017) Effect of crop establishment methods and nutrient management on soil health and productivity of basmati rice (*Oryza sativa* L.) *Progressive Agriculture*, 17(2): 311-314.

Kumar, A., Kumar, A., Dhyani, B.P., Shahi, U.P., Tomar, S.S., Senger, R.S. (2017) Yield and quality of scented rice under customized and conventional fertilizer practices. *Progressive Agriculture*, 17(2):197-204.

Kumar, A., Tripathi, B.N., Kumar, M., Tomar S.S. (2017) Physicochemical and biological properties of soil as influenced by crop establishment methods and nutrient management in basmati rice (*Oryza sativa* L.). *Progressive Agriculture*, 17(2): 276-279.

Singh, A., Tomar, S.S., Sharma, J., Tomar, S.S., Rai, A.K. (2017) Effect of weed management practices on weeds, yield and economics of mustard. *Progressive Research: An International Journal*, 12(Special-III):2023-2025.

Tomar, S.S., Singh, R., Singh, A., Singh, A., Yadav, A., Sharma., J. (2017) Effect of different herbicides combination on weed flora, yield and economics of maize (*Zea mays* L.). *Journal of Pharmacognosy and Phytochemistry*, 6(SPL K):465-469.

Tomar, S.S., Kumar, A., Naresh, R.K., Singh, Y.P., Singh, A., Singh., R. (2017) Effect of fertility levels and herbicides combination on weed dynamics and productivity of wheat (*Triticum aestivum* L.) of maize (*Zea mays* L.). *Journal of Pharmacognosy and Phytochemistry*, 6(SPL K):474-477.

Spoorthi, G.S., Singh, R., Sharma, R., Kumar, A.S., Singht, N., Tomar, S.S. (2017) Efficacy of insecticide and biopesticides against *Helicoverpa armigera* (Hubner) on chickpea in western Uttar Pradesh. *Journal of Pharmacognosy and Phytochemistry*, 6(SPL):1034-1039.

Singh, Y.P., Tomar, S.S., Singh, A.K., Yadav, R.P. (2017) Effect of nutrition management and irrigation methods and schedule on productivity, economics and water-use efficiency in soybean (*Glycine max*) - chickpea (*Cicer arietinum*) cropping sequence in alluvial soil. *Indian Journal of Agronomy*, 62(4):424 – 430.

Navsari

Savani, N.G., Patel, R.B., Solia, B.M., Patel, J.M., Usadadia, V.P. (2017) Productivity and profitability of *rabi* pigeonpea increased through drip irrigation with mulch under South Gujarat condition. *International J of Agriculture Innovations and Res.*, 5(5):578-560.

Nayak, V.R., Mistri, P.M., Savani, N.G., Patel, K.K., Usadadia, V.P. (2017) Effect of irrigation and sulphur on yield of summer cluster bean under south Gujarat conditions. *Green Farming*, 8(2):480-482.

Deshmukh, S.P., Usadadia, V.P. (2017) Weed management influence on crop-weed competition in sorghum under south Gujarat conditions. *Indian J. of Weed Science*, 49(3):272-275.

Damor, K.S., Usadadia, V.P., Arvadia, L.K., Patil, V.A., Patel, P.B. (2017) Productivity and profitability of hybrid rice (*Oryza Sativa* L.) as influenced by spacing and age of seedling under system of rice intensification. *International J of Agriculture Innovations and Res.*, 5(6): 983-985.

Vishnu, V., Usadadia, V.P., Mawalia, A.K., Patel, M.M. (2017) Effect of land configuration and bio-organic on exchangeable cations and exchangeable sodium percentage of soil after harvest of chickpea (*Cicer arietinum* L.) under costal salt affected soils. *Int. J. Curr. Microbiol. App. Sci.*, 6(4):477-482.

Vishnu, V., Usadadia, V.P., Mawalia, A.K., Patel, M.M., Patel, V.K. (2017) Impact assessment of land configuration and bio-organic on nutrient uptake and quality of chickpea under coastal salt affected soil. *Int. J. Pure App. Biosci.*, 5(3):726-734.

Thakor, K.P., Usadadia, V.P., Savani, N.G., Arvadia, L.K., Patel, P.B. (2018) Effect of irrigation schedule and nitrogen management on productivity, profitability of summer pearl millet grown under clay soils of south Gujarat. *International J of Agriculture Innovations and Res.*, 6(4):10-13.

Patel, M.M., Patel, B.K., Naik, V.R., Joshi, H.K., Usadadia, V.P. (2017) Effect of irrigation and sowing dates on production potential of salicornia in costal saline soil. *J. of Soil and Salinity and Water Quality*, 9(1):111-114.

Parbhani

Gadade, G.D., Dhopte, R.V., Khodke, U.M. (2017) Effect of different spacing on growth and yield of BBF raised summer groundnut (*Arachis hypogea* L.) under drip irrigation. *Int. J. Curr. Microbial. App. Sci.*, Special Issue 5:593-597.

Nayak, A.K., Nanda, P., Srivastava, R.C., Das, M., Ghosh, S., Kumar, A., Ambast, S.K., Patil, R.G., Khodke, U.M., Yadav, B.S. (2017) Application of ICT in development of agriculture water management portal *J. Indian Soc. Coastal Agric. Res.*, 35(1): 96-98.

Awari, H.W., Khodke, U.M. (2018) Development of modified crop coefficients based on weather parameters of Parbhani for *Kharif* crops. *Trends in Biosciences*, 11(4):495-499.

Awari, H.W., Khodke, U.M. (2018) Comparative performance of different reference evapotranspiration estimation methods for Parbhani. *Trends in Biosciences*, 11(4):529-534.

Chilplima

Mohapatra, S., Mohanty, A.K., Nayak, B.R., Panigrahy, N., Samanta, P. and Lenka, S. (2017) Effect of irrigation and weed management on weed dynamics and yield of summer rice (*Oryza sativa*) under SRI. *Indian Journal of Agronomy*, 62(3): 315-320.

Panigrahy, N., Mohanty, A.K., Mohapatra, S., Lenka, S. (2017) Optimal crop planning for Retamunda branch canal system under uncertainty of canal release. *J. Indian Soc. Coastal Agric. Res.*, 35(2):19-24.

Mohapatra, S., Tripathy, S.K., Nayak, B.R. Mohanty, A.K. (2017) Efficacy of pre-emergence herbicides for control of complex weed flora in transplanted rice. *Indian Journal of Weed Science*, 49(3):216–218. DOI: 10.5958/0974-8164.2017.00057.0.

Tripathy, S.K., Mohapatra, S. (2017) Research and development of sabai grass (*Eulaliopsis binata*) in India. *Range Mgmt. and Agroforestry*, 38(1):1-9.

Nayak, B.R., Panigrahy, N., Mohapatra, S., Mohanty, A.K., Sahoo, B., Jagdev, P.N. and Patel, S. (2017) Heat utilization and productivity of summer transplanted rice (*Oryza sativa* L.) in relation to irrigation schedules and date of transplanting. *Journal of Agrometeorology*, 19(3):242-245.

Jorhat

Barman, S., Doley, N., Thakuria, R.K. (2017) Impact of farmers training programme on scaling up of water productivity in Agriculture - An analytical study in Assam. *Indian Research Journal of Extension Education*, 17(2):28-32.

Baro, B., Pathak, K., Sharma, A. (2017) Productivity and Water use studies in rice under different establishment method. *Journal of Agricultural Engineering and Food Technology*, 4(1):56-59.

Baruah, R., Medhi, B.K., Patgiri, D.K., Bhattacharyya, D., Deka, C.R. (2017) Soil organic carbon stock in agricultural land of Jorhat district of Assam. *Journal of Soil and Water Conservation*, 16 (1):25-31.

Baruah, N., Medhi, B.K., Borah, N., Baruah, A.M., Saikia, G.K. (2017) Effect of long term tea cultivation in soil quality in deep, fine loamy, well drained soil of Jorhat district, Assam, *Journal of Soil and Water Conservation*, 16(4):347-355.

Dutta, M., Medhi, B.K., Rizongba Kichu. (2017) Impact of continuous fourteen years of integrated nutrient management practices on forms of soil N and P on terraced land, *An Asian Journal of Soil Science*, 12(1):80-85.

Saikia, M., Bhattacharyya, D., Patgiri, D.K., Thakuria, R.K., Deka, P., Borah, N. (2017) Physical characteristics of puddle rice soils as influenced by agro-ecological and land situations. *Journal of Soil and Water Conservation*, 16(3):221-227.

Palampur

Juvairia, J., Katoch, K.K., Sandal, S.K. (2017) Effect of drip irrigation levels and NPK fertilizer application methods on soil water dynamics, water use efficiency, yield and quality parameters of broccoli (*Brassica oleracea* L. *var. italica*) in wet temperate zone of Himachal Pradesh. *Indian J Soil Cons*, 45 (*In press*)

Kapoor, R., Sandal, S.K. (2017) Response of cauliflower root-shoot growth parameters, nutrient uptake and productivity to varying drip irrigation levels and fertigation in wet temperate zone of western Himalayas. *Progressive Res – An International J*, 12(2):244-249.

Kapoor, R., Sandal, S.K., Banyal, A. (2017) Response of drip irrigation, fertigation and mulching in fruit crops for enhanced quality attributes and productivity – A Review. *Progressive Res – An International J*, 12(1):1-6.

Kumar, J., Kapoor, R., Sandal, S.K., Sharma, S.K., Saroch, K. (2017) Effect of drip irrigation and NPK fertilization on soil – plant water, productivity, fertilizer expense efficiency and nutrient uptake of capsicum (*Capsicum annuum L.*) in an acid Alfisol. *Indian J Soil Cons*, 45:105-111.

Kumar, S., Datt, N., Sandal, S.K., Sharma, S.K. (2017) Effect of cow urine and bio-fertilizers based fertigation schedule at varying levels of drip irrigation on yield, growth, quality parameters and economics of cucumber under protected condition. *Int. J. Curr. Microbiol. App. Sci.*, 6(6):1242-1249.

Shillong

Goswami, B., Hussain, R., Kumar, P.V. Saikia, U.S., Banarjee, S. (2017) Simulation study of the effects of climate change on potato at Jorhat, Assam using SUBSTOR-Potato model. *Journal of Agrometeorology*, 20(2). (*Accepted*)

Chakraborty, D., Saha, S., Singh, R.K., Sethy, B.K., Kumar, A., Saikia, U.S., Das, S.K., Makdoh, B., Borah, T.R., Chanu, A.N., Walling, I., Anal, P.S.R., Chowdhury, S., Daschoudhuri, D. (2017) Spatio-temporal trends and change point detection in rainfall in different parts of North-eastern Indian states. *Journal of Agrometeorology*, 19(2): 160-163.

Coimbatore

Balathandayutham, K., Valliammai, A. (2017) Analysis of Rainfall Parameters in Walayar Watershed of Parambikulam- Aliyar - Palar Basin, Coimbatore, Tamil Nadu. *Trends in Bio Science.*, 10(1):152-158.

Balathandayutham, K., Valliammai, A., Kottiswaran, S.V. (2017) Simulation of surface runoff and sediment yield for Walayar watershed using SWAT model. *Trends in Bio Science*, 10(1):171-175.

Sharmil, A.S, Tamilmani, D., Valliammai. A., Kumaraperumal, R. (2017) Identification of groundwater recahrgable zone in Uppar Odai (South)-Amaravathi river basin using RS and GIS. *International Journal of Agriculture Science*, 9(46):4765-4769.

Valliammai, K., Balathandayutham, Pandian, B.J. (2017) Assessment of climate change using SWAT, *Agriculture Update*, 12(Special issue 7):1788-1793.

Balathandayutham. K., Valliammai, A. (2017) Evaluation of artificial neural networks and regression PTF's in estimation of soil hydraulic properties, *Agriculture Update*, 12(TECHSEAR-4):1105-1112.

Angaleeswari, M., Valliammai, A. (2017) Assessment of groundwater quality using water quality index in western zone of Tamil Nadu, India. *Chemical Science Review and Letters*, 6(23):1750-1757.

Madurai

Anbarasau, M., Gurusamy, A., and Indirani, R. (2017) Enhancing growth and yield attributes of sugarcane sustainable initiative (SSI) through sub-surface drip fertigation. *Progressive Research an International Journal*, 12(Special 1):1361-1364.

Sathayamoorthy, N.K., Gurusamy, A., Ragavan, T., Prabhaharan, J., Rajeshwari, M., Venkatraman, N.S., Pandian, B.J. (2017) Optimization of nutrient levels and sources of nutrients for sustainable sugarcane initiative (SSI) under sub surface drip fertigation system. *Agriculture Update*. (Accepted for publication)

Anbarasau, M., Gurusamy, A., and Indirani, R. (2017) Water soluble fertilizer and economics of sustainable sugarcane cultivation under sub-surface drip fertigation system. *Agriculture Update*. (Accepted for publication).

Bhavanisagar

Manikandan, M., Thenmozhi, S., Natarajan, S.K., Bhuvaneswari, J., Prabhakaran, N.K. (2017) Optimization of irrigation and fertigation levels to turmeric under different drip lateral spacing for western zone of Tamil Nadu. *The Bioscan*, 12 (1):561-564.

Natarajan, S.K., Prabhakaran, N.K., Usharani, K.S. (2017) Residue management and nutrient dynamics in combine harvester operated rice field. *Int. J. Curr. Microniol. App. Sci*, 6 (11):1517-1524.

Manikandan, M., Thenmozhi, S., Natarajan, S.K., Bhuvaneswari, J., Prabhakaran, N.K. (2017) Optimization of irrigation and fertigation levels to turmeric under different drip lateral spacing for western zone of Tamil Nadu. *The Bioscan*, 12 (1):561-564.

Manikandan, M., Thiyagarajan, G., Bhuvaneswari, J., Prabhakaran, N.K. (2017) Wet and dry spell analysis for agricultural crop planning using markov chain probability model at Bhavanisagar. *International J. of Mathematics and computer Application Res.*, 7(1):2249-8060.

Junagadh

Vekariya, P.B., Rank, H.D., Vadher, P.G., Gontia, N.K. (2017) Groundwater utilization and management policy guidelines for the South west Saurashtra region. *J. Sustain. Water Resour. Manag.* (Springer) DOI 10.1007/s40899-017-0086-7.

Bhatu, H., Rank, H.D. (2017) Estimating the water balance component in Rangmati river basin using SWAT model. *International Journal of Agricultural Science and Research* (IJASR), 7(4):547-554. ISSN(P): 2250-0057; ISSN(E): 2321-0087.

Bhatu, H., Rank, H.D. (2017) Simulating the climate change impact on water resources system in UND river basin using SWAT model. *AGRES – An International e. Journal*, 6(2):376-382. ISSN : 2277-9663.

Bhatu, H., Rank, H.D. (2017) Climate simulation using RCM data for Jamnagar district. *Curr World Environ*, 2(2):1-10.

Sondarva, K.N., Rank, H.D., Jayswal, P.S., Trivedi, K.R. (2017) Techno economic study of summer sesame crop under drip irrigation with various irrigation interval and thermal regimes. *Res. Environ. Life Sci.*, 10(2):123-128. ISSN 0974-4908

Wandre, S.S., Rank, H.D. (2017) Bias correction for RCM predictions of precipitation In Vartu river basin of Gujarat, India. *International Journal Of Agricultural Science and Research* (IJASR), 7(1):187-194. ISSN(P):2250-0057, ISSN(E): 2321-0087.

Sojitra, M.A., Rank, H.D. (2017) Bias correction of RCM simulated precipitation and temperature for Und basin. *Trends in Biosciences* 10(10):1945-1954. Print : ISSN 0974-8431,

Maheta, H.Y., Rank, H.D. (2017) Estimation of groundwater recharge in Karmal watershed of Bhadar basin using empirical models. *AGRES – An International e. Journal* (2017) 6(3):486-493. ISSN : 2277-9663.

Maheta, H.Y., Rank, H.D. (2017) Trend analysis of rainfall using mann-kendall test in Karmal watershed of Bhadar basin. *AGRES – An International e. Journal* (2017), 6(3):435-441. ISSN : 2277-9663

Wandre, S.S., Rank, H.D., Shinde, V.B. (2017) Simulating the hydrologic response to climate change: Sani river basin, Gujarat (India). *Advances in Research* 9(1):1-9. Article no. AIR.31473 ISSN: 2348-0394, NLM ID: 101666096.

Paghadal, A.M., Rank, H.D., Pandya, P.A. (2018) Hypsometric analysis of Ozat river basin (Gujarat) using remote sensing and GIS techniques. *AGRES – An International e. Journal*, 7(1):17-29. ISSN : 2277-9663.

Bathinda

Kaur, A., Thaman, S., Sidhu, A.S., Sekhon, K.S., Buttar, G.S. (2017) Effect of variable irrigation supply based diversification of *Bt* cotton (*Gossypium hirsutum*)-wheat (*Triticum aestivum*) system on productivity, profitability, soil fertility and water expense efficiency. *Indian Journal of Agronomy*, 62(4):431-437.

Kaur, A., Sidhu, A.S., Sekhon, K.S., Thaman, S., Buttar, G.S. (2017) Economically viable cropping sequence for diversification in south-western region of Punjab. *Journal of Soils and Crops*, 27(2):12-16.

Buttar, G.S. Thind, H.S., Sekhon, K.S., Kaur, A., Gill, R.S., Sidhu, B.S., Aujla, M.S. (2017) Management of saline-sodic water in cotton-wheat cropping system. *Journal of Agricultural Science Technology*, 19:465-474.

Ludhiana

Dar, Meliraju Din, Aggarwal, R., Kaur. S (2017) Effect of climate change scenarios on yield and water balance components in rice wheat cropping system in Central Punjab, India. *Journal of Agrometeorology*, 19(3):226-229.

Singh, P., Garg, S., Satpute, S., Singh., A. (2017) Use of rice husk ash to lower the sodium adsorption ratio of saline water. *International Journal of Current Microbiology and Applied Sciences*, 6(6):448-458.

Satpute, S., Singh, M. (2017) Modeling phosphorus distribution under different fertigation strategies in onion (*Allium cepa* L.) crop. *Journal of Applied and Natural Sciences*, 9(2):720-729.

Satpute, S., Singh, M. (2018) Potassium and sulfur dynamics in drip fertigated onion. *Journal of Soil Salinity and Water Quality* (*Accepted*)

Kaur, H., Satpute, S., Raheja, A. (2017) Blockwise assessment of crop evapotranspiration in central Punjab, *India Agriculture Science Digest*, 37(3):171-178.

Pusa

Chandra, R., Jain, S.K., Singh, A.K. (2017) Estimation of water consumption and crop water productivity of wheat crop in farmers field of North Bihar. *Environment & Ecology*, 35(2A):954-957.

Kumar, P., Kumari, P, Kumar, V., Roy, D.K., Rai, S., Raj, R., Prakash, N., Kumar, V. (2017) Effect of organic nutrition treatments on aromatic rice cooking quality. *Bulletin of Environment Pharmacology and Life Sciences*, 6(Special Issue 4):373-383.

Kumar, P., Kumari, P, Kumar, V., Roy, D.K., Rai, S., Raj, R., Prakash, N., Kumar, V. (2017) Effect of organic–inorganic nutrition in aromatic rice (*Oryza sativa* L.). *Bulletin of Environment Pharmacology and Life Sciences*, 6(Special Issue 4):384-98.

Kumar, P., Kumari, P, Kumar, V., Roy, D.K., Rai, S., Raj, R., Prakash, N., Kumar, V. (2017) Response of fine aromatic rice (*Oryza sativa* L.) to different moisture regimes and NPK levels. *Bulletin of Environment, Pharmacology and Life Sciences*, 6(Special Issue 4):399-406.

Kumar, P., Kumari, P, Kumar, V., Roy, D.K., Rai, S., Raj, R., Prakash, N., Kumar, V. (2017) Soil fertility relationship with respect to organic and inorganic nutrient sources in aromatic rice. *Bulletin of Environment Pharmacology and Life Sciences*, 6(Special Issue 5):23-32.

Hussain, M., Gupta, S.P. (2017) A field study on hydraulic performance of drip irrigation system for optimization of operating pressure. *Journal of Applied and Natural Science*, 9(4):2261-2263.

Kumar, A., Anand, S., Kumar, M., Chandra, R., (2017) Groundwater Assessment: A case study in Patna and Gaya districts of Bihar, India. *Int. J. Curr. Microbiol. App. Sci.*, 6(12):184-195.

Kumar, V., Sharma, J.C., Kumar, M., Singh, S.K. (2017) Soil and Plant Nutrient Status as Modified by Different Types of Mulching in Cauliflower. *Current Journal of Applied Science and Technology*, 24(1):1-8.

Sapkota, T.B., Jat, R.K., Singh, R.G., Jat, M.L., Stiriling, C.M., Jat, M.K., Bijarniya, D., Kumar, M., Singh, Y., Sahrawat, Y.S., Gupta, R.K. (2017) Soil organic carbon changes after seven years of conservation agriculture in a rice-wheat system of the eastern Indo-Gangetic plains. *Soil Use and Management*. doi:1111/Sum.12331.

Udaipur

Jadeja, Y., Maheshwari, B., Singh, P.K., Chinnasamy, P., Chew, M. (2018) Managing aquifer packham, recharge and sustaining groundwater use: developing a capacity building program for creating local groundwater champions. *Sustainable Water Resources Management*. 10.1007/s40899-018-0228-6

Kumar, D., Singh, P.K., Kothari, M., Singh, R.S., Yadav, K.K. (2017) Application of RS and GIS techniques in the analysis of morphometric characteristics of upper Berach river basin, Rajasthan state. *International Journal of Agricultural Science and Research*, 7(5): 521-530.

Machiwal, D., Singh, P.K., Yadav, K.K. (2017) Estimating aquifer properties and distributed groundwater recharge in a hard-rock catchment of Udaipur, India. *Applied Water Science*, 7, 3157–3172.

Dahiphale, P., Singh, P.K. (2017) Identification of groundwater potential zones and artificial recharge sites in Jaisamand catchment using remote sensing and geographical information system. *Indian Journal of Soil Conservation*, 45(3):244-254.

Kumar, D., Singh, P.K., Kothari, M., Singh, R.S., Yadav, K.K. (2018) Ground water quality study of pre monsoon in upper Berach river basin, Rajasthan state. *Environment and Ecology*, 36(2):397-404.

Radha Srivalli, C.H., Singh, M. (2017) Estimation of runoff for the watershed using SCS-curve number method and GIS. *International Journal of Agricultural Science and Research*, 7(5):83-88.

Jabalpur

Pathak, R., Awasthi, M.K., Sharma, S.K., Hardaha, M.K., Nema, R.K. (2017) Impact of groundwater recharge and withdrawal on water table fluctuation in alluvial area. *International Journal of Agriculture Sciences*, 9(36):4546-4549.

Upadhyay, R., Nema, R.K., Awasthi, M.K., Tiwari, Y.K. (2017) Spatial distribution of crop mapping of Narsinghpur district, MP. *International Journal of Agriculture Sciences*, 9(36):4538-4541.

Upadhyay, R., Nema, R.K., Awasthi, M.K., Tiwari Y.K. (2017) Change detection analysis of cropland using geospatial technique-A case study of Narsinghpur district. *International Journal of Environment, Agriculture and Biotechnology*, 2(4):1725-1731.

Yadav, D., Awasthi, M.K., Nema, R.K. (2017) Estimation of crop water requirement of microirrigated orchard crops for different agroclimatic conditions of Madhya Pradesh. *International Archive of Applied Sciences and Technology*, 8(3):18-24.

Yadav, D., Awasthi, M.K., Nema, R.K. (2017) Estimation of reference evaporation using Aquacrop model for agro-climatic conditions of MP. *Indian Journal of Agriculture Research*, 51(6):596-600.

Thakur, S., Awasthi, M.K., Dubey, S. (2017) Assessment of groundwater quality in selected blocks of MP. *International Journal of Chemical Studies*, 5(6):2144-2149.

BUDGET ALLOCATION 2017-18

(₹ in lakhs)

Name of Center (University/ Centre/ Institute)	Grant-in-aid Salary	Grant-in-aid General (Res. Oper.)	TA	Equipment	IT	TSP	Total
PAU, Ludhiana	229.95	2.00	0.30	0.00	0.20	0.00	232.45
UAS, Dharward	75.00	2.00	0.25	0.00	0.17	0.00	77.42
TNAU, Coimbatore	186.50	3.00	0.50	5.00	0.00	0.00	195.00
IGKV, Raipur	136.00	2.00	0.40	0.00	0.20	0.00	138.60
KAU, Thrissur	69.00	2.00	0.30	0.00	0.17	0.00	71.47
OUAT, Bhubaneswar	35.00	2.00	0.25	0.00	0.17	0.00	37.42
BSKKV, Dapoli	75.00	2.00	0.25	0.00	0.17	0.00	77.42
NDUAT, Faizabad	43.50	1.00	0.25	0.00	0.18	0.00	44.93
BCKV, Kalyani Nadia	53.00	2.00	0.30	0.00	0.18	0.00	55.48
CCSHAU, Hisar	41.75	1.00	0.25	0.00	0.18	0.00	43.18
SKUAST, Jammu	112.75	2.00	0.25	0.00	0.18	0.00	115.18
MPUAT, Udaipur	35.00	1.05	0.25	0.00	0.17	5.00	41.47
AU, Kota(Raj.)	98.45	2.30	0.25	0.00	0.18	0.00	101.18
JAU, Junagadh	41.50	1.00	0.25	0.00	0.18	0.00	42.93
RVSKVV, Morena	74.10	2.15	0.25	0.00	0.18	0.00	76.68
NAU, Navsari	89.25	2.00	0.25	0.00	0.18	5.00	96.68
CSKHPKV, Palampur	137.75	2.00	0.30	0.00	0.18	0.00	140.23
GBPUAT, Pantnagar	140.00	2.00	0.40	0.00	0.20	0.00	142.60
VNMKV, Parbhani	53.50	2.50	0.35	0.00	0.18	0.00	56.53
JNKVV, Jabalpur	103.25	2.00	0.40	0.00	0.20	0.00	105.85
MPAU, Rahuri	80.45	2.00	0.40	0.00	0.20	0.00	83.05
SKRAU, Bikaner	77.00	2.00	0.30	0.00	0.17	0.00	79.47
AAU, Jorhat	85.00	2.00	0.30	0.00	0.18	0.00	87.48
Dr.RPCAU, Pusa	33.30	1.30	0.40	0.00	0.00	0.00	35.00
ICAR-RC-NEH, Umiam	0.00	1.00	0.25	0.00	0.00	0.00	1.25
VPKAS, Almora	0.00	1.00	0.35	0.00	0.00	0.00	1.35
IIWM (PCU)	0.00	5.70	0.00	0.00	1.00	0.00	6.70
Sub total	**2106.00**	**53.00**	**8.00**	**5.00**	**5.0**	**10.0**	**2187.0**

STAFF POSITION

Almora	
Chief Scientist	Dr. S.C. Panday
Agronomist	Dr. Sher Singh
Soil Physicist	Dr. S.C. Panday
Agril. Engineer	Vacant
Jr. Agronomist	Dr. D. Mahanta
Belavatagi	
Chief Scientist	Dr. Kumar D. Lamani
Agronomist.	Vacant
Soil Physicist	Dr. Punitha B.C.
Agril. Engineer	Vacant
Jr. Agronomist	Dr.U.K. Shanawad
Coimbatore + Madurai + Bhavanisagar	
Chief Scientist	Dr. B. J. Pandian
Associate Professor	Dr. A.Raviraj
Assistant Professor	Dr. A. Valliammai
Assistant Professor	Dr. Elayarajan
Agronomist Prof.	Dr. T. Ragavan
Agril. Engineer	Dr. M. Rajeswari
Soil Physicist	Dr. J. Prabhaharan
Jr. Agronomist	N.K. Sathiyamoorthy
Res. Engineer	Dr. N.K. Prabhakaran
Sr. Agronomist	Dr. S.K. Natarajan
Soil Physicist	Dr. S. Thenmozhi
Agril. Engineer	Vacant
Jr. Agronomist	Dr. J. Bhuvaneswari
Chalakudy	
Chief Scientist	Dr. E.K. Kurien
Sr. Agronomist	Dr. Anitha S.
Sr. Agronomist	Dr. Mini Abraham
Soil Physicist	Smt. Bhindhu P.S.
Agril. Engineer	Dr. Mary Regina F.
Chiplima	
Chief Scientist	Dr. A.K. Mohanty
Sr. Agronomist	Dr. Sanjukta Mohapatra
Soil Physicist	Vacant
Agril. Engineer	Dr. N. Panigrahy
Jr. Agronomist	Mrs. S. Lenka
Dapoli	
Chief Scientist	Dr. R.T. Thokal
Horticulturist	Dr. Smt. R.S. Patil
Soil Physicist	Dr. K.P. Vaidya
Agril. Engineer	Dr. B.L. Ayare
Jr. Agronomist	Dr. T.N. Thorat
Faizabad	
Chief Scientist	Vacant

Agronomist	Vacant
Soil Physicist	Vacant
Agril. Engineer	Er. R.C. Tiwari
Jr. Agronomist	Dr. B.N. Singh
Gayeshpur	
Chief Scientist	Dr. S.K. Patra
Agronomist	Dr. B. Biswas
Soil Physicist	Dr. K. Bhattacharya
Agril. Engineer	Er. S. Saha
Jr. Agronomist	Mr. R. Poddar
Hisar	
Chief Scientist	V.K. Phogat
Agronomist	Vacant
Soil Physicist	V.K. Phogat
Agril. Engineer	Vacant
Jr. Agronomist	Vacant
Jammu	
Chief Scientist	Dr. A.K. Raina
Sr. Agronomist	Vacant
Soil Physicist	Dr. Abhijit Samanta
Agril. Engineer	Er. N.K. Gupta
Jr. Agronomist	Dr. Vijay Bharti
Powarkheda + Jabalpur	
Chief Scientist	Dr. N.K. Seth
Sr. Agronomist	Dr. P.B. Sharma
Soil Physicist	Dr. P.S. Kulhare
Agril. Engineer	Vacant
Jr. Agronomist	Dr. Vinod Kumar
Irrigation Engineer	Dr. R.K. Nema
Junior Scientist	Dr. M.K. Awasthi
	Er. Y.K. Tiwari
Jorhat	
Chief Scientist	Dr. R.K. Thakuria
Agronomist	Dr. K. Pathak
	Dr. A. Sharma
Agril. Engineer	Dr. P. Barua
Soil Physicist	Dr. B.K. Medhi
Junagadh	
Chief Scientist	Dr. H.D. Rank
Agril. Engineer	Prof. P.B. Vekariya
Soil Physicist	Dr. M.S. Dulavat
Agronomist	Vacant
Kota	
Chief Scientist	Dr. Pratap Singh
Soil Physicist	Vacant
Sr. Agronomist	Dr. H.P. Meena

Agril. Engineer	Er. I.N. Mathur
Jr. Agronomist	Dr. R.S. Narolia
Ludhiana + Bathinda	
Chief Scientist	Dr. Rajan Aggarwal
Asst. Res. Engineer	Dr. (Mrs.) Samanpreet Kaur
Asst. Res. Engineer	Dr. Sanjay Satpute
Asst. Res. Engineer	Er. Amina Raheja
Sr. Scientist (Irrigation)	Dr. A.S. Sidhu
Soil Physicist	Dr. K.S. Sekhon
Asst. Agronomist	Dr. Anureet Kaur
Asst. Agril. Engineer	Dr Sudhir Thaman
Morena	
Chief Scientist	Dr. Y.P. Singh
Soil Physicist	Dr. N.S. Yadav
Agril. Engineer	Er. S.K. Tiwari
Sr. Agronomist	Dr. Sandeep Singh Tomar
Jr. Agronomist	Dr. Janmejay Sharma
Navsari	
Chief Scientist	Dr. V.P. Usadadiya
Sr. Agronomist	Vacant
Soil Physicist	Dr. J.M. Patel
Agril. Engg	Er. N.G. Savani
Jr. Agronomist	Prof. R.B. Patel
Palampur	
Chief Scientist	Dr Sanjay K. Sharma
Agril. Engg	Vacant
Sr. Agronomist	Dr. Kapil Saroch
Soil Physicist	Dr. S.K. Sandal
Jr. Agronomist	Vacant
Pantnagar	
Chief Scientist	Dr. Subhash Chandra
Soil Physicist	Dr. H.S. Kushwaha
Senior Agril Engineer	Dr. Yogendra Kumar
Agronomist	Vacant
Agril. Engineer	Dr. Vinod Kumar
	Dr. H.C. Sharma
	Dr. Harish Chandra
	Dr. U.C. Lohni
Jr. Agronomist	Dr. Gurvinder Singh
Parbhani	
Chief Scientist	Vacant
Agril. Engineer	Dr. U.M. Khodke
Agronomist	Prof. G.D. Gadade
Soil Physicist	Prof. U.N. Karad
Jr. Agronomist	Vacant
Pusa	
Chief Scientist	Vacant

Agronomist	Dr. Vinod Kumar
Soil Physicist	Dr. Mukesh Kumar
Agril. Engg	Dr. S.K. Jain
	Dr. S.P. Gupta
Jr. Soil Chemist	Dr. A.K. Singh
Jr. Agril. Engineer	Dr. Ravish Chandra
Jr. Agronomist.	Dr. Rajan Kumar
Rahuri	
Chief Scientist	Dr. S.D. Gorantiwar
Agronomist	Prof. J.B. Shinde
Agril. Engineer	Dr. S.B. Gadge
Research Engineer	Dr. S.D. Dahiwalkar
Soil Physicist	Dr. B.D. Bhakare
Junior Agronomist	Prof. S.S. Tuwar
Asst. Res. Engineer	Er. S.A. Kadam
Junior Res. Asst.	Er. K.G. Pawar
Bilaspur	
Chief Scientist	Dr. A.K. Sahu
Agronomist	Dr. A.K. Swarnkar
	Dr. J.R. Patel
Soil Physicist	Sh. P.K. Keshry
Agricultural Engineer	Dr. Devesh Pandey
Junior Agronomist	Dr. Geet Sharma
Shillong	
Chief Scientist	Dr. U.S. Saikia
Agronomist	Vacant
Agril. Engineer	Vacant
Soil Physics	Vacant
Jr. Agronomist	Vacant
Jr. Soil Physicist	Vacant
Sriganganagar	
Chief Scientist	Vacant
Soil physicist	Dr. B.S.Yadav
Agronomist	Dr. R.P.S. Chauhan
Agril. Engineer	Vacant
Jr. Agronomist	Vacant
Udaipur	
Chief Scientist	Dr. P.K. Singh
Soil Physicist	Dr. K.K. Yadav
Agril. Engineer	Er. Manjeet Singh
Agronomist	Vacant
Jr. Agronomist	Vacant

APPENDIX - I













भाकृअनुप - भारतीय जल प्रबंधन संस्थान

भुवनेश्वर, ओडिशा, भारत

ICAR - Indian Institute of Water Management

Bhubaneswar - 751023, Odisha, India

(An ISO 9001:2015 Certified Organization)

director.iiwm@icar.gov.in http://www.iiwm.res.in