सिचाई जल प्रबंधन पर
अखिल भारतीय समन्वित
अनुसंधान परियोजना

All India Coordinated Research Project on Irrigation Water Management

भाकृअनुप
ICAR

वार्षिक प्रतिवेदन

ANNUAL REPORT
2021




ICAR-IIWM

भाकृअनुप-भारतीय जल प्रबंधन संस्थान

ICAR-Indian Institute of Water Management
Bhubaneswar, Odisha, India

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भाकृअनुप - भारतीय जल प्रबंधन संस्थान
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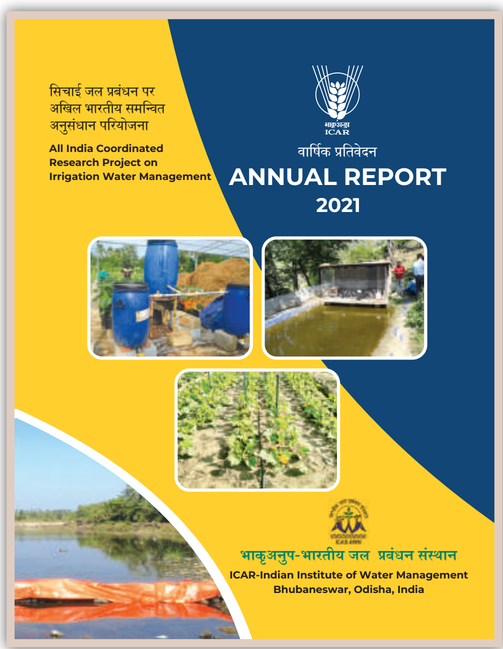

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PREFACE

The Annual Report of All India Coordinated Project on Irrigation Water Management (AICRP on IWM) contains the research findings of different coordinating centres for the year 2021 along with extension activities, human resource development programme, publication and recommendations of various centres. With the growing demand for water by different sectors, the economic use of water is of paramount importance. I take this opportunity to present the consolidated report of the centres under different themes. The scientists have been engaged in carrying out research on improving water use efficiency in different crops and cropping sequences under different sources of irrigation in various agro-climatic conditions of the country. Significant achievements have been made during the reporting year 2021. On station and on farm research endeavors of the scientists resulted in replicable water management technologies that helped in improving irrigation application efficiency in canal commands, groundwater recharge, improved water use efficiency and water productivity under pressurized irrigation and saved water and fertilizer inputs. On station and on farm research output not only improved water productivity but also enhanced farmers' income and livelihoods. 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 places. Some of the pilot interventions contributed in rainwater harvesting and groundwater recharge in rainfed areas of the country.

I take this opportunity to express my gratitude to Dr. Himanshu Pathak, 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. S.K. Chaudhari, Deputy Director General (NRM) and Dr. A. Velmurugan, 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 farmers' income and water productivity. I appreciate the team work of Dr. S. Mohanty, Principal Scientist, Dr. Prabhakar Nanda, Principal Scientist, Dr. Dibakar Ghosh, Scientist, ICAR-IIWM and Pragna Dasgupta, Research Associate, AICRP-IWM for compiling the research outcomes of the centres and editing the annual report.

(A. Sarangi)
Director, ICAR-IIWM

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कार्यकारी सारांश

वर्ष 2021 के दौरान जल प्रबंधन पर अखिल भारतीय समन्वित अनुसंधान परियोजना के 26 केन्द्रों ने जल की उपलब्धता का आकलन, भूजल का पुन:भरण, क्षेत्रीय स्तर पर भूजल का उपयोग, दबावयुक्त सिंचाई पद्धति का मूल्यांकन, भूजल का मूल्यांकन एवं पुन:भरण, बागवानी एवं अधिक मूल्य वाली फसलों में जल प्रबंधन, मृदा-जल-पौधों के संबंध और उनकी पारस्परिक क्रिया पर बुनियादी अध्ययन, नहरी और लवणीय भूजल का संयोजी उपयोग, जल उत्पादकता को बढ़ाने के लिए जल निकासी का अध्ययन, जल के बहुआयामी उपयोग द्वारा जल उत्पादकता में वृद्धि, अधिक वर्षा वाले क्षेत्रों में वर्षा जल का प्रबंधन इत्यादि के क्षेत्र में अनुसंधान एवं विस्तार का कार्य किया। वर्ष 2021 के दौरान प्राप्त की गई प्रमुख अनुसंधान उपलब्धियां नीचे सूचीबद्ध की गई हैं।

अध्याय 1. सतही जल और भूजल उपलब्धता का आकलन

- केरल के थ्रीशुर जिले की दो लिफ्ट सिंचाई योजनाओं मुनिप्पारा और पूलानी की दक्षता का मूल्यांकन किया गया। मुनिप्पारा और पूलानी लिफ्ट सिंचाई योजनाओं के कमांड क्षेत्र में सापेक्ष जल की आपूर्ति (RWS) की मात्रा क्रमशः 1.14 से 3.43 और 2.60 से 2.96 तक के बीच थी। मुनिप्पारा और पूलानी लिफ्ट सिंचाई योजनाओं के कमांड क्षेत्र में सापेक्ष सिंचाई आपूर्ति (IRS) की मात्रा क्रमशः 1.17 से 3.89 और 3.05 से 3.66 के बीच थी। दोनों लिफ्ट सिंचाई योजनाओं में फसलों के उत्पादन के लिए प्रचुर मात्रा में जल उपलब्ध था। मुनिप्पारा लिफ्ट सिंचाई योजना की तुलना में पूलानी योजना में जल का समान वितरण अधिक था। कमांड क्षेत्र के कुंओं में जल का पुन:भरण भी हुआ जिससे दोनों योजनाओं के कमांड क्षेत्र में पीने के जल की उपलब्धता बनी रही। लघु सिंचाई योजनाओं में देखी गई सापेक्ष जल आपूर्ति की मात्रा के आधार पर जल की आपूर्ति को विनियमित करके या फसली क्षेत्र में वृद्धि करके इन सिंचाई योजनाओं के प्रदर्शन में आगे सुधार की गुंजाइश है। यह योजना लाभार्थियों को अधिक सिंचाई के द्वारा बेहतर जल प्रबंधन की तकनीकों को अपनाने के लिए भी सशक्त करेगी (चलाकुड़ी केंद्र)।

- छत्तीसगढ़ राज्य में ऊपरी शिवनाथ केचमेंट में स्थित कोटानी वाटरशेड के जल संसाधनों को चिन्हित किया गया और विभिन्न कृषि की स्थितियों के आधार पर इष्टतम फसल योजना बनाई गई। जल संसाधन विकास योजना भी विकसित की गई। भूजल के पुन:भरण के लिए सात चैक बांधों और 10 रिसाव टैंक प्रस्तावित किए गए जबकि, खेत में वर्षा जल संचयन के लिए 20 चैक बांध और 61 तालाबों को उपयुक्त स्थानों पर निर्माण करने का सुझाव दिया गेया। कमांड क्षेत्र में खरीफ और रबी मौसमों की फसलों के लिए स्टोकेस्टिक लीनियर प्रोग्रामिंग मॉडल की मदद और वाटरशेड की विभिन्न कृषि की स्थितियों का उपयोग करके इष्टतम फसल पैटर्न विकसित किया गया। इससे खरीफ और रबी मौसम के दौरान क्रमशः ₹1165/हे और ₹8020/हे का अतिरिक्त लाभ प्राप्त किया जा सकता है। रबी के मौसम के दौरान 1580 हेक्टर के अतिरिक्त क्षेत्र में भी खेती की जा सकती है (रायपुर केंद्र)।

- बठिंडा शाखा की नहर की बहमान डिस्ट्रीब्यूटरी के पांच आउटलेट्स को सिंचाई पद्धति के प्रदर्शन का मूल्यांकन करने के लिए चुना गया तथा सिंचाई पद्धति एवं इसके प्रबंधन में सुधार के लिए तकनीकों को तैयार किया गया। रबी के मौसम में कुल 129 दिनों के दौरान पांच चयनित आउटलेट्स में औसत सापेक्ष जल आपूर्ति (RWS) की मात्रा 0.537 थी। यहाँ, यह सुझाव दिया गया कि खेती वाले क्षेत्र के बड़े हिस्से में गेहूँ की खेती को जौ, चना और राया की खेती के साथ बदल दिया जाए। रबी के मौसम के दौरान इन फसलों को जल की आवश्यकता के साथ जल की आपूर्ति बनाए रखने के लिए कम जल की आवश्यकता होती है। खरीफ के मौसम में कुल 148 दिनों के दौरान नहर के जल की आपूर्ति हुई और फसलों की जल की आवश्यकता 11028.57 से 19543.34 हेक्टर सेंटीमीटर के बीच प्राप्त हुई। खरीफ के दौरान औसत सापेक्ष जल की आपूर्ति 0.676 थी। इसलिए जल की आपूर्ति को बढ़ाने के लिए अधिक जल की मांग वाली फसलों की जगह कपास, ज्वार और बाजरा जैसी कम जल की मांग वाली फसलों को उगाने की आवश्यकता है (बठिंडा केंद्र)।

- दाहिनी मुला नहर के कमांड क्षेत्र में मृदा एवं जल की गुणवत्ता के प्रबंधन के उपायों को विकसित करने के लिए मृदा एवं जल के नमूनों का विश्लेषण किया गया। इसके लिए मृदा एवं जल के क्रमश: 150 एवं 90 नमूनों को विश्लेषण के लिए एकत्रित किया गया। परिणामों ने बताया कि इस नहर के क्षेत्र की मृदा खराब हो रही है और कुंओं तथा नलकूपों के

जल की गुणवत्ता भी काफी हद तक खराब हो गई है जिसके कारण यहाँ की मृदा एवं जल के लवणीय-क्षारीय एवं क्षारीय प्रवृति में बदलने की संभावना हो गई है। मृदा एवं जल के नमूनों के विश्लेषण के आधार पर प्रबंधन के उपायों का सुझाव दिया गया है (राहुरी केंद्र)।

अध्याय 2. भूजल संभावित क्षेत्रीकरण एवं पुन:भरण

- गुजरात राज्य की ओजत नदी बेसिन में संभावित भूजल पुन:भरण क्षेत्रों की पहचान की गई। इस सर्वेक्षण में यह पाया गया कि अधिकांश क्षेत्र भूजल पुन:भरण के लिए उपयुक्त हैं। अधिक अच्छी श्रेणी के क्षेत्र के अंतर्गत 220.14 वर्ग किलोमीटर (6.93%) और अच्छा श्रेणी के तहत 2,094.81 वर्ग किलोमीटर (65.95%) क्षेत्र आता है। कृत्रिम भूजल पुन:भरण के लिए विभिन्न संरचनाओं जैसे चैक बांध, तालाब, कुएं और ट्यूबवेल आदि के निर्माण का अधिक अच्छी और अच्छी श्रेणी के अंतर्गत आने वाले संभावित भूजल पुन:भरण क्षेत्रों लिए सुझाव दिया गया। कुछ ऐसे क्षेत्र भी पाए गए जो बहुत खराब, खराब और मध्यम भूजल पुन:भरण क्षेत्रों के अंतर्गत आते हैं और इनका क्षेत्रफल क्रमशः 0.36 (0.01%), 430.87 (13.57%) और 430.05 वर्ग किलोमीटर (13.54%) पाया गया। मृदा संरक्षण संरचनाओं जैसे वनस्पति अवरोध और वृक्षारोपण, कंटूर खाइयों और स्टेगर्ड खाइयों, गली प्लग और गैबियन इत्यादि का बहुत खराब, खराब और मध्यम श्रेणी के संभावित भूजल पुन:भरण क्षेत्रों में निर्माण करने का सुझाव दिया गया (जूनागढ़ केंद्र)।
- केन नदी बेसिन में भूजल संभावित क्षेत्रों का क्षेत्रीकरण आवृत्ति अनुपात (FR) मॉडल और भू-सूचना विज्ञान तकनीक का उपयोग करके किया गया। भूजल संभावित क्षेत्रों के मानचित्र विकसित किए गए और इनको पांच अलग-अलग क्षेत्रों अर्थात् बहुत अधिक, अधिक, मध्यम, कम और बहुत कम में वर्गीकृत किया गया। कुल क्षेत्रफल का लगभग क्रमशः 7.09, 25.09 और 30.66 % 'बहुत अच्छा', 'अच्छा' और 'मध्यम' संभावित श्रेणी के क्षेत्रों के अंतर्गत आता है। भूजल संभावित क्षेत्रीकरण के लिए सत्यापन परिणाम क्षेत्रीकरण की उचित संतोषजनक भविष्यवाणी की सटीकता को यानी 78.1% के उदाहरण से स्पष्ट किया जा सकता है। यह अध्ययन सूखे को कम करने की योजना को बनाने, भूजल पुन:भरण योजनाओं के लिए महत्वपूर्ण स्थलों की पहचान करने के द्वारा नीति निर्माताओं और इंजीनियरों को विंध्य और बुंदेलखंड जैसे कठोर चट्टानी क्षेत्रों में भूजल के संसाधनों को बढ़ाने हेतु फायदेमंद साबित हो सकता है (जबलपुर केंद्र)।
- उत्तराखंड राज्य की ढ़ेला नदी बेसिन में संभावित भूजल पुन:भरण क्षेत्रों की पहचान के लिए एक अध्ययन किया गया। ढ़ेला वाटरशेड के मोर्फोमेट्रिक विश्लेषण के आधार पर 7 उप-वाटरशेड्स को उच्च प्राथमिकता वर्ग में, 3 को मध्यम प्राथमिकता वर्ग में और केवल एक को न्यूनतम प्राथमिकता श्रेणी में वर्गीकृत किया गया। जियो विजअलाइजेसन की तकनीकों की मदद से कृत्रिम भूजल पुन:भरण के लिए संभावित स्थलों की पहचान की गई और जल संरक्षण संरचनाओं जैसे कि तालाबों और चैक बांधों के निर्माण के लिए उपयुक्त स्थानों का सुझाव दिया गया। ये सभी संरचनाएं ढ़ेला नदी वाटरशेड में कृषि एवं अन्य विभिन्न गतिविधियों के लिए जल की उपलब्धता बढ़ाने में मदद कर सकती हैं (पंतनगर केंद्र)।
- ऊपरी बनास नदी बेसिन के भूजल संभावित क्षेत्रों को चित्रित किया गया । ऊपरी बनास नदी घाटी के पूरे जलग्रहण (Catchment) क्षेत्र (4940 वर्ग किमी) को कुल 21 उप-बेसिनों को प्राथमिकता दी गई। मानसून से पहले और बाद की अवधि के लिए जल गुणवत्ता सूचकांक के मानचित्र तैयार किए गए। कुल 100 स्थलों के लिए भूजल पुन:भरण का अनुमान लगाया गया। विषयगत मानचित्र तैयार किए गए और भूजल पुन:भरण संभावित क्षेत्रों का क्षेत्रीकरण किया गया। कृत्रिम भूजल पुन:भरण के लिए अनुकूल क्षेत्र 815.79 वर्ग किमी पाया गया जो कुल जलग्रहण क्षेत्र में केवल 16.51% योगदान देता है। भूजल पुन:भरण के लिए कुल 96 स्थानों को उपयुक्त पाया गया। इन 96 स्थानों में से 33 स्थानों पर भूजल पुन:भरण/वर्षा जल संचयन संरचनाओं का निर्माण किया जा चुका है। यह सुझाव दिया गया कि ऊपरी बनास नदी घाटी में कुल 27 रिसाव तालाबों, 29 जल संचयन संरचनाओं (एनीकट) और सात उपसतही बांधों का निर्माण किया जाना है (उदयपुर केंद्र)।
- लुधियाना कृषि विश्व विद्यालय के अनुसंधान फार्म पर मृदा-जल संतुलन विधि का उपयोग करके सीधी बिजाई एवं रोपाई किए गए धान के खेतों में संभावित भूजल पुन:भरण का आकलन किया गया। सीधी बिजाई एवं रोपाई किए गए धान के खेतों में गहरे रिसाव की हानि का हाइड्रस-1 डी (HYDRUS-1D) मॉडल का उपयोग करके सिमुलेशन के द्वारा अनुमान लगाया गया। सीधे बीज बुवाई एवं रोपाई किए गए धान के खेतों से गहरे रिसाव की हानि का क्रमश: 1139 एवं 1305.6 मिमी का अनुमान लगाया गया। इससे

यह प्राप्त हुआ कि रोपाई किए गए धान के खेत की तुलना में सीधी बिजाई वाले खेत से 14.6% तक अधिक गहरे रिसाव की हानि हुई जो कि अधिक संभावित भुजल पुन:भरण में योगदान देती है (लुधियाना केंद्र)।

- भोगडोई नदी बेसिन में आर्सेनिक प्रदूषित भूजल के सुधार के सुरक्षात्मक उपाय के रूप में जल संचयन संरचना के सभावित स्थलों की पहचान करने के लिए अनुसंधान किया गया। भू सूचना पद्धति (GIS) उपकरण एवं मोर्फोमेट्रिक गुणांकों के अनुमान से मोर्फोमेट्री मानचित्र तैयार किया गया। बेसिन के पूरे क्षेत्र से जीपीएस (GPS) आधारित मृदा, जल एवं सेडीमेंट के नमूनों को एकत्रित किया गया और उनका विश्लेषण किया गया। भोगडोई नदी बेसिन में आर्सेनिक प्रदूषित भूजल के क्षेत्रों में जल संचयन संरचनाओं के सभावित स्थलों की पहचान की गई (जोरहाट केंद्र)

अध्याय 3. सतही एवं दबावयुक्त सिंचाई पद्धतियों द्वारा सिंचाई के समय का निर्धारण

- पंजाब राज्य में ग्रीष्मकालीन मूंग की जल उत्पादकता में सुधार के लिए सिंचाई व्यवस्था और गेहूं की फसल के अवशेष प्रबंधन पर अध्ययन किया गया। खेत में गेहूं के अवशेषों को मृदा में नहीं मिलाने से मूंग की किस्म SML-668 की उपज 0.65 टन/हे) ही प्राप्त हुई। लेकिन शून्य जुताई के साथ बचे हुए गेहूं के अवशेषों के मृदा में उपचार तथा जुताई के साथ गेहूं के अवशेषों को मृदा में शामिल करने से मूंग की उपज 0.75 टन/हे एवं 0.77 टन/हे के रूप में काफी अधिक प्राप्त हुई। सिंचाई प्रबंधन अर्थात वानस्पतिक, फूल बनने, फली बनने तथा फली भरने की अवस्थाओं में चार सिंचाईयों के परिणामस्वरूप गेहूं के तीनों अवशेष प्रबंधन के उपचारों के साथ मूंग की उपज काफी अधिक प्राप्त हुई। शून्य जुताई एवं जुताई के साथ गेहूं के अवशेषों को शामिल करने के साथ अधिक जल उपयोग दक्षता (2.22 एवं 2.28 किग्रा/हे-मिमी) प्राप्त हुई तथा लाभ-लागत अनुपात (1.56 एवं 1.74) अधिक प्राप्त हुआ। जुताई के साथ बिना गेहूं के अवशेषों के समावेश से सबसे कम जल उपयोग दक्षता (1.89 किग्रा हे-मिमी) प्राप्त हुई और लाभ:लागत अनुपात (1.42) भी कम प्राप्त हुआ (बठिंडा केंद्र)।

- बीटी कपास पर धान के पुआल की पलवार और सिंचाई जल की गुणवत्ता के प्रभाव का अध्ययन किया गया तथा अगले मौसम की गेहूँ की फसल पर इनके अवशिष्ट प्रभाव का भी अध्ययन किया गया। सिंचाई के विभिन्न स्तरों के बीच IW/CPE 0.5 (3.29 टन/हे) एवं IW/CPE 0.7 (3.32 टन/हे) के साथ सिंचाई से कपास की उपज बराबर प्राप्त हुई। पलवार के अवशिष्ट प्रभाव ने बताया कि IW/CPE 1.0 के सिंचाई के स्तर से गेहूँ की अधिकतम उपज (4.01 टन/हे) प्राप्त हुई। कपास में नहर के जल से IW/CPE 0.3 के सिंचाई स्तर पर सिंचाई करने से अधिकतम जल उपयोग दक्षता (4.14 किग्रा/हे-मिमी) प्राप्त हुई जबकि, गेहूँ की फसल में नलकूप के जल से IW/CPE 0.7 के सिंचाई स्तर पर सिंचाई करने से अधिकतम जल उपयोग दक्षता (10.71 किग्रा/हे-मिमी प्राप्त हुई (बठिंडा केंद्र)।

- किसानों के खेत पर बासमती धान-गेहूं फसल पद्धति के लिए स्प्रिंकलर सिंचाई पद्धति के साथ सिंचाई के समय का निर्धारण किया गया ताकि, इस क्षेत्र के नहरी कमांड क्षेत्र में फसल पद्धति के लिए स्प्रिंकलर सिंचाई की रणनीति बनाई जा सके। धान में बाली के बनने से लेकर फसल की कटाई से 15 दिन पहले स्प्रिंकलर से सिंचाई करने पर अधिकतम दाना उपज (2.62 टन/हे) प्राप्त हुई जबकि, पडलिंग से लेकर फसल की कटाई से 15 दिन पहले तक की गई स्प्रिंकलर सिंचाई के साथ अधिकतम जल उपयोग दक्षता (2.29 किग्रा/हे-मिमी) प्राप्त हुई। रबी के मौसम में गेहूं की फसल में वृद्धि की सभी अवस्थाओं में स्प्रिंकलर सिंचाई के प्रयोग से अधिकतम उपज (3.48 टन/हे) और जल उपयोग दक्षता (7.20 किग्रा/हे-मिमी) प्राप्त हुई (जम्मू केंद्र)।

- नाली सिंचित ऊंची क्यारी पद्धति (FIRBS) के साथ मिनी स्प्रिंकलर, नाली सिंचित ऊंची क्यारी पद्धति, नाली सिंचित ऊंची क्यारी पद्धति के साथ ड्रिप एवं बाढ़ सिंचाई विधियों के बीच नाली सिंचित ऊंची क्यारी पद्धति के साथ ड्रिप सिंचाई से गेहूँ (किस्म-WH1105) की अधिकतम पैदावार (5.56 टन/हे) एवं जल उत्पादकता (3.05 किग्रा/घन मीटर) प्राप्त हुई। उसके बाद नाली सिंचित ऊंची क्यारी पद्धति (FIRBS) के साथ मिनी स्प्रिंकलर द्वारा सिंचाई से (5.57 टन/हे, 3.03 किग्रा/घनमीटर) प्राप्त हुई। जबकि सबसे कम बाढ़ सिंचाई विधि (उपज - 4.84 टन/हे, जल उत्पादकता- 2.57 किग्रा/घनमीटर) से प्राप्त हुई। इससे यह निष्कर्ष निकाला जा सकता है कि गेहूँ की अधिकतम पैदावार एवं जल उत्पादकता के लिए नाली सिंचित ऊंची क्यारी पद्धति के साथ ड्रिप पद्धति से सिंचाई करना सबसे अच्छा तकनीकी विकल्प साबित हुआ (हिसार केंद्र)।

- धान की फसल में सिंचाई प्रबंधन एवं फसल स्थापना की

विधियों ने बताया कि पूरी वृद्धि अवस्था के दौरान लगातार जल भरे रखने एवं साधारण रोपाई से अधिकतम दाना उपज (4.38 टन/हे) प्राप्त हुई तथा अधिक शुद्ध लाभ एवं लाभ:लागत अनुपात भी प्राप्त हुआ। जबकि अन्य उपचार संयोजनों के साथ दाना उपज में अंतर प्राप्त नहीं हुआ। लगातार जल भरे रखने एवं एकांतर नम एवं सुखी विधि (पेनीकल की शुरुआत की अवस्था तक खेत में जल सूखने के 3 दिनों के बाद 5 सेमी की सिंचाई एवं इसके बाद 5±2 सेमी की सिंचाई) के साथ अधिकतम जल उपयोग दक्षता (53.54 किग्रा/हे-सेमी) प्राप्त हुई (पूसा केंद्र)।

अध्याय 4 फर्टिगेशन

- केले की पूवन किस्म में जल और पोषक तत्वों के निर्धारण पर किए गए अध्ययन से पता चला कि 2 दिनों के अंतराल पर 75% PE पर ड्रिप सिंचाई महत्वपूर्ण रूप से अधिक उपज प्राप्त करने और फसल की वृद्धि को बनाए रखने के लिए पर्याप्त पाई गई। अधिक उपज, जल उत्पादकता, कुल लाभ और लाभ-लागत अनुपात प्राप्त करने के लिए यही सिंचाई स्तर उपयुक्त पाया गया। सिंचाई जल में घुलनशील उर्वरक का उपयोग करके नाइट्रोजन और पोटेशियम की 75% सुझाई गई मात्रा के साथ बुवाई के समय और साप्ताहिक अंतराल पर ड्रिप फर्टिगेशन के रूप में फर्टिगेशन निर्धारित किया गया (चलाकुड़ी केंद्र)।

- फूलगोभी में ड्रिप फर्टिगेशन के प्रयोग ने यह बताया कि फूलगोभी की अधिक उपज प्राप्त करने के लिए नाइट्रोजन, फॉस्फोरस और पोटेशियम की 100% मात्रा का प्रयोग करने की आवश्यकता है। बुवाई के समय फॉस्फोरस की 100% मात्रा का प्रयोग तथा फर्टिगेशन के माध्यम से 100% नाइट्रोजन एवं 100% पोटेशियम की सुझाई गई मात्रा का प्रयोग फसल की उपज के लिए समान रूप से फायदेमंद है (नवसारी केंद्र)।

- कपास आधारित फसल पद्धति के तहत लौकी की फसल में बुवाई के समय बिना कोई उर्वरकों के प्रयोग की तुलना में ड्रिप फर्टिगेशन (75% N, P एवं K का प्रयोग) के साथ लौकी की अधिकतम उपज (55.87 टन/हे) प्राप्त हुई। बुवाई के समय बिना कोई उर्वरकों के प्रयोग की तुलना में फर्टिगेशन के माध्यम से 100% NPK की मात्रा का प्रयोग एवं 100% NPK में से 25% NPK का प्रयोग बुयाई के समय व शेष 75% NPK की मात्रा का प्रयोग फर्टिगेशन के द्वारा करने पर बराबर उपज प्राप्त हुई (श्रीगंगानगर केंद्र)।

- रेतीली दोमट मृदा में उर्वरकों की सुझाई गई 100% मात्रा के प्रयोग के साथ 0.8 के वाष्पोत्सर्जन पर ड्रिप फर्टिगेशन से बेर की फसल में 9.33 किलोग्राम फल/पेड़ की पैदावार और 20.23 किलोग्राम/पेड़-मिमी की अधिकतम जल उपयोग दक्षता प्राप्त हुई। ये परिणाम केंचुआ की खाद के रूप में 25% NPK का प्रयोग + 75% NPK उर्वरकों के प्रयोग के साथ 0.8 के वाष्पोत्सर्जन पर ड्रिप सिंचाई के तहत 9.21 किलोग्राम फल पैदावार/पेड़ और 19.9 किलोग्राम/पेड़-मिमी की जल उपयोग दक्षता के बराबर प्राप्त हुए (ग्येशपुर केंद्र)।

- बीटी कपास-ग्रीष्मकालीन स्क्वैश फसल पद्धति में सिंचाई जल और ड्रिप फर्टिगेशन के संयुक्त उपयोग ने बताया कि अकेले नहर के जल की तुलना में नहर और नलकूप (अवशोषित सोडियम कार्बोनेट= 1.10 to 1.36 मिली इक्विवेलेंट/लीटर[1]; विद्त चालकता = 3.8 to 4.2 डेसी सिमन्स/मीटर) के विकल्प से सिंचाई करने पर कपास की उपज बराबर प्राप्त हुई जो अकेले नलकूप के जल से ड्रिप के तहत सिंचाई की तुलना में काफी अधिक थी। जब नाइट्रोजन की सुझाई गई 80% और 100% मात्रा का प्रयोग किया गया तो कपास की उपज बराबर प्राप्त हुई लेकिन, नाइट्रोजन की सुझाई गई 60% मात्रा के प्रयोग की तुलना में काफी अधिक थी। ग्रीष्मकालीन स्क्वैश की फसल में ड्रिप पद्धति के तहत प्रयोग किए गए विभिन्न जल के गुणों के उपचारों के बीच इसकी पैदावार काफी भिन्न-भिन्न प्राप्त हुई। विभिन्न फर्टिगेशन के स्तरों में से 80% एवं 100% फर्टिगेशन के स्तरों (नाइट्रोजन की सुझाई गई 80 एवं 100% मात्रा का प्रयोग) से ग्रीष्मकालीन स्क्वैश की उपज बराबर प्राप्त हुई लेकिन, नाइट्रोजन की सुझाई गई 60% मात्रा के फर्टिगेशन के स्तर से काफी अधिक थी। केवल नहरी जल की सिंचाई से अधिक जल उपयोग दक्षता प्राप्त हुई और उसके बाद नहरी जल/नलकूप जल से प्राप्त हुई तथा सबसे कम जल उपयोग दक्षता नहरी जल – नलकूप जल के संयोजी उपयोग से प्राप्त हुई। लवणीय जल के प्रयोग से मृदा की पीएच, विद्त चालकता और बल्क डेंसीटी बढ़ गई जबकि, इससे मृदा में उपलब्ध जैविक कार्बन, नाइट्रोजन एवं फॉस्फोरस तथा सिंचाई आवश्यकता आदि में कमी प्राप्त हुई (बठिंडा केंद्र)।

अध्याय 5. मृदा-पौधे-जल-पर्यावरण संबंध पर बुनियादी अध्ययन

- गेहूं की फसल में नमी की व्यवस्थाओं और खरपतवार प्रबंधन की विधियों के प्रभाव का अध्ययन करने के लिए

ड्रम सीडर की सहायता से धान की फसल को उगाया गया। उपचार संयोजन यानी खेत में भरे 6 सेमी जल को सूखने के 4 दिनों के बाद सिंचाई और खरपतवारनाशी बिस्पायरीबैक सोडियम 10% SC के 200 मिमी/हे की दर से प्रयोग के बाद धान की फसल से दाना उपज 5.02 टन/हे प्राप्त हुई तथा कुल लाभ ₹ 57,770/ हे और लाभ-लागत अनुपात 2.65 प्राप्त हुआ (अयोध्या केंद्र)।

- केरल राज्य में किसानों के बाड़े में बागवानी एवं खेती के लिए कपड़े धोने के अपशिष्ट जल को शुद्ध करने हेतु एक कम लागत वाला फिल्टर विकसित किया गया। कपड़े धोने के अपशिष्ट जल की गुणवत्ता के मानकों जैसे पीएच, विद्त चालकता (EC), अवशिष्ट सोडियम कार्बोनेट (RSC) और सोडियम अवशोषण अनुपात (SAR) के प्रारंभिक विश्लेषण से पता चला कि यह अपशिष्ट जल फसलों की सिंचाई के लिए उपयुक्त नहीं है। इसलिए, एक फिल्टर का निर्माण किया गया जो 200 लीटर क्षमता वाले एक सेटलिंग टैंक, बाएँ और दाएँ फिल्टर तथा एक आउटलेट (नल) से मिलकर बना होता है। इस फिल्टर में मुख्य रूप से पांच परतें जैसे की चारकोल, क्ले बॉल, फाइन सैंड, फाइन बजरी और मोटी बजरी के रूप में होती हैं। टैंक के तल पर जल के मुक्त प्रवाह के लिए एक उल्टा किया हुआ प्लास्टिक का एक जाल लगा होता है। इस फिल्टर से शुद्ध किए हुए लॉन्ड्री के अपशिष्ट जल ने स्वीकृत सीमा के भीतर पीएच, आरएससी और एसएआर को प्रदर्शित किया। इस फिल्टर से शुद्ध किए गए जल की सिंचाई के साथ उगाई गई भिंडी की फसल से तालाब के जल, उपचारित अपशिष्ट जल, अपशिष्ट जल + तालाब के जल के साथ सिंचाई की तुलना में खाद्य भाग में भारी धातुओं के प्रदूषण के बिना सांख्यिकीय रूप से समान फल उपज प्राप्त हुई (चलाकुड़ी केंद्र)।
- हीराकुंड कमांड की नीची भूमि वाले क्षेत्रों में ऊंची-नीची क्यारी पद्धति का फसलों की उपज पर प्रभाव का अध्ययन करने के लिए इसकी ऊंचाई निर्धारित किया गया। तीन वर्षों के आंकड़ों से यह पता चला कि हीराकुंड कमांड के नीची भूमि वाले क्षेत्र में धान-टमाटर फसल क्रम के साथ ऊंची-नीची क्यारी पद्धति की 60 सेमी की ऊंचाई सबसे अच्छी पाई गई जहां, धान की समतुल्य उपज 68.54 टन/हे प्राप्त हुई तथा शुद्ध लाभ ₹ 70,307/हे और लाभ-लागत अनुपात 2.41 प्राप्त हुआ (चिपलिमा केंद्र)।
- गहरी काली चिकनी मृदा में लाइसिमेट्रिक अध्ययन के माध्यम से मक्का की चारे की फसल और सूरजमुखी के फसल गुणांकों की गणना की गई। मक्का में वाष्पोत्सर्जन (ET) 128.92 मिमी और वाष्पीकरण (EP) 348.63 मिमी था। फसल वृद्धि की टैसलिंग अवस्था में अधिकतम ET/EP अनुपात 0.42 था जबकि, सिल्किंग अवस्था में न्यूनतम ET/EP अनुपात 0.28 मिमी था। फिट किए गए चौथे क्रम के पॉलीनोमीयल फन्कसंस द्वारा फसल गुणांकों के मानों को अच्छी तरह से पूर्व-अनुमानित किया जा सकता है। मक्का की चारे की फसल का औसत फसल गुणांक का मान 0.38 से 1.13 के बीच प्राप्त हुआ। सूरजमुखी में ET 139.24 मिमी और EP 421.00 मिमी था। फूल आने की अवस्था में अधिकतम ET/EP अनुपात 0.42 प्राप्त हुआ, जबकि, अंकुरण अवस्था में न्यूनतम ET/EP अनुपात 0.22 मिमी प्राप्त हुआ। फिट किए गए तीसरे क्रम के पॉलीनोमीयल फन्कसंस द्वारा फसल गुणांकों के मानों को अच्छी तरह से पूर्व-अनुमानित किया गया। सूरजमुखी का औसत फसल गुणांक का मान 0.40 से 1.11 के बीच प्राप्त हुआ। इस प्रकार समान कृषि-जलवायु की परिस्थितियों में मक्का की चारा की फसल और सूरजमुखी के लिए सिंचाई के समय-निर्धारण के प्रबंधन हेतु अनुमानित फसल गुणांक के मानों का उपयोग किया जा सकता है (राहुरी केंद्र)।
- पंजाब में रबी के मौसम के दौरान गेहूं की बुवाई के समय को इष्टतम करने के लिए सेरेस-व्हीट (CERES-Wheat) मॉडल की सहायता से डीसेट (DSSAT) सिमुलेशन किया गया। प्रयोग के परिणाम ने बताया कि गेहूं की फसल की समय पर बुवाई (15 नवंबर) से काफी अधिक दाना उपज प्राप्त हुई और उसके बाद 30 नवंबर को बुवाई करने से प्राप्त हुई जबकि, देरी से बुवाई (15 दिसंबर) करने पर काफी कम उपज प्राप्त हुई। सिंचाई के स्तरों के बीच, IW:CPE 1.0 के स्तर पर सिंचाई करने से अधिक उपज प्राप्त हुई जबकि, सबसे कम उपज IW:CPE 0.6. के सिंचाई के स्तर के साथ प्राप्त हुई। बुवाई के समय, सिंचाई एवं नाइट्रोजन के उपचारों के लिए अधिकतम कॉफीसियण्ट ऑफ डिटर्मिनेशन (R^2) एवं न्यूनतम RMSE गुणांक प्राप्त हुए। सेरेस-व्हीट (CERES-Wheat) मॉडल गेहूं की दाना उपज, अंकुरण एवं फिजियोलोजिकल परिपक्वता का अच्छे से अनुमान लगा सकता है (बठिंडा केंद्र)।
- फसल की कटाई के बाद मृदा के स्वास्थ्य एवं फसल पद्धति की उत्पादकता के लिए धान आधारित फसल पद्धति और नमी की व्यवस्था को अनुकूलित किया गया। धान-मक्का+आलू-ढैंचा फसल पद्धति के साथ धान की

समतुल्य उपज काफी अधिक प्राप्त हुई। इस पद्धति से ही अधिकतम भूमि उपयोग दक्षता 89.86%, जल उपयोग दक्षता 202.46 किलोग्राम/हे-सेमी एवं जल उत्पादकता ₹ 23.05 हे-सेमी प्राप्त हुई और फसल पद्धतियों के बीच अधिक शुद्ध लाभ ₹ 319734/हे प्राप्त हुआ। पारंपरिक फसल पद्धति यानी धान-गेहूं-परती की तुलना में इस उन्नत फसल पद्धति से 251.8% से अधिक धान समतुल्य उपज, 28.12% से अधिक भूमि उपयोग दक्षता, 186.4% से अधिक जल उपयोग दक्षता, 298.1% से अधिक जल उत्पादकता प्राप्त हुई और 112.8% से अधिक लाभ-लागत अनुपात प्राप्त हुआ। इस फसल पद्धति को अपनाने से पहले मृदा की तुलना में धान-मक्का+आलू-ढेंचा फसल पद्धति से फसलों की कटाई के बाद मृदा में जैविक कार्बन में 19.2% और उपलब्ध जिंक में 5.9% की अधिकतम वृद्धि हुई (पूसा केंद्र)।

अध्याय 6. जल का संयोजी और बहुउपयोग

- दक्षिण-पश्चिम पंजाब में चारे की फसल पद्धतियों अर्थात् बरसीम-ज्वार और राईघास-ज्वार की जल उत्पादकता और उपज पर जल की गुणवत्ता के प्रभाव का अध्ययन किया गया। इन फसल पद्धतियों की सिंचाई के लिए अच्छी गुणवत्ता वाले नहर के जल और सेलाइन-सोडिक नलकूप के जल का संयोजी रूप से उपयोग किया गया। रबी के मौसम में अकेले नलकूप के जल से सिंचाई की तुलना में नहर के जल और नलकूप के जल की वैकल्पिक सिंचाई के परिणामस्वरूप बरसीम और राईघास की फसलों में हरे चारे की उपज क्रमशः 26.7 और 18.9% तक अधिक प्राप्त हुई। बरसीम-ज्वार पद्धति की तुलना में राईघास-ज्वार की फसल पद्धति ने जल के संयोजी उपयोग के तहत बेहतर प्रदर्शन दिखाया। राईग्रास-ज्वार फसल पद्धति से अकेले नलकूप के जल के उपयोग की तुलना में नहर-नलकूप के जल के वैकल्पिक उपयोग के साथ 31.5% अधिक हरे चारे की उपज एवं 68.4% अधिक सूखे चारे की उपज प्राप्त हुई और 31.4% से अधिक लाभ:लागत अनुपात प्राप्त हुआ (बठिंडा केंद्र)।
- चलाकुड़ी नदी डाइवर्जन स्कीम में मौजूद भूजल संसाधनों की जियोरेफ्रेंसिंग एवं पहचान करने, नई जल संचयन संरचनाओं के स्थल निर्धारित करने तथा जल संयोजी योजना को विकसित करने के उद्देश्य से एक अध्ययन किया गया। भू सूचना पद्धति (GIS) का उपयोग करके चलाकुड़ी नदी डाइवर्जन स्कीम के विषय मानचित्र तैयार किए गए जो नहरी पद्धति एवं भूमि के उपयोग को प्रदर्शित करते हैं। बाईं और दाईं तरफ की नहरों की शाखाओं की फसल जल मांग आकलित की गई। वहाँ पर मौजूद तालाब जो कि नहर के बहाव से पुन:भरित होते हैं की पहचान की गई और उनको चिन्हित किया गया। नई जल संचयन संरचनाओं के स्थलों को निर्धारित एवं चिन्हित करके जल संयोजी योजना को बनाया गया (चलाकुड़ी केंद्र)।
- अवानपुर डिस्ट्रीब्यूटरी के शीर्ष एवं मध्य छोर पर धान आधारित एकीकृत कृषि पद्धति के माध्यम से जल के बहुआयामी उपयोग का अध्ययन किया गया। मत्स्य पालन के साथ एकीकृत कृषि पद्धति पारंपरिक धान-गेहूं+सरसों फसल पद्धति की तुलना में सबसे अधिक उत्पादक और लाभकारी पाई गई जिसमें ₹ 184619/हे/वर्ष का अधिकतम शुद्ध लाभ और 3.88 का लाभ-लागत अनुपात प्राप्त हुआ जो कि पारंपरिक कृषि पद्धति के तहत अर्जित शुद्ध लाभ ₹ 95832/हे/वर्ष से 92.6% अधिक और 2.47 के लाभ:लागत अनुपात से 57.1% अधिक प्राप्त हुआ (अयोध्या केंद्र)

अध्याय 7. जनजातीय उप योजना और परिचालन ओपरेशनल अनुसंधान परियोजना

- वर्ष 2020-21 के दौरान विक्रमगढ़ तालुका में कुल 200 कोंकण जलकुंडों का निर्माण किया गया जिससे लाभान्वित होने वाले 100 आदिवासी किसानों ने कुल 8 लाख लीटर वर्षा के जल का संचयन किया और आम और काजू की फसलों के तहत कुल 20 हेक्टर का कमांड क्षेत्र उनको मिला। आम और काजू की कलमों की उत्तरजीविता में क्रमशः 28.85% और 41.5% तक की वृद्धि हुई और खेती योग्य भूमि उपयोग सूचकांक 0.25 से बढ़कर 0.45 हो गया जिससे ₹ 1,30,334/हे की बचत प्राप्त हुई। पारंपरिक तरीके के आम और काजू के खेतों में चमेली की अंतरफसल के रूप में खेती करके कुल ₹ 1,29,324/हे का लाभ प्राप्त किया गया। जवाहर तालुका में कुल 10 कोंकण विजय बंधारों का निर्माण किया गया जिससे 50 आदिवासी किसानों को लाभ हुआ जिनके द्वारा कुल 3980 घन मीटर वर्षा जल का संचयन किया गया। इससे सब्जी, काजू, आम और चमेली की खेती के तहत किसानों को 7.12 हेक्टर का कमांड क्षेत्र प्राप्त हुआ। इसी तरह विक्रमगढ़ तालुका में 5 कोंकण विजय बंधारों का निर्माण किया गया जिससे 15 आदिवासी किसान लाभान्वित हुए। आम, काजू, ग्वार, लोबिया और चमेली की फसलों की सिंचाई के लिए

कुल 5870 घन मीटर वर्षा के अपवाह का संचयन किया गया जिससे 11.26 हेक्टर का कमांड क्षेत्र प्राप्त हुआ (दापोली केंद्र)।

- वर्ष 2020-21 के दौरान महाराष्ट्र राज्य के अहमदनगर जिले की अकोले तहसील को टीएसपी कार्यक्रम के कार्यान्वयन के लिए चुना गया। अकोले तहसील के म्हालुंगी आदिवासी गांव के कुल 30 किसानों और दूसरे अन्य 30 किसानों को सिंचाई सुविधा प्रदान करने के लिए प्रति किसान 0.4 हेक्टर क्षेत्र में क्रमशः ड्रिप सिंचाई और स्प्रिंकलर सिंचाई पद्धति के सेट वितरित किए गए। इन तकनीकों के प्रभावी कार्यान्वयन में मदद करने के लिए किसानों के लाभ हेतु प्रशिक्षण और प्रदर्शन आयोजित करने का निर्णय भी लिया गया (राहुरी केंद्र)।
- फसलों की खेती के लिए सिंचाई जल की कमी को दूर करने हेतु खेतों में निर्मित तालाब के माध्यम से सूक्ष्म सिंचाई पद्धतियों का प्रचार-प्रसार किया जा रहा है जिससे खेत पर और खेत से बाहर प्रशिक्षण गतिविधियों का आयोजन करके कृषक समुदाय और लाइन विभाग के कर्मियों के बीच जल के कुशल उपयोग के बारे में जागरूकता पैदा की जा सके। इसके अलावा उत्तरी कर्नाटक के मालाप्रभा लेफ्ट बैंक कैनाल कमांड क्षेत्र में प्रमुख फसलों में सूक्ष्म सिंचाई पद्धतियों का उपयोग करके जल उपयोग दक्षता को बढ़ाया जा सके। तालाबों के जल के अच्छे स्रोत वाले कुल 15 किसानों के खेतों में ड्रिप सिंचाई तकनीक स्थापित की गई है। किसानों के लाभ के लिए सिंचाई जल प्रबंधन अनुसंधान केंद्र (IWMRC) बेलवातगी ने 24 एकड़ क्षेत्र में सेंसर आधारित ड्रिप सिंचाई स्वचालन पद्धति को प्रदर्शन एवं फील्ड डे और प्रशिक्षण कार्यक्रम आयोजित करने के माध्यम से स्थापित किया गया है। इस क्षेत्र के किसानों, खेतिहर महिलाओं और स्कूल और कॉलेज के छात्रों के लिए छह प्रशिक्षण और क्षेत्र प्रदर्शन आयोजित किए गए हैं (बेलवातगी केंद्र)।
- मध्य प्रदेश में श्योपुर जिले की विजयपुर तहसील के डांगपुरा गांव में आदिवासी किसानों के खेतों में खरीफ के मौसम में ग्वार, अरहर और मूंग की फसलों और रबी के मौसम में गेहूं, सरसों और चने की खेती का प्रदर्शन किया गया। इन प्रदर्शन के परिणामों ने यह दिखाया कि बेहतर सिंचाई के साथ खेती के परिणामस्वरूप किसानों की पारंपरिक पद्धति की तुलना में 5.9-42.3% अधिक फसल उपज प्राप्त हुई तथा 2.5-80.5% अधिक शुद्ध लाभ और 12.5-38.5% अधिक लाभ-लागत अनुपात प्राप्त हुआ (मॉरेना केंद्र)।
- गिरते हुए भूजल के साथ उत्तरी बिहार क्षेत्र में जल निकासी सह पुनःभरण इकाई का डिजाइन तैयार किया गया और मूल्यांकन किया गया। उत्तर बिहार के विभिन्न स्थानों पर किसानों के खेत में कुल 6 भूजल पुनःभरण सह जल निकासी इकाईयां स्थापित/निर्मित की गईं। विश्वविद्यालय परिसर में कुल 7 भूजल पुनःभरण सह जल निकासी इकाईयां स्थापित की गई हैं और एक पुनःभरण इकाई कृषि विज्ञान केंद्र, पिपराकोठी, पूर्वी चंपारण में स्थापित की गई है। पूर्व उपमहानिदेशक (NRM) और बिधान चन्द्र कृषि विश्वविद्यालय, कल्याणी के कुलपति को पुनःभरण इकाईयों के कामकाज का सफलतापूर्वक प्रदर्शन दिखाया गया। बिहार के मधुबनी जिले के झंझारपुर ब्लॉक के सुखेत गांव के एक किसान के खेत में इस इकाई को आंशिक रूप से स्थापित किया गया, जहां हर साल जुलाई से मार्च तक जलभराव की समस्या का सामना करना पड़ता था। किसान ने बताया कि कई वर्षों के बाद खेत से अतिरिक्त जल की समय पर निकासी के कारण रबी के मौसम में गेहूं की समय पर बुवाई संभव हो पाई है (पूसा केंद्र)।
- चालू वर्ष के दौरान हिमाचल प्रदेश के चंबा जिले में प्रदर्शन के लिए 250 वर्ग मीटर के 50 ड्रिप किट वितरित और स्थापित किए गए। अनुसूचित जाति उप योजना (SCSP) के तहत, ड्रिप सिंचाई पद्धति के साथ एक पॉलीलाइन जल संचयन टैंक बनाया जा रहा है और जो मई 2022 से पहले पूरा हो जाएगा ताकि, मानसूनी वर्षा के जल का संचयन किया जा सके और इसके प्रदर्शन को सही साबित किया जा सके (पालमपुर केंद्र)।
- असम राज्य के गोपालपुरा जिले के बाढ़ ग्रसित क्षेत्र दुधनोई में वहाँ स्थित कृषि विज्ञान केंद्र के सहयोग से तकनीक का प्रदर्शन किया गया। सिंचित स्थितियों के तहत एक अधिक उत्पादक कम अवधि वाली औटमन धान की किस्म "दिशांग" का प्रदर्शन किया गया ताकि इस किस्म की कटाई इस क्षेत्र में बाढ़ आने से पहले की जा सके। माटिया गोस्साईबाड़ी गाँव में किसान के कुल 5 हेक्टर के खेत पर उथले नलकूप के जल से धान के खेत में जल सूखने के 3 दिनों बाद 5 सेमी की सिंचाई की प्रबंधन विधि का परीक्षण किया गया। फरवरी 2020 के पहले सप्ताह में नर्सरी की क्यारियों में बीजों को उगाया गया और जून में फसल की सफलतापूर्वक कटाई की गई (जोरहाट केंद्र)।

Executive Summary

During the year 2021, 26 centres carried out research and extension work in the field of assessment of water availability, groundwater recharge, groundwater use at regional level, evaluation of pressurized irrigation system, groundwater assessment and recharge, water management in horticultural and high value crops, basic studies on soil, water, plant relationship and their interaction, conjunctive use of canal and underground saline water, drainage studies for enhancing water productivity, enhancing productivity by multiple use of water, rainwater management in high rainfall areas. Salient achievements of year 2021 are enlisted below.

Assessment of surface water and ground water availability

- Performance evaluation of two lift irrigation schemes namely, Munippara and Poolani of Thrissur district of Kerala was done. Relative water supply (RWS) in the command area of Munippara and Poolani lift irrigation schemes ranged from 1.14 to 3.43 and 2.60 to 2.96, respectively. Relative irrigation supply in the command area of Munippara and Poolani lift irrigation schemes ranged from 1.17 to 3.89 and 3.05 to 3.66, respectively. Water was abundant for crop production in both the lift irrigation schemes. There was more equitable distribution of water in Poolani scheme compared to Munippara lift irrigation scheme. Well recharge also takes place and sustains drinking water availability in the command area of both the schemes. High RWS values observed in the minor irrigation schemes shows scope for further improvement of performance by regulating water supply or by increasing cropped area. It would also empower the beneficiaries to change from over irrigation to better water management practices. (Chalakudy centre)

- Optimal crop planning was done based on delineation of water resources and different farming situations of Kotani watershed in Chhattisgarh. Water resource development plan was developed. Seven check dams and 10 percolation tanks were proposed for groundwater recharge, whereas 20 check dams and 61 farm ponds were proposed in appropriate locations for water harvesting. Optimal cropping pattern was developed for *kharif* and *rabi* crops in the command area with the help of stochastic linear programming model and using different farming situations of the watershed. Additional benefits of ₹ 1165 ha^{-1} and ₹ 8020 ha^{-1} can be obtained during *kharif* and *rabi* seasons, respectively. An additional area of 1580 ha can also be cultivated during *rabi* season. (Raipur centre)

- Five outlets of Behman distributary of Bathinda branch canal were selected to evaluate irrigation system performance and work out intervention for improvement of irrigation system and its management. Average RWS was 0.537 in the five selected outlets during 129 total running days of canal water in *rabi* season. It was suggested to replace large parts of the cultivated area under wheat with barley, chickpea and mustard. These crops will require less water to match water supply with crop water requirement during *rabi* season. In *kharif* season, there was 148 total running days of canal water and crop water requirement varied from 11028.57 to 19543.34 ha-cm. Average RWS was 0.676 during *kharif*. So, there is need to either increase water supply or replace high water consuming crops with low water consuming crops like cotton, clusterbean and bajra. (Bathinda centre)

- Analysis of soil and water samples in Mula right bank canal command area was done to develop soil and water quality management strategy. About 150 soil and 90 water samples were collected for analysis. It was found that the soils and bore/well waters in the area of MRBC are getting deteriorated to a great extent with a fear of soils getting converted to saline sodic to sodic in nature. Management strategies have been recommended in the study area based on soil and water sample analysis. (Rahuri centre)

Groundwater potential zoning and recharge

- Identification of potential groundwater recharge zones was done for Ozat river basin in Gujarat. Most of the area was suitable for groundwater recharge. Area under excellent recharge zone is 220.14 km^2 (6.93%) and good recharge zone is 2,094.81 km^2 (65.95%). Structures for artificial groundwater recharge such as check dam, farm ponds, open wells and tubewells were suggested for construction in excellent and good recharge zones. Area that fell under very poor, poor and moderate groundwater recharge zones was 0.36 km^2 (0.01%), 430.87 km^2 (13.57%) and 430.05 km^2 (13.54%) respectively. Soil conservation structures such as vegetative barriers & tree plantations, contour trenches & staggered trenches and gully plugs & gabion structures are suggested in very poor, poor and moderate zones. (Junagadh centre)

- Groundwater potential zoning of Ken river basin was done using frequency ratio model and geoinformatics technique. Groundwater potential zone map was developed and classified into five different zones namely, very high, high, moderate, low, and very low. About 7.09, 25.09 and 30.66% of the total area fell under very good, good and moderate potential zones, respectively. Validation results for the groundwater potential zoning illustrated fair satisfactory prediction accuracy of the zoning i.e. 78.1%. The study will be beneficial for planning of drought mitigation strategies, identification of critical sites for groundwater recharge plans, policymakers and engineers to work for enhancement of groundwater resources in hard rock regions such as Vindhyan & Bundelkhand. (Jabalpur centre)

- A study was conducted in Dhela river watershed to prioritize the sub-watersheds on the basis of morphometric analysis and delineate potential sites for artificial groundwater recharge. Based on morphometric analysis, seven sub-watersheds were categorized in high priority class, three in medium priority class and only one in least priority class. Potential sites for artificial groundwater recharge were identified with the help of geo-visualization techniques and suitable locations were suggested for construction of water conservation structures such as farm ponds and check dams. These structures can help in enhancing water availability for various activities in Dhela river watershed. (Pantnagar centre)

- Groundwater potential zones of Upper Banas river basin were delineated. The entire catchment area (4940 km^2) of Upper Banas river basin was prioritized into 21 sub-basins. Water quality index maps were prepared for pre- and post-monsoon periods. Groundwater recharge was estimated for 100 sites, thematic maps were prepared and groundwater potential zoning was done. In the basin, 45.12 and 20.98% area are under moderate and good groundwater potential zones, respectively. Area favourable for artificial recharge is 815.79 km^2 i.e. only 16.51% of the total catchment area. Ninety-six locations were found suitable for groundwater recharge, out of which groundwater recharge/ water harvesting structures have been constructed in 33 locations. More recharge structures i.e. 27 percolation ponds, 29 water harvesting structures (anicuts) and seven subsurface dykes sites can be constructed in Upper Banas river basin. (Udaipur centre)

- Assessment of potential groundwater recharge in direct seeded rice (DSR) and transplanted rice (TPR) fields was done using soil water balance method at PAU university research farm. Field estimation as well as simulation (using HYDRUS-1D) of deep percolation from DSR and TPR fields was performed. Deep percolation was estimated to be 1139 and 1305.6 mm for TPR and DSR, respectively. This showed that there was 14.6% more deep percolation in DSR compared to TPR that may potentially contribute to groundwater recharge. (Ludhiana centre)

- An experiment was conducted in Bhogdoi river basin to identify potential sites for rainwater harvesting as a preventive measure against use of arsenic contaminated groundwater. Stream morphometry map was prepared using GIS tool and morphometric parameters were estimated. GPS based soil, water and sediment samples were collected across the whole basin area and analysed. Potential sites for rainwater harvesting in the arsenic contaminated areas of Bhodoi river basin were identified. (Jorhat centre)

Irrigation scheduling using surface and pressurized irrigation system

- Wheat residue management and irrigation level showed significant effect on performance of summer moong bean. Yield (0.87 and 0.90 t ha^{-1}), water use efficiency (2.15 and 2.22 kg ha-mm^{-1}) and benefit-cost ratio (2.01 and 1.82) of moong bean was significantly higher under wheat residue incorporation with zero tillage and wheat residue incorporation with tillage, respectively as compared to no residue incorporation. Without residue incorporation resulted in yield of 0.78 t ha^{-1}, water use efficiency of 1.90 kg ha-mm^{-1} and benefit-cost ratio of 1.69 with four irrigations at vegetative, flowering, pod filling & pod formation stages (Bathinda centre).

- Effect of rice straw mulching and irrigation water quality on Bt cotton and its residual effect on succeeding wheat crop was studied. Among the different irrigation levels, seed cotton yield was at par with irrigation levels of IW/CPE 0.5 (3.29 t ha^{-1}) & IW/CPE 0.7 (3.32 t ha^{-1}). Residual effect of mulch on the following wheat crop showed maximum wheat grain yield of 4.01 t ha^{-1} under IW/CPE 1.0. Maximum water use efficiency was found under canal water irrigation in cotton IW/CPE 0.3 (4.14 kg/ha mm) and tubewell water irrigation in wheat at IW/CPE 0.6 level (10.71 kg/ha.mm) (Bathinda centre).

- Scheduling of sprinkler irrigation for basmati rice-wheat cropping system was carried out on farmer's field to strategize sprinkler irrigation for the cropping system in canal commands of the region. In rice, sprinkler irrigation at panicle initiation to 15 days before harvest recorded highest yield (2.62 t ha^{-1}), whereas highest water use efficiency (2.29 kg ha-mm^{-1}) was recorded with sprinkler irrigation introduced after puddling to 15 days before harvest. In wheat, application of sprinkler irrigation at all physiological stages recorded highest yield (3.48 t ha^{-1}) and WUE (7.20 kg ha-mm^{-1}) (Jammu centre).

- Among mini-sprinkler, furrow irrigated raised bed system (FIRBS), drip on FIRBS, and flooding, wheat variety WH 1105 showed highest grain yield and water productivity under drip on FIRBS (5.56 t ha^{-1}, 3.05 kg m^{-3}) followed by use of mini-sprinklers (5.57 t ha^{-1}, 3.03 kg m^{-3}). The performance of the wheat variety was lowest (4.84 t ha^{-1}, 2.57 kg m^{-3}) under flooding. Drip on FIRBS was best for wheat in terms of grain yield and water productivity (Hisar centre).

- Irrigation management and methods of establishment on rice crop showed that continuous submergence throughout crop growth and normal transplanting resulted in highest grain yield of 4.38 t ha^{-1}, net return and benefit-cost ratio. However, there was no significant difference in grain yield with other treatment combinations. Water use efficiency was highest (53.54 kg ha-cm^{-1}) with continuous submergence and alternate wetting and drying (5 cm irrigation at 3 days after disappearance of ponded water) up to panicle initiation thereafter 5 ± 2 cm irrigation after panicle initiation (Pusa centre).

Fertigation

- A study on water and nutrient scheduling in *Poovan* banana showed that drip irrigation at 75% PE at 2 days interval was sufficient to obtain significantly higher yield and to sustain the crop. Significantly higher yield, water productivity, gross return and benefit-cost ratio were obtained where fertigation was scheduled with phosphorus as basal and drip fertigation at weekly interval with 75% recommended dose of nitrogen and potassium using water soluble common fertilizer (Chalakudy centre).

- An experiment on drip fertigation in cauliflower indicated that application of 100% RDF of N, P_2O_5 and K_2O is required for getting higher yield of cauliflower. The application of 100% RDF through fertigation or 100% N and K through fertigation with 100% P applied as basal are equally beneficial for crop yield (Navsari centre).

- Drip fertigation to bottle gourd crop under cotton based cropping system showed maximum yield of bottle gourd (55.87 t ha^{-1}) with the application of 75% N, P & K through fertigation with no basal application. This was statistically at par with application of 100% N, P & K through fertigation with no basal application, and 25% NPK of 100% as basal and remaining NPK through fertigation (Sriganganagar centre).

- Drip fertigation to Indian jujube crop at 0.8 ET_0 along with 100% RDF in sandy loam soil showed highest fruit yield of 9.33 kg tree^{-1} and WUE of 20.23 kg tree^{-1}mm^{-1}. The results were at par with those under drip irrigation at 0.8 ET_0 coupled with 75% RDF + 25% RDF as vermicompost showing yield of 9.21 kg tree^{-1} and WUE of 19.9 kg tree^{-1} mm^{-1} (Gayeshpur centre).

- Conjunctive use of water and drip fertigation to *Bt* cotton-summer squash cropping system showed that seed cotton yield was at par when irrigating with canal water (CW) alone and alternate of canal & tube well (TW) water (RSC = 1.10 to 1.36 meq L^{-1}; EC = 3.8 to 4.2 dS m^{-1}) and was significantly higher than irrigation with tube well water alone under drip. The seed cotton yields were at par when 80% and 100% of recommended dose of nitrogen was applied and were significantly higher than application of 60% recommended dose of nitrogen. In summer squash, the yields were significantly different among different water qualities treatments under drip. Among different fertigation schedules, summer squash yields for fertigation level of 80% and 100% recommended dose of nitrogen were at par but significantly higher than fertigation level of 60% recommended dose of nitrogen. The WUE was higher in CW irrigation followed by CW/TW and least in CWg-TW. Saline water application increased the pH, EC and BD of soil while it decreased the organic carbon, available N, available P and IR of soil, etc (Bathinda centre).

Basic studies on soil-plant-water-environment relationship

- Drum seeded rice was grown to study the effect of moisture regimes and weed management practices on performance of wheat. Treatment combination i.e. 6 cm at 4 days after disappearance of ponded water (DADPW) and application of herbicide Bispyribac Sodium 10% SC at 20 mL ha^{-1} as post emergence resulted in rice grain yield of 5.02 t ha^{-1}, net return of ₹ 57,770 ha^{-1} and benefit-cost ratio of 2.65. (Ayodhya centre)

- A low cost filter was developed to purify laundry wastewater for homestead farming in Kerala. Initial analysis of quality parameters of laundry wastewater such as pH, EC, residual sodium carbonate (RSC) & sodium absorption ratio (SAR) showed that the wastewater is not suitable for irrigation. The filter unit comprises of one settling tank of 200 L capacity, left & right filters and an outlet (tap). The filter consists of mainly five layers viz., charcoal, clay ball, fine sand, fine gravel and coarse gravel. At the bottom of the tank, there is an inverted plastic net placed for free flow of water. Filtered laundry wastewater showed pH, RSC and SAR within permissible limits. Okra crop grown with the filtered water showed statistically similar yield with irrigation (pond) water, with no heavy metal contamination in the edible part. (Chalakudy centre)

- Optimization of the height of raised and sunken bed system was done for the lowlands of Hirakud command to study its impact on crop yield. Pooled data of three years showed that elevation difference of 60 cm between raised and sunken bed was best with rice-tomato cropping sequence where rice equivalent yield was 68.54 t ha^{-1}, net return was ₹ 70,307 ha^{-1} and benefit-cost ratio was 2.41 in the lowlands of Hirakud command. (Chiplima centre)

- Crop coefficient (K_c) of fodder maize and sunflower was derived through lysimetric study in deep black clayey soil. In fodder maize, evapotranspiration (ET) was 128.92 mm and evaporation (EP) was 348.63 mm. Maximum ET/EP was 0.42 at tasseling stage, whereas minimum ET/EP was 0.28 mm at silking stage. K_c values can be well predicted by fitted 4th order polynomial functions. Average K_c of fodder maize varied from 0.38 to 1.13. In sunflower, ET was 139.24 mm and EP was 421.00 mm. Maximum ET/EP was 0.42 at flowering stage, whereas minimum ET/EP was 0.22 mm at seedling stage. K_c values can be well predicted by fitted 3rd order polynomial functions. Average K_c value of sunflower varied from 0.40 to 1.11. Estimated K_c values can be used to manage irrigation scheduling for fodder maize and sunflower under similar agro-climatic conditions. (Rahuri centre)

- At Bathinda, DSSAT simulation was done using CERES-Wheat model to optimize sowing date of wheat crop during *rabi* season in Punjab. Experimental results showed that grain yield of wheat was significantly higher in timely sown crop (15th November) crop followed by late (30th November) and lowest in very late sown on 15th December. Among irrigation regimes, significant increase in grain yield was obtained with IW:CPE 1.0 and lowest with 0.6. Higher coefficient of determination (R^2) and lower RMSE was obtained for sowing time, irrigation and nitrogen treatments. CERES-Wheat model produced better estimates for grain yield, emergence and physiological maturity. (Bathinda centre)

- Rice based cropping system and moisture regime was optimized for system productivity and post-harvest soil health. Rice equivalent yield was significantly higher with rice-maize+potato-dhaincha cropping system, along with highest land use efficiency of 89.86%, WUE of 202.46 kg ha-cm^{-1}, and net return of ₹ 319734 ha^{-1} among the cropping systems. There was 251.8% higher rice equivalent yield, 28.12% higher land use efficiency, 186.4% higher WUE, 298.1% higher WP, 112.8% higher benefit-cost ratio compared to traditional cropping system, i.e. rice-wheat-fallow. There was maximum increase in organic carbon i.e. 19.2% and available zinc i.e. 5.9% in post-harvest soil with over rice-maize+potato-dhaincha the soil before cropping. (Pusa centre)

Conjunctive use of water and multiple use of water

- Conjunctive use of good quality canal water (CW) and saline sodic tubewell water (TW) was applied to study the effect of water quality on yield and water productivity of fodder-fodder cropping systems viz., berseem-sorghum and ryegrass-sorghum in south-west Punjab. Alternate irrigation with CW and TW resulted in 26.7 and 18.9% higher green fodder yield for berseem and ryegrass, respectively compared to irrigation with TW alone during *rabi* season. Ryegrass-Sorghum system performed better under conjunctive use of water compared to berseem-sorghum system. Ryegrass-Sorghum system showed 31.5% higher green fodder yield, 68.4% higher dry fodder yield and 31.4% higher benefit-costratio with alternate use of CW-TW over use of TW alone. (Bathinda centre)

- A study was conducted with the aim of identification and geo-referencing existing ground water resources, locating site for new water harvesting structures and developing a conjunctive use plan in the Chalakudy River Diversion Scheme. The thematic map depicting the canal system and land use map of Chalakudy River Diversion Structure was prepared using GIS. Branch wise crop water demand of LBC and RBC were estimated. Existing ponds which are recharged from canal flows were identified and geo-referenced. Identification and locating new water harvesting structures for the conjunctive water use planning was done. (Chalakudy centre)

- Multiple use of water was studied through rice based integrated farming system at head and middle ends of Awanpur distributary. Integrated farming system with pisciculture was found to be most productive and remunerative in comparison to conventional rice-wheat+mustard cropping system with highest net return of ₹ 184619 ha^{-1} year^{-1} and benefit-cost ratio of 3.88, that is 92.6% higher net return of ₹ 95832 ha^{-1} year^{-1} and 57.1% higher benefit-cost ratio of 2.47 accrued under conventional farming system. (Ayodhya centre)

Tribal Sub Plan (TSP) and Scheduled Caste Sub Plan (SCSP)

- During the year 2020-21, 200 *Konkan Jalkund* were constructed benefitting 100 tribal farmers storing 8 lakh litre rainwater and commanding 20 ha under mango and cashew in Vikramgad taluka of Maharashtra. Survival of mango and cashew grafts increased by 28.85 and 41.5%, respectively, cultivated land utilization index increased from 0.25 to 0.45, ₹1,30,334 ha^{-1} was saved, ₹1,29,324 ha^{-1} fetched by cultivating jasmine as intercrop in mango and cashew fields over conventional method. Ten *Konkan Vijay Bandhara* was constructed in Jawhar taluka benefitting 50 tribal farmers, storing 3980 m^3 runoff and commanding 7.12 ha under vegetable, cashew, mango and jasmine cultivation. Similarly, 5 *Konkan Vijay Bandhara* were constructed in Vikramgad taluka benefitting 15 tribal farmers, storing 5870 m^3 of runoff for irrigating mango, cashew, clusterbean, cowpea and jasmine crops thereby commanding 11.26 ha. (Dapoli centre)

- During the year 2020-21, Akole tahsil of Ahmednagar district of Maharashtra was selected for implementation of TSP programme. Thirty farmers from Mhalungi tribal village of Akole tahsil have been selected for distribution of drip irrigation sets and 30 farmers for sprinkler irrigation sets to provide irrigation in an area of 0.4 ha per farmer. (Rahuri centre)

- Propagation of microirrigation through farm pond constructed in fields was done to overcome acute shortage of irrigation water for crop cultivation, to create awareness among farming community and line department personnel about efficient use of water by organizing on farm and off farm training activities, and to enhance water use efficiency using microirrigation systems in major crops in Malaprabha Left Bank Canal command of northern Karnataka. Drip irrigation systems were installed in 15 farmers' fields having good source of water from farm ponds. Sensor based drip irrigation automation system for 24 acres was installed in Irrigation Water Management Research Centre, Belavatagi for demonstration, organizing field days and training programmes for the benefit of farmers. Six trainings and field demonstrations were organized for farmers, farm women, and school and college students of the region. (Belavatagi centre)

- Field demonstrations on clusterbean, pigeonpea and greengram was done during *kharif* season and wheat, mustard and chickpea during *rabi* season in tribal farmers' fields in Dangpura village, Vijaypur tehsil, Sheopur district in Madhya Pradesh. Results of the demonstration showed that cultivation with improved irrigation resulted in 5.9-42.3% higher crop yield, 2.5-80.5% higher net return and 12.5-38.5% higher benefit-cost ratio compared to farmers' traditional practice. (Morena centre)

- Drainage cum recharge unit was designed and evaluated for north Bihar with declining groundwater. Six Ground Water Recharge cum Drainage units were installed/ constructed in farmer's field at different places of North Bihar. Functioning of the recharge unit was successfully demonstrated to Former DDG (NRM) and Vice Chancellor of BCKV, Kalyani. One unit was partially installed in a farmer's field at Sukhet village, Jhanjharpur block, Madhubani district, Bihar that faced a chronic waterlogging issue from July to March every year. The farmer reported that after many years timely sowing of wheat was possible during *rabi* season due to timely drainage of excess water from field. (Pusa centre)

- During the year 2021, 50 drip kits for 250 m^2 area each were distributed and installed for demonstration in Chamba district of Himachal Pradesh. Under Scheduled Caste Sub Plan , a polyline water harvesting tank with drip irrigation system is being executed and will be completed before May 2022, so that monsoon rain can be harvested and demonstration can be carried out. (Palampur centre)

- Technology demonstration was performed in collaboration of KVK in Dudhnoi area, a flood prone area in Goalpara district of Assam. A high yielding short duration autumn rice variety Dishang was demonstrated under irrigated condition so as to harvest before occurrence of flood in the region. Recommended irrigation management practice i.e. 5 cm irrigation after 3 days after disappearance of ponded water was tested using shallow tubewell water in a 5 hectare area of farmer's field in village Matia Gossaibari. Seed was sown on nursery bed during first week of February 2020 and successfully harvesting was done during 9.06.2020 to 15.06.2020.

Introduction

All Indian Coordinated Research Project on Water Management (WM) and All India Coordinated Research Project on Groundwater Utilization (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 network centres and their controlling institutions under AICRP on Irrigation Water Management are given in Table I. Geo-referenced map of the network centres and project coordinating unit has been depicted in Figure I.

Table I. 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	Ayodhya	NDUAT, Ayodhya
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

Figure I. Geo-referenced location map of twenty-six network centres and Project Coordinating Unit of AICRP on IWM

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 II.

Table II. 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

ECO-SYSTEM	AER Description	AESR	Description of AESR	Irrigation region	Centre	Controlling organization
ARID ECO-SYSTEM	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	Sriganga-nagar 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 ECO-SYSTEM	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	Malaprabha	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
		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 ECO-SYSTEM	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	Ayodhya	NDUA&T, Ayodhya
	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
		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 days	-	-	-
		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
	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 inclusion of perhumid) eco-region	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 medium AWC and LGP 90-120 days	-	-	-
		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 AWC and LGP 150-210 days	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 ECO-SYSTEM	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 ECO-SYSTEM	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 ECO-SYSTEM	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	-	-	-

Note : AER- Agro-ecological region; AWC- Available water content; LGP- Length of growing period

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 III.

Table III. Locality characteristics of AICRP centres in irrigation commands

Name of centre	Soil texture	Depth of water table (m)	Annual rainfall (mm)	Source of irrigation
Almora	Loamy sand to clay/silty clay loam	No groundwater. Subsurface water concentrated at specific place and come out in surface in the form of water springs	1150 (Almora) 1003 (Hawalbagh)	Lift irrigation Canal
Belavatagi	Sandy loam to clay	Very deep	556	Canal
Bathinda	Loamy sand to sandy loam	1-4 m	400	Canal Tubewell
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
Coimbatore	Red loamy (Black soil)	5-20 m	774	Dug well Tubewell Canal
Dapoli	Sandy loam to sandy clay loam	0.2-5 m	1349	Canal
Ayodhya	Silty loam to silty clay loam	4-7.5 m	1022	Canal Tubewell
Gayeshpur	Sandy loam to clay loam	0.2-2 m	1315	Canal Tubewell
Hisar	Loamy sand to sandy loam	0.4-1 m	430	Canal Tubewell
Jabalpur	Clay loam to clay	>3 m	1354	Canal Tubewell
Jammu	Sandy loam to silty loam	>4 m	1175	Canal
Jorhat	Sandy loam to sandy clay loam, slightly to moderately acidic	0.5-4.5 m	2083	Canal Tubewell
Junagadh	Clay loam (medium black)	2-20 m	800	Tubewell Open well
Kota	Clay loam to clay	0.7-2 m	777	Canal
Madurai	Sandy loam to clay loam	0.5-2 m	858	Canal
Ludhiana	Sandy loam to loamy sand	25-30 m	550	Tubewell Canal
Morena	Sandy loam to sandy clay loam	5-15 m	875	Canal Tubewell
Navsari	Clayey	1-5 m	1418	Canal
Palampur	Silty clay loam to clay loam	1.56-15.44 m (Pre-monsoon) 0.48-12.30 m (Post-monsoon)	1751	*Kuhl* (Natural gravity stream)
Pantnagar	Sandy loam to clay loam	0.5-3 m	1370	Canal Tubewell
Parbhani	Medium to deep black clayey	>1- 3 m	861	Canal Well
Powarkheda	Deep black clay	3-6 m	1087	Canal Tubewell
Pusa	Sandy loam	2-6 m	1200	Canal Tubewell
Rahuri	Deep black clayey	2-5 m	523	Canal
Raipur	Sandy loam to clay loam	>2 m	1154	Canal Tubewell
Shillong	Sandy loam	>2 m	2400	*Jalkund* ponds
Sriganganagar	Loam to silty clay loam	> 10 m	276	Canal Tubewell
Udaipur	Sandy loam	12-18 m	670	Canal Tubewell

Chapter 1

Assessment of Surface Water and Ground Water Availability

1.1. Chalakudy

1.1.1. Water productivity enhancement of lift irrigation projects

Performance evaluation of two lift irrigation schemes namely Munippara and Poolani of Thrissur district was done using performance indicators namely, Relative Water Supply (RWS), Relative Irrigation Supply (RIS), Standardized Gross Value of Production (SGVP), SGVP per cropped area and SGVP per unit irrigation supply. The command area of the lift irrigation scheme was demarcated using ArcGIS 10.8 (Figure 1). A field survey was conducted and data for the calculation of performance indicators were collected from 30% beneficiaries of lift irrigation schemes. Discharge measurements were taken in head, middle and tail reaches of the canal. Crop water requirements for six months period (December to May) was calculated using CROPWAT 8.0.

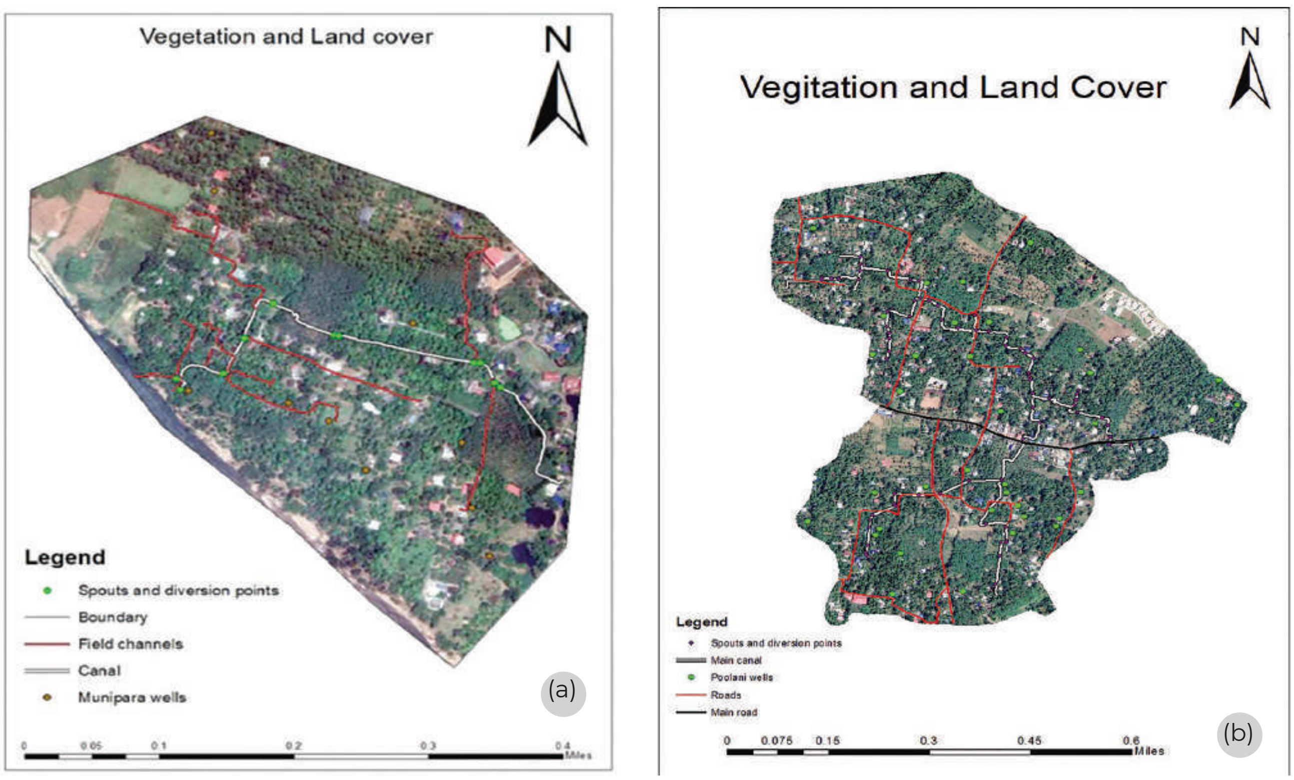


Figure 1. Canal system and command area of (a) Munippara and (b) Poolani lift irrigation system

Land use map prepared using Google Earth Pro and Arc GIS 10.8 showed that total command area was 31.74 ha and 77.38 ha for Munippara and Poolani lift irrigation schemes respectively. The main crops grown under mixed cropping system in Munippara lift irrigation scheme are Nutmeg, Banana, Coconut, Rambutan and Mangosteen. Rubber is cultivated in 2.08 ha as a rainfed crop. In Poolani lift irrigation scheme, the main crop cultivated is Nutmeg and other crops grown under mixed cropping system are Coconut, Arecanut, Banana, etc.

Water availability in the command areas of the lift irrigation schemes were assessed (Table 1) using relative water supply (RWS) and relative irrigation supply (RIS). RWS is more than 2.5 in the head reach of Munippara system which showed that irrigation performance is not affected by water stress. RWS slightly more than one in the middle reach indicated that water supplied is sufficient in meeting crop demand. RWS values in both the schemes indicated adequacy of water supply. Relative irrigation supply (RIS) showed whether irrigation supply meets demand. From RIS of both the lift irrigation schemes, it can be inferred that irrigation supply is more in Poolani compared to Munippara lift irrigation scheme. It is apparent from RWS and RIS in Munippara and Poolani lift irrigation schemes that equitable water distribution in the command area is more for Poolani compared to Munippara lift irrigation scheme.

Table 1. Relative water supply and relative irrigation supply of Munippara and Poolani lift irrigation scheme

Indicators	Munippara Lift Irrigation			Poolani Lift Irrigation			
	Canal reach			Zones			
	Head	Middle	Tail	Zone 1 (North east)	Zone 2 (North west)	Zone 3 (South east)	Zone 4 (South west)
Relative water supply (RWS)	3.43	1.14	2.48	2.89	2.60	2.96	2.84
Relative irrigation supply (RIS)	3.89	1.17	2.84	3.43	3.05	3.54	3.66

Assessment of water table showed that wells in the command areas of Munippara and Poolani lift irrigation scheme are recharged during canal water supply (Figure 2). Under Munippara scheme, rise in water table is 90-120 cm in the head end. Rise of water table in the tail end is less compared to head and middle reaches, because water reaches the tail end through longer unlined supply channels.

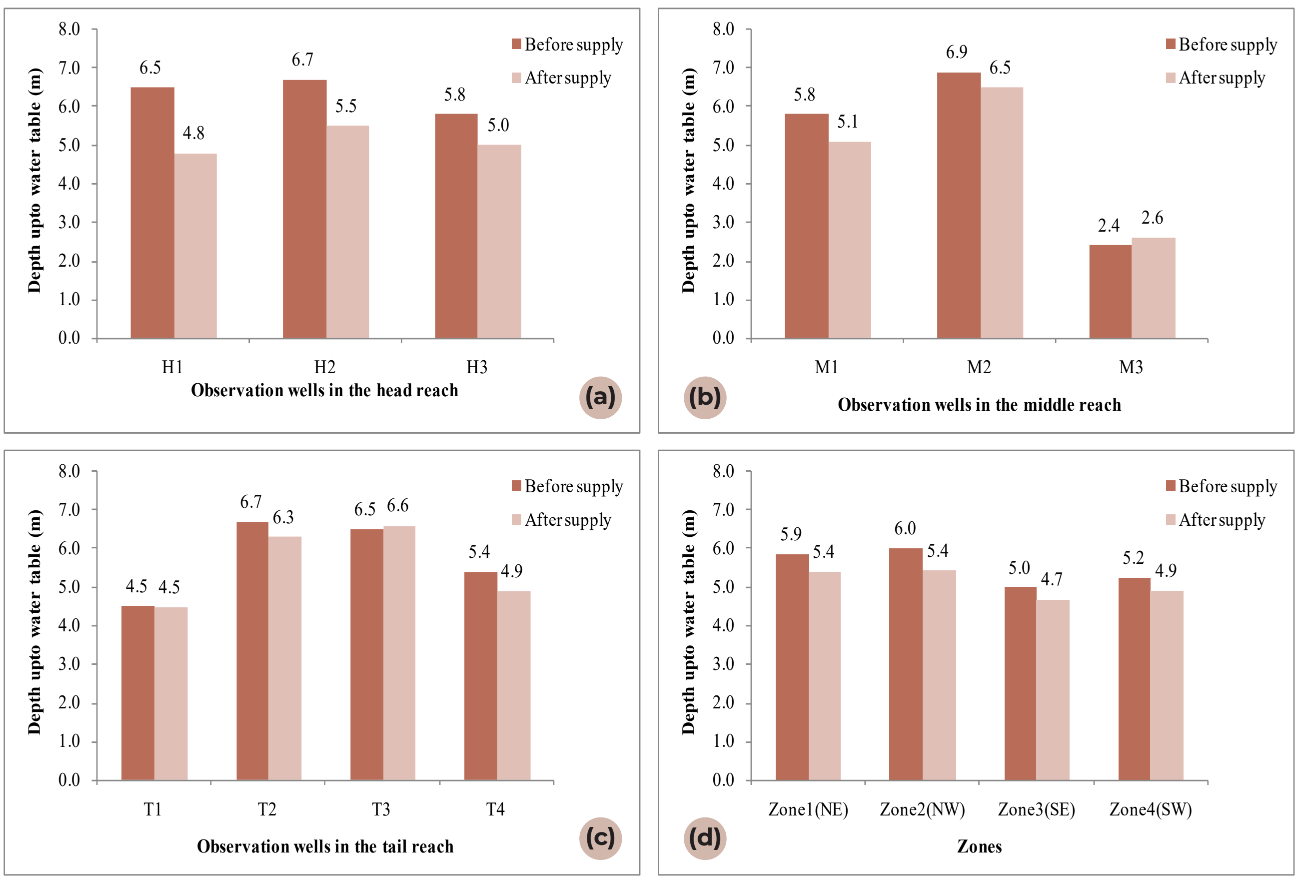


Figure 2. Depth to water table for wells of (a) head, (b) middle and (c) tail ends of Munippara lift irrigation scheme; (d) Depth to water table for different zones of Poolani lift irrigation scheme

Survey conducted with beneficiaries of the lift irrigation schemes about the availability of irrigation water supply showed that majority of the beneficiaries (farmers) agreed that sufficient water is available in both the schemes (Table 2). For Munippara scheme, about 90% beneficiaries reported sufficient water availability, with 10% of them facing problems regarding the quantity of water supplied. The farmers' association is taking keen interest in the maintenance of canal system and distribution of water to all beneficiaries as per the schedule maintained by them as shown in Table 3. Witnessing the high value of land productivity, it is evident that farmers are interested in operation and maintenance of the lift irrigation systems. Farmer's association is active and about 90-95% of the farmers cooperate for the distribution of water at the right time.

Table 2. Feedback of beneficiaries on water availability in the lift irrigation schemes

Beneficiaries' feedback	Munippara	Poolani
Always adequate water available (%)	75	85
Sometimes adequate water available (%)	15	13
Never adequate water available (%)	10	2
Adequate and timely water availability (%)	60	80

Table 3. Involvement of farmers in maintenance of lift irrigation schemes

Activity	Farmer's Participation (%)					
	Munippara			Poolani		
	A	S	N	A	S	N
Contributing money for the maintenance of pump/ canal/structure	80	15	5	90	8	2
Contributing labour for the maintenance of canal	80	15	5	90	8	2
Distributing water among beneficiaries	90	5	5	95	3	2

Note: A, Always; S, Sometimes; N, Never

Due to the sheer availability of sufficient and timely water, beneficiaries are interested in increasing agricultural productivity and increasing their economic return on investment. In Poolani scheme, high value of standardised gross value of production (SGVP) relates to high value of RWS and RIS, whereas in Munippara, highest value of SGVP coincides with low values of RWS and RIS (Table 4). This shows chances to increase SGVP for irrigation water supply by reducing the quantity of water supplied in Poolani irrigation scheme. In Munippara scheme, middle reach beneficiaries obtain maximum SGVP compared to head and tail reach beneficiaries. Zone 3 beneficiaries of Poolani scheme get maximum value of production. Land productivity of ₹0.95 lakh ha^{-1} is same for head, middle and tail end reaches of Munippara scheme, whereas the value ranges from ₹1.19 lakh ha^{-1} to 3.29 lakh ha^{-1} in Poolani scheme. Water productivity variation is different from land productivity variation in Munippara scheme. However, the water productivity variation follows land productivity in case of Poolani scheme.

Table 4. Indicators for assessing value of crop production

Indicator	Munippara lift Irrigation			Poolani lift Irrigation			
	Canal reach			Zone			
	Head	Middle	Tail	Zone1 (North east)	Zone2 (North west)	Zone3 (South east)	Zone4 (South west)
SGVP (₹ in lakhs)	5.29	7.23	5.33	19.53	14.12	36.55	28.8
SGVP per cropped area (₹ in lakhs per hectare)	0.95	0.95	0.95	1.74	1.19	3.29	2.48
SGVP per irrigation supply (₹ m^{-3})	3.03	5.52	6.11	9.96	7.20	18.64	14.68

Thus it was concluded that water supply is abundant for crop production in both Munippara and Poolani lift irrigation schemes as indicated by high relative water supply and relative irrigation supply. Along with irrigation, well recharge is also taking place. This sustains drinking water availability in the command areas. High relative water supply observed in irrigation schemes shows scope for further improvement of performance of the schemes by regulating water supply or by increasing cropped area. Through beneficiary participation approaches, suitable water management measures such as water harvesting can be implemented to increase well recharge and irrigation scheduling based on area and water requirement. This would empower beneficiaries to change from practice of over irrigation to better water management and to associate more in water management activities among themselves.

1.2. Raipur

1.2.1. Optimal crop planning based on water resources for different farming situations of Kotani watershed

The study was conducted to delineate different farming situations of Kotani watershed (located in the Upper Shivnath Catchment) using geospatial technique, identify critical sub-watershed based on morphological characteristics, develop surface water harvesting and ground water recharge plan, and develop an optimal crop plan for different farming situations of the critical watershed based on available water resources. Thematic maps like drainage, slope aspect and morphometric parameters were assessed. Soil data and meteorological data showed water availability as runoff was 509.72 Mm^3. Groundwater (GW) assessment showed GW availability was 207.89 Mm^3, which made total water availability to be 717.89 Mm^3. Land use/land cover map showed that 472575 ha (67.42%) in the watershed is under agriculture, with standard water consumption of crops during *kharif* and *rabi* was 319.61 and 90 Mm^3, respectively making total water consumption to be 409.61 Mm^3. Mostly monocrop culture is practiced in the watershed, *kharif* being the main cropping season and rice as the main crop followed by soybean and sugarcane.

Kotani watershed was divided into 10 sub-watersheds. To represent the whole watershed, highly prioritized sub-watersheds were selected. Prioritization of 10 sub-watersheds and delineation of farming situation was done based on land suitability for farming or cultivation including normalized difference soil index (NDSI), land slope, soil texture, and land use cover map. Overlay analysis was done based on the weightage of each map on its influence over farming situation. Based on the weighted criteria, characterization of farming situation of the prioritized sub-watershed was evaluated. Prioritization showed that sub-watersheds 1, 6 and 10 have largest area under agriculture ranging from 80.1-81.0% i.e. under highest priority zone. This was followed by sub-watersheds 4 and 7 falling under high priority zone with 73.9 and 74.7% area under agriculture, respectively. Farming situation of prioritized sub-watersheds was evaluated and area under different farming situations was calculated. Farming situation viz., *Kanhar* (Vertisols) covered 511 km^2 (58.74%) area followed by *Dorsa* (Alfisols) *covering* 339 km^2 (38.97%) and *Bhatha* (Entisols) *covering* 6 km^2 (0.7%) area. Water body in the prioritized sub-watersheds covers 13.99 km^2 (1.61%) area.

A water resource management plan was developed to make judicious and effective use of water resources in the watershed to enhance productivity and mitigate drought. It was done by integrating information on surface water availability, land use/land cover, drainage, current condition of groundwater utilization, and the present and long-term water demands of the study area. Water balance in the prioritized sub-watersheds during *kharif* and *rabi* seasons is shown in Table 5. Life-saving irrigation from the planned water structure and groundwater can make up for the water deficit during *rabi* season.

Table 5. Water balance for *kharif* and *rabi* season in Kotani watershed

Input/Output	Water balance			
	Kharif		***Rabi***	
Input	Rainfall	1157	Groundwater available	69.27
	Tank water	31.29	Tank water	31.29
	Sum	1188.29	Sum	100.56

Output	Crop water requirement	650	Crop water requirement	90
	Runoff	483	-	-
	Tank recharge	31.29	-	-
	Groundwater recharge	76	Groundwater recharge	15
	Sum	1240.29	-	105

As per the proposed water resource management plan, suitable structures are suggested for surface water harvesting and groundwater recharge. Proposed sites identified for creating groundwater recharge structures i.e. 7 check dams and 10 percolation tanks (Figure 3). Sites were also proposed for constructing water storage structures such as 20 check dams and 61 farm ponds (Figure 4).

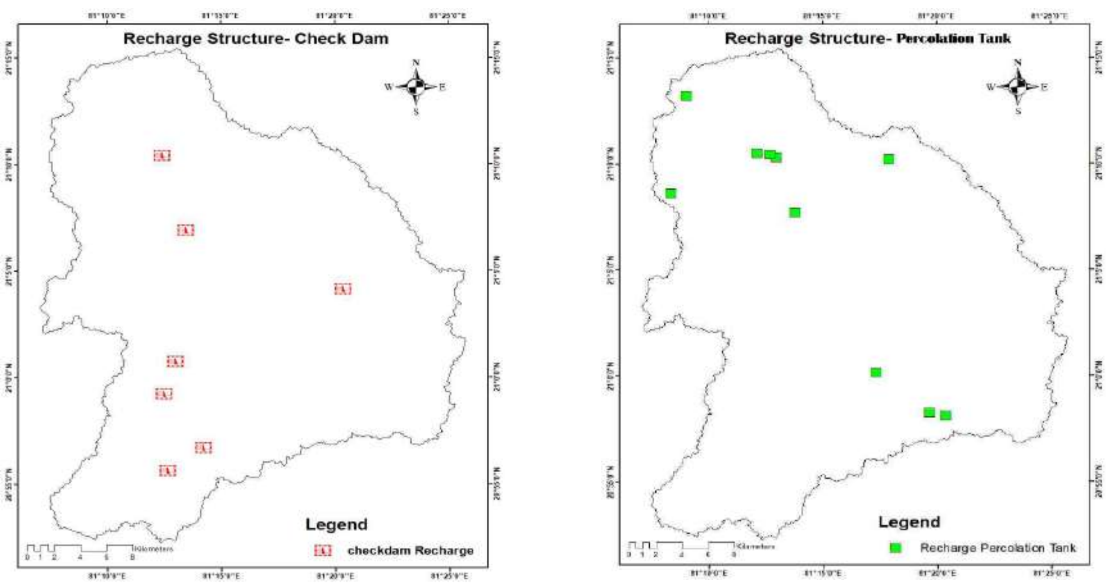


Figure 3. Proposed sites for constructing seven check dams and ten percolation tanks as groundwater recharge structures in Kotani watershed

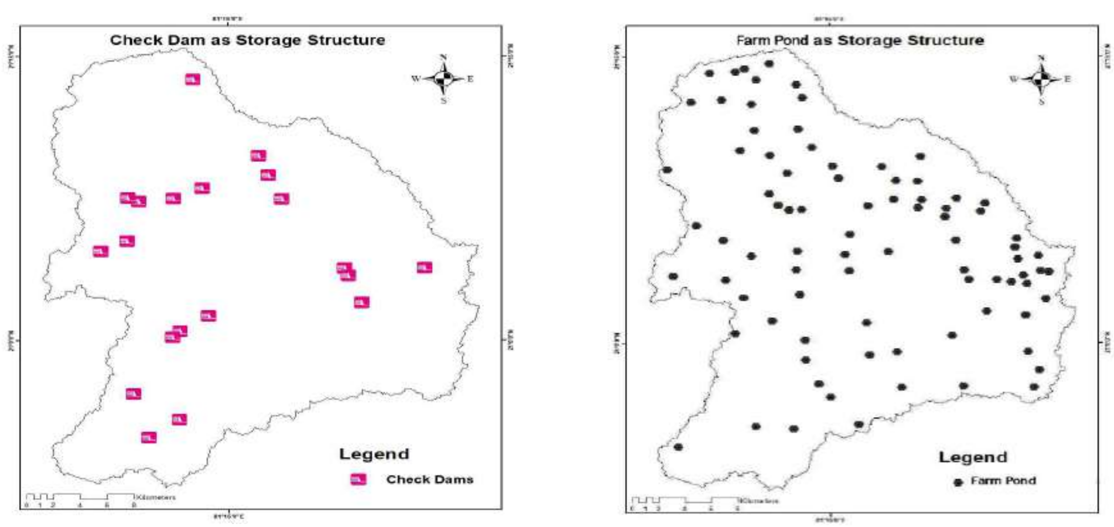


Figure 4. Proposed sites for constructing 20 check dams and 61 farm ponds as water storage structures in Kotani watershed

Capacity to hold water by the proposed structures was also estimated with the help of 1 m contour line generated by ArcGIS 15, Google Earth Pro and QGIS. Groundwater recharge structures i.e. check dam and percolation tank can hold 0.246 and 0.027 Mm^3 per structure, respectively. Water storage structures i.e. check dams and farm ponds have capacity to hold 0.78 and 1.26 Mm^3 per structure, respectively. Optimal crop planning was done for *kharif* and *rabi* seasons in the prioritized sub-watersheds utilizing the available water and land resources in the prioritized sub-watersheds. Maximum area (58.74%) is covered by *kanhar* farming situation followed by *dorsa* and *bhatha* covering 38.97% and 0.7% area, respectively. Only rice crop is recommended during *kharif* for *kanhar* since it holds a lot of water and is ideal for growing rice. The utilizable water for *Kharif* is anticipated to be about 650 Mm^3.

Table 6 shows that with constraints of water (280 Mm^3) and land (277 km^2), proposed cropping area of 4000 ha devoted to rice, 15300 ha for soybean and 8000 ha for sugarcane can maximize profit upto ₹ 79,33,920 approximately, with unit profit of ₹ 1165 ha^{-1}. On the other hand, optimal crop planning for *rabi* season showed that proportions of wheat and chickpea grown on proposed area of 15000 ha (wheat) and 13300 ha (chickpea) may be used to maximize profit with constraints of water (115 Mm^3) and land (700 km^2). Additional profit of about ₹ 8020 ha^{-1} may be obtained when this proportion is employed, and additional cultivable land of 1580 ha approximately would be added in *rabi* season. Thus, this crop planning will be optimal as well as beneficial for a farm in Kotani watershed.

Table 6. Results of optimum crop planning for *kharif* and *rabi* seasons in prioritized sub-watershed

	Paddy (Proposed area 4000 ha)	Soybean (Proposed area 15300 ha)	Sugarcane Proposed area 8000 ha)		
Optimum crop planning for *Kharif* season					
Required resource/ Input	**Proportion**			**Input used**	**Available resource**
Water (Mm^3)	0.9	0.6	1.9	279.8	280
Land (km^2)	1.0	1.0	1.0	273.0	277
Output	**Unit profit (₹ ha^{-1}) gained**			**Total profit gained (₹)**	
	20,973	15,000	60,000	7933920	
Optimum crop planning for *Rabi* season					
	Wheat (Proposed area 15000 ha)	**Chickpea (Proposed area 13300 ha)**			
Required resource/ Input	**Proportion**			**Input used**	**Available resource**
Water (Mm^3)	0.5	0.3	-	114.9	115.5
Land (km^2)	1.0	1.0	-	283.0	700.8
Output	**Unit profit (₹ ha^{-1}) gained**			**Total profit gained (₹)**	
	45950	25802	-	10323900	

1.3. Bathinda

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

Behman distributory of Bathinda branch canal was selected to evaluate performance of the irrigation system and to work out intervention for improvement of irrigation system and its management, improved and sustainable crop, and water productivity. The Behman distributory has total length of 10.804 km having total cultivable command area (CCA) of about 6374.62 hectare covering Bathinda district. Behman distributary has 31 outlets with 48.84 cusec discharge. Out of 31 outlets, 5 outlets (i.e. 31580-R for Sivian, 34775-L for Behman Dewana, 39980-R for Behman Dewana, & Bulade Wala, 54709-L for Chughe Khurd, and 64900-R for Balluana) were selected for the study. Design discharge and CCA of these outlets are given in Table 7.

Table 7. Design discharge and cultivable command area (CCA) of selected outlets of Behman distributory

Outlet No.	Villages covered	Discharge (cusec)	CCA (ha)
31580-R	Sivian	1.51	197.88
34775-L	Behman Dewana	1.13	143.24
39980-R	Behman Dewana, Bulade Wala	1.20	157.58
54709-L	ChugheKhurd	1.38	180.80
64900-R	Balluana	1.96	257.00

Total canal running days in a year was 277 days. Total canal running days varied from 8 to 31 days in different months with the highest in May and July 2021, and lowest in October 2021. During *rabi* season, total running days of canal water was 129 days on each outlet with a minimum of 3998.95 ha-cm and a maximum of 6962.05 ha-cm at 34775-L and 64900-R outlets, respectively. Different crops grown during *rabi* season were wheat, barley, chickpea, vegetables, orchard and fodder crops. Crop water requirement of *rabi* crops was calculated at all the outlets and was found varying between 7255.51 to 13078.39 ha-cm in different outlets. During the *kharif* season, total running days of canal water was 148 days for each outlet and the release of water varied between 11028.57 and 19543.34 ha-cm. Total crop water requirement in *kharif* season varied between 16204.40 to 27390.05 ha-cm in different outlets.

Relative water supply (RWS) i.e. adequacy of water supply in relation to water demand was calculated using the following formula:

$$RWS = \frac{Total\ water\ supply}{Crop\ water\ demand}$$

The data presented in Table 8 indicates that in *rabi* season, relative water supply (RWS) was less than one in all the outlets. This means that water supply by rainfall and canal was less than demand in all the five outlets. In the overall system, average RWS was 0.537. So, there is a need to replace a large part of the area under wheat with barley, chickpea, and *raya,* which require less water to match the water supply with crop water requirement during *rabi* season at the outlets. Table 9 shows the relative water supply in different outlets during *kharif* season. In the overall system, average RWS was 0.676, which means demand is more than supply. So, there is a need to either increase the supply of water or replace high water requiring crops with low water requiring crops like cotton, *guar* and bajra.

Table 8. Relative water supply (RWS) during rabi season in Behman distributory

Outlet No.	Canal water diverted (ha-cm)	Effective rainfall (ha-cm)	Total water supply (ha-cm)	Water requirement (ha-cm)	RWS
31580-R	4765.68	597.59	5363.27	10047.44	0.534
34775-L	3566.37	432.57	3998.95	7255.51	0.551
39980-R	3787.30	475.89	4263.19	7986.92	0.534
54709-L	4355.39	546.00	4901.40	9143.50	0.536
64900-R	6185.92	776.13	6962.05	13078.39	0.532

Table 9. Relative water supply (RWS) during *kharif* season in Behman distributory

Outlet No.	Canal water diverted (ha-cm)	Effective rainfall (ha-cm)	Total water supply (ha-cm)	Water requirement (ha-cm)	RWS
31580-R	5467.61	9583.13	15050.74	23092.58	0.652
34775-L	4091.65	6936.92	11028.57	16204.40	0.681
39980-R	4345.12	7631.60	11976.72	16793.64	0.713
54709-L	4996.88	8755.95	13752.84	22069.43	0.623
64900-R	7097.02	12446.32	19543.34	27390.05	0.714

1.4. Rahuri

1.4.1. Development of soil and water quality management strategies under special reference to GIS and remote sensing in minor of Mula right bank canal command area

A study was conducted in Mula right bank canal (MRBC) command area to analyze soil and water quality and develop management strategy. The study covering an area of about 540 ha with average elevation of 522.23 m was selected in Minor no. 2. Soil samples were collected from the surface using GPS based sampling methodology on grid basis, while representative water samples were collected from the available water sources (well) in the area. The soil samples were collected at every 100 m × 500 m on grid basis and adjacent well or bore well water samples were collected. About 150 soil and 90 water samples were collected along with primary data of cropping pattern, yields, net profits etc. The systematic sampling based on GPS was used and soil fertility and irrigation water quality maps were prepared with GIS software. The Sentinel-2 satellite data (10 m resolution) was used to prepare thematic maps and crop maps. All maps were prepared at 1:20,000 scale as per NBSSLUP Nagpur, and MPKV recommendations.

The texture of soils was clayey, medium deep to deep dark brown to grayish brown colour. Average bulk density was observed to be 3.33 Mg m^{-3} with standard deviation (SD) ± 0.07, and porosity of 49.75% with SD±2.29. Average soil pH was 8.49 with SD±0.29, average electrical conductivity (EC) was 0.68 dS m^{-1} with SD±0.57, average organic carbon was 0.46% with SD±0.22. Average calcium carbonate content was 12.26% with SD±3.29. Average soil available nitrogen (N) was 134.91 kg ha^{-1} with SD±24.34, average available soil phosphorous (P) was 18.77 kg ha^{-1} with SD±9.74. Average available potassium (K) was 459.46 kg ha^{-1} with SD±109.91. Average pH and EC of water was 7.90 and 1.41 dS m^{-1}, respectively. The average cations viz., calcium 3.03, magnesium 1.75, sodium 31.33, potassium 0.04 and anions viz., carbonates 2.52, bicarbonates 7.61, chlorides 4.80 and sulphates 15.64 me L^{-1} were observed. Derived parameter of irrigation water viz., soluble sodium percentage was 81.30%, sodium adsorption ratio (SAR) was 21.06%, residual sodium carbonate (RSC) was 5.34 me L^{-1}. Average calcium magnesium ratio in water was 2.81 and $Cl^-:SO_4^{2-}$ ratio was 0.38. Based on the study, following conclusions were made:

- Mula right bank canal command area of Minor no. 2 is tending towards salinity and the soil is getting deteriorated.
- Most of the area is having alkaline pH with normal EC and low in available N and P. However, very high in available K content and sufficient in Mn, Zn and Cu while deficient in Fe content.
- The cations are in the order of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ while anions are in the order of $SO_4^{2-} > Cl^- > HCO_3^- > CO_3^{2-}$.
- Water in most of the wells is moderate to unsuitable for irrigation.
- In general, it is concluded that the soils and borewell water in the area of MRBC are getting deteriorated to a great extent with a fear of soils getting converted to saline sodic to sodic in nature.

Recommendation of management strategy

On the basis of the study, it is evident that soil and water quality in the study area is deteriorating tending towards salinity and sodicity. Thus, the following management strategies were recommended.

- Crop rotation with inclusion of leguminous crops and avoiding continuous growing of annual crops like sugarcane followed by sugarcane.
- Inclusion of salt tolerant crops like sugarbeet, cotton, berseem, wheat, jowar, maize, sunflower, spinach, cabbage, etc.
- Sowing of vegetable/ row crops in ridge and furrow to avoid salt injuries.
- Use of mixing of moderately saline water with good quality water for irrigation.
- Adoption of pressurized irrigation system and drainage system.
- Cultivation of minimum water requirement and short duration crops.
- Fertilizer application should be based on soil test values.
- Use of chemical amendments for reclamations of degraded soils.
- Use of organic manures and green manuring crops like sunhemp, dhaincha and glyricidia.
- Use of subsurface drainage system, wherever possible.

Chapter 2

Groundwater Potential Zoning and Recharge

2.1. Junagadh

2.1.1. Identification of potential groundwater recharge zones in Ozat river basin

The study was conducted to map potential groundwater recharge zones in Ozat river basin and to suggest suitable recharge planning in the basin for sustainable management of groundwater. Ozat river is a non-perennial river that falls under a semi-arid area, belonging to the South-Saurashtra agro-climatic area in Gujarat. Therefore, during the dry period, people need to resort to groundwater for irrigation and domestic demand. As a result, it becomes crucial to maximizing the recharge of the groundwater. An attempt is made to quantify the recharge through various groundwater recharge structures in the river basin area. To identify groundwater recharge potential zone of the river basin, base map was prepared to demarcate the boundary of Ozat river basin. The base was used as reference to prepare thematic maps on geomorphology, slope, drainage density, land use/ land cover, geology, soil, lineament density and rainfall. The thematic maps were integrated into ArcGIS 10.2.2 environment to compute Groundwater Recharge Potential Zone Index. The output map was reclassified into five different categories of groundwater recharge potential zoning viz., excellent, good, moderate, poor and very poor (Figure 5). Areal coverage of the different zones are: excellent (220.14 km^2, 6.93%), good (2,094.81 km^2, 65.95%), moderate (430.05 km^2, 13.54%), poor (430.87 km^2, 13.57%) and very poor (0.36 km^2, 0.01%).

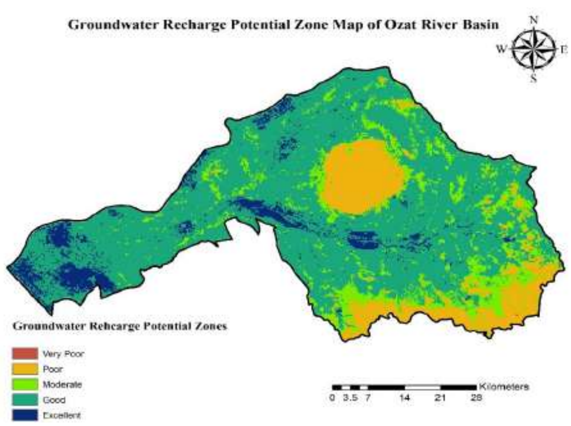


Figure 5. Groundwater recharge potential zone map of Ozat river basin

Suitable locations for the construction of groundwater recharge structures were determined taking into account parameters such as land slope, stream order, groundwater recharge potential zone and catchment area for the particular structure to be made. Artificial groundwater recharge can be induced to its best potential only in the areas which fall under the good and excellent groundwater recharge potential zone. But the area falling under the moderate, poor and very poor groundwater recharge potential zone should be treated with soil conservation structures. For areas under moderate, poor and very poor groundwater recharge potential zones, vegetative barrier/tree plantation and Contour/Staggered trenches are options for soil conservation. Total area suitable for development of soil conservation structure/technique in Ozat river basin in 43123 hectare.

Total runoff generated in the Ozat river basin is 1,219.03 MCM. But artificial groundwater recharge induced by all the structures combined and considering 100% structure density was estimated to be 1239.0616 MCM per annum i.e. recharge volume greater than runoff generated in Ozat river basin. It was inferred that if structures are built with 100% structure density, it will be a waste of financial resources. Therefore, it was advised to plan and manage recharge structures with structure density less than 100%. Thus assessment of recharge capacity was done for various structure densities i.e. 100%, 90%, 80%, 70%, 60%, 50%, 40% and 30%. Probability of exceedance for runoff data was estimated. Rainfall data of 40 years (1981-2020) was analysed for the calculation of the runoff and the probability analysis for the runoff was carried out using Weilbull's method. The probability of exceedance was calculated for each runoff data as:

$$P(x \geq X) = \frac{m}{n+1}$$

Runoff at the confidence level of 60%, 75%, and 90% were taken into consideration and weighted runoff for the whole Ozat basin was calculated. The structure density that recharged the corresponding weighted runoff was selected and the number of structures and corresponding project costs were estimated. Results suggested that 75% probability of exceedance of runoff in basin with runoff of 610.18 MCM was optimum for consideration of constructing recharge structures (Table 10). Therefore, to plan recharge of 610.18 MCM, 48.81% structure density is required for which maximum 4520 check dams, 51113 farm ponds, 22599 open wells, 5650 tube wells and 10496 Gabion/loose rock dams (GB/LRD) were suggested. The estimated project cost as per prevailing rates for 48.81% structure density is ₹ 526.56 crores. This has been recommended to the farmers, NGOs and government line departments of Gujarat.

Table 10. Structure density and estimated projected cost at various probability of exceedance for runoff volume

Probability of exceedance (%)	Runoff volume (MCM)	Structure density (%)	Total recharge capacity (MCM)	Runoff excess = Runoff volume- Total recharge capacity (MCM)	Number of structures					Total cost (₹ in crores)
					Check dam	Farm pond	Open well	Tube well	GB/ LRD	
60	764.72	61.17	764.72	0	5664	64058	28321	7080	13153	659.90
75	610.18	48.81	610.18	0	4520	51113	22599	5650	10496	526.56
90	258.54	20.68	258.54	0	1915	21649	9575	2394	4447	223.10

Note: GB/LRD- Gabion/loose rock dams

2.2. Jabalpur

2.2.1. Groundwater potential zoning in Ken river basin using geoinformatics technique

A study was conducted to make groundwater potential zones map for Ken river basin using the frequency ratio (FR) model and geoinformatics technique. The study area extends over 28,671 km^2 approximately. About 86.73% area of this basin lies in Madhya Pradesh covering eight districts. Assessment of factors/themes contributing to groundwater potential were done by preparing thematic maps on geology, geomorphology, lineament density, land use/land cover, soil texture, rainfall, slope, drainage density, depth to water level (pre- and post-monsoon) with 10 m spatial resolution in ArcGIS 10.8 environment. Every theme consisted of several classes. FR model was prepared using all the classes under every theme. To perform FR model, 296 observation wells were randomly selected as training datasets for the calibration of the model and 129 observation wells were used as a training dataset for validation purpose. FR value was calculated for every class (under each theme) as the ratio of the percentage of observation wells to the percentage of area covered by each class in Ken river basin. Once the FR values were obtained, all the thematic layers were reclassified by FR values using ArcGIS 10.8 and groundwater potential index (GPI) was estimated. GPI ranged from 1.39 to 4.37, where high GPI denotes high groundwater potentiality and low GPI depicts low groundwater potentiality. GPI was further classified into five groundwater potential zones i.e. very poor, poor, moderate, good and very good zones covering an area of 3157.82 km^2 (11.01%), 7497.75 km^2 (26.15%), 8789.82 km^2 (30.66%), 2032.30 km^2 (7.09%), and 7193.31 km^2 (25.09%), respectively. The groundwater potential zones map of Ken river basin is shown in Figure 6.

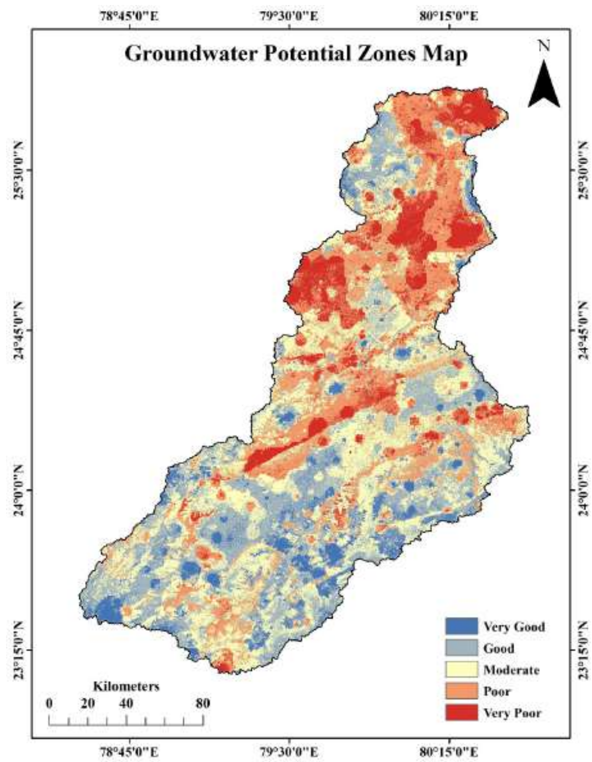


Figure 6. Groundwater potential zone map of the Ken river basin

Once groundwater potential zoning was done, relative operating characteristics (ROC) statistical approach was used as a validation process to determine the accuracy of the groundwater potential zones map furnished using FR model.

Area under curve (AUC) of ROC shows the accuracy of a prediction system by representing a model's capability to correctly or incorrectly identify a successful event. In the ROC approach, AUC ranges from 0.5 to 1 which can be further classified into the following categories: 0.5–0.6 (poor) 0.6–0.7 (average); 0.7–0.8 (good); 0.8–0.9 (very good); and 0.9–1 (excellent). In the present study, AUC obtained was 78.1%, which showed that the groundwater potential zoning is acceptable. It was concluded that the study will be beneficial for planning of drought mitigation strategies and identification of critical sites for groundwater recharge plans. The generated groundwater potential map can help policymakers and engineers to work for enhancement of groundwater resources in hard rock regions too.

2.3. Pantnagar

2.3.1. Identification of potential groundwater recharge zones in Dhela River basin of Uttarakhand

The study was conducted in the Dhela river watershed with the objective to prioritize the sub-watersheds on the basis of morphometric analysis of the watershed and delineation of potential sites for artificial groundwater recharge. The Dhela river watershed falls under the *Tarai* and *Bhabhar* region of Udham Singh Nagar and Nainital districts of Uttarakhand. The relief parameters considered for the morphometric analysis included basin relief, relative relief, relief ratio and ruggedness number. It was observed that the maximum elevation for the whole study area was found to be 0.986 km and the minimum elevation was 0.172 km. The values of relief aspects of Dhela River watershed is presented in Table 11.

Table 11. Different relief aspects of the Dhela river watershed

Relief Aspects			
Maximum Elevation (H) (km)	GIS software analysis	0.986	-
Minimum Elevation (h) (km)	GIS software analysis	0.172	-
Basin Relief (km)	Basin Relief = H-h	0.814	Strahler (1952)
Relative relief (R_r)	$R_r = \frac{H-h}{P} \times 100$	0.579	Melton (1957)
Relief Ratio	Relief Ratio = $\frac{H-h}{L}$	0.020	Schumm (1956)
Ruggedness Number (R_n)	$R_n = (H-h) \times D_d$	2.145	Baker *et al.* (1979)

The morphometric parameters such as stream length ratio, bifurcation ratio, drainage density, drainage texture, stream frequency and length of overland flow were used in prioritization and these parameters have a direct relationship with the erodibility. The parameters such as elongation ratio, circulatory ratio, compactness coefficient, form factor and shape factor were also used in prioritization, but these parameters have an inverse relationship with the erodibility. After assigning ranks to all the parameters, the ranks were added up and the compound priority (C_p) value was calculated for the sub-watersheds (Figure 7). Based on the calculated C_p values, the final prioritization of sub-watersheds was done. Based on the compound value, the sub-watersheds were classified into high, medium and low priority classes. The categorisation of sub-watersheds into different priority classes is shown in Table 12.

Table 12. Categorization of sub-watersheds in Dhela river watershed

Ranking range	Priority value	Priority class	Sub-watersheds	Area (km²)
$5.00 \leq C_p < 6.00$	1	High	SWS3, SWS4, SWS7, SWS8, SWS9, SWS10, SWS11	194.838
$6.00 \leq C_p < 7.00$	2	Medium	SWS1, SWS2, SWS5	46.204
$C_p \geq 7.00$	3	Low	SWS12	11.019

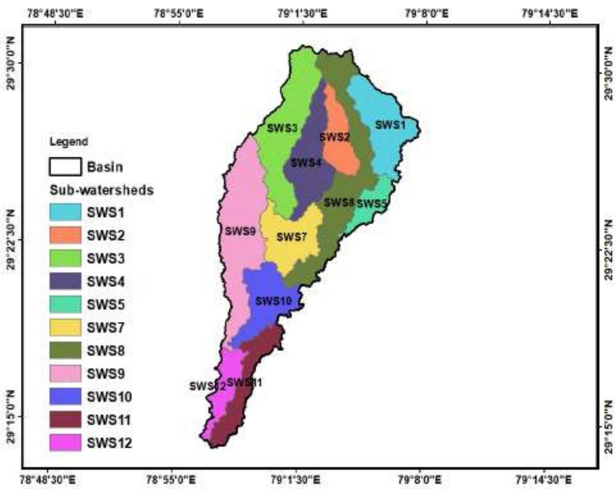


Figure 7. Sub-watersheds of the Dhela river watershed

The land use, soil and slope map of the watershed was prepared. The maximum area of watershed (138.89 km^2) was of *Tarai* (nutrient rich) soil type and the remaining area has a *Bhabhar* (stony loamy) soil type. The North and North-East aspects of the study area have thicker vegetation in the form of forests.

About 68.50% (172.65 km^2) of the area was covered with closed forests (mainly broadleaf deciduous type) and 23.56% (59.38 km^2) of the area was found to be favourable for cultivation. The potential sites for artificial groundwater recharge were visualised as per the priority assigned for the delineation of the potential zones in the watershed area. These structures could help in enhancing the water availability for various activities in the Dhela river watershed.

Decision rules: The rules to be considered for identification of potential sites are as follows:

a) **Farm ponds:** Farm ponds could be constructed on 1st order streams, according to IMSD guidelines on the lands having slope 0-5%. Keeping in view the guidelines, the potential sites for the construction of farm ponds were identified and are presented in the Figure 8(a).

b) **Check dams:** According to guidelines, the check dams could be constructed in 1st to 4th stream order and having a land of slope <15%. Considering the guidelines, the potential sites for the check dams were identified and are presented in Figure 8(b).

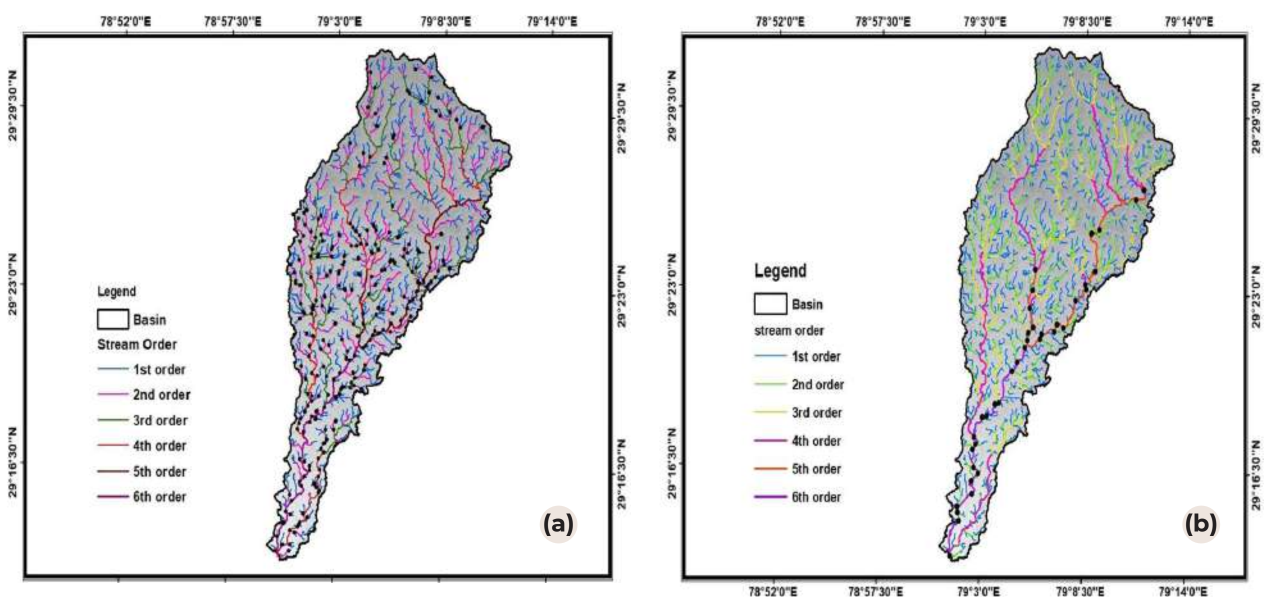


Figure 8. Locations for building water harvesting structures: (a) farm ponds and (b) check dams

2.4 Udaipur

2.4.1. Delineation of groundwater potential zones of Upper Banas river basin

The upper Banas river basin falls in Udaipur, Rajsamand, Bhilwara and Chittorgarh districts of Rajasthan. The gross catchment area of the basin is 4940 km^2 and the entire area is having undulating topography in which the velocity of runoff is high. The Upper Banas River Basin was subdivided into twenty one sub basins. Out of them, sub basin 5, 10 and 16 were observed to be sixth order basins. The geomorphologic analysis of the basin was done which included linear aspects, aerial aspects and relief aspects. The drainage density in the whole basin and sub-basins of the study area showed variation from 1.12 to1.95 km per km^2 suggesting very coarse drainage density. The first priority was given to sub basin number 10 for treatment and execution of conservation measures.

The major ion chemistry data revealed that Na^+ and Mg^{++} are the most predominant cationic constituents followed by Ca^{++} during pre-monsoon period as well as post-monsoon period. In the basin, 5.58% area in pre-monsoon and 12.09% area in post-monsoon season were found to have good quality groundwater for drinking purpose measured on the basis of water quality index. In the basin, 19.55% area in pre-monsoon and 34.63% area in post-monsoon season have no restriction on groundwater for irrigation purpose on the basis of water quality index. Pumping tests were conducted at 11 different geological formation of the study area and were analyzed by Papadopulos and Cooper type curve-matching technique. The aquifer transmissivity varied from 48.558 m^2 day^{-1} to 330.191 m^2 day^{-1} and the specific yield ranged from 0.0028 to 0.03112 in the basin. Groundwater recharge for 100 sites were estimated by using water table fluctuation method. The average value of specific yield estimated at various locations was taken for different geological formations in computation of groundwater recharge. The minimum computed recharge is 0.30 cm year^{-1} and the maximum value is 29.96 cm year^{-1}. Average value of groundwater recharge for the study area is found to be 8.58 cm.

The eight thematic maps namely geomorphology, soil, slope, topographic elevation, land use/land cover, post monsoon groundwater depth, net recharge and transmissivity were considered for identifying groundwater potential zones in the study area. After understanding the behaviour of different thematic features with respect to groundwater control in the study area, the different themes and their individual features of these themes were assigned suitable weights. The weights assigned to all the thematic layers are presented in Table 13. Analytical Hierarchical Process (AHP) was used for groundwater potential zoning in the river basin.

Table 13. Weights of eight themes for groundwater potential zoning

S. No.	Themes	Weight
1	Geomorphology	5
2	Land use/land cover	4
3	Soil	3.5
4	Slope	3.5
5	Topographic elevation	3
6	Net recharge	4.5
7	Postmonsoon groundwater depth	4
8	Transmissivity	1

The groundwater potential map of the study area (Figure 9) reveals four distinct zones representing 'good', 'moderate', 'poor' and 'very poor' groundwater potential in the area. The 'good' groundwater potential zone is mainly existing in middle part of the basin. It demarcates the areas where the terrain is most suitable for groundwater storage and also indicates the availability of water below the ground. The area covered by 'good' groundwater potential zone is about 20.98 per cent of total area. The maximum area falls under moderate groundwater potential zone and it covers 45.12 per cent area, whereas 24.76% area falls under poor groundwater potential zone (Table 14).

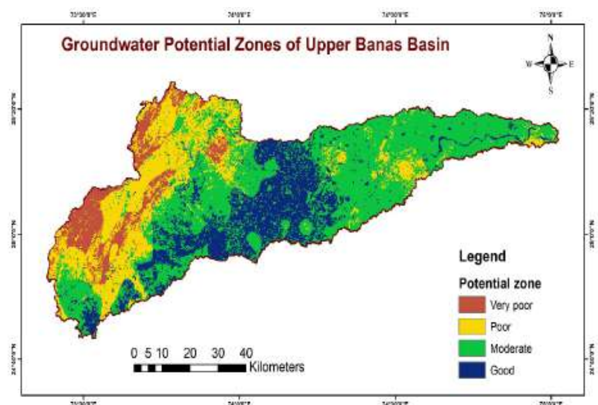
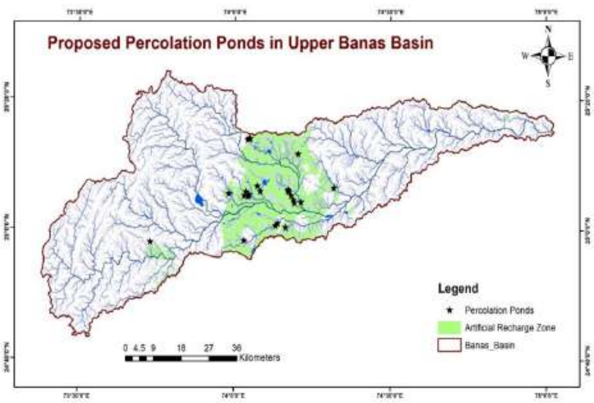


Figure 9. Groundwater potential zone of Upper Banas river basin

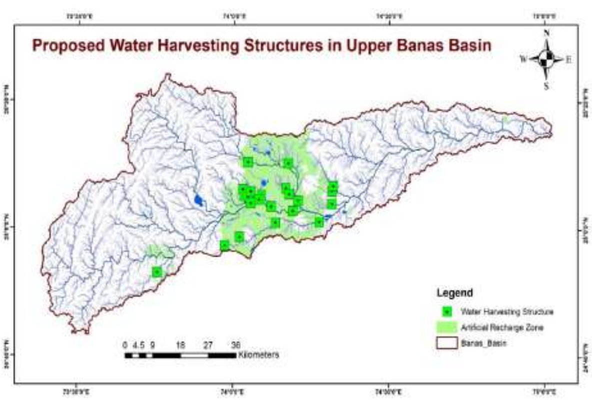
Table 14. Groundwater potential zone class & area

Class	Area (km^2)	Area (%)
Good	1036.31	20.98
Moderate	2228.88	45.12
Poor	1223.31	24.76
Very poor	451.50	9.14

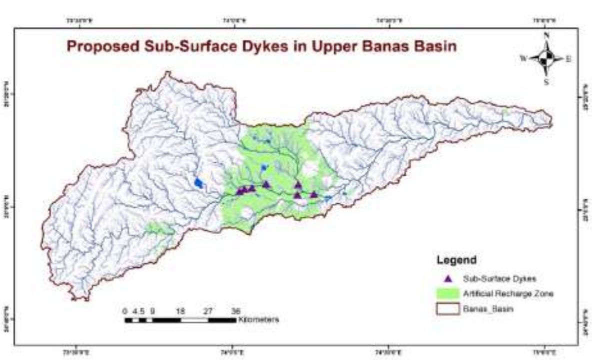
The favourable artificial groundwater recharge zone for the study area was delineated using RS and GIS techniques. The area favourable for artificial recharge zone in the basin is 815.79 km^2, which contributes 16.51% of the total study area. In artificial recharge zone, potential sites of 26 percolation ponds (Figure 10a), 29 water harvesting structures (Figure 10b) and 7 subsurface dykes (Figure 10c) were identified and proposed for construction to ensure sustainable groundwater management.



(a)



(b)



(c)

Figure 10. Proposed sites for constructing water harvesting structures

2.5. Ludhiana

2.5.1. Simulation of groundwater recharge in rice field

Water balance components were estimated for transplanted rice (TPR) and direct seeded rice (DSR) through *kharif* season field experiments and potential groundwater recharge was estimated using HYDRUS-1D model. The HYDRUS-1D is a mathematical model for simulating water flow, solute and heat movement in one-dimensional unsaturated, partially saturated or fully saturated uniform or non-uniform soil conditions. HYDRUS-1D uses the Richards equation for simulating variably saturated flow. The soil hydraulic properties were determined using Van Genuchten model. Penman-Monteith equation was used to calculate reference evapotranspiration (ET_o) from available climate parameters. The reference evapotranspiration (ET_o) was converted into crop evapotranspiration (ET_c) by multiplying it with the crop coefficient (K_c) values. The total amount of rainfall received during the growing period of TPR and DSR was 835.5 mm which was 30% higher than average rainfall received during the crop growth period which caused excessive surface runoff losses. The percolation losses were less in TPR compared to DSR because of puddling which hinders the vertical movement of surface water and may cause more surface runoff losses in TPR fields during heavy rainy days.

The HYDRUS-1D predicted moisture contents and water parameters were in good agreement with observed moisture content and estimated water parameters. The paired *t*-test was applied under both treatments (t=1.28 and t=1.30 for TPR and DSR, respectively) for mean of moisture content and found to be non-significant at p=0.05 which shows the correspondence between predicted and estimated parameters. Furthermore, statistical parameters endorsed that the HYDRUS-1D model can be successfully adopted for simulating potential groundwater recharge (deep drainage) in TPR and DSR fields under sandy loam soil conditions. HYDRUS-1D was successfully able to quantify bottom flux, evaporation, transpiration and surface runoff with marginal difference from estimated values under given conditions.

Apart from effectiveness of HYDRUS-1D to simulate water parameters under different establishment techniques of rice, water saving in terms of irrigation and potential groundwater recharge was also observed in DSR fields. There was 9% more water applied in TPR field compared to DSR as no water is required during harvesting stage in DSR which help in water saving. The cumulative bottom flux was 1131 mm (~55.6% of total water input) and 1336 mm (~69% of total water input) in TPR and DSR, respectively, which results in 14.6% more deep percolation in DSR that may potentially contribute to groundwater recharge. Therefore, sum of 23.6% water in terms of irrigation and deep percolation was saved under DSR fields compared to TPR during crop period. If about 5 lakh hectare area is cultivated using this technology in Punjab, India, then about 2400 Mm^3 water can be saved. The HYDRUS-1D was fairly successful in simulating potential groundwater recharge under different establishment techniques of rice, thus can be helpful in judicious water management and sustaining groundwater resources.

Deep percolation was estimated using water balance equation and it was 1139 mm and 1305.6 mm in transplanted and direct seeded rice, respectively, as shown in Table 15. About 14.6% more deep percolation was observed in case of DSR as compared to TPR due to higher infiltration rate in non-puddled soil in case of DSR porous root zone soil. The total measured water input from TPR and DSR was 2035.5 mm and 1935.5 mm respectively. Potential crop evapotranspiration accounted for 26.77% and 27.85% of total water input for TPR and DSR, respectively. Runoff accounted for 20.43% and 7.89% of total water input for TPR and DSR, respectively, whereas the deep percolation after the depth of 100 cm accounted for 55.95% and 67.45% of the total water input in TPR and DSR, respectively.

Table 15. Water balance components in transplanted and direct seeded rice

Treatment	Water input		Water output			
	Rainfall (mm)	Irrigation (mm)	Crop evapotranspiration (mm)	Surface runoff (mm)	Soil moisture change (mm)	Deep percolation (mm)
Transplanted rice (TPR)	835.5	1200	545	416	64.9	1139
Direct seeded rice (DSR)	835.5	1100	539	152.9	62	1305.6

2.6. Jorhat

2.6.1. A GIS-based approach for identifying potential sites of rainwater harvesting in arsenic contaminated areas of Bhogdoi river basin

Arsenic contamination in groundwater of Bhogdoi river basin is prominent in Jorhat district of Assam. Irrigation by arsenic contaminated groundwater has the potential risk of bringing arsenic to food chain. The present study was formulated with the assumption that construction of rainwater harvesting structure in Arsenic contaminated areas may be a viable solution to avoid use of ground water for irrigation. In the project, a GIS based approach was used for identifying potential sites of rainwater harvesting in arsenic contaminated areas of Bhogdoi river basin.

The study area i.e. Bhogdoi river basin (Latitude: 26.61-26.78°N, Longitude: 94.21-94.41°E) was delineated using satellite image. The reported arsenic contaminated sites were demarcated in the base map and GIS based land use/ land cover map were prepared. The stream morphometry map was prepared by on screen digitization using Quantum GIS software. The morphometric parameters viz. linear, aerial and relief aspects were also estimated. GPS based soil, water and sediment samples were collected at a regular interval across the whole basin area and were analysed. Table 16 shows the morphometric parameters of Bhogdoi river basin.

Table 16. Morphometric parameters of Bhogdoi river basin (Linear aspects)

Stream order	Number of streams	Total length of stream (km)	Mean stream length (km)
I	63	50.5	0.80
II	13	26.73	2.06
III	5	10.97	2.19
IV	1	28.86	28.86
Total stream length (Lu)	82	117.06	
Stream order	**Stream length ratio**	**Bifurcation ratio**	**Mean bifurcation ratio**
I	-	4.85	-

II	0.53	2.60	4.15
III	0.41	5.00	-
IV	2.63	-	-

Note: Basin area = 144.21 km^2; Basin perimeter = 52.24 km; Basin length = 16.21 km

Various quality parameters of surface water of Bhogdoi river during pre-monsoon and post-monsoon period were analyzed. The mean values of water quality parameters like pH, electrical conductivity, total dissolved solid, chloride, carbonate, bicarbonate, calcium, magnesium, total hardness and residual sodium carbonate were found to be higher in pre monsoon period than that of post monsoon season. On contrary, quality parameters like dissolved oxygen, chemical oxygen demand, total suspended solid and turbidity were observed to be more in post-monsoon season. During pre-monsoon season, arsenic content of the surface samples (mean value 0.033 mg L^{-1}) was slightly higher than that of post-monsoon season (mean value 0.029 mg L^{-1}). The concentration of fluoride in the surface water samples was slightly more in pre-monsoon season (mean value 0.740 mg L^{-1}) than in post-monsoon season (mean value 0.711 mg L^{-1}). Arsenic concentration of the groundwater samples exhibited a range from 0.016 to 0.134 mg L^{-1}. The concentration of fluoride in all the six numbers of groundwater samples were observed within the permissible limit (0.775 to 1.138 mg L^{-1}). Water quality index of Bhogdoi river exhibited a wide range of variation and an increasing trend from upstream to downstream both in the pre-monsoon as well as in the post monsoon season was noticed. During the pre-monsoon period, the index ranged from 21.87 to 32.18 with a mean value of 25.80, whereas it ranged from 15.13 to 26.22 in the post-monsoon season averaging 21.10.

Various soil parameters were also analyzed in the Bhogdoi river basin. It was observed that the coarser materials like total sand content were found more in upslope and it was less in the downslope. On the contrary, the finer materials like the silt and clay content were found highest in the downstream. The hydraulic conductivity of the soils of the studied basin varied from 0.85 cm h^{-1} to 8.32 cm h^{-1} with a mean value of 2.66 cm h^{-1}. Water retention parameters like water holding capacity, field capacity, permanent wilting point and available water content of soils was found higher in lower elevation area. The pH of the analyzed soil samples were found strongly acidic to moderately acidic in nature and ranged from 4.16 to 5.39. The organic matter content of the study area displayed a range from low to high and varied from 6.21 g kg^{-1} to 17.58 g kg^{-1} with a mean value of 12.43 g kg^{-1}. The analyzed soil samples of the experimental area revealed a low to medium available nitrogen, phosphorous and potassium content. The annual soil loss in the basin varied from 0.30 t ha^{-1} year^{-1} (very slight) to 54.23 t ha^{-1} year^{-1} (very severe) with a mean value of 18.95 t ha^{-1} year^{-1}. The soil erosion was found to follow a decreasing trend from upstream to downstream.

Based on stream morphometry, land use, slope, hydrology and soil properties, the rain harvesting water sites were identified as given in Figure 11.

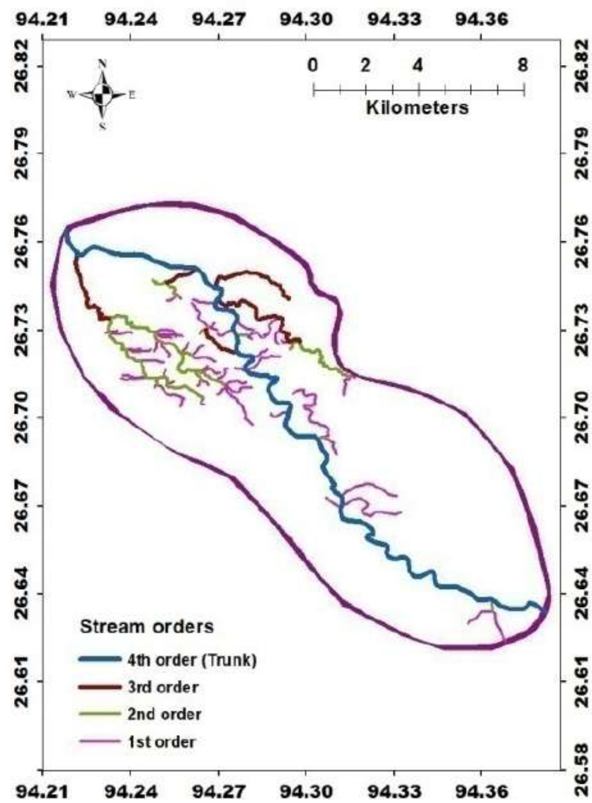


Figure 11. Map showing rainwater harvesting sites in Bhogdoi river basin

Chapter 3

Irrigation Scheduling using Surface and Pressurized Irrigation Systems

Surface irrigation

3.1. Bathinda

3.1.1. Enhancing water productivity of summer moong (*Vigna radiata* L.) with different wheat residue management and irrigation regimes

A field experiment was conducted to evaluate the interactive effect of irrigation regimes and wheat residue management practices on water productivity of summer moong. The treatments comprised of three wheat residue management practices (T_1: Preparatory tillage after removal of wheat residue, T_2: Leftover wheat straw and zero tillage, and T_3: Incorporation of leftover wheat residue in soil and preparatory tillage) and three irrigation scheduling levels (I_1 - Two irrigations i.e. at vegetative growth & flowering stages, I_2 - Three irrigations i.e. at vegetative, flowering and pod filling stages and I_3 - Four irrigations i.e. at vegetative, flowering, pod filling & pod formation stages). Results showed that grain yield of moong was significantly higher in both residue incorporation and leftover residue zero tillage treatment as compared to no residue addition tillage treatment (Table 17). Both the residue incorporation and leftover residue zero tillage treatments were statistically at par in terms of grain yield. Irrigation regimes I_2 and I_3 gave significantly higher moong yield than I_1 under all the three wheat residue management tillage practices, difference in yield between I_2 and I_3 was non-significant. Among the irrigation regimes, the water use efficiency (WUE) was found to be the highest in I_2. WUE was higher in wheat residue incorporated and leftover residue treatment and least in the treatments where no residue was retained in soil.

Table 17. Moong yield and water use efficiency (WUE) as influenced by wheat residue management tillage practices and irrigation levels (pooled mean of four years)

Treatments		IWA (cm)	TWU (cm)	Grain yield (t ha^{-1})	WUE (kg ha^{-1} mm^{-1})	B:C ratio
Wheat residue management practice	Irrigation level					
No wheat residue along with tillage (T_1)	I_1: 2 irrigations	15.0	27.8	0.495	1.77	1.08
	I_2: 3 irrigations	22.5	34.5	0.688	2.00	1.49
	I_3: 4 irrigations	30.0	41.4	0.784	1.90	1.69
	Mean	22.5	34.6	0.656	1.89	1.42
Leftover wheat residue with zero tillage (T_2)	I_1: 2 irrigations	15.0	27.2	0.579	2.13	1.36
	I_2: 3 irrigations	22.5	33.3	0.794	2.39	1.85
	I_3: 4 irrigations	30.0	40.5	0.869	2.15	2.01
	Mean	22.5	33.6	0.747	2.22	1.74
Incorporated wheat residue along with tillage (T_3)	I_1: 2 irrigations	15.0	27.2	0.585	2.15	1.19
	I_2: 3 irrigations	22.5	33.6	0.826	2.47	1.67
	I_3: 4 irrigations	30.0	40.7	0.901	2.22	1.82
	Mean	22.5	33.8	0.771	2.28	1.56
Overall average	I_1: 2 irrigations	15.0	27.4	0.553	2.02	-
	I_2: 3 irrigations	22.5	33.8	0.769	2.29	-
	I_3: 4 irrigations	30.0	40.9	0.851	2.09	-
CD (5%) for wheat residue management tillage				0.023	-	-
CD (5%) for irrigation level				0.026	-	-

Note: IWA, irrigation water applied; TWU, total water used

Summer moong crop

3.1.2. Response of rice straw mulch and irrigation water quality on water productivity of *Bt* cotton under different levels of irrigation and its residual effect on succeeding wheat crop

A field experiment was conducted to study the effect of mulching and irrigation water quality on *Bt* cotton and its residual effect on succeeding wheat crop. The treatments comprised two levels of irrigation water quality, I_1-canal water (CW) only, I_2- poor quality tubewell water (TW) and two levels of mulching (M_1-without mulch and M_2-straw mulch @ 6 t ha^{-1}) and replicated thrice. Results showed that the irrigation water quality and rice straw mulching had significant effect on seed cotton yield (Table 18). Among different irrigation levels, seed cotton yields were at par when irrigated at IW/CPE 0.5 & 0.7 and were significantly higher than irrigation at IW/CPE 0.3. The residual effect of rice straw mulch on grain yield of wheat was found to be significant (Table 19). Irrigation water quality had non-significant effect on wheat yield. Wheat grain yields increased significantly upto irrigation regimes IW/CPE 1.0. Among the irrigation regimes, the highest WUE (4.14 kg ha-mm^{-1} and 10.71 kg ha-mm^{-1}) was found at IW/CPE 0.3 level of canal water irrigation in cotton and at IW/CPE 0.6 level of irrigation with tube well water in wheat, respectively.

Table 18. Effect of straw mulch and irrigation water quality on yield and water use efficiency (WUE) of *Bt* cotton under different levels of irrigation (pooled mean)

Irrigation level	Yield (t ha^{-1})	Water use (cm)	WUE (kg ha-mm^{-1})	Yield t ha^{-1})	Water use (cm)	WUE (kg ha-mm^{-1})
	Canal water (I_1)					
	Without mulch (M_1)			With straw mulch (M_2)		
IW/CPE 0.3	2.66	71.3	3.74	2.90	70.2	4.14
IW/CPE 0.5	3.06	84.1	3.66	3.29	83.5	3.96
IW/CPE 0.7	3.07	98.3	3.13	3.32	98.0	3.39
	Tubewell water (I_2)					
	Without mulch (M_1)			With straw mulch (M_2)		
IW/CPE 0.3	1.99	70.7	2.76	2.25	70.3	3.16
IW/CPE 0.5	2.11	84.2	2.47	2.44	84.6	2.86
IW/CPE 0.7	2.19	97.7	2.22	2.54	98.0	2.57
Overall Mean (Yield)						
Canal water = 3.05; Tubewell water = 2.25; CD (p=0.05) = 0.064						
No mulch = 2.51; With mulch = 2.79; CD 5% = 0.058						
IW/CPE 0.3 = 2.45; IW/CPE 0.5 = 2.72; IW/CPE 0.7 = 2.78; CD (p=0.05) = 0.079						

Table 19. Effect of straw mulch and irrigation water quality on yield and water use efficiency (WUE) of wheat under different levels of irrigation (pooled mean)

Irrigation level	Yield (t ha^{-1})	Water use (cm)	WUE (kg $ha\text{-}mm^{-1}$)	Yield (t ha^{-1})	Water use (cm)	WUE (kg $ha\text{-}mm^{-1}$)
	Canal water					
	Without mulch			**With mulch**		
IW/CPE 0.6	3.32	34.4	9.67	3.60	34.5	10.54
IW/CPE 0.8	3.84	41.7	9.25	4.10	41.7	9.92
IW/CPE 1.0	4.01	45.9	8.75	4.26	45.2	9.49
	Tubewell water					
	Without mulch			**With mulch**		
IW/CPE 0.6	3.46	35.2	9.86	3.65	34.3	10.71
IW/CPE 0.8	3.97	42.5	9.38	4.18	40.5	10.37
IW/CPE 1.0	4.15	48.7	8.53	4.33	47.7	9.12
Overall Mean (Yield)						
Canal water = 3.85; Tubewell water = 3.96; CD 5% = NS						
No mulch = 3.79; With mulch = 4.02; CD 5% = 0.10						
IW/CPE 0.6 = 3.51; IW/CPE 0.8 = 4.02; IW/CPE 1.0 = 4.19; CD 5% = 0.11						

Wheat during *rabi* 2020-21

Bt cotton during *kharif* 2021

Pressurized irrigation

3.2. Jammu

3.2.1. Strategizing on-farm research in sprinkler irrigation for basmati rice-wheat sequence within canal command areas of Jammu

An on-farm research on sprinkler irrigation system for basmati rice-wheat cropping system was conducted for two years (2018-2020). The experiment was laid out in strip plot design with irrigation method and irrigation scheduling as two factors replicated thrice. For rice crop, irrigation methods were sprinkler irrigation from puddling to 15 days before harvest (S_1), sprinkler irrigation after puddling to 15 days before harvest (S_2) and sprinkler irrigation from panicle initiation to 15 days before harvest (S_3). Whereas, irrigation scheduling treatments include 100% ET_c (I_1), 150% ET_c (I_2) and 200% ET_c (I_3). For wheat crop, irrigation methods were sprinkler irrigation at pre-sowing irrigation and CRI stage (S_1), sprinkler irrigation at pre-sowing irrigation, CRI stage and late booting (S_2) and sprinkler irrigation at all physiological stages (S_3) with irrigation scheduling treatments of 100% ET_c (I_1), 80% ET_c (I_2) and 60% ET_c

(I_3). Frequency of sprinkler irrigation was alternate days in *kharif* and weekly twice in *rabi* season. Recommended irrigation practice was taken as the control where four surface irrigations each of 6 mm depth were applied at IW/CPE 1.0.

Pooled data of two years revealed that application of sprinkler irrigation at panicle initiation to 15 days before harvest recorded highest rice grain yield of 2.62 t ha^{-1}, net return of ₹ 42579 ha^{-1} and benefit-cost ratio of 1.59 among the sprinkler irrigation treatments and recommended practice (control). Irrigation scheduled at 200% ET_c resulted in highest yield of 2.71 t ha^{-1} and maximum WUE of 2.03 kg ha-mm^{-1}, highest net return of ₹ 46259 ha^{-1} and B:C of 1.64 (Table 20). There was irrigation water saving of 31% with sprinkler irrigation applied at panicle initiation to 15 days before harvest over recommended practice of irrigation (control).

In wheat, application of sprinkler irrigation at all physiological stages recorded highest grain yield of 3.48 t ha^{-1}, highest net return of ₹ 45818 ha^{-1} and benefit-cost ratio of 2.15 among the sprinkler treatments and the control. On the other hand, irrigation scheduled at 80% ET_c recorded highest yield and WUE with maximum economic return (Table 20). Sprinkler irrigation at pre-sowing, CRI and late booting stage of wheat saved 36% of irrigation water as compared to recommended practice of irrigation at IW/CPE 1.0.

Table 20. Effect of different irrigation methods and irrigation schedules on irrigation amount, grain yield, water use efficiency and economics of rice and wheat (pooled data)

Treatment	Irrigation (mm)		Grain yield (t ha^{-1})		WUE (kg ha-mm^{-1})		Net return (₹ ha^{-1})		B-C ratio	
	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat
Irrigation method										
S_1	298	137	2.12	2.75	2.23	6.20	20559	28409	1.28	1.71
S_2	417	144	2.45	3.30	2.29	7.30	34759	41415	1.48	2.04
S_3	1028	175	2.62	3.48	1.56	7.20	42579	45818	1.59	2.15
CD (*p*=0.05)	-	-	0.31	0.31	-	-	-	-	-	-
Irrigation schedule										
I_1	554	181	2.03	3.21	1.68	6.60	18719	39368	1.26	1.99
I_2	597	152	2.46	3.21	1.97	7.50	35679	39410	1.49	1.99
I_3	674	124	2.71	3.10	2.03	6.80	46259	36826	1.64	1.93
CD (*p*=0.05)	-	-	0.28	NS	-	-	-	-	-	-
Recommended irrigation (60 mm depth)	1285	210	2.75	2.95	1.44	5.90	68009	32889	2.29	1.83

Note: *In rice*: S_1, Sprinkler irrigation from puddling to 15 days before harvest; S_2, Sprinkler irrigation after puddling to 15 days before harvest; S_3, Sprinkler irrigation from panicle initiation to 15 days before harvest; I_1, 100% ET_c; I_2, 150% ET_c; I_3, 200% ET_c. *In wheat*: S_1, Sprinkler irrigation at pre-sowing irrigation and CRI stage; S_2, Sprinkler irrigation at pre-sowing irrigation, CRI stage and late booting; S_3, Sprinkler irrigation at all physiological stages; I_1, 100% ET_c; I_2, 80% ET_c; I_3, 60% ET_c; NS, non-significant

3.3. Hisar

3.3.1. Effect of high frequency irrigation systems on water productivity and yield of wheat

A study was conducted to evaluate performance of wheat variety WH 1105 under various systems of irrigation viz., mini-sprinkler, furrow irrigated raised bed system (FIRBS), drip on FIRBS, and flooding. Results showed that wheat grain yield of 5.56 t ha^{-1} and irrigation water productivity of 3.05 kg m^{-3} was highest under drip on FIRBS followed by use of mini-sprinklers (5.57 t ha^{-1}, 3.03 kg m^{-3}) and least (4.84 t ha^{-1}, 2.57 kg m^{-3}) under flood irrigation (Table 21). It was concluded that drip on FIRBS was best for wheat in terms of grain yield and water productivity.

Table 21. Performance of wheat under different systems of irrigation

Irrigation method	Irrigation (mm)	Grain yield (t ha^{-1})	Irrigation water productivity (kg m^{-3})	Total water productivity (kg m^{-3})
Mini-sprinkler	18.4	5.57	3.03	1.88
Drip on FIRBS	18.2	5.56	3.05	1.95
FIRBS	18.4	4.98	2.70	1.75
Flooding	18.8	4.84	2.57	1.67

Note: Rainfall, 2.32 mm; IWP, irrigation water productivity; TWP, total water productivity

3.4. Pusa

3.4.1. Effect of irrigation management and method of establishment on performance of rice

A field experiment was conducted to assess the performance of irrigation management and crop establishment methods on performance of rice and economics. Treatments consisted of three levels of irrigation management and four levels of crop establishment methods. Irrigation management included I_1- Continuous submergence throughout crop growth, I_2- Saturation maintenance upto panicle initiation (PI) and ponding (5±2 cm) after PI, and I_3- Alternate wetting and drying i.e. 5 cm irrigation at 3 days after disappearance of ponded water (DADPW) upto PI and ponding (5±2 cm) after PI. Four levels of crop establishment methods included E_1- Normal transplanting, E_2- Direct wet seeding on puddled soil, E_3- Direct dry seeding, and E_4- Broadcasting on unpuddled soil. Results revealed that maximum yield (3.91 t ha^{-1}) and highest net return (₹ 44219 ha^{-1}) was obtained with continuous submergence among the irrigation management treatments (Table 22). But the yield with continuous submergence was at par with yields obtained under two other irrigation management treatments. Among the crop establishment methods, transplanting recorded significantly highest yield (4.26 t ha^{-1}), water use efficiency (50.29 kg ha mm^{-1}) and maximum net return (₹ 50597 ha^{-1}) compared to direct wet seeding on puddled soil, direct dry seeding, and broadcasting on unpuddled soil. Maximum water use efficiency (45.66 kg ha mm^{-1}) was recorded with alternate wetting and drying (5 cm irrigation at 3 DADPW) upto PI and ponding (5±2 cm) after PI under irrigation management.

Table 22. Performance of rice crop under different irrigation management and crop establishment methods (Pooled data of five years)

Treatment	Grain yield (t ha^{-1})	WUE (kg ha mm^{-1})	Net return (₹ ha^{-1})	B : C ratio
Irrigation management				
I_1: Continuous submergence throughout crop growth period	3.91	36.86	44219	0.92
I_2: Saturation maintenance upto panicle initiation (PI) and (5±2 cm) after PI	3.63	42.17	41205	0.95
I_3: Alternate wetting and drying (5 cm irrigation at 3 DADPW) upto PI and ponding (5±2 cm) after PI	3.53	45.66	41106	1.03
CD (p=0.05)	NS	4.62	NS	NS
Crop establishment method				
E_1: Transplanting	4.26	50.29	50597	0.99
E_2: Direct wet seeding on puddled soil	3.68	35.55	39650	0.94
E_3: Direct dry seeding	3.61	42.24	43155	0.96
E_4: Broadcasting on unpuddled soil	3.21	38.16	35305	0.98
CD (p=0.05)	0.36	3.51	9186	NS

Note: DADPW, days after disappearance of water; WUE, water use efficiency; B:C, benefit-cost ratio

Chapter 4

Fertigation

4.1. Chalakudy

4.1.1. Water and nutrient scheduling for drip fertigated Rasthali (AAB) / Poovan (local) banana

Rasthali banana, commonly called as *"Poovan"* in Kerala is gaining importance because of its sweetness, aroma, and increased use in rituals and public gatherings. An experiment was conducted to standardize drip irrigation and nutrient scheduling in *Rasthali* banana. The experimental design was factorial randomized block design replicated thrice. Treatments comprise of level of irrigation namely, drip irrigation at 50, 75 and 100% pan evaporation (PE), fertigation schedule namely, 100% phosphorus (P) as basal along with weekly drip fertigation of 100% nitrogen (N) & potassium (K), 75% P as basal along with weekly drip fertigation of 75% N & K, 100% P as basal along with weekly application of 75% N & K as drip fertigation + 25% N & K as foliar spray. Basin irrigation once in six days and fertilizer application at 2 and 4 months after planting (MAP) was taken as control. Recommended dose of fertilizer (RDF) for *Rasthali* banana is 100:75:125 kg NPK ha^{-1}.

Application of drip irrigation at 75% PE along with application of P as basal, 75% N & K as drip fertigation and remaining 25% N & K as foliar spray resulted in best performance of the banana crop in sandy loam soil. The treatment combination resulted in highest fruit yield of 27.25 t ha^{-1}, irrigation water productivity of 5.31 kg m^{-3}, nutrient use efficiency of 26.51 kg kg^{-1}, and benefit-cost ratio of 2.30 among the treatment combinations and the control (Table 23). The above treatment combination showed 40.8%, 88.1%, 78.9% and 30.3% higher fruit yield, irrigation water productivity, nutrient use efficiency and benefit-cost ratio over the control.

Table 23. Effect of irrigation level and fertigation on yield, water productivity and economics in Poovan banana (pooled data)

Treatment	Yield (t ha^{-1})	IWP (kg m^{-3})	TWP (kg m^{-3})	NUE (kg kg^{-1})	Cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	B-C ratio
Irrigation levels (I)							
I_1- 50% PE	23.64	6.90	4.32	22.0	287930	591003	2.05
I_2- 75% PE	25.49	4.96	3.11	23.6	287930	637231	2.21
I_3- 100% PE	26.55	3.87	2.43	24.6	287930	663793	2.31
CD (p=0.05)	0.20	0.49	0.30	1.9	-	-	-
Fertigation (F)							
F_1- 100% RDF	22.37	4.60	2.88	17.1	288288	559276	1.94
F_2- 75% RDF	26.49	5.54	3.47	27.1	279216	662214	2.37
F_3- 75% RDF+25% foliar	26.82	5.59	3.50	26.1	296287	670537	2.26
CD (p=0.05)	0.20	0.49	0.30	1.9	-	-	-
Interaction effect (I×F)							
I_1×F_1	19.92	5.81	3.64	15.3	288288	498078	1.73
I_1×F_2	25.52	7.46	4.67	26.1	279216	637875	2.29
I_1×F_3	25.48	7.43	4.66	24.8	296287	637056	2.15
I_2×F_1	22.82	4.44	2.78	17.5	288288	570476	1.98
I_2×F_2	26.40	5.14	3.22	27.0	279216	659978	2.36
I_2×F_3	27.25	5.31	3.32	26.5	296287	681240	2.30
I_3×F_1	24.37	3.56	2.23	18.7	288288	609273	2.11
I_3×F_2	27.55	4.02	2.52	28.1	279216	688790	2.47
I_3×F_3	27.73	4.03	2.53	27.0	296287	693315	2.34
CD (p=0.05)	NS	NS	NS	NS	-	-	-
Control	19.36	2.82	1.77	14.8	274288	483903	1.76

Note: F_1, 100% RDF [phosphorus (P) as basal, nitrogen (N) and potassium (K) through drip fertigation]; F_2, 75% RDF [P as basal, N and K through drip fertigation]; F_3, 75% RDF + 25% foliar [100% P as basal, 75% N and K through drip fertigation and 25% N and K through foliar spray]; IWP, irrigation water productivity; TWP, total water productivity, NUE, nutrient use efficiency, NS, non-significant


Drip fertigated banana crop

4.2.1. Navsari

4.2.1. Fertigation study in cauliflower grown on clay soil of South Gujarat

The experiment was initiated during *rabi* season 2018-19 to develop drip fertigation schedule for cauliflower variety Snowball 1. Randomized block design was adopted with eleven treatments and four replications. Treatments (T_1 to T_{11}) have been described in Table 24. Results of the experiment revealed significantly higher average head weight recorded in treatments T_1 to T_5 than rest of the treatments. Different fertigation treatments were found to significantly affect the head yield of cauliflower during all the three years of experiment. Higher head yield was recorded with 100% NPK through fertigation T_3 (27.70 t ha^{-1}), but was found at par with treatment T_2 (25.54 t ha^{-1}) and significantly higher over rest of the treatments. Nitrogen uptake by cauliflower head for treatment T_3 (102.7 kg ha^{-1}) remained at par with T_2 (98.3 kg ha^{-1}) and significantly higher over rest of the treatments. In case of P & K, significant higher uptake was observed with T_3 (16.5 t ha^{-1}) as compared to rest of the treatments. Nutrient uptake by foliage indicated that T_3 recorded significant higher N uptake (46.2 kg ha^{-1}) being at par with T_2 (45.1 kg ha^{-1}) and T_1 (41.6 kg ha^{-1}). Uptake of K was significantly higher in T_2 and T_3 compared to rest of the treatments. However, T_2 recorded higher K uptake (104.9 kg ha^{-1}) but was found at par with treatments T_1 (96.8 kg ha^{-1}), T_3 (100.4 kg ha^{-1}) and T_8 (92.3 kg ha^{-1}). Three years of pooled results indicated that higher head yield of 27.7 t ha^{-1} was recorded in T_3 that also fetched maximum net income ₹ 1,59,828 ha^{-1} followed by treatment T_2 with head yield of 25.5 t ha^{-1} and net income of ₹ 1,48,750 ha^{-1}. Growth and yield attributes of cauliflower clearly indicated that application of 100% RDF of N, P_2O_5 and K_2O is required for getting higher yield. The application either 100% RDF through fertigation or 100% N and K through fertigation with 100% P applied as basal are equally beneficial.

Table 24. Performance of cauliflower under drip fertigation

Treatment	Yield (t ha^{-1})	Nutrient uptake (kg ha^{-1})						Net income (₹ ha^{-1})
		Cauliflower head			Foliage			
		N	P	K	N	P	K	
T_1: 100% N through fertigation with 100% P & K applied as basal	24.2	89.7	12.9	102.4	41.6	10.4	96.8	135500
T_2: 100% N & K through fertigation with 100% P applied as basal	25.5	98.3	15.0	109.2	45.1	13.5	104.9	148750
T_3: 100% NPK through fertigation	27.7	102.7	16.5	119.9	46.2	13.5	100.4	159828
T_4: 75% NPK through fertigation with 25%NPK applied as basal	24.6	81.8	12.8	90.3	38.2	10.7	79.3	132542
T_5: 75% N through fertigation with 75% P & K applied as basal	22.7	79.9	11.5	82.5	40.4	10.8	75.1	123457
T_6: 75% N & K through fertigation with 75% P applied as basal	22.5	77.9	12.5	84.7	36.8	11.4	86.9	120910
T_7: 75% NPK through fertigation	22.8	81.4	13.4	83.7	31.9	10.5	79.7	117399

T_8: 19% NPK basal and 56% NPK through fertigation	21.2	69.4	13.2	91.3	37.0	12.0	92.3	103553
T_9: 100% NPK conventional fertilizer	17.9	57.5	11.0	63.6	31.8	10.7	74.2	75974
T_{10}: Absolute control	11.1	30.4	5.6	38.2	16.6	5.7	54.3	17552
T_{11}: Surface irrigation with 100% RDF	16.4	54.5	10.1	62.0	33.7	8.8	62.2	85034
CD at 5%	0.8	8.3	1.5	9.6	4.1	1.3	8.7	-

Cauliflower var. Snowball 1 under fertigation

4.3. Sriganganagar

4.3.1. Studies on fertigation schedule in bottle gourd (*Lagenaria siceraria*) under low tunnel in cotton based cropping system

Traditional *rabi* crops like wheat, mustard, chickpea grown in irrigated North Western Plain Zone of Rajasthan are not compatible with drip layout for cotton under low tunnel condition in cotton based system. Bottle gourd, an important cucurbitaceous vegetable crop in the region may be a suitable option for cotton-vegetable system that will save the vegetable crop from chilling injury and also save irrigation water. A field experiment was done from *rabi* 2018-19 to 2020-21 on bottle gourd variety MHBG-8 under cotton-bottle gourd cropping sequence. Randomized block design was adopted with ten treatments replicated thrice. Drip irrigation was applied at 0.8 ET_c in all the treatments, whereas flood irrigation was provided for the control. Pre-sowing irrigation of 100 mm was applied to all the treatments. Three years of experimentation showed that drip fertigation treatments had significant effect on yield of bottle gourd. Maximum fruit yield of bottle gourd of 55.9 t ha^{-1} was recorded with the application of 75% N, P & K through fertigation with no basal application which was statistically at par with application of 100% N, P & K through fertigation with no basal application, and 25% NPK as basal and remaining NPK through fertigation, which was significantly higher than rest of other treatments in the study (Table 25).

Table 25. Performance of bottle gourd under cotton based cropping system

Treatment	Yield (t ha^{-1})	WUE (kg ha-mm^{-1})
T_1- 100% N through fertigation with 100% P & K applied as basal	38.0	112.21
T_2- 100% N & K through fertigation with 100% P applied as basal	42.8	127.15
T_3- 100% N, P & K through fertigation with no basal application	53.1	153.58
T_4- 25% NPK of 100% as basal and remaining NPK through fertigation	53.6	159.66
T_5- 75% N through fertigation with 75% P & K applied as basal	40.0	121.61
T_6- 75% N & K through fertigation with 75% P applied as basal	43.3	129.24
T_7- 75% N, P & K through fertigation with no basal application	55.9	184.30
T_8- 25% NPK of 75% as basal and remaining NPK through fertigation	42.3	126.95
T_9- 100% NPK through conventional fertilizers & method (Control)	34.6	109.56
T_{10}- Absolute control (no fertilizer)	26.9	43.65
CD (p=0.05)	7.6	-

Note: T_1 to T_9, Irrigation water applied=322.8 mm, T_{10}=820.0 mm


Drip fertigation in bottlegourd var. MHBG-8

4.4. Gayeshpur

4.4.1. Gravity drip irrigation and integrated nutritional management schedules on yield, quality and profitability of Indian jujube

An experiment was conducted from 2018 in gravity drip irrigation in Indian jujube with following objectives i) to study the effects of various irrigation and nutritional management schedules on growth, yield, yield components and quality of crop, ii) to determine the consumptive water use and water use efficiency of crop under different water and nutritional supply, and iii) to estimate the benefit-cost ratio of the system. The experimental design was split plot replicated thrice with drip irrigation practice as main factor and nutrient management as sub factor (Table 26). The growth, yield components and fruit yield of Indian jujube were significantly differed by various irrigation regimes and nutrient management. The growth characteristics, yield components and fruit yield consistently and significantly increased with increase in drip irrigation level. However, highest tree height (4.94 m), tree circumference (0.53 m), number of fruits per tree (847), fruit weight (14.9 g) and fruit yield (10.43 kg tree^{-1}) were obtained with drip irrigation at 0.8 E_0 (pan evaporation) which were statistically at par with surface irrigation excepting fruit yield, but superior over other drip irrigation levels. Higher level of deficit

Table 26. Effect of different levels of drip irrigation and nutrient management on growth, yield components and fruit yield of Indian Jujube

Treatment	Tree height (m)	Tree circumfe-rence (m)	No. of fruits tree^{-1}	Fruit weight (g)	Fruit yield (kg tree^{-1})
Irrigation (I)					
I_1: Surface irrigation @ 1.0 IW/CPE at 5 cm depth	4.75	0.47	733	14.0	9.57
I_2: Drip irrigation at 0.8 E_0 (pan evaporation)	4.94	0.53	847	14.9	10.43
I_3: Drip irrigation at 0.6 E_0	4.40	0.45	774	14.5	8.84
I_4: Drip irrigation at 0.4 E_0	3.71	0.31	519	13.0	6.82
CD (*p*=0.05)	0.27	0.06	24	1.2	0.56
Nutrient management (F)					
F_1: 100% RDF as mineral fertilizers	4.64	0.49	760	14.5	9.34
F_2: 75% RDF as mineral fertilizers + 25% RDF as vermicompost	4.54	0.46	747	14.2	9.11
F_3: 50% RDF as mineral fertilizers + 50% RDF as vermicompost	4.17	0.38	648	13.7	8.29
CD (*p*=0.05)	0.14	0.04	15	NS	0.26

Note: E_0, pan evaporation; 20 mm depth of irrigation water applied in all plots for establishing uniform irrigation regime in field; NS, non-significant irrigation at 0.4 E_0 with drip system recorded the lowest growth, yield variables and fruit yield. On the other hand, maximum tree height (4.64 m), tree circumference (0.49 m), number of fruits per tree (760), fruit weight (14.5 g) and fruit yield (9.34 kg tree^{-1}) were accomplished with 100% RDF as mineral fertilizer which were on parity with 75% RDF as mineral fertilizer + 25% RDF as vermicompost. Application of 50% RDF as mineral fertilizer + 50% RDF as vermicompost recorded the lowest growth, yield constituents and fruit yield. This implies that incremental substitution of chemical fertilizer with organic manure progressively decreased the growth and yield characteristics and thus fruit yield. The relationship between average fruit yield and seasonal irrigation water applied for Indian jujube was computed through a non-linear regression analysis. Fruit yield (y) taken as the dependent variable and irrigation water (x) as the independent variable was plotted to derive a mathematical functional model (Figure 12). A second-degree polynomial equation was best fitted between fruit yield and irrigation water used. The predicted regression equation is developed as:

$$y = -8E - 05x^2 + 0.0455x + 2.5173$$

The coefficient of determination (R^2) was estimated to be 0. 0.8661 which was statistically highly significant. In this modular approach, all drip and surface irrigation treatments were considered for projecting the fruit yield. The linear portion of the graph designating the yield increase was proportional to the incremental irrigation, while the quadratic effect displays the marked decrease in yield with further increase in irrigation level. This indicates that beyond a certain limit of applied irrigation water, the yield did not increase; rather a sharp dropping in yield was noticed with a further increase in watering. The predicted highest fruit yield (9.05 kg tree^{-1}) was obtained at the inflection point of the quadratic regression curve with 280 mm irrigation water. The soil moisture content down the soil layers did follow the non-consistency or, asymmetrical pattern of distribution under different irrigation treatments across the plant growth stages. The soil moisture content values increased variably up to 15-30 cm layer in sprout lead development and fruit maturity stages, and 30-45 cm layer in fruit development stage of plant

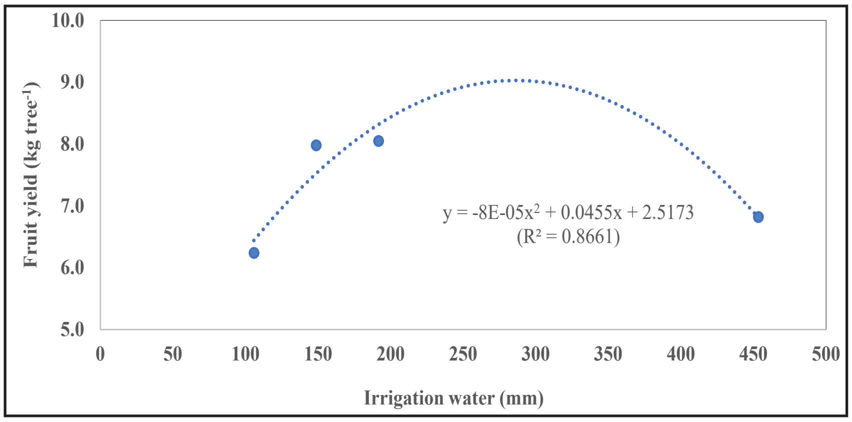


Figure 12. Relationship between irrigation water applied (y) and fruit yield (x) of Indian jujube (based on 3-year mean data)

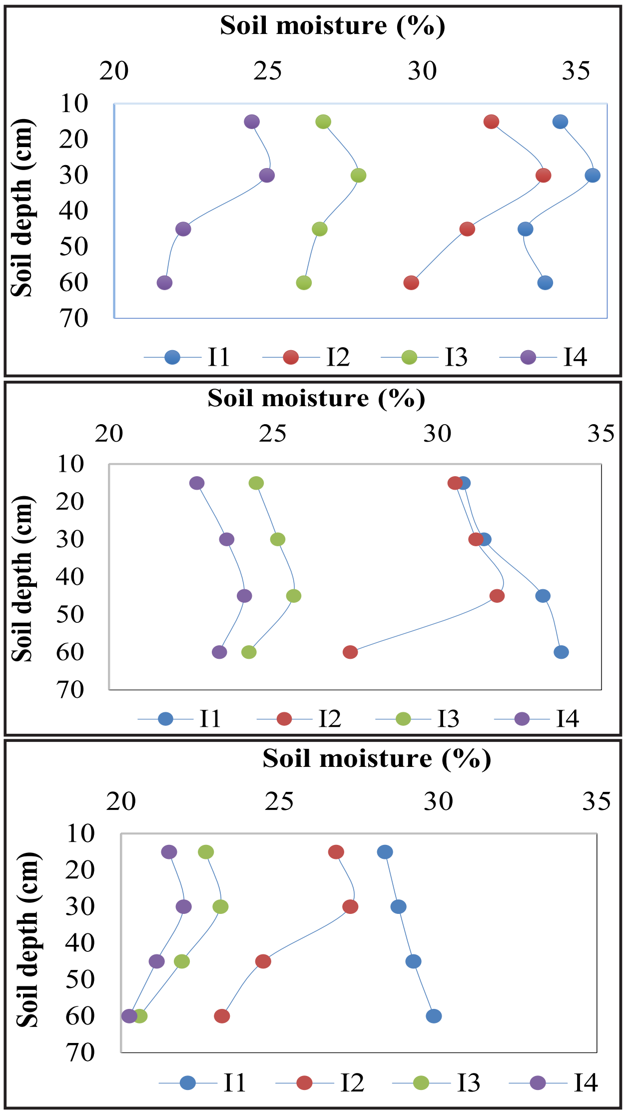


Figure 13. Soil moisture contents across the soil profile under different irrigation regimes in (a) sprout lead development, (b) fruit development and (c) fruit maturity stages of Indian jujube

with all drip irrigation levels, thereafter decreased with increase in soil depth (Figure 13). In case of surface irrigation, the soil moisture contents increased up to 15-30 cm layer in sprout lead development, then decreased inconsistently; while the values gradually increased with increasing soil depth in fruit development and fruit maturity stages. Notably, soil moisture content decreased progressively with the advancement of crop growth period in all the soil layers at all irrigation regimes. Among drip irrigation levels, highest soil moisture content was found in drip irrigation at 0.8 E_0, followed by 0.6 E_0 and 0.4 E_0, respectively. Surface irrigation maintained higher soil moisture contents along the soil profile layers at all growth stages as compared with drip irrigation levels.

4.5. Bathinda

4.5.1. Growth and yield response of *Bt* cotton in rotation with summer squash to water quality and fertigation levels under drip system

A field experiment was conducted on sandy soil from 2016 to 2021. Split plot design was used with different fertigation level (main factor) and irrigation water quality (sub factor) for cotton in *kharif* and summer squash in *rabi* season. Fertigation levels were 60%, 80% and 100% recommended dose of nitrogen (RDN). Irrigation water quality treatment comprised of Canal water (CW), Irrigation with canal water till germination & subsequent irrigations with poor quality tubewell water (CW_g-TW), and Alternate use of CW & TW (CW/TW). Tubewell water (TW) was saline sodic having residual sodium carbonate (RSC) of 1.36 meq L^{-1} and electrical conductivity (EC) of 4.2 dS m^{-1}.

Summer squash: Irrigation water quality and fertigation levels had significant effect on growth and yield parameters of summer squash. Maximum yield (9.39 t ha^{-1}) and water use efficiency (34.2 kg ha-mm^{-1}) was obtained with use of CW alone and 100% RDN. This was at par with yield (8.74 t ha^{-1}) and WUE (32.3 kg ha-mm^{-1}) with application of CW alone and 80% RDN (Table 27).

***Bt* cotton:** Seed cotton yields were at par when 80% and 100% of RDN was applied and were significantly higher than application of 60% RDN. Drip irrigation with CW alone and fertigation with 100% RDN resulted in highest yield (3.88 t ha^{-1}), water use efficiency (5.40 kg ha-mm^{-1}), and benefit-cost ratio (3.27). The above results were statistically similar to drip irrigation with CW alone and fertigation at 80% RDN with yield of 3.71 t ha^{-1}, WUE of 5.15 kg ha-mm^{-1} and B:C ratio of 3.14 (Table 28). Use of CW along with 80% RDN and 100% RDN resulted in 15.6 to 20.9% higher seed cotton yield, 42.3-49.2% higher water use efficiency, and 3.0-7.2% higher benefit-cost ratio over check basin method of irrigation and application of 100% RDN using conventional method (Table 28).

Physico-chemical characteristics of soil after crop harvest (Table 29) showed that drip irrigation with CW alone and fertigation with 80% RDN showed least EC (0.28 dS m^{-1}). There was maximum available nitrogen, phosphorus and potassium of 150.5 kg ha^{-1}, 22.1 kg ha^{-1} and 175.4 kg ha^{-1}, respectively. Soil organic carbon was 2.8 g kg^{-1}.

Table 27. Pooled performance of summer squash under different fertigation level and irrigation water quality treatments

Treatment combination		Yield (t ha^{-1})	Total water applied (mm)	WUE (kg ha-mm^{-1})
Fertigation level	**IWQ**			
60% of RDN	CW	7.39	272	27.6
	CW_g-TW	3.19	277	11.8
	CW/TW	4.81	279	17.4
	Mean	5.13	276	18.9
80% of RDN	CW	8.74	276	32.3
	CW_g-TW	3.97	274	14.9
	CW/TW	6.07	271	22.7
	Mean	6.25	274	23.3

100% of RDN	CW	9.39	276	34.2
	CW_g-TW	4.21	271	15.9
	CW/TW	6.39	273	23.7
	Mean	6.67	273	24.6
Overall average	CW	8.51	272	27.6
	CW_g-TW	3.79	277	11.8
	CW/TW	5.76	279	17.4
Fertilizer level (CD at 5%)	-	0.81	-	-
Water quality (CD at 5%)	-	0.53	-	-

Note: CW, canal water; CW_g – TW, irrigation with canal water till germination and subsequent irrigation with poor quality tubewell water; CW/TW, alternate application of canal water and tubewell water; IWQ-irrigation water quality; RDN-recommended dose of nitrogen; WUE-water use efficiency

Table 28. Performance of *Bt* cotton under different fertigation level and irrigation water quality treatments

Treatment combination		Irrigation applied (mm)	Seed cotton yield (t ha^{-1})	WUE (kg $ha\text{-}mm^{-1}$)	B-C ratio
Fertigation level	**IWQ**				
60% of RDN	CW	271	3.37	4.62	2.86
	CW_g-TW	271	2.90	4.01	2.46
	CW/TW	271	3.18	4.36	2.70
80% of RDN	CW	271	3.71	5.15	3.14
	CW_g-TW	271	3.22	4.36	2.72
	CW/TW	271	3.64	5.00	3.07
100% of RDN	CW	271	3.88	5.40	3.27
	CW_g-TW	271	3.43	4.70	2.89
	CW/TW	271	3.72	5.11	3.13
100% of RDN	CW (CB)	425	3.21	3.62	3.05
100% of RDN	SW (CB)	425	2.54	2.84	2.42
Fertigation level					
60% of RDN		-	3.15	-	-
80% of RDN		-	3.52	-	-
100% of RDN		-	3.68	-	-
CD (p=0.05)		-	0.19	-	-
Irrigation water quality					
CW		-	3.65	-	-
CW_g-TW		-	3.19	-	-
CW/TW		-	3.51	-	-
CD (p=0.05)		-	0.16	-	-

Note: CW, canal water; CW_g–TW, irrigation with canal water till germination and subsequent irrigation with poor quality tubewell water; CW/TW, alternate application of canal water and tubewell water; IWQ-irrigation water quality; RDN-recommended dose of nitrogen; CB-check basin method of irrigation; WUE-water use efficiency; B:C-benefit-cost

Table 29. Physico-chemical characteristics of soil after crop harvest (0-15 cm)

Treatment	$pH_{1:2}$	$EC_{1:2}$ (dS m^{-1})	OC (g kg^{-1})	Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})	BD (Mg m^{-3})
F_{60} - CW	8.16	0.268	2.8	129.6	23.0	176.9	1.44
F_{60} - TW	8.55	0.377	1.9	100.4	16.2	190.8	1.54
F_{60} - CW/TW	8.31	0.337	2.4	117.1	20.0	178.3	1.48
F_{80} - CW	8.14	0.276	2.8	150.5	22.1	175.4	1.43
F_{80} - TW	8.53	0.387	2.0	104.5	16.1	193.5	1.56
F_{80} - CW/TW	8.30	0.344	2.5	125.4	19.6	185.7	1.52
F_{100} - CW	8.12	0.281	2.9	158.9	21.6	173.0	1.42
F_{100} - TW	8.50	0.402	2.0	112.9	15.5	190.1	1.57
F_{100} - CW/TW	8.30	0.337	2.6	129.6	19.3	191.6	1.50

Note: EC, electrical conductivity; OC, organic content; Av. N, available nitrogen; Av. P, available phosphorus; Av. K, available potassium; BD, bulk density

Drip fertigation in summer squash

Drip fertigation in *Bt* cotton

Chapter 5

Basic Studies on Soil-Plant-Water-Environment Relationship

5.1. Ayodhya

5.1.1. Effect of moisture regimes and weed management practices on availability of nutrients in drum seeded rice

An experiment was investigated to find out an appropriate irrigation schedule and suitable weed management practice for drum seeded rice. The treatments comprised of three levels of moisture regimes [I_1: 6 cm at 1 days after disappearance of ponded water (DADPW, I_2: 6 cm at 4 DADPW and, I_3: 6 cm at 7 DADPW] and four levels of weed management practices W_0: Control, W_1: Organic mulch (rice straw @ 5 t ha^{-1}), W_2: Weedicide (Bispyribac Sodium 10% SC 20 mL ha^{-1} post emergence) and, W_3: Two hand weedings (at 20-25 and 40-45 DAS) with three replications. Moisture regimes were considered in main plot and weed management practices were taken as sub plot treatments. The results (Table 30) indicated that the moisture regime of 6 cm water at 1 DADPW (I_1) recorded the significant higher yield of rice at 4.64 t ha^{-1} with water expense efficiency (WEE) of 5.10 kg ha-mm^{-1} as compared to moisture regime of 6 cm water at 7 DADPW (I_3. This was at par with moisture regime of 6 cm water at 4 DADPW (I_2) in which the rice yield was 4.41 t ha^{-1} with WEE 5.64 kg ha-mm^{-1}. The weed management practices also had significant effect on rice yield and the mechanical weed management practice. Two hand weeding at 20-25 DAS and 40-45 DAS (W_3) harvested the significant higher yield of rice 5.01 t ha^{-1} with WEE of 6.43 kg ha-mm^{-1} over other weed management practices but it was at par with chemical weeding (W_2) in which the rice yield was obtained as 4.84 t ha^{-1} with WEE of 6.21 kg ha-mm^{-1}. The economic analysis showed that treatment combination (moisture regime of 6 cm at 1 DADPW and application of weedicide Bispyribac Sodium 10% SC 20 mL ha^{-1} as post emergence) accrued the maximum net return of ₹ 60,691.00 ha^{-1} with B-C ratio of 2.64 followed by the treatment combination of I_2W_2 (moisture regime of 6 cm at 4 DADPW and application of weedicide Bispyribac sodium 10% SC 20 mL ha^{-1} as post emergence) resulted in highest benefit cost ratio of 2.65 which, accrued the net return of ₹ 57770.00 ha^{-1} with B-C ratio of 2.65 (Table 31).

Table 30. Yield and water expense efficiency (WEE) under different moisture regimes and weed management practices in drum seeded rice

Treatment	Rice yield (t ha^{-1})	WEE (kg ha-mm^{-1})
Moisture regime		
I_1: 6 cm at 1 DADPW	4.64	5.10
I_2: 6 cm at 4 DADPW	4.41	5.64
I_3: 6 cm at 7 DADPW	3.80	6.65
CD (*p*=0.05)	0.44	-
Weed management practice		
W_0: Control	3.24	4.16
W_1: Organic mulch (Rice straw @ 5 t/ha)	4.04	5.03
W_2: Weedicide (Bispyribac sodium 10% SC 20 g ha^{-1}, post-emergence)	4.83	6.21
W_3: Two hand weeding (at 20-25 and 40-45 DAS)	5.01	6.43
CD (*p*=0.05)	0.32	-

Table 31. Economics of rice production under different moisture regimes and weed management practices in drum seeded rice

Treatment combination	Average rice yield (t ha^{-1})	Cost of cultivation (₹ ha^{-1})	Net income (₹ ha^{-1})	B-C ratio
I_1W_0	3.47	35600	28533	1.80
I_1W_1	4.34	36200	44152	2.22
I_1W_2	5.29	37100	60691	2.64
I_1W_3	5.47	43600	57595	2.32
I_2W_0	3.25	33600	26587	1.79
I_2W_1	4.08	34200	41280	2.21
I_2W_2	5.02	35100	57770	2.65
I_2W_3	5.20	41600	54538	2.31
I_3W_0	2.98	31600	23592	1.75
I_3W_1	3.66	32200	35448	2.10
I_3W_2	4.29	33100	46265	2.40
I_3W_3	4.46	39600	42931	2.08

Note: The sale price of rice ₹ 1850 per quintal

Drum seeded rice crop

5.2. Chalakudy

5.2.1. Development of a suitable filtering techniques for reusing household waste water for irrigation

A sand filter is designed and developed for the treatment of laundry wastewater. A fiber tank of 60 litre capacity and dimensions of 0.6 m height and 0.3 m diameter filled with different materials such as charcoal, clay balls, fine sand and two layers of gravel are being used as filter. The proportions of different filtering media used is schematically shown in Figure 14. The top most portion of filter contains charcoals of thickness 5 cm followed by clay balls of 8 to 10 mm size and thickness 10 cm. A free space of 5 cm is provided at the top layer of the charcoal for ponding waste water. The next layer of filter media is fine sand of size 0.25 to 0.125 mm and thickness 10 cm. It is followed by fine gravel layer of size 2 to 4 mm and coarse gravel layer of size 4 to 8 mm. The thickness of both the gravel layers are 10 cm. A nylon mesh sheet is provided at the bottom of each layer for easiness in separating each layer of filter media for cleaning the filter after the continuous use for a period of two months. At the bottom of tank, an inverted plastic net basket is kept for free flow

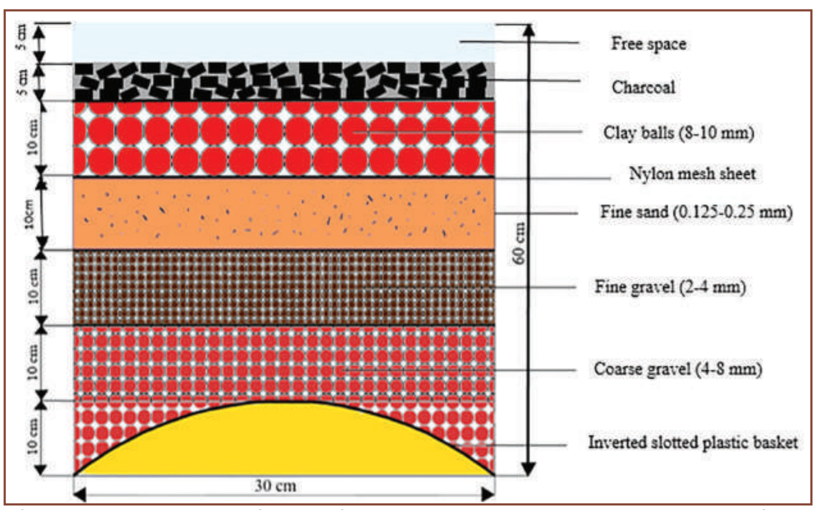


Figure 14. Cross sectional view of laundry waste water sand filter

of water from the upper layers. A tap is provided at the bottom of the fiber tank for collecting the filtered water. The cost of the filter is ₹ 650.

Field experiment for evaluating the treated water for growing vegetable crops is conducted during the year 2021. The treatments consist of irrigating crop using laundry waste water (LWW), T_1, treated laundry waste water (TLWW), T_2, normal irrigation water (T_3) and mixed water (T_4). The mixed water consists of laundry waste water and normal irrigation water mixed in a ratio of 1:1. The treatments are replicated 3 times and design of experiment is CRD. The test crop okra is grown in grow bag of size 40×38×24 cm filled with potting mixture of soil, compost and coir pith in a ratio of 1:1:1/2. The crop seedling is raised in nursery and transplanted to the grow bags after 2 weeks. The grow bags are kept in rain shelter in the entire cropping period. The treatments are imposed after giving one irrigation with normal irrigation water. The quality parameters of different irrigation waters used is shown in Table 32. Analytical results showed that pH of water used for irrigation ranges from 6.08-8.90. The pH of laundry waste water (T_1) is higher than the permissible limit. The EC values of water in all treatments ranges from 0.26-1.27 indicating that the values are within the permissible limit. Significant differences in values of SAR and RSC are observed for all treatments. SAR and RSC values of laundry waste water (T_1) and mixed water (T_4) are higher than the permissible limit. Presence of heavy metals in all treatments is found to be negligible and within the permissible limit.

Table 32. Characteristics of different type of irrigation water used for irrigating crop

S. N.	Parameter	T_1 – Laundry waste water	T_2 – Treated laundry waste water	T_3 – Normal irrigation water	T_4 – Mixed water (1:1)	CD (5%)	Safe limit value for irrigation
1	pH	8.90^a	7.37^b	6.08^c	8.37^a	0.709	6.50-8.50*
2	EC (dS m^{-1})	1.27^a	0.87^b	0.26^c	0.68^b	0.243	1.50*
3	CO_3^{2-} (meq L^{-1})	0.00	0.00	0.00	0.00	NS	-
4	HCO_3^- (meq L^{-1})	4.20^a	2.43^b	0.75^c	1.85^b	0.616	-
5	Na^+ (meq L^{-1})	11.40^a	5.03^b	0.55^c	4.21^b	2.436	-
6	K^+ (meq L^{-1})	9.90^a	6.67^b	5.53^b	7.33^b	2.165	-
7	Ca^{2+} (meq L^{-1})	4.87^b	27.93^a	3.24^b	2.00^b	3.708	-
8	Mg^{2+} (meq L^{-1})	1.30^b	4.60^a	0.99^b	1.85^b	2.638	-
9	B (meq L^{-1})	0.28^a	0.17^c	0.23^b	0.05^d	0.030	<1*
10	SAR (meq L^{-1})	27.93^a	5.30^c	1.58^d	11.83^b	1.96	10.00*
11	RSC (meq L^{-1})	3.83^a	0.67^c	0.51^c	1.57^b	0.79	1.25*
12	Ni (meq L^{-1})	BDL$^\#$	BDL	0.00088	0.00153	-	0.20**
13	Cd (meq L^{-1})	BDL	BDL	BDL	BDL	-	-
14	Cr (meq L^{-1})	0.003	0.001	0.001	0.001	0.00	0.10**
15	Pb (meq L^{-1})	BDL	BDL	BDL	BDL	-	5.00**

Note: *Bureau of Indian standards (1986); **FAO (1985); BDL, below detectable level

Result of laboratory analysis of N, P, K and presence of heavy metals in edible plant part of the crop is depicted in Table 33. Significant difference in N and K content is found out with the highest value for laundry water irrigated crop followed by mixed water, treated laundry water and normal irrigation water irrigated crop respectively. No significant difference in P content is recorded in all treatments.

Results of concentration of heavy metals in plant show that only Cr is present in plant sample. Concentration of Cr in treated waste water irrigated crop is 3.4 mg kg^{-1} which is negligible compared to the safe limit value of 20 mg kg^{-1}. From the results, it is concluded that presence of nutrients and heavy metals content in plant irrigated with treated waste water is in safe limit.

Table 33. Effect of different types of irrigation water on chemical composition of plant

Parameter	T_1-Laundry waste water	T_2-Treated laundry waste water	T_3-Normal irrigation water	T_4-Mixed water (1:1)	CD (5%)	Safe limit plant
N (%)	1.363^{a}	1.097^{b}	0.930^{c}	1.330^{a}	0.08	-
P (%)	0.526	0.475	0.384	0.525	NS	-
K (%)	2.094^{a}	1.153^{c}	0.91^{d}	1.652^{b}	0.24	-
Ni (mg kg^{-1})	BDL	BDL	BDL	BDL	-	1.50*
Cd (mg kg^{-1})	BDL	BDL	BDL	BDL	-	-
Cr (mg kg^{-1})	4.60^{a}	3.40^{b}	0.80^{d}	2.30^{c}	0.83	20.00*
Pb (mg kg^{-1})	BDL	BDL	BDL	BDL	-	2.50*

Note: *Indian Standards (Awasthi 2000), BDL# Below detectable level

Okra crop grown with treated laundry wastewater irrigation

5.3. Chiplima

5.3.1. Optimization of height of raised beds in raised – sunken bed system in lowlands of Hirakud command area (*rabi* season)

Raised-sunken bed system has been useful for crop diversification in lowlands. Previous experiments have shown that it is feasible in growing vegetables during *rabi* season through land modification which entails growing both paddy and non-paddy crops round the year with surface irrigation. It is required to standardize width and elevation difference in sunken-raised beds in relation to soil physical properties, crop characteristics (cultivated on the raised bed) and water availability. Accordingly, the experiment is being conducted with the objectives; i) to determine the optimum elevation difference of raised and sunken beds; and, ii) to determine the optimum crop combination in the raised bed based on economics and water requirement. In this system, twelve treatments with three irrigation schedules (Elevation difference: H_1- 30 cm, H_2- 45 cm and H_3- 60 cm and four cropping systems (C_1: Rice + Okra, C_2: Rice + Maize, C_3: Rice + Tomato and C_4: Rice + Cowpea were evaluated from *rabi* seasons 2018-2020 in a split plot design.

Results revealed that highest rice equivalent yield of 6.69 t ha^{-1} was obtained with elevation difference of 60 cm (H_3) which was at par with 45 cm (H_2) with yield of 6.57 t ha^{-1} and significantly higher than 30 cm (H_1) in raised-sunken bed system (Table 34). Higher rice equivalent yield of 7.02 t ha^{-1} was obtained with Rice + Tomato (C_3) crop combination which was at par with Rice + Okra (C_1) crop combination (6.68 t ha^{-1}) and was significantly more as compared to other crop combinations. Both net return (₹ 67744.21 ha^{-1}) and B-C ratio (2.36) were higher under elevation difference of 60 cm (H_3). With respect to crop combination, Rice + Tomato intercropping system gave highest net return of ₹ 72870 ha^{-1} and B-C ratio of 2.46, respectively.

Table 34. Effect of elevation difference and crop combination on yield and economic return (pooled mean of three years)

Treatment	Rice equivalent yield (t ha^{-1})	Net return (₹ ha^{-1})	B-C ratio
Main plot (Elevation Difference)			
H_1: 30 cm	6.11	56973	2.14
H_2: 45 cm	6.57	64894	2.30
H_3: 60 cm	6.69	67744	2.36
CD (p=0.05)	0.42	-	0.15
Sub-plot (Crop combination)			
C_1: Rice + Okra	6.68	63880	2.34
C_2: Rice + Maize	5.74	50444	2.01
C_3: Rice + Tomato	7.02	72870	2.46
C_4: Rice + Cowpea	6.10	62620	2.25
CD (p=0.05)	0.39	-	0.05


Raised and sunken bed farming system at Chiplima

5.4. Rahuri

5.4.1. Estimation of water requirement and development of crop coefficients of fodder maize through lysimetric technique

A study was undertaken to develop crop coefficients of fodder maize and sunflower crops for Rahuri region. Locally available crop evapotranspiration data derived from lysimetric experiments and corresponding estimates of reference crop evapotranspiration were used to develop crop coefficient equations. The experiment was carried out in field of size 78 m × 45 m. Two lysimeters were used with dimension of 1.3 m × 1.3 m × 0.9 m per lysimeter. Moisture depletion from lysimeter was monitored daily and irrigation water applied after considering moisture depletion at 100 mm cumulative pan evaporation (CPE). Penman Monteith method was used to estimate reference crop evapotranspiration (ET_r). Crop coefficient (K_c) was estimated as the ratio of crop evapotranspiration (ET_c) to ET_r based on the following equation:

$$Kc = \frac{ETc}{ETr}$$

Weekly values of crop coefficients were computed for both the crops as the ratio of weekly ET_c and ET_r. Crop evapotranspiration values of two lysimeters were averaged to compute the crop coefficient values.

Fodder maize

Polynomial equations of different orders with K_c as a function of the ratio of days since sowing/planting to total crop growth period were fitted for the year 2020-21 for fodder maize to estimate K_c of fodder maize and sunflower. Polynomial equations used for developing the functions for crop coefficients are shown below.

Polynomial K_c equations

$$K_t = a_o\left(\frac{t}{T}\right)^0 + a_1\left(\frac{t}{T}\right)^1 + a_2\left(\frac{t}{T}\right)^2$$

$$K_t = a_o\left(\frac{t}{T}\right)^0 + a_1\left(\frac{t}{T}\right)^1 + a_2\left(\frac{t}{T}\right)^2 + a_3\left(\frac{t}{T}\right)^3$$

$$K_t = a_o\left(\frac{t}{T}\right)^0 + a_1\left(\frac{t}{T}\right)^1 + a_2\left(\frac{t}{T}\right)^2 + a_3\left(\frac{t}{T}\right)^3 + a_4\left(\frac{t}{T}\right)^4$$

$$K_t = a_o\left(\frac{t}{T}\right)^0 + a_1\left(\frac{t}{T}\right)^1 + a_2\left(\frac{t}{T}\right)^2 + a_3\left(\frac{t}{T}\right)^3 + a_4\left(\frac{t}{T}\right)^4 + a_5\left(\frac{t}{T}\right)^5$$

where, Kc_t is crop coefficient of t^{th} day, a_0, a_1, a_2, a_3, a_4 and a_5 are constants of equations, t is the day considered and T is the total period of crop growth from sowing to harvesting in days.

Results revealed that the fodder maize yield from field and lysimeter was 50.68 and 58.40 t ha^{-1}, respectively (Table 35). Data of evapotranspiration (ET) and evaporation (EP) of the crop derived from daily monitoring of moisture depletion were 155.45 and 359.60 mm, respectively. Irrigation water was applied after moisture depletion at 100 mm CPE. Average ET/ EP was 0.43 (Table 36). Maximum ET/EP was 0.47 mm at tasseling stage, whereas lowest ET/ EP was 0.39 at silking stage of the crop.

Table 35. Yield and WUE of fodder maize and other climatological parameters of fodder maize (2020-21).

S.No.	Particulars	Values	
1.	Crop and Variety	Fodder maize var. *African Tall*	
2.	Season	*Kharif*	
3.	Duration	80 days	
4.	Total ET	155.45 mm	
5.	Total EP	359.60 mm	
6.	Average ET	1.94 mm	
7.	Average EP	4.50 mm	
8.	ET/EP ratio	0.43	
	Yield and WUE	**Lysimeter**	**Field**
9.	Yield (t ha^{-1})	58.40	50.68
10.	WUE (t ha cm^{-1})	3.76	1.41
11.	No. of irrigations applied	2	
12.	Total depth of irrigation water applied	200 mm	
13.	Total rainfall received during the crop growth period	559.8 mm	

Table 36. Ratio of ET and EP at various growth stage of fodder maize (2020-21)

S. No.	Physiological growth stage	Duration days (No.)	ET (mm)	EP (mm)	Average ET	Average EP	ET/EP ratio
1	Germination	25	53.24	118.00	2.13	4.72	0.45
2	Tasseling	20	41.22	86.30	2.06	4.32	0.47
3	Silking	35	60.98	155.30	1.74	4.44	0.39
	Total	**80**	**155.45**	**359.60**	**1.94**	**4.50**	**0.43**

Among the polynomial equations, fourth polynomial equation was found suitable for estimation of K_c of fodder maize during the year 2020-21. The K_c equation and curve from the polynomial equations are presented in Figure 15.

$$Kc_t = 13.741\left(\frac{t}{T}\right)^4\left(\frac{t}{T}\right)^4 -31.844\left(\frac{t}{T}\right)^3\left(\frac{t}{T}\right)^3 +21.399\left(\frac{t}{T}\right)^2\left(\frac{t}{T}\right)^2 -3.2678\left(\frac{t}{T}\right)^4\left(\frac{t}{T}\right)^4 + 0.4966; \qquad R^2=0.9879$$

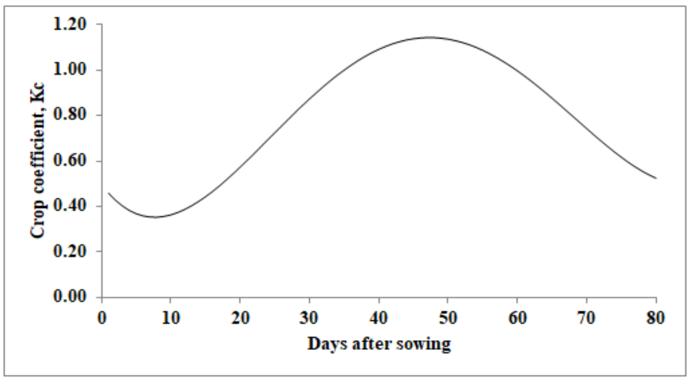


Figure 15. K_c curve for fodder maize for the year 2020-21

Sunflower

Field experiment to determine crop coefficient of sunflower crop was conducted during year 2018-19 and 2019-20. Lysimetric study for sunflower crop was conducted during year 2018-19 and 2019-20. Results revealed that the sunflower yield from field and lysimeter were 1.65 and 1.91 t ha^{-1}, respectively. Moisture depletion was monitored daily and data in respect of ET and EP of crop were 166.4 and 431.2 mm, respectively. Irrigation water was applied after considering moisture depletion at 100 mm CPE. The average ET/EP was 0.38. Maximum ET/EP ratio was 0.60 mm at flowering stage, whereas lowest ratio was 0.17 at seedling stage of sunflower crop. Crop coefficient curves were developed for ET_r estimated by Penman-Monteith method. Polynomial equations of different orders with crop coefficient as a function of the ratio of days since sowing/planting to total crop growth period were fitted for years 2018-2019 and 2019-2020 to estimate crop coefficient of sunflower. The fourth and third order polynomial equations were found suitable for estimation of K_c as given below:

Year: 2018-19

$$Kc_t = 5.780\left(\frac{t}{T}\right)^4 -17.16\left(\frac{t}{T}\right)^3 +12.27\left(\frac{t}{T}\right)^2 -0.866\left(\frac{t}{T}\right) + 0.334; \qquad R^2=0.956$$

Year: 2019-20

$$Kc_t = -6.574\left(\frac{t}{T}\right)^3 +6.1126\left(\frac{t}{T}\right)^2 +0.6579\left(\frac{t}{T}\right) + 0.3671; \qquad R^2=0.8194$$

These K_c curves derived from the fourth and third order polynomial equations are presented in Figure 16 and Figure 17 for the years 2018-19 and 2019-20, respectively.

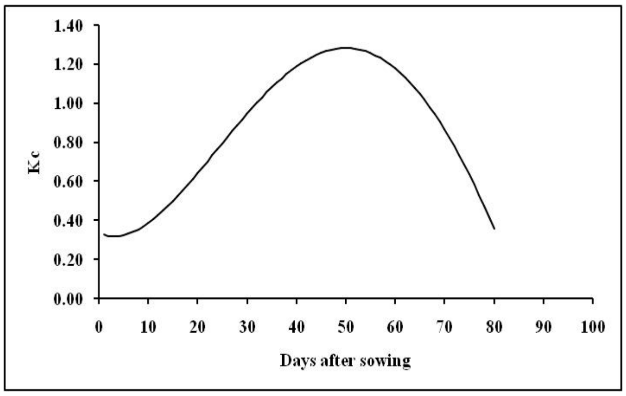


Figure 16. K_c curve for sunflower (2018-19)

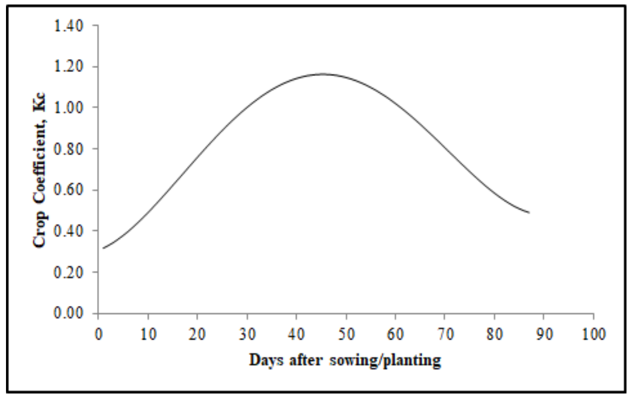


Figure 17. K_c curve for sunflower (2019-20)

5.5. Bathinda

5.5.1. Climate change adaptation of wheat in south-western region of Punjab through management practices

A study was investigated to simulate DSSAT for south-western Punjab, to study the impact of climate change on water requirement and crop yield of wheat and to formulate adaption strategies in wheat under different climate change scenarios. The grain yield of wheat was significantly higher in timely sown crop (15th November) followed by late (30th November) and lowest in very late (15th December) sown wheat. But crop sown on 15th and 30th November did not differ statistically. The quantum of decrease noticed in D_2 and D_3 than D_1 was 2.75% and 9.63%, respectively. Among irrigation regimes, significant increase in all yield attributes and grain yield was noticed in IW:CPE 1.0 (I_3) and lowest in IW:CPE 0.6 (I_1). Highest water use efficiency was found in 15th December sown crop. The lowest water use efficiency was noticed in 15th November sown crop. Highest water use efficiency (14.76 kg ha-mm^{-1}) was noticed under I_1 followed by I_2 (12.83 kg ha-mm^{-1}) and minimum in I_3 (11.66 kg ha-mm^{-1}) treatment. The highest WUE was computed under N_3 treatment. While values of N_3 (13.63 kg ha-mm^{-1}) treatment were very in close proximity to N_2 (13.39 kg ha-mm^{-1}). Lowest WUE was worked out under N_1 (12.25 kg ha-mm^{-1}) treatment.

Simulated phenology as well as yield also showed similar trend in which higher value of simulated yield was found with the crop sown on November 15. Model also simulated higher grain yield under I_3 irrigation treatment and N_3 nitrogen treatment. Model showed underestimation among the phenology and yield attributes except harvest index, in which minimum deviation in simulated value over observed was noted for physiological maturity and grain yield. Among the sowing time, irrigation and nitrogen treatments, having higher value of R^2, and lower value of RMSE indicated better performance of model. Results revealed that the applied CERES-Wheat model produced better estimates for grain yield, emergence, and physiological maturity than other attributes.

5.6. Pusa

5.6.1. Effect of moisture regimes and rice based cropping system on system productivity and soil health

A field experiment was conducted to study the effect of moisture regimes and cropping system on system productivity, soil health, water productivity and profitability of rice based cropping system from year 2018 to 2021. The treatments consisted of five cropping sequences (C_1: Rice-Wheat-fallow, C_2: Rice-Wheat-Greengram, C_3: Rice-Maize-Dhaincha, C_4: Rice-Maize+Potato-Dhaincha, and C_5: Rice-Maize+Pea–Dhaincha) and three moisture regimes (I_1: IW/CPE 0.6, I_2: IW/CPE 0.8, and I_3: IW/CPE 1.0). Residue of previous crop was incorporated for the subsequent crop. Rice was sown by direct seeding, wheat by zero tillage, maize in raised bed, dhaincha was used as green manuring crop.

Experimental results showed significantly higher rice equivalent yield of 27.58 t ha^{-1} under Rice-Maize+Potato-Dhaincha over the other cropping systems (Table 37). Among the moisture regimes, application of surface irrigation at IW/CPE 1.0 recorded highest rice equivalent yield of 17.22 t ha^{-1}. Thus, irrigation at IW/CPE 1.0 and Rice-Maize+Potato–Dhaincha system showcased highest production efficiencies of 53.81 and 84.05 kg ha^{-1} day^{-1}, respectively. Rice-Maize+Potato-Dhaincha system also resulted in maximum water use efficiency, water productivity and net profit of 202.46 kg ha-cm^{-1}, ₹ 23.05 ha-cm^{-1} and ₹ 319734 ha^{-1}, respectively among the cropping systems (Table 37). However, Rice-Maize+Pea-Dhaincha system recorded improved soil health in terms of significantly higher organic carbon (0.5%) and available zinc (0.85 ppm) after crop harvest (Table 38), including significantly higher benefit-cost ratio of 2.23 over the other cropping systems. On the other hand, irrigation at IW/CPE 1.0 also resulted in highest water use efficiency, water productivity and net profit of 126.18 kg ha cm^{-1}, ₹ 14.12 ha^{-1} and ₹ 196457 ha^{-1} over other moisture regimes.

Thus, recommendation was given for farmers that they may choose Rice-Maize+Potato-Dhaincha system and irrigation at IW/CPE 1.0 in order to get maximum system productivity and Rice-Maize+Pea-Dhaincha system as a viable alternative for improving soil health and getting higher benefit-cost ratio.

Table 37. Performance of rice based cropping systems (Pooled data of three years)

Treatment	Rice equivalent yield (t ha^{-1})	Production efficiency (kg ha^{-1} day^{-1})	Land use efficiency (%)	Water use efficiency (kg ha-cm^{-1})	Water productivity (₹ ha-cm^{-1})	Net return (₹ ha^{-1})	B:C ratio
Cropping System							
C_1: Rice-Wheat-Fallow	7.84	30.38	70.14	70.69	5.79	64551	0.86
C_2: Rice-Wheat-Greengram	12.13	36.36	91.23	93.69	8.75	114206	1.11
C_3: Rice-Maize-Dhaincha	14.42	43.92	89.86	107.62	11.86	163217	1.72
C_4: Rice-Maize+Potato-Dhaincha	27.58	84.05	89.86	202.46	23.05	319734	1.84
C_5: Rice-Maize+Pea-Dhaincha	19.51	59.43	89.86	143.45	17.48	240717	2.23
CD(p=0.05)	1.03	3.15	-	7.60	1.36	18144	0.15
Moisture Regime							
I_1: IW/CPE 0.6	15.33	47.83	86.19	120.28	12.67	163377	1.47
I_2: IW/CPE 0.8	16.28	50.85	86.19	123.15	13.35	180621	1.63
I_3: IW/CPE 1.0	17.22	53.81	86.19	126.18	14.12	196457	1.76
CD(p=0.05)	0.52	1.66	-	3.82	0.69	9481	0.10

Note: Depth of irrigation water applied per irrigation = 6 cm

Table 38. Pre and post values of soil health under different treatments

Treatment	pH	EC (dS m^{-1})	Organic Carbon (%)	Bulk density (g cm^{-3})	Available Zn (ppm)
Cropping System					
C_1: Rice-Wheat-Fallow	8.337	0.393	0.392	1.420	0.796
C_2: Rice-Wheat-Greengram	8.309	0.386	0.447	1.412	0.803

C_3: Rice-Maize-Dhaincha	8.305	0.366	0.478	1.370	0.817
C_4: Rice-Maize+Potato-Dhaincha	8.324	0.371	0.472	1.375	0.810
C_5: Rice-Maize+Pea-Dhaincha	8.282	0.366	0.498	1.359	0.845
CD(p=0.05)	NS	NS	0.017	0.025	0.018
Moisture Regime					
I_1: IW/CPE 0.6	8.331	0.381	0.451	1.391	0.818
I_2: IW/CPE 0.8	8.322	0.378	0.460	1.390	0.816
I_3: IW/CPE 1.0	8.318	0.371	0.462	1.380	0.809
CD (p=0.05)	NS	NS	NS	NS	NS
Initial value	8.374	0.410	0.396	1.416	0.765

Note: NS, non-significant

Rice based cropping system

Chapter 6

Conjunctive Use and Multiple Use of Water

6.1. Bathinda

6.1.1. Evaluating water productivity of fodder based cropping sequences for different irrigation water qualities

Field trial was conducted from 2015-16 to 2019-20 to study the effect of water quality on fodder yield and water productivity in fodder-fodder crop sequence and compare the effects of different irrigation water qualities on soil properties. Fodder crops berseem and ryegrass were grown during *rabi* season and sorghum was grown in *kharif* season. Six treatments on quality of water were canal water (CW) alone, saline sodic tubewell water (TW) alone, CW-TW (alternately), 1CW-2TW, 2TW-1CW and CW-subsequent irrigation with TW. Tubewell water has residual sodium carbonate (RSC) of 1.36 meq L^{-1} and electrical conductivity (EC) of 3.8-4.2 dS m^{-1}.

Effect of varying qualities of irrigation water on berseem crop (var. BL-10) with respect to green fodder yield (GFY), dry fodder yield (DFY) and water use efficiency (WUE) are given in Table 39. GFY was statistically higher with the use of CW (112.5 t ha^{-1}), which was at par with CW-TW (85.4 t ha^{-1}). In contrary to these, WUE was highest (219.2 kg ha-mm^{-1}) with the use of CW alone, followed by alternate use of CW-TW (209.9 kg ha-mm^{-1}) and lowest (159.3 kg ha-mm^{-1}) where all irrigations were given with TW alone. Irrigations with CW-TW showed 21.1% higher GFY over irrigation with TW alone. DFY behaved similarly to GFY. There was 22.5% reduction in DFY where all the irrigations were given with poor quality TW against CW-TW. WUE and benefit-cost ratio (B:C) was 21.2% and 18.4% higher with use of CW over TW. With CW-TW, WUE and B:C ratio was 18.4% and 18.8%, respectively over sole application of tubewell water. Quality analysis of berseem fodder revealed that highest percentages of crude protein (18.4%) was found in CW followed by CW-TW treatment.

Ryegrass (var. *Punjab Ryegrass* 1) grown with varying qualities of irrigation water showed that GFY was statistically higher with CW alone (104.3 t ha^{-1}), but at par with alternate use of CW-TW (100.1 t ha^{-1}) and 1CW-2TW (98.1 t ha^{-1}) (Table 39). Irrigations with TW alone showed 18.9% and 23.8% reduction in GFY than CW and CW-TW, respectively. DFY also got reduced by 20.6% and 16.7% with CW irrigation and CW-TW, respectively. WUE was highest under CW irrigation (190.3 kg ha-mm^{-1}) followed by CW-TW (185.9 kg ha-mm^{-1}) and minimum (157.0 kg ha-mm^{-1}) under TW alone. WUE and B:C was 37.6 and 31.2% higher with CW irrigation over TW irrigation.

Succeeding sorghum crop (var. PSC-4) showed significant increase in GFY by 25.06% and 29.1% with CW-TW compared to use of TW alone for sorghum with preceding berseem and ryegrass, respectively. DFY was higher with CW irrigation followed by CW-TW and lowest with TW alone. Maximum WUE (151.5 kg ha-mm^{-1}) was recorded under CW irrigation (Table 40). The effect of preceding crop (berseem and ryegrass) and various qualities of water on GFY of sorghum is also given in graphical form in Figure 18.

It is to be noted that pH and electrical conductivity (EC), sodium adsorption ratio (SAR) values of soil increased with use of saline sodic TW irrigation. Organic carbon content of soil decreased under TW irrigation.

Table 39. Effect of water quality on berseem and ryegrass during *rabi* season (pooled result from 2015-16 to 2019-20)

Treatment	Green fodder yield (t ha^{-1})		Dry fodder yield (t ha^{-1})		WUE (kg ha-mm^{-1})		B : C ratio	
	Berseem	Ryegrass	Berseem	Ryegrass	Berseem	Ryegrass	Berseem	Ryegrass
CW	112.5	104.3	0.237	0.217	219.2	190.3	1.85	2.05
TW	85.4	84.2	0.174	0.180	159.3	157.0	1.41	1.65
CW-TW	108.2	100.1	0.229	0.210	209.9	185.9	1.78	1.96
1CW-2TW	101.7	98.1	0.215	0.207	188.7	179.5	1.67	1.93
2TW-1CW	95.5	90.7	0.192	0.188	181.5	165.2	1.57	1.78
1CW-TW(s)	96.7	91.7	0.193	0.189	179.5	165.3	1.59	1.80
CD (%)	5.3	6.24	0.009	0.007	-	-	-	-

Note : Mean irrigation water applied for berseem and ryegrass (2015-16 to 2019-20) = 36.0 cm, Rainfall=16.09 cm; CW, Canal water; TW, Tubewell water; 1CW-TW(s), One irrigation with canal water and subsequent irrigation with tubewell water

Table 40. Effect of water quality on sorghum succeeding berseem and ryegrass (pooled result from 2015-16 to 2019-20)

Treatment	Green fodder yield (t ha^{-1})	Dry fodder yield (t ha^{-1})	WUE (kg ha-mm^{-1})	B-C ratio
Berseem–Sorghum				
CW	121.7	0.341	159.3	2.90
TW	91.3	0.195	120.7	2.18
CW-TW	115.0	0.320	149.4	2.74
1CW-2TW	108.2	0.304	137.5	2.58
2TW-1CW	96.5	0.230	126.2	2.30
1CW-TW(s)	95.3	0.219	119.2	2.27
Ryegrass–Sorghum				
CW	118.8	0.327	151.6	2.83
TW	86.6	0.187	113.3	2.07
CW-TW	113.9	0.315	144.7	2.72
1CW-2TW	107.2	0.298	138.2	2.56
2TW-1CW	94.5	0.216	123.7	2.25
1CW-TW(s)	94.4	0.210	122.4	2.25
CD (%)	6.82	0.021	-	-

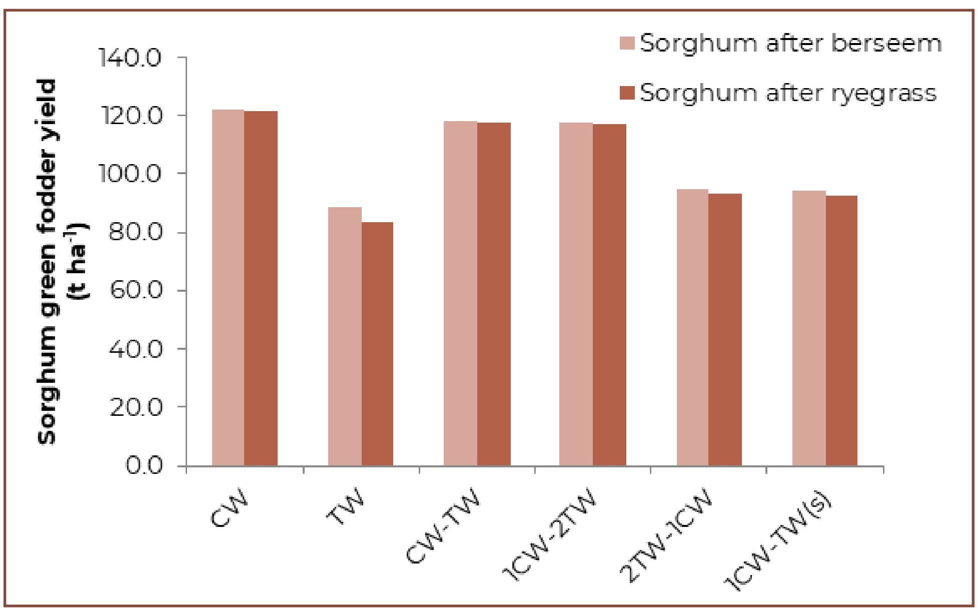


Figure 18. Green fodder yield of sorghum crop with preceding berseem and ryegrass crops under conjunctive use of water

Berseem and ryegrass crops under trial during *rabi* season

6.2. Chalakudy

6.2.1. Conjunctive water use planning for enhancing water availability in the command area of Chalakudy River Diversion Scheme

The Chalakudy River Diversion Scheme (CRDS) is the largest among the four major diversion schemes under the water resource department of Kerala. It diverts the water in Chalakudy river by a weir of height 3.96 m to both right bank main canal (48.2 km) and left bank main canal (33.2 km). Left bank canal (LBC) branching off from Thumboormuzhi, covers its command area with 14 branches and their distributaries. Right bank canal (RBC) also branching off from Thumboormuzhi distributes water to the command area through 24 branch canals and their distributaries. Extraction of cultivable command area from land use map was done using ArcGIS software. The area commanded by each branch canal was extracted using buffer wizard tool. From the land use of whole command area of CRDS, land use of each branch was clipped out using buffer area as a clipping feature. FAO CROPWAT 8.0 model was used for calculation of crop water requirement of branch canals. The effective rainfall was estimated using standard procedure. The calculated net irrigation requirement for each branch canal of LBC and RBC are given in Table 41 and Table 42, respectively. The annual net irrigation requirement of LBC and RBC estimated is 59.81 Mm^3.

The existing ponds in the entire left bank canal and right bank canal which are influenced by the canal were located and the capacities of the existing ponds were worked out. The estimated storage volume of existing ponds along the LBC is 394941 m^3 and RBC is 366795 m^3. The total storage capacity of the ponds is 7.61 Mm^3. Analysis was also done for identifying new sites for water harvesting strictures. The thematic map considered for locating new water harvesting structures are base maps of CDRS command area, slope, soil and land use maps. Weighted overlay analysis with GIS software was used to find suitable places for water harvesting based on three criteria: soil type, slope, and land use. Each specified criteria is given a ranking and weightage scale in order to discover relevant locations. Twenty eight new locations for water harvesting structures are located and shown in the Figure 19.

Table 41. Annual net irrigation requirement of branch canals of Left Bank Canal (LBC)

Sl. No.	Branch	Net irrigated crop area (ha)	Annual net irrigation requirement (Mm^3)
1	Adichily	205.31	1.14
2	Boothamkutty	133.25	0.73
3	Meloor	418.73	2.21
4	Thanguchira	259.58	1.42
5	Kalady	1565.14	7.54
6	Edakunny	173.1	0.95
7	KV main	1079.85	6.22

8	Kizhakkummury	155.85	0.88
9	Marangadan	153.53	0.85
10	Karukutty Karayamparambu	533.9	2.94
11	Chirangara	103.62	0.58
12	Mambra	255.25	1.31
13	Peechanikkadu	87.81	0.52
14	Parakadavu	243.32	1.27
	Total	**5368.24**	**28.56**

Table 42. Annual net irrigation requirement of branch canals of Right Bank Canal (RBC)

Sl. No.	Branch	Net irrigated crop area (ha)	Annual net irrigation requirement (Mm^3)
1	Echippara	145.69	0.81
2	Kuttikad	247.79	1.39
3	Kundukuzhipadam	116.27	0.63
4	Vellikulamthodu	134.00	0.69
5	Mattathur	630.29	3.39
6	Mettipadam	91.99	0.51
7	Areswaram	51.64	0.29
8	Kalikkakunnu	162.5	0.87
9	Thessery	158.08	0.86
10	Chalakudy-Pariyaram	317.16	1.80
11	Potta	137.84	0.80
12	Blachira	501.66	2.89
13	Kodakara	597.22	3.23
14	Perambra	338.75	1.96
15	Muriyad	98.43	0.55
16	Aloor	9.04	0.05
17	Kallettumkara	391.11	2.23
18	Thazhekkad	193.73	1.04
19	Kaduppassery	249.61	1.44
20	Parayanthodu	347.72	2.02
21	Annallur	118.06	0.67
22	Kottanallur	335.51	1.91
23	Annamannada	115.08	0.66
24	Alathur	106.93	0.56
	Total	**5596.1**	**31.25**

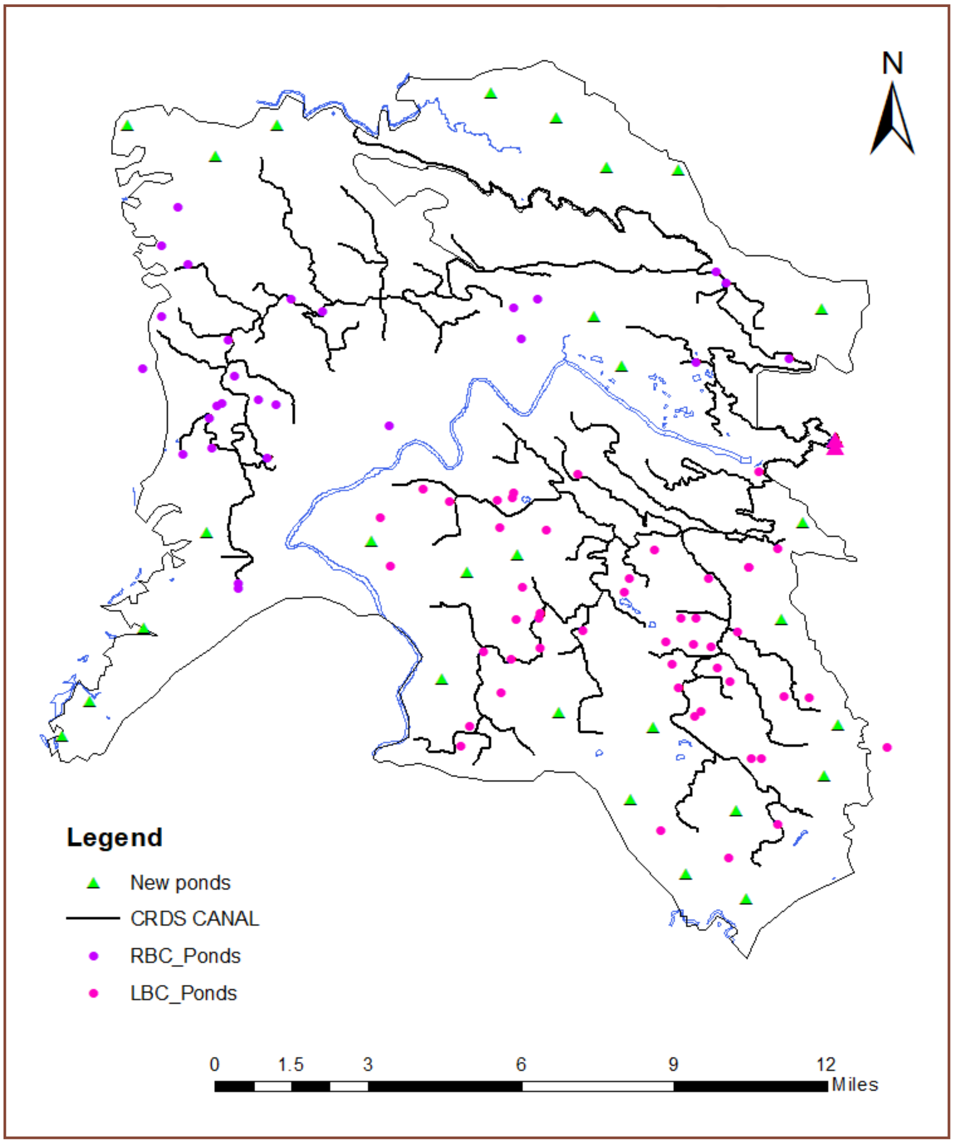


Figure 19. Location of new water harvesting structures in Chalakudy River Diversion Scheme

6.3. Ayodhya

6.3.1. Multiple use of water through rice based integrated farming system at head and middle of the Awanpur distributory

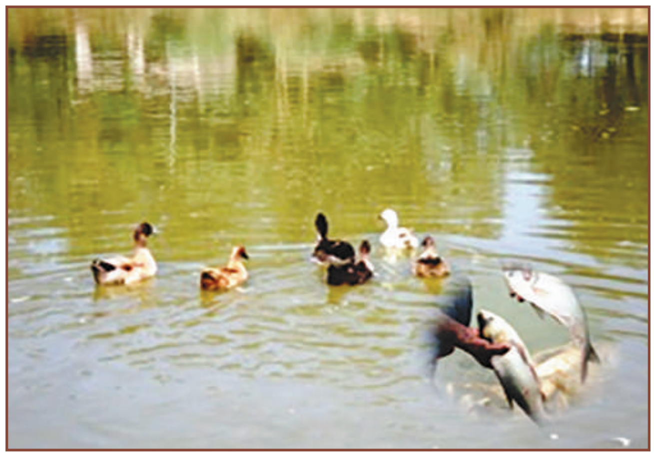
Multiple use of water was studied in Madhupur and Panapur of Awanpur distributory. Objectives of the study were i) to develop existing village ponds for water harvesting, ii) efficient use of harvested water for pisciculture and duckery, iii) efficient use of harvested water, canal water and tubewell water for different cropping systems in the command area, and iv) study the economics of the integrated farming system. Integrated farming system consisted of four cropping systems and Pisciculture+Duckery. Cropping systems such as Rice-Chickpea+Mustard (4:1), Rice-Pea+Mustard (2:2), Rice-Wheat+Mustard (9:1) and Rice-Lentil+Mustard (4:1) were put under trial. Rice var. NDR 359, Wheat var. PBW-154, Mustard var. NDR 8501, Chickpea var. Awrodhi, Pea var. Rachna and Lentil var. IPL 316 were chosen for the study. Two ponds owned by Sri Ram Prakash, Birauli village at head end and Sri Surendra Verma, Naktipur village at middle end of Awanpur distributory were selected for the study. Fish fingerlings were dropped by both the farmers in the month of August 2020 in ponds of size 0.15-0.20 ha with water depth 1-3 m. Pond water was also used for irrigating *rabi* crops. Crop trials were conducted over an area of 0.80-0.85 ha during *rabi* 2020-21. For *rabi* crop of wheat, three irrigations of 6 cm each were applied at CRI, late jointing and milking stages. Pulse crops like chickpea, pea and lentil were also sown during *rabi* season. Two irrigations of 5 cm depth each were applied at pre-flowering and pod formation stages of the pulse crops. Rice was transplanted in all the fields during *kharif* 2021 at both the locations.

Performance and economics of *rabi* and *kharif* crops in comparison to conventional rice-wheat+ mustard cropping system is shown in Table 43. Integrated farming system with pisciculture was found to be most productive and remunerative in comparison to conventional Rice-Wheat+Rai system with highest net return of ₹ 184619 per hectare per year with B-C ratio of 3.88. The net return was 92.65% higher than that obtained under conventional farming system i.e. ₹ 95832 per hectare per year with benefit-cost ratio of 2.47.

Table 43. Performance of conventional system and integrated farming system with multiple use of water

Cropping system	Plot area (ha)	Crop yield (q plot⁻¹)			Cost of cultivation (₹ ha⁻¹)	Gross return (₹ ha⁻¹)	Net return (₹ ha⁻¹)	B-C ratio
		Kharif	*Rabi*					
			Main	Intercrop				
Conventional system								
Rice-wheat+mustard	1.0	44.30	32.80	3.75	65000	160832	95832	2.47
Integrated farming system								
Rice-wheat+ mustard	0.2	9.30	10.95	1.2	14200	45569	31369	-
Rice-gram+ mustard	0.2	11.20	4.00	1.90	11700	49169	37469	-
Rice-lentil+ mustard	0.2	10.70	3.90	2.00	11700	46313	34613	-
Rice-pea+ mustard	0.2	10.40	2.05	3.75	11550	44593	33043	-
Pisciculture	0.2	Fish	505 kg	-	15000	63125	48125	-
Duckery	-	-	-	-	-	-	-	-
Total	**1.0**	**-**	**-**	**-**	**64150**	**248769**	**184619**	**3.88**

Note: Unit price of rice ₹ 1850.00 q^{-1}, Wheat ₹ 1950.00 q^{-1}, Gram ₹ 4400.00 q^{-1}, Mustard ₹ 4200.00 q^{-1}, Lentil ₹ 4300 q^{-1}, Pea ₹ 3500 q^{-1}, Fish ₹ 125 kg^{-1}



Integrated farming system in Awanpur distributory

Chapter 7

Operational Research Project (ORP)

7.1. Bathinda

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

Behman distributory of Bathinda branch was selected to evaluate irrigation system performance and to work out intervention for improvement of irrigation system and its management through improved and sustainable crop and water productivity. The Behman distributory has 31 outlets with discharge of 48.84 cusec, with total cultivable command area of about 6374.62 hectares covering Bathinda district. Under "On-Farm Development (OFD)" works in the command, considerable progress has been made for providing irrigation to a larger area, improving water availability to individual farmers, and to maximize the water use efficiency. Canal running days varied from 8 to 31 days in different months with the highest in May and July 2021, and lowest in October 2021. The total canal running days from November 2020 to October 2021 was 277 days. The contribution through total effective rainfall varied between 432.57 to 776.13 ha-cm at different outlets.

Wheat, barley, mustard/chickpea, vegetables, fruits, fodder crops and other crops were grown during *rabi* season, with crop water requirement at all the outlets varying from 7255.51 to 13078.39 ha-cm. During *rabi* 2020-21, total running days of canal water was 129 days on each outlet. The adequacy of water supply in relation to water demand was calculated to obtain relative water supply (RWS). RWS varied from 0.53 to 0.55 i.e. less than one in all the outlets (Table 44). This implied water supply by rainfall and canal was less than demand in all the five outlets. Thus, there is a need to replace a large part of the area under wheat with barley, chickpea and mustard, which require less water to match the water supply with water requirement during the season at both outlets. During *kharif* 2021, total of 484.30 mm rainfall was received. Cotton and rice were the main crops at all the outlets. Total running days of canal water was 148 days on each outlet. Contribution through total effective rainfall was 6936.92 to 12446.32 ha-cm. Crop water requirement was varied from 16204.40 to 27390.05 ha-cm. Average RWS was 0.68, which meant that demand was more than supply (Table 44). So, there is a need to either increase the supply of water or replacing high water requirement crops with low water requirement crops like cotton, clusterbean (guar), and pearlmillet (bajra).

Soil and water resource status showed that soils of the command area under study are loamy sand to sandy loam in texture. The canal water supply is inadequate. The groundwater is brackish in nature and is not suitable for direct use to raise field crops. The soils of the selected outlets are low in organic carbon, low to medium in available phosphorus, and medium to high in available potassium content.

Table 44. Relative water supply (RWS) during *rabi* 2020-21 and *kharif* 2021

Outlet No.	Canal water 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*
31580-R	4765.68	5467.61	597.59	9583.13	5363.27	15050.74	10047.44	23092.58	0.534	0.652
34775-L	3566.37	4091.65	432.57	6936.92	3998.95	11028.57	7255.51	16204.40	0.551	0.681
39980-R	3787.30	4345.12	475.89	7631.60	4263.19	11976.72	7986.92	16793.64	0.534	0.713
54709-L	4355.39	4996.88	546.00	8755.95	4901.40	13752.84	9143.50	22069.43	0.536	0.623
64900-R	6185.92	7097.02	776.13	12446.32	6962.05	19543.34	13078.39	27390.05	0.532	0.714

7.2. Almora

7.2.1. Micro water resource development at farmer's field and their multiple water utilization

Uttarakhand receives large amount of rainfall (670-2800 mm) and has several perennial rivers. Despite this, the hill region faces shortage of water supply for agriculture and other uses. The intervention was done to mitigate water shortage in the hills of Uttarakhand. Micro water resources development plan was initiated at farmers' field to meet irrigation and other multiple uses requirement of water to ensure high water productivity and sustain livelihood security of hill farmers.

The study area is 35 km away from Almora at an elevation of 1800-2250 m from mean sea level. In addition to the above area, additional farmers were selected from Hawalbagh block, village Challar Mussoli, Kasoon and Jur kafoon.

Micro-water resource development

A tank with capacity of 20-198 m^3 was constructed at farmers' field to store rainwater, runoff or spring water, irrigate vegetable crops and combat intermittent dry spells during *kharif* and provide supplementary irrigation to *rabi* crops. The harvested water from these tanks was delivered with gravity-fed drip or sprinkler irrigation system to high value crops. Existing drip system was modified as per the suitability of farmer's site. Three types of storage structures i.e. polyfilm, polycement tank as well as poly tank available in the market were installed at farmer's field and joined with drip irrigation system for small terraces to utilize water efficiently. The farmers were advised to schedule irrigation based on water requirement of vegetable crops and rest available surplus water were diverted towards irrigating *rabi* crops. The farmers were also advised to prioritize crops as per their economic importance and availability of water in the tank.

Multiple water utilization experiment has been established at 15 farmers' fields. Components of the multiple water use system were; water harvesting pond, fish farming, vermicomposting, temperate fruit plantation (kiwi fruit), vegetable cultivation, animal rearing, duckery/poultry, azolla cultivation, small moving polyhouse for vegetable production.

Kiwi: 35 plants were planted in six farmer's field during 2020-21 and five at Hawalbagh farm. In the year 2021, kiwi yielded 0.30 to 0.50 q ha^{-1} per tree. Farmers are convinced and demand of kiwi seedlings has risen. Mid hill farmers are establishing kiwi orchards with kiwi variety Alison.

Vermicompost: Vermicompost units were developed with total capacity of 124.18 m^3. In 2021, 10 m^3 was added to the unit. It is estimated that 124.18 m^3 vermicompost unit can yield around 1.86 lakh kg in two cycles with a total earning of ₹ 5.58 lakh in two cycles.

Cattle: Average milk yield reported by farmers is 3.0 to 9.0 kg per cattle with one family rearing six cattle. Dung production is around 20 to 35 kg from one cattle per day. Estimated income from six cows is about ₹ 3.76 lakh from milk and cowdung.

Fish: Fingerlings in the ratio of 30:40:30 of silver carp, grass carp and common carp, respectively were introduced in tanks in the year 2016.

Crops: Land near the tank has been converted into terraces to grown pulses and mostly vegetables.

Poultry/Duckery: Poultry shed has been constructed by farmers with the help of AICRP on IWM scientists. In year 2018, chicks were distributed to the farmers. In year 2020 to 2021, farmers' gross income by selling eggs was ₹ 16800-798000 and ₹ 3500-140000 by selling birds.

Azolla- Azolla cultivation is being carried out by five farmers in an area of 70 m^2, especially for feeding cattle and poultry. Around 2240 kg green azolla was produced in eight months. The state agriculture department also purchased around 3 quintals of azolla from the farmers.

Vegetable cultivation in polyhouse: Two polyhouses of 21 m^2 and one polyhouse of 70 m^2 were constructed at farmers' fields. Bean, capsicum and tomato cultivated inside as well outside the polyhouse showed that tomato yield was 48% higher and bean yield was 30% higher than yields outside polyhouse.

7.3. Ayodhya

7.3.1. Assessment of equity distribution of water over space and time in Awanpur Distributory

Water balance of Awanpur distributory is being studied to address demand and supply of water in the command area during different cropping seasons, to suggest measures for utilizing canal water effectively, and to give alternate water distribution schedules on the distributory. Total length of Awanpur distributory is 11.2 km. The distributory has three minors and one sub minor with total 51 outlets, discharge capacity of 20.0 cusec and total command area of 1207 ha.

During 2020-21, water availability was studied under which the proposed and actual area irrigated in *rabi* and *kharif* crop seasons in the command of

Awanpur distributory and its minors was calculated (Table 45). Water availability in distributory and minors will be estimated by calibrating the gauge height and water discharges in distributory and the minors.

Table 45. Proposed and actual irrigated area (ha) under different crops in Awanpur distributory command during year 2021

SN	Name of canal	*Rabi*					*Kharif*				
		Proposed	Actual				Proposed	Actual			
			Wheat	Potato	Other crops	Total		Rice	Sugarcane	Other crops	Total
1	Awanpur	5.79	2.52	2	109	363	809	354	100	79	533
2	Madhupur	185	30	2	112	112	259	76	16	30	122
3	Panapur	100	90	32	25	57	139	19	19	18	56
4	Narayanpur	238	27	-	17	44	332	25	31	-	56
5	Alwalpur	206	9	1	6	16	287	287	3	-	-
Total		**1308**	**408**	**37**	**269**	**592**	**1826**	**477**	**166**	**127**	**770**

7.3.2. Conjunctive use of surface and ground water at middle and tail end of Awanpur distributory to enhance the wheat yield

A trial on conjunctive use of water was conducted at ten locations on middle and tail end of the of Awanpur distributory i.e. command area Panapur minor during *rabi* 2020-21. Improved water management practice i.e. 6 cm water by canal water and ground water in the ratio 2:1 at critical crop growth stages (3 irrigations one each at crown root initiation, late jointing and milking stage) and compared with farmers' practice i.e. 10-12 cm water by flooding/field to field irrigation as and when the canal water is available (two irrigations). Check basin method of irrigation was applied in checks of 5 × 10 m^2. Results of the trial showed that conjunctive use of canal water and groundwater (2:1) at critical crown root initiation, late jointing and milking stage produced significantly higher yield of wheat at 4.18 t ha^{-1} as compared to farmers' practice in which the yield was 3.25 t ha^{-1} in which 20 cm canal water was applied by flooding (Table 46). There was 28.84% increase in yield with the improved practice over farmers' practice. The improved practice accrued net income of ₹ 49030 ha^{-1} with a benefit-cost ratio of 2.51 compared to farmers' practice where net income was ₹ 31778 ha^{-1} with B-C ratio of 2.01.

Table 46. Performance of wheat with conjunctive use of water compared to farmers' practice

Irrigation system	Average yield (t ha^{-1})	WUE (kg ha-mm^{-1})	Cost of cultivation (₹ ha^{-1})	Gross income (₹ ha^{-1})	Net return (₹ ha^{-1})	B-C ratio
Improved practice: Conjunctive use of canal water and groundwater	4.18	22.00	32500	81530	49030	2.51
Farmers' practice: Canal irrigation with farmers' practice	3.25	15.45	31500	63278	31778	2.01

Note: Total water applied with improved practice and farmers' practice was 18 and 20 cm, respectively


Wheat grown with conjunctive use of canal and ground water in canal command

Chapter 8

Tribal Sub Plan (TSP) and Scheduled Caste Sub Plan (SCSP)

8.1. Dapoli

8.1.1. Impact assessment of water management interventions in Tribal areas of Konkan region using physical indicators

Water management interventions in tribal areas were started from 2012-13 after implementation of Tribal Sub-Plan (TSP). The TSP program was first implemented on a small area in Ratnagiri district and later extended on a larger scale to Palghar district. The study was conducted in Mahad taluka of Raigad district and Vikramgad, Mokahda and Jawhar talukas of Palghar districts. Total 200 *Jalkund* were constructed during the year 2020-21 benefitting 100 tribal farmers, storing 8.0 lakh litre rainwater and commanding 20 ha area under mango and cashew in Vikramgad taluka (Table 47). Total 10 *Konkan Vijay Bandhara* were constructed in Jawhar taluka benefitting 50 tribal farmers, storing 3980 m^3 runoff and commanding total area of 7.12 ha under vegetables, cashew, mango and jasmine cultivation. Similarly, 5 *Konkan Vijay Bandhara* were constructed in Vikramgad taluka benefitting 15 tribal farmers, storing 5870 m^3 of runoff for utilization of irrigation to mango, cashew, clusterbean, cowpea and jasmine. These bandharas commanded total 11.26 ha area in Vikramgad taluka.

Table 47. Water management interventions in Jawhar and Vikramgad talukas during 2020-21

Name of village	Number of *Jalkund* constructed during 2020-2021	Number of beneficiaries (Tribal farmers)	Area commanded (ha)
Jalkund			
13 villages	200	100	20.0
Konkan Vijay Bandhara			
7 villages	21	79	20.9

The status of water management interventions in tribal areas of Konkan region from 2012-13 to 2020-21 is presented here under in Table 48. Total 959 *Jalkund* were constructed in these talukas and 529 farmers were benefitted from this intervention during last eight years. Thus, total 95.9 ha land was brought under irrigation through this rainwater harvesting technology.

Total 49 bandharas were constructed in 25 villages creating irrigation facility for *rabi* crops on 158.8 ha land and more than 263 farmers were benefitted due to this intervention during past nine years. Most of the farmers are growing seasonal crops like vegetables, and perennial crops like jasmine, cashew and mango. It is observed that farmers in Jawhar taluka irrigate horticulture crops in WADI project and they grow mostly vegetables on the arrested runoff water, while farmers in Vikramgad taluka grow mainly clusterbean, cowpea and jasmine along with horticulture crops in WADI project. Presently, area under jasmine in Vikramgad taluka is increasing. 20 low pressure drip irrigation sets will also be installed for jasmine crop on 20 farmers' fields in Vikramgad taluka for judicious use of water.

Table 48. Details of *Konkan Jalkund* and constructed from year 2013-14 to 2020-21, (b) Details of *Konkan Vijay Bandhara* constructed from year 2012-13 to 2020-21

Location	Villages covered (No.)	Jalkund / Bandhara (No.)	Beneficiaries (No.)	Area commanded (ha)
(a) *Konkan Jalkund* constructed during last 8 years				
Mahad taluka, Dist. Raigad	06	180	90	18.0
Jawhar taluka, Dist. Palghar	14	265	182	26.5

Vikramgad taluka, Dist. Palghar	33	368	186	36.8
Mokhada taluka, Dist. Palghar	18	142	71	14.2
Grand Total	**71**	**955**	**529**	**95.5**
(b) *Konkan Vijay Bandhara* constructed during last 9 years				
Mandangad taluka, Dist. Ratnagiri	02	04	28	29.0
Mahad taluka, Dist. Raigad	01	02	05	2.0
Jawhar taluka, Dist. Palghar	11	32	132	29.22
Vikramgad taluka, Dist. Palghar	07	13	71	62.06
Mokhada taluka, Dist. Palghar	02	04	30	38.0
Grand Total	**23**	**55**	**268**	**160.28**

8.2. Rahuri

8.2.1. Dissemination of irrigation water management technologies to tribal farmers

Akole tahsil of Ahmednagar district was selected for implementation of TSP programme as per the guidelines provided by ICAR. Scientists of AICRP on IWM along with field staff of Taluka Agricultural Officer, Akole (Agril. Department) discussed with the farmers regarding implementation of TSP programme. Farmers expressed their needs to implement following technologies on their farms in order to enhance the water use productivity viz., drip irrigation, sprinkler irrigation, training to farmers, and operation & maintenance. The following things were distributed free of cost by AICRP on IWM:

- **Drip and sprinkler irrigation sets:** For the distribution of drip and sprinkler irrigation sets, 60 tribal farmers from Mhalungi tribal village of Akole Tahsil were selected whose economic and social status is very poor. Both drip and sprinkler irrigation sets will cover an area of 0.4 ha per farmer to 30 farmers.
- **Transfer of Technology:** It was decided to organize trainings and demonstrations to help the tribal farmers in effective implementation of the technologies in the tehsil.

Interventions to propagate microirrigation among tribal farmers of northern Karnataka

8.3. Belavatagi

8.3.1. Propagation of microirrigation in farm pond water

The intervention is being carried out with a broad objective of enhancing water use efficiency using microirrigation systems in Malaprabha Left Bank Canal command areas of northern Karnataka. The intervention will help overcome the acute shortage of irrigation water for crop cultivation, create awareness among the farmer community and line department personals about the efficient use of water by organizing on farm and off farm training activities, and re-orient irrigation water management through participatory research cum demonstration suitable to Malaprabha command area.

Progress made in this direction includes installation of drip irrigation technology in 15 farmers' fields having access to farm pond water. This has been done to evaluate the increase in crop yield, water saving and water productivity and its economic feasibility in row crops by comparing the results with conventional method used by the farmers. Sensor based drip irrigation automation system for 24 acres has been installed in Irrigation Water management Research Center (IWMRC), Belavatagi for demonstration, organizing field days and training programmes for benefit of the farmers. Six trainings and field demonstrations have already been organized for farmers, farm women, and school and college students of the region. The benefits of microirrigation have been briefed by the scientists during the events.

8.4. Morena

8.4.1. Demonstrations of improved irrigation practice to tribal farmers

Demonstration of improved irrigation practice was successfully conducted on tribal farmers' fields for clusterbean, pigeonpea and greengram during *kharif* and wheat, mustard and chickpea during *rabi* seasons. Results of the demonstration are given in Table 49.

Table 49. Results of demonstrations conducted during *Rabi* 2020-21 and *Kharif* 2021

Technology	Crop	Village	No. of beneficiaries	Yield ($t\ ha^{-1}$)		Cost of cultivation (₹ ha^{-1})	Net return (₹ ha^{-1})	B-C ratio
				Grain/ Seed	Foliage			
FP	Clusterbean	Dangpura	15	1.18	3.02	21740	29990	2.38
IP				1.25	3.28	24180	30740	2.27
FP	Pigeonpea	Dangpura	10	1.35	4.13	30460	62850	3.06
IP				1.82	5.12	32160	92740	3.88
FP	Greengram	Dangpura	20	0.52	1.22	20120	20150	2.00
IP				0.74	1.54	20550	36365	2.77
FP	Wheat	Dangpura	25	3.45	4.15	32110	52628	2.64
IP				4.37	4.98	35160	71068	3.02
FP	Mustard	Dangpura	20	1.66	3.97	24650	56510	3.29
IP				2.02	5.12	26800	72250	3.70
FP	Chickpea	Dangpura	20	1.38	2.21	27150	47650	2.76
IP				1.87	2.95	28500	72770	3.55
FP	Pearlmillet	Dangpura	25	1.56	3.86	25500	19620	1.77
IP				2.01	5.22	28000	30875	2.10

Note: FP, Farmers' practice; IP, Improved practice; Sale price of Clusterbean seed @ 4000 q^{-1} in local market and stover @ ₹ 150 q^{-1}; MSP for Pigeonpea @ ₹ 6300 q^{-1} seed and straw @ Rs. 200 q^{-1}; Greengram @ ₹ 7275 q^{-1} and straw @ ₹ 200 q^{-1}; Wheat @ ₹ 1975 q^{-1} seed and stover @ ₹ 400 q^{-1}, Mustard @ ₹ 4650 q^{-1}, stover ₹ 100 q^{-1} in local market; Chickpea @ ₹ 5100 q^{-1} seed and stover @ ₹ 200 q^{-1}

8.5. Pusa

8.5.1. Design and evaluation of drainage cum recharge unit under north Bihar condition

Declining groundwater in *Taal* area and drainage problem exist in *Chaur* area of Bihar. Delay in drainage delay sowing of *rabi* crops in *Chaur* areas. The intervention includes 2nd aquifer as the target aquifer with recharge capacity of 22000-24000 litre per hour, solid removal efficiency (SRE) of 80-82%, recharging depth of 45-55 m, and annual groundwater recharge potential of 2.0-2.5 ha-m.

Ground Water Recharge cum Drainage unit was developed by Pusa centre of AICRP on IWM. A Ground Water Recharge cum Drainage unit has four sub-units namely, stilling basin, siltation tank, recharge filter and boring unit. The technology was released by Research Council of DrRPCAU during 8th research council meeting. Seven units have been installed in the university campus and one recharge unit is installed at KVK, Piprakothi, East Champaran.

During 2020, six units were constructed and installed in six farmers' fields at different places of north Bihar. Two units were installed in two farmers' fields under KVK Sukhet, and one unit each in KVK Gopalganj, KVK Jale, KVK Bhagwanpur Haat Siwan and KVK Saraiya.

Experience of functioning of the unit was shared by a farmer of Sukhet village, Jhanjharpur tehsil of Madhubani district. Before the intervention, rainwater would vacate his field in the month of March. However after installing the unit, water was drained out of his field in the end of November and timely sowing of wheat crop was possible after many years of waterlogging problem. During the year 2020, there was no crop during *rabi* season, but he could obtain wheat yield of 2.5 t ha^{-1} in the year 2021.

It was concluded that

- early drainage of rainwater is possible in wet and waterlogged areas
- groundwater recharge of 2nd aquifer is possible,
- second aquifer is under stress in summer and has capacity to absorb water
- cultivation of *rabi* crop (wheat) is possible in waterlogged areas where water used to recede in March-April
- preponement of *rzbi* sowing in some of the less waterlogged area is also possible

Ground Water Recharge cum Drainage unit

Inundated field of Rajendra Mahto in Sukhet village of Madhubani district

Wheat crop after 15 days of sowing (2nd December) in farmer's field

8.6. Palampur

8.6.1. Dissemination of water management technologies to tribal farmers of Himachal Pradesh

TSP: During the year 2021, 50 drip irrigation kits were distributed to tribal farmers of Chamba district of Himachal Pradesh. The kits were installed for demonstration in farmers' field. Every kit would cover 250 m^2 for irrigation.

SCSP: During the year 2021, a polyline water harvesting tank with drip irrigation system is being executed and will be completed by May 2022 to harvest monsoon rain and demonstrate its operation.

Distribution and drip irrigation kits to tribal farmers of Chamba district

8.7. Jorhat

8.7.1. Demonstration of water management practices on autumn (*ahu*) rice

Under SCSP, large scale demonstration was conducted on water management practices on autumn (*ahu*) rice at farmers' fields of Dudhnoi area in Goalpara district of Assam in collaboration with KVK. The area being flood prone, the technology was relevant because the demonstration was done for short duration cum high yielding autumn rice variety Dishang under irrigated condition so as to harvest before flood occurrence. Objectives of the study were to demonstrate the effect of recommended water management practices on *ahu* rice in farmers' fields.

The demonstration was conducted at the farmers' field in village Matia Gossaibari, Dudhnoi, Goalpara on an area of 5 ha. Seeds were sown on nursery bed during first week of February 2020. Transplantation of 21 days old seedlings was done. Crop was harvested during 9-15 June 2020. Recommended irrigation management practice i.e. 5 cm irrigation 3 days after disappearance of ponded water (DADPW) was tested. All other recommended agronomic practices for autumn rice were followed. Shallow tubewell (STW) water was used for irrigation. Results showed that rice grain was 4.2 t ha^{-1}. Total 13 irrigations were given resulting in 650 mm ha^{-1} irrigation water used. Irrigation water use efficiency was 6.46 kg $ha\text{-}mm^{-1}$.

Other activities were also arranged at the demonstration site i.e. training on improved cultivation of autumn (ahu) rice, and preparation of video on performing agricultural operation maintaining Covid-19 protocol.

Demonstration of autumn (*ahu*) rice starting from seed distribution to crop cultivation

Chapter 9

Technology Assessed, Refined and Transferred

9.1. Belavatagi

9.1.1. Assessment of groundwater recharge technique

Assessment of influence of groundwater recharge on groundwater yield, quality and fluctuations has been initiated during 2020. Installation cost was ₹ 25000 approximately. Groundwater recharge unit for the existing tubewell was recharged with 3.35 lakhs litre rainwater harvested during 2020 (up to December 2020). After point recharge through 7 recharge events, there was considerable rise in the water table from more than 100 feet below ground level to about 22 feet below ground level. This resulted in considerable reduction in electrical conductivity (EC) of groundwater from more than 10 dS m^{-1} to an average EC of 1.6 dS m^{-1} and increase in tubewell water yield from 0.4 lps to around 2.4 lps.

During the year 2021, ground water recharge happened with excess surface runoff through six rainfall events. Total recharge from lifting collected water and diversion of excess runoff water generated from rainfall events to groundwater recharge unit during January-December 2021 was estimated as 6.80 lakh litre. Total 4.64 lakh litre of tubewell water was withdrawn in 2021 for domestic uses. Monthly average results from point recharge through recharge events during year 2021 revealed considerable rise in water table from more than 100 feet below ground level to about 24 feet below ground level.

Sensor based micro irrigation automation technology

Sensor based drip irrigation automation system has been installed in IWMRC Belavatagi with a refinement of normal drip irrigation system to study the effect of drip automation system for row crops of the region. Six training and demonstration programmes were conducted in the year 2021. Benefits of microirrigation was explained to the stakeholders.

9.2. Navsari

9.2.1. Development of fertigation schedules

Fertigation schedules were developed for two cropping systems and transferred to farmers in heavy rainfall zone of south Gujarat.

Sorghum-vegetable cowpea: Sorghum-vegetable cowpea cropping sequence grown during *rabi* followed by summer season performed best with drip irrigation at 0.6 pan evaporation fraction (PEF) and application of N @ 8 kg per hectare and P_2O_5 @ 40 kg per hectare as basal and remaining 72 kg N in 6 equal splits at weekly interval starting from 20 days after sowing (DAS) through fertigation to *rabi* sorghum and 40 kg P_2O_5 as basal and 20 kg N per hectare to cowpea in 3 equal splits at weekly interval for securing higher crop yield and net return.

Details of the technology

Crop spacing : 30 × 15(4):60 (*in centimetre*, cm)
Lateral spacing : 180 cm
Dripper spacing : 60 cm
Dripper discharge : 4 litre per hour (lph)
Operating pressure : 1.2 kg cm^{-2}
System operating period: Twice a week
Operating time:
Sorghum (*rabi*) : December to March: 2 hrs 20 minute to 3 hrs 15 minute (0.6 PEF)
Cowpea (summer): April to May: 3 hrs 20 minute to 3 hrs 45 minute (0.6 PEF)

Country bean-Sweet corn: Country bean (vegetable)-Sweet corn cropping sequence grown during *rabi* followed by summer season performed best with drip irrigation with dripper discharge rate of 8 litre per hour, lateral placed at 1.60 m distance for 4 rows of Indian bean and 30 cm row spacing and 3 rows of sweet corn at 53 cm spacing for getting higher yields and net return from the cropping sequence. Fertigation should be applied with 40 kg P_2O_5 per hectare as basal and 20 kg N to Indian bean, and 60 kg P_2O_5 as basal and 140 kg N per hectare and 40 kg K_2O per hectare to sweet corn in 6 equal splits at weekly interval starting from 20 DAS.

Details of the technology

Crop spacing: Indian bean: 30 × 10(4): 40 cm and sweet corn: 53 cm × 20 cm
Lateral spacing : 160 cm
Dripper spacing : 60 cm
Dripper discharge : 8 lph
Operating pressure : 1.2 kg cm^{-2}
System operating period : twice in a week
Operating time:
Indian bean (*rabi*): December to March: 1

hour to 1 hour 20 minute (0.6 PEF)

Sweet corn (summer): April to May: 1 hour 30 minutes to 2 hours (0.6 PEF)

9.3. Chalakudy

9.3.1. Extension of water management technology

Water management technologies were developed for crops like banana, nutmeg and chilli-amaranth system. Results of the experiment conducted for three years were presented in the Zonal Research Extension Advisory Committee of the Kerala Agricultural University and approved research findings were proposed for conducting multi locational field trials. Four farmers, that is Saju Tharayil, Sivaraman Thumbarathy, Augustine and Raveendran were identified and field trials were conducted for banana, nutmeg and chilli-amaranth system in three different districts viz., Thrissur, Ernakulam and Palakkad.

9.4. Ludhiana

9.4.1. Technology included in package of practice

Technology of growing fodder-fodder cropping systems i.e. Berseem-Sorghum and Ryegrass-Sorghum was developed for south-west Punjab having saline sodic groundwater. Instead of using only canal water, sorghum and berseem can be successfully grown with alternate irrigation of canal water and saline sodic groundwater whereas, ryegrass can be cultivated in rotation of two irrigations with saline sodic water followed by one irrigation of canal water in sandy loam soil with optimum fodder yield, water productivity and higher benefit-cost ratio for both the cropping systems. The technology has been approved in the 287th REC meeting on 14.10.2021 and included in Package of Practices of Punjab Agricultural University.

9.5. Gayeshpur

9.5.1. Arsenic mitigation in vegetables

Technology was generated on arsenic mitigation in edible parts of vegetables like cauliflower and broccoli through conjunctive use of fresh pond water and arsenic contaminated ground water in the arsenic contaminated area of Nadia district, West Bengal to avoid variable arsenic toxicity and serious health related problems.

Micro-irrigation schedule was developed for broccoli and cauliflower crops to reduce accumulation of arsenic in the edible parts of the crops. Four demonstrations on microirrigation *vis-a-vis* surface irrigation to broccoli and cauliflower were conducted at farmers' fields for a comparative evaluation. Microirrigation reduced arsenic accumulation in edible parts by 7.91 to 19.27% for cauliflower and 7.28 to 16.5% for broccoli over surface irrigation. Surface irrigation resulted in higher contamination of arsenic in soil, whereas drip/sprinkler irrigation at 0.7 ET_c led to low arsenic content in soils. Crop yield and water productivity was also significantly higher with microirrigation over surface irrigation. Thus drip/sprinkler system at 0.7 ET_c was advocated to the farmers for higher crop and water productivities as well as better human health and environmental safety.

9.6. Pusa

9.6.1. Dissemination of groundwater recharge technology

Drainage cum recharge unit was designed and evaluated for north Bihar with declining groundwater. Six Ground Water Recharge cum Drainage units were installed/constructed in farmer's field at different places of North Bihar for demonstration of the unit. Two units were installed at two farmers' fields in Sukhet village (Madhubani district), one unit in Barai Patti village (Gopalganj district), one unit in Ratanpur village (Darbhanga district), one unit in Sikatiya village (Siwan district), and one unit in Dwarikanathpur village (Muzaffarpur district). Technology release of Ground Water Recharge cum Drainage unit was done by the research council of RPCAU, Pusa during the 8th research council meeting. Seven Ground Water Recharge cum Drainage Unit were installed in the university campus and one recharge unit was installed at KVK, Piprakothi, East Champaran. Functioning of the recharge unit was successfully demonstrated to Former DDG (NRM) and Vice Chancellor of BCKVV, Kalyani.

The installed recharge structure indicated that it can be used for recharging groundwater through runoff water and can drain excess water. Performance evaluation of the recharge structure indicated that recharge rate was 6.5 litre per second and solid removal efficiency was about 82%. Annual groundwater recharge potential of groundwater recharge structure varied between 2.0-2.5 ha-m.

Chapter 10

Recommendations

Ayodhya

Moisture regime of 6 cm water at 4 days after disappearance of ponded water (DADPW) with chemical weeding (Bispyribac sodium 10% SC 20g/ ha; post emergence at 30 DAS) was recommended for obtaining higher yield and net profit from drum seeded rice.

Chalakudy

High density planting of banana with 3 plants per pit at a spacing of 3 m × 3 m between pits and 1 m between plants within the pit, accommodating 3330 plants per hectare was recommended to be a viable practice for banana cultivation in Kerala. Installing drip irrigation @ 4 emitters per pit, with one emitter each at the base of each plant and the fourth emitter at the centre of the pit and providing irrigation at 75% pan evaporation compensation (30 L per plant) on alternate days can save water upto 25% over basin irrigation. The technology has been accepted in the Package of Practices recommendation of KAU for high density planting.

Chiplima

Raised and sunken bed farming system with an elevation difference of 60 cm, and cultivation of rice-tomato cropping system was recommended for fetching more system yield and profit from *rabi* season crops in the lowland Hirakud command area and is recommended to the farmers for higher net profit and benefit-ratio of 2.41.

Junagadh

It was recommended to farmers, NGOs and government line departments to recharge 610.18 MCM runoff in Ozat river basin by constructing artificial groundwater recharge structures i.e. 4520 check dams, 51113 farm ponds, 22599 open wells, 5650 tubewells and 10496 Gabion/loose rock dams at an estimated project cost of ₹ 526.56 crores.

Bathinda

Under Berseem/ Ryegrass-Sorghum cropping systems, berseem can be successfully grown with alternate irrigation with good quality canal water and saline sodic tubewell water whereas, ryegrass can be cultivated in rotation of two irrigations with saline sodic water followed by one irrigation of canal water under sandy loam soil.

Rahuri

Planting of two eye bud *suru* sugarcane at a spacing of 45 cm in 5 feet long furrows under subsurface drip irrigation scheduled at 80% crop evapotranspiration every alternate day with 80% RDF (200:136:136, $N:P_2O_5:K_2O$ kg ha^{-1}) through water soluble fertilizers in 30 weekly splits is recommended for medium deep black soil of western Maharashtra for higher monetary returns.

Coimbatore

Among the surface irrigation methods, irrigation at hairline crack formation under alternate wetting and drying was recommended for reducing water requirement in rice, improving higher water use efficiency and obtaining grain yield at par with flood irrigation.

Gayeshpur

Conjunctive use of arsenic contaminated groundwater and safe surface (pond) water in the ratio 1:1 in high arsenic prone areas was recommended for minimising accumulation of arsenic in the edible parts of broccoli and cauliflower.

Pusa

Drip irrigation at IW/CPE 0.8 was recommended for maximum yield, water saving and water use efficiency of *rabi* maize compared to furrow and alternate furrow irrigation at IW/CPE 0.8.

Farmers were recommended to grow rice-maize+potato-dhaincha (*Sesbania sp.*) cropping system with surface irrigation at IW/CPE 1.0 in order to get maximum system productivity with higher benefit-cost ratio.

Udaipur

De-siltation every 4 years was recommended for three rainwater harvesting structures namely, Shishvi-I, Shishvi-II and Karmal located in Shishvi and Karmal villages of Girwa block of Udaipur district, Rajasthan to check loss of storage capacity of the structures.

In Upper Banas river basin in Rajasthan, construction of artificial recharge structures such as

27 percolation ponds, 29 anicuts and 7 subsurface dykes have been suggested.

Navsari

Farmers of south Gujarat heavy rainfall agro-climatic zone following *rabi* sorghum-vegetable cowpea (summer) crop sequence were recommended to irrigate the crops with drip irrigation system at 0.6 PEF and apply 8 kg N ha^{-1} and 40 kg P_2O_5 ha^{-1} as basal and remaining 72 kg N in 6 equal splits at weekly interval starting from 20 DAS through fertigation to *rabi* sorghum and 40 kg P_2O_5 as basal and 20 kg N ha^{-1} to cowpea in 3 equal splits at weekly interval for securing higher yield and net return.

PUBLICATIONS 2021

Almora

Panday, S.C., Mishra, D.C., Yadava, R.P., Pattanayak, A. 2021. Studies on mechanical, vegetative, and roof water harvesting: strategies to enhance recharge of spring and its discharge in Himalaya. *Desalination and Water Treatment*, 244, 27-40.

Parihar, M., Panday, S.C., Meena, R.P., Kumar, U., Meena, V.S., Choudhary, M., Singh, A.K., Bisht, J.K., Kant, L., Pattanayak, A. 2021. Long-term organic and inorganic fertilization on economics, energy budgeting and carbon footprint of soybean-wheat cropping system in the Indian mid-Himalayas. *Archives of Agronomy and Soil Science*, 68(14), 1-15.

Ayodhya

Singh, S., Singh, B.N., Singh, A., Tiwari, R.C., Agrawal, Y. 2021. Effect of irrigation methods, moisture regimes and integrated nitrogen management on growth, yield and quality of potato (*Solanum tuberosum* L.). *The Pharma Innovation Journal,* 10(4), 525-530.

Singh, S., Singh, B.N., Singh, A., Tiwari, R.C., Hasanain, M., Singh, T., Singh, A., Agrawal, Y., 2021. Response of potato (*Solanum tuberosum* L.) to irrigation methods, moisture regimes and integrated nitrogen management. *Indian Journal of Agronomy,* 66(2), 237-240.

Chalakudy

Bhindhu P.S., Sureshkumar, P. 2021. Availability indices of calcium and magnesium in soil of Kerala. *Journal of Tropical Agriculture,* 59(1), 38-44.

Arya., P., Anitha, S., Menon., M.V., Bhindhu P.S., Antony, S. 2021. Foliar application of micronutrients on growth and yield of Okra under different irrigated condition. *Journal of Tropical Agriculture,* 59(1), 76-82.

Soniya V.P., Bhindhu P.S. 2021. Response of cowpea (Vigna unguiculata (L.) Walp) to magnesium nutrition in lateritic soils of Kerala. *Research Journal of Agricultural Sciences,* 12(1), 82-85.

Soniya, V.P., Bhindhu, P.S., Sureshkumar, P. 2021. Critical level of magnesium for cowpea (*Vigna unguiculata* L. Walp.) in Ultisols of Kerala. *Legume Research,* 44(9), 1-5.

Coimbatore

Nagarajan, M., Porpavai, S., Thiyagarajan, G. 2021. Evaluation of safe alternative wetting & drying and its influence on growth, yield and water use of the efficiency of rice (*Orzya sativa* L.). *Journal of Applied and Natural Science,* 13(1), 407-413.

Selvaperumal, A., Thiyagarajan, G., S., Thangamani, S., Vallalkannan, Ramaswamy, K. 2021. Design and performance of subirrigation system in maize (*Zea mays*) in Kumulur farm, Trichy district, Tamil Nadu, India. *Journal of Applied and Natural Science,* 13(2), 470-475.

P., Aravind, P., Ponnuchakkamal, G., Thiyagarajan, Kannan, B., 2021. Estimation of crop water requirement for sugarcane in Coimbatore district using FAO CROPWAT. *Madras Agricultural Journal,* 108(4-6), 280-286.

P., Aravind, S., Selvakumar, Thiyagarajan, G., K., Boomiraj, Kannan, B., 2021. Assessment of the seasonal water quality changes in semi-urban surface tanks of Noyyal river basin. *International Journal of Environment and Climate Change,* 11(11), 121-134.

A., Selvaperumal, Rajammal, S.J., Thiyagarajan, G., S. Thangamani, Ramaswamy, K. 2021. Performance of water table management system for alleviating sodic soil reclamation at Kumulur farm, Trichy District, Tamil Nadu. *Journal of Applied and Natural Science*, 13(4), 1365-1371.

Bhuvaneswari, J., Thiyagarajan, G., Manikandan, M., Thenmozhi, S., Natarajan, S.K. 2021. Impact of Improved Water Management Technique for Groundnut in LBP Command Area. *International Journal of Current Microbiology and Applied Sciences,* 10(1), 1457-1462.

Reddy, D.M., Lalitha, R., Raviraj, A., Kannan, S.V., Baskar, M., Nagarajan, M. 2021. Temperature gradient modeling in a greenhouse equipped with fan-pad operated evaporative cooling system. *The Pharma Innovation Journal,* SP-10(12), 1895-1899.

Ponnuchakkammal, P., Lalitha, R., Raviraj, A., Nagarajan, M., Bharani, A. 2021. Comparative analysis of watershed divides from digital elevation model of Ayyar watershed, Tamil Nadu using remote sensing and GIS technique. *The Pharma Innovation Journal*, SP-10(11), 2010-2014.

Dapoli

Salunkhe, S.S., Ayare, B.L., Bhange, H.N., Thokal, R.T., Dhekale, J.S., Nandgude, S.B. 2021. Study of physical properties of soils from mango of Ratnagiri district of Konkan region. *The Pharma Innovation Journal,* SP-10(4), 290-294.

Salunkhe, S.S., Ayare, B.L., Bhange, H.N., Thokal, R.T., Dhekale, J.S. 2022. Assessment of biomass and carbon stocks in mango (*Mangifera indica* L.) orchards of Ratnagiri district of Maharashtra State, India. *International Journal of Environment and Climate Change,* 11(12), 487-494.

Hisar

Babal B., Phogat, V.K., Sharma, M.K., Ahlawat, S. 2020. Impact of long-term conservation agriculture induced changes in soil properties on persistence of pendimethalin under different cropping systems. *Soil Research,* 59(3), 299-308.

Phogat, V.K., Parihar, M.D., Dahiya, R., Sharma, M.K., Singh, S.K. 2021. Scheduling of irrigation in different cultivars of cotton under semi-arid conditions. *Journal of Plant Development Sciences*, 13 (8), 663-666.

Parihar, M.D., Singh, S.K., Sharma, M.K., and Sutaliya J.M. (2021) Performance of barley as influenced by irrigation scheduling and cultivars. *Journal of Plant Development Sciences,* 13 (9):713-718.

Abdallah, A.M., Parihar, C.M., Patra, S., Nayak, H.S., Saharawat, Y.S., Singh, U., Parihar, M.D., Kakraliya, S.K., Nassar, I.N., Ugolini, F., Zohir, W.F., Shalaby, M.M. 2021. Critical evaluation of functional aspects of evaporation barriers through environmental and economics lens for evaporation suppression - a review on milestones from improved technologies. *Science of The Total Environment*, 788(20), 147800.

Jammu

Banotra, M., Sharma, B.C., Gupta, L. M., Kumar, R., Samanta, A., Verma, A., Sharma, J. 2021. Impact of differential substitution nutrients through organics on yield, nutrient uptake and profitability of knol-khol (*Brassica oleracea var gonylodes* L.) in subtropical region of J&K. *Agricultural Mechanization in Asia, Africa and Latin America,* 51 (3), 1425-1433.

Sharma, J., Bharti,V., Kumar, D., Menia, M., Bochalya, R.S. 2021. Resource conservation technology for enhancing the rice productivity in India: A review. *The Pharma Innovation Journal,* SP-10(9), 163-167.

Junagadh

Parmar, H.V., Gontia, N.K. 2021. Estimation of evapotranspiration using remote sensing and Surface Energy Balance Algorithm for Land (SEBAL) in canal command. *Journal of Agricultural Engineering,* 58(3), 274-285.

Patel, R.J., Vekariya, P.B., Vadar, H.R., Rank, H.D., Pandya, P.A., Modhvadiya, J.M. 2021. Hydraulic performance evaluation of double nozzle full circle micro-sprinkler irrigation system under semi-arid conditions. *International Research Journal of Modernization in Engineering Technology and Science,* 3(1), 39-50.

Deepak, K., Rank, H.D. 2021. Comparison of fenugreek crop evapotranspiration measured by a micro-lysimeter, field water balance method and automatic closed canopy chamber. *International Journal of Agriculture, Environment and Biotechnology,* 14(1), 29-49.

Vekariya, P.B., Rank, H.D., Patel, R.J. 2021. Evaluation of recharge basins technique in Junagadh region. *International Research Journal of Modernization in Engineering Technology and Science,* 3(12), 143-149.

Vekariya, P.B., Rank, H.D., Patel, R.J. 2021. Conjunctive water use for higher return of wheat crop in south Saurashtra region. *International Research Journal of Modernization in Engineering Technology and Science,* 3(12), 797-803.

Patel, R.J., Rank, H.D. 2020. Water use efficiency of wheat under different irrigation regimes using high discharge drip irrigation system. *Agricultural Engineering Today,* 44(2), 19-31.

Jorhat

Deka, B., Bharteey, P.K., Dutta, M., Patgiri, D.K., Saikia, R. 2021. Morphometric analysis of Moridhal watershed in Dhemaji district of Assam, India using remote sensing and Geographic Information System techniques. *Desalination and Water Treatment,* 242, 235–242.

Borgohain, S., Deka, B., Dutta, M., Thakuria, R.K., Patgiri, D.K. 2021. Geospatial assessment of water induced soil and nutrient erosion in Pabho watershed of Assam. India using USLE model. *Journal of Environmental Biology,* 42, 406-413.

Medhi, B.K., Hazarika, I.H., Hazarika, P.P., Thakuria, R.K., Sanjay-Swami. 2021. Assessment of groundwater arsenic vulnerable zones using Geographic Information System for employing biochar as soil amendment in irrigated rice ecosystem - a case study from central Assam. *Journal of Environmental Biology,* 42, 462-470.

Deka, B., Dutta, M., Patgiri, D.K. 2021. Productivity, potentiality and soil-site suitability evaluation for rice crop in the Ghiladhari watershed of Assam. *Journal of Soil and Water Conservation,* 20(4), 365-374.

Bordoloi, P., Goswami, J., Pathak, K., Deka, B. 2020. Biological properties of soil after cultivation of indigenous quality rice under different methods of establishment. *International Journal of Current Microbiology and Applied Science,* 9(2), 1960-1964.

Kota

Yadav, R.K., Purakayastha, T.J., Ahmed, N., Das, R., Chakrabarty, B., Biswas, S., Sharma, V.K., Singh, P., Talukdar, D., Mourya, K.K., Walia, S.S. 2021. Long-term effect of fertilization and manuring on soil aggregate carbon mineralization. *The Indian Journal of Agricultural Sciences,* 91(2), 74-77.

Meena, S.K., Yadav, R.K., Ram, B., Yadav, V.K., Yadav, S.L., Sharma, M.K., Meena, A. 2021. Effect of irrigation schedules and soil amendments on growth and nutrient content and uptake of soybean under Vertisols of south-eastern Rajasthan. *The Pharma Innovation Journal,* 10(12), 1298-1302.

Yadav, B.D., Yadav, R.K., Nogiya, M., Yadav, M.R., Mahala, D.M., Meena, S.N., Yadav, B., Verma, A.K., Yadav, S., Devi, S., Kumawat, R. and Bijarniya, A. 2021. Phosphorus management strategies to enhance P-use efficiency and sustainable crop production. *International Journal of Chemical Studies,* 9(1), 3562-3567.

Choudhary, M., Tetarwal, J.P., Ram, B., Kumar, R., Bijarnia, A., Kumawat, R. 2022. Effect of land configuration and irrigation scheduling on productivity and water use of quinoa (*Chenopodium quinoa*) under south-eastern ecologies of Rajasthan. *Annals of Agricultural Research* New Series, 67(1), 108-112.

Kumawat, R., Ram, Baldev, Tetarwal, J. P., Yadav, R. K., Kumar, R., Bijarnia, A. and Choudhary, M. 2021. Growth, yield and quality parameters of summer mungbean (*Vigna radiata* Wilczek L.) influenced by different phosphorus levels, biophos liquid biofertilizer and growth regulator in south-eastern Rajasthan. *Agricultural Mechanization in Asia, Africa and Latin America,* 53 (01): 5433-5443.

Ludhiana

Gulati, D. Satpute, S., Kaur, S., Aggarwal, R. 2022. Estimation of potential recharge through direct seeded and transplanted rice fields in semi-arid regions of Punjab using HYDRUS-1D. *Paddy and Water Environment,* 20(1) 79-92.

Sanjay, S., Singh, M.C., Garg, S. 2021. Assessment of irrigation water requirements for different crops in central Punjab, India. *Journal of Agrometeorology,* 23(4), 481-484.

Kaur, N., Kaur, S., Kaur, P., Aggarwal, R. 2021. Impact of climate change on groundwater levels in Sirhind Canal Tract of Punjab, India. *Groundwater for Sustainable Development,* 15, 100670.

Gupta, A., Aggarwal, R., Kaur, S. 2020. Field evaluation of abandoned open well for recharging surplus canal water. *Indian Journal of Agricultural Science*, 90 (7), 143-145.

Sharma, K., Bhardwaj, A., Satpute, S. 2021. Rainfall intensity–duration–frequency curves for Ballowal Saunkhri in the Shivalik foot–hills of Punjab. *Indian Journal of Soil Conservation,* 49 (1), 72-76.

Garg, S., Kaur, H., Satpute, S. 2021. Carbon emissions due to groundwater pumping and crop diversification in Fatehgarh Sahib district. *Journal of Soil Salinity and Water Quality,* 13(1), 61-69.

Bathinda

Kaur, A., Dhillon, G.S., Sekhon, K.S. 2021. Quinoa (*Chenopodium quinoa*): Promising salinity stress-tolerant crop for diversification and nutritional security. *Journal of Soil Salinity and Water Quality*, 13 (2), 147-156.

Kaur, L, Kaur, A., Brar, A.S. 2021. Water use and productivity of green gram (*Vigna radiata* L.) impacted by paddy straw mulch and irrigation regimes in north-western India. *Agricultural Water Management,* 258, 107184.

Kumar, S., Kumar, D., Sekhon, K.S., Singh, P., Phogat, M., Kakralia, S., Choudhary, O.P. 2021. Effect of soil applied boron on depth-wise distribution of root biomass of cotton grown in a calcareous soil of north-western India. *Journal of Soil Salinity and Water Quality,* 13, 79-85.

Kumar, S., Kumar, D., Sekhon, K.S., Singh, P., Phogat, M., Choudhary, O.P. 2021. Soil application of boron impacts its solubility, yield and fibre quality of cotton in calcareous soils of north-western India. *Journal of Environmental Biology,* 42(6), 1534-1543.

Singh, R., Sekhon, K.S., Thaman, S., Mavi, M.S. 2021. Dry matter partitioning at successive stages of Bt cotton influenced by water quality and N fertigation under drip irrigation. *Journal of Soil Salinity and Water Quality,* 13(2), 237-247.

Malik, A., Kumar, A., Rai, P., Kuriqi, A. 2021. Prediction of multi-scalar standardized precipitation index by using artificial intelligence and regression models. *Climate*, 9(2), 28.

Ghorbani, M.A., Kahya, E., Roshni, T., Kashani, M.H., Malik, A., Heddam, S. 2021. Entropy analysis and pattern recognition in rainfall data, north Algeria. *Theoretical and Applied Climatology,* 144(1), 317-326.

Abba, S.I., Abdulkadir, R.A., Gaya, M.S., Sammen, S.S., Ghali, U., Nawaila, M.B., Oğuz, G., Malik, A.**,** Al-Ansari, N. 2021. Effluent's quality prediction by using nonlinear dynamic block-oriented models: a system identification approach. *Desalination and Water Treatment*, 218, 52-62.

Malik, A., Tikhamarine, Y., Souag-Gamane, D., Rai, P., Sammen, S.S., Kisi, O. 2021. Support vector regression integrated with meta-heuristic algorithms for meteorological drought prediction. *Meteorology and Atmospheric Physics,* 133(3), 891-909.

Rehamnia, I., Benlaoukli, B., Jamei, M., Karbasi, M., Malik, A. 2021. Simulation of seepage flow through embankment dam by using a novel extended Kalman filter based neural network paradigm: case study of Fontaine Gazelles Dam, Algeria. *Measurement,* 176, 109219.

Malik, A., Tikhamarine, Y., Sammen, S.S., Abba, S.I., Shahid, S. 2021. Prediction of meteorological drought by using hybrid support vector regression optimized with HHO versus PSO algorithms. *Environmental Science and Pollution Research*, 28(29), 39139-39158.

Elbeltagi, A., Aslam, M.R., Mokhtar, A., Deb, P., Abubakar, G.A., Kushwaha, N.L., Venancio, L.P., Malik, A., Kumar, N., Deng, J. 2021. Spatial and temporal variability analysis of green and blue evapotranspiration of wheat in the Egyptian Nile Delta from 1997 to 2017. *Journal of Hydrology*, 594, 125662.

Malik, A., Kumar, A. 2021. Application of standardized precipitation index for monitoring meteorological drought and wet conditions in Garhwal region (Uttarakhand). *Arabian Journal of Geosciences,* 14(9), 1-21.

Morena

Singh, Y.P., Tomar, S.S., Singh, S. 2021. Effect of precise levelling, tillage and seed sowing methods of pearlmillet based cropping systems on productivity and soil quality in dryland area. *Soil and Tillage Research,* 212, 105069.

Singh, Y.P., Tomar, S.S., Singh, S., Singh, A.K., Gupta, R.K. 2021. Influence of tillage and relay cropping of berseem in mustard-pearl millet system on soil quality productivity of crops and water. *Agriculture Research*, 10(4), 645-655.

Tomar, S.S., Singh, R., Singh, D., Tomar, S.S. 2021. Impact analysis of K.V.K. adopted village for beekeeping with special reference to status of pests and predators in gird zone of Morena district. *The Pharma Innovation Journal,* SP-10(6), 461-467.

Singh, Y.P., Sinha, R.B., Singh, S. 2021. Performance of tree species and natural vegetation after rain water conservation in ravine land based on biomass, carbon stock and soil properties.*Range Management and Agroforestry*, 42(1), 7-14.

Palampur

Akarsh, S.G., Tigangam, P., Gangmei, Sahu, K.K., Kumar, A., Rana, S.S. 2020. Effect of irrigation scheduling and nutrient management on yield, water use efficiency and economics in garden pea (*Pisum sativum* L.) *International Journal of Chemical Studies*, 8(5), 323-328.

Kumar, A., Rana, S.S., Manuja, S. 2020. Influence of nutrient management practices and varieties on the productivity and economics of maize (*Zea mays* L.) and their residual effect in Gobhi Sarson (*Brassica napus* L.) under rainfed conditions. Communications in Soil Science and Plant Analysis, 51(18), 2323-2330.

Reenu Kapoor and Sandal Sanjeev K 2019. Growth and yield response of broccoli (*Brassica oleracea* var. *italica*) to varying drip irrigation and fertigation levels. *Indian Journal of Agricultural Sciences,* 89(12), 2014–2019.

Jaswal, R., Sandal, S.K. 2020. Effect of drip irrigation and NK fertigation on soil water dynamics and water productivity of strawberry under protected conditions. *Indian Journal of Soil Conservation* (Accepted)

Baghla, S., Gangmei, T.P., Kumar, A., Rana, S.S. 2020. Effect of irrigation and weed management practices on weed studies, water use efficiency and yield of cauliflower (*Brassica oleracea* var. *botrytis* L.) *International Journal of Chemical Studies,* 8(5), 2703-2706.

Pantnagar

Datta, D., Chandra, S., Nath, C.P., Kar, G., Ghosh, S., Chaturvedi, S., Bhatnagar, A., Singh, G., Singh, V. 2022. Soil-plant water dynamics, yield, quality and profitability of spring sweet corn under variable irrigation scheduling, crop establishment and moisture conservation practices. *Field Crops Research,* 279, 108450.

Kumara, S., Kumar, V., Tomar, A.S. 2021. Spatial distribution of water quality for Indo-Gangetic alluvial plain using Q-GIS. *Pantnagar Journal of Research*, 19(3):497-504.

Durga, K.K., Kumar, V., Kumar, A., Tomar, A.S. 2021. Morphometric analysis based prioritization of Bour river watershed of Uttarakhand using GIS and remote sensing. *International Journal of Enhanced Research in Science Technology & Engineering (IJERSTE)*, 10(7):52-60.

Pradhan, S., Kumar, S., Kumar, Y., Sharma, H.C. 2021. Implication of intensive agriculture on groundwater utilization in Ganga-Ramganga interbasin, India. *Environmental Earth Sciences*, 80(9), 342.

Rajwade, Y.A., Adamala, S., Kumar, Y. Kumar S. 2021. Application of artificial neural networks for BOD and COD modelling in Golar river, Uttarakhand, India. *Arabian Journal of Geosciences,* 14(14), 1326.

Parbhani

Gadade, G.D., Gokhale, D.N., Kadale, A.S. 2021. Yield enhancement of pigeonpea through drip irrigation and fertigation management. *Legume Research-An International Journal*, 1, 7.

Phupate, A.B., Ingle, V.K., Awari, H.W., Khodke, U.M., Jadhav, S.B., Pendke, M.S. 2021. Quantitative morphometric analysis using RS and GIS techniques in VNMKV-Pingali watershed of Pingalgarh Nala Catchment of Parbhani district, Maharashtra, India. *International Journal of Current Microbiology and Applied Sciences,* 10(12), 258-267.

Jadhavv, R.N., Jadhav, S.B., Awari, H.W., Ingle, V.K. Khodke, U.M. 2021. Assessment of AquaCrop model for irrigated cotton under deficit irrigation in semi-arid tropics of Maharashtra. *International Journal of Current Microbiology and Applied Sciences,* 11(1), 123-135.

Pusa

Chandra, R., Kumari, S. 2021. Estimation of crop water requirement for rice-wheat and rice-maize cropping system using CROPWAT model for Pusa, Samastipur district, Bihar. *Journal of AgriSearch,* 8(2), 143-148.

Chandra, R., Singh, P.K., Kumar, A. 2021. Performance Evaluation of AquaCrop model for broccoli crop under *Tarai* condition of Indo-gangetic plain. *Indian Environment and Ecology*, 40(2C), 201-207.

Kumar, R., Sharma, P., Verma, A., Jha, P.K., Singh, P., Gupta, P.K., Chandra, R., Prasad, P.V.V. 2021. Effect of physical characteristics and hydrodynamic conditions on transport and deposition of microplastics in riverine ecosystem. *Water*, 13, 2710.

Pandey, S. K., Tiwari, S., Singh, A.K. (2022). Influence of inorganic fertilizers and organics on inorganic P, organic P and their fractions in calcareous soil of Bihar under rice-wheat cropping system. *Current Advances in Agricultural Science*, 13(2), 90-95.

Singh, S.K, Kumar, V., Singh, P., Tiwari, S., Singh, A.K. (2021). Effect of different cropping system on soil strength in calcareous soil. *Journal Soils and Crops*, 31(2), 247-250.

Rani, Sonal and Singh, A. K. (2021). Study of changes in properties of calcareous soil at industrial diaposal site of tannery industry in Bela, Muzaffarpur. *The Pharma Innovation Journal*, SP-10(10), 190-196.

Adilakshmi, G., Kumar, Rajan., Varalakshmi, P, Mohan babyu, Y N., and Kartika, M.2021. Nutrient content and uptake by grain and straw of different rice varieties at different moisture regimes under direct seeded rice. *The Pharma Innovation,* 10(5), 561-563.

Raipur

Delineation and characterization of land resources to assess agro-climatic zone based farming situation in Chhattisgarh plains. 2021. Sameer Mandal, Dhiraj Khalkho, M. P. Tripathi, Susanta Das and Love Kumar. *Journal of Soil and Water Conservation,* 20(3), 257-268.

Remote Sensing and GIS based approach in morphometric analysis of thirteen sub-watersheds of Mand river catchment, Chhattisgarh. 2021. Shreeya Baghel, Mahendra Prasad Tripathi, Dhiraj Khalkho and Aekesh Kumar. *Journal of Soil and Water Conservation,* 20(3), 269-278.

Artificial Groundwater Recharge Planning of a Critical Sub-watershed for Kotani Watershed Using Geospatial Techniques. 2022. Dileshwari, MP Tripathi and Dhiraj Khalkho. *Biological Forum – An International Journal*, 13(4), 233-241.

Assessment of groundwater quality using GIS in Kurud block of Dhamtari district Chhattisgarh. 2020. Aekesh Kumar, M.P. Tripathi, Dhiraj Khalkho and Shreeya Baghel. *Journal of Soil and Water Conservation,* 19(4), 426-435.

Udaipur

Yadav, M., Yadav, K.K. and Singh, D.P. 2021. Effect of Irrigation and Zinc on quality and nutrient uptake by Indian Mustard (*Brassica juncea* (L.). *International Research Journal of Humanities and Interdisciplinary Studies*, 2 (6), 280-289.

Mali, N.L., Yadav, K.K. and Malakar, P. 2021. Assessment of Groundwater Quality using GISbased WAWQI Method for Chittorgarh district, Rajasthan, India. *International Journal of Pharmaceutical Research and Applications*, 6 (6): 933-938.

Yadav, K.K., Meena, M.K. and Mali, N.L. 2021. Impact of graded levels of fertility and biofertilizers on yield attributes and yield of mungbean [*Vigna radiata* (L.) Wilczek]. *International Research Journal of Humanities and Interdisciplinary Studies*, 2(6), 280-289.

Singh, Manjeet, Singh, P.K., Yadav, K.K., Kothari, M. and Bhakar, S.R. 2021. Fluoride Distribution in the Groundwater of Upper Banas River Basin, Rajasthan, India. *International Research Journal of Humanities and Interdisciplinary Studies*, 2 (6), 74-85.

Tirunagari Rupesh, Singh, D.P., Meena, R.H, Yadav, K.K. and Choudhary, R.S. 2020. Effect of Organic and Inorganic Sources of Nitrogen on Growth, Quality Parameters, Yield and Yield Attributes of Sweet Corn (*Zea mays* L. sachharata) in Typic Haplusteps. *Indian Journal of Pure and Applied Biosciences*, 8(4), 660-668.

Reddy, K.H.N., Kothari, M., Reddy, K.S., Singh, P.K. and Yadav, K.K. 2020. Assessment of Surface Runoff using ArcSWAT for Rela Watershed, Rajasthan, India. *Journal of Geography, Environment and Earth Science International,* 24(10), 22-32.

Yadav, K.K., Meena, M.K., Mali, N.L. and Raj, J.T. 2022. Effect of integrated nutrient management on symbiotic efficiency and soil fertility under green gram [Vigna radiata (L.) Wilczek] cultivation. *Pollution Research*, 41(1), 256-262.

Gautam, V.K., Kothari, M., Singh, P.K., Bhakar, S.R. and Yadav, K.K. 2022. Decadal Groundwater Level Changes in Pratapgarh District of Southern Rajasthan, India. *Ecology Environment and Conservation,* 28 (1), 283-289.

Gautam, V.K., Kothari, M., Singh, P.K., Bhakar, S.R. and Yadav, K.K. 2022. Analysis of groundwater level trend in Jakham River Basin of Southern Rajasthan. *Journal of Groundwater Science and Engineering,* 10 (1): 1-9.

Yadav, M., Yadav, K.K. Singh, D.P., Lakhawat, S.S. and Vyas, A.K. 2021. Effect of irrigation frequency and zinc fertilization on growth and yield of Indian mustard (Brassica juncea (L.). *The Pharma Innovation Journal,* 10(9), 1427-1431.

Sharma, Vikas, Singh, P.K., Bhakar, S.R., Yadav, K.K., Lakhawat, S.S. and Singh, Manjeet 2021. Pan evaporation and sensor based approaches of irrigation scheduling for crop water requirement, growth and yield of okra. *Journal of Agrometeorology,* 23(4), 243-248.

Gautam, V.K, Kothari, M., Singh, P.K., Bhakar, S.R. and Yadav, K.K. 2021. Determination of Geomorphological Characteristics of Jakham River Basin using GIS Technique. *Indian Journal of Ecology*, 48(6), 1627-1634.

Jat, H., Yadav, K.K., Meena, R.H., Jat, G., and Singh, D.P., Mundra, S.L. and Jain, H.K. 2021. Productivity of Maize as Influenced by Soil and Foliar Application of Zinc and Iron. *Indian Journal of Fertilisers,* 17 (2), 652-657.

Sharma, Vikas and Yadav, K.K. 2021. Comparative study on Crop Water Requirement Using CROPWAT Model for Different Vegetable Crops Grown Under Protected and Open Field Cultivation. *Indian Journal of Ecology*, 48(2), 588-591.

STAFF POSITION 2021

Almora	
Chief Scientist	Dr. S.C. Panday
Soil Physicist	Dr Manoj Parihar
Agril Chemist	Tilak Mondal
Agril. Engineer	Er Shyamnath
Ayodhya	
Chief Scientist	Dr. H.C. Singh
Agril. Engineer	Er. R.C. Tiwari
Jr. Agronomist	Dr. B.N. Singh
Belavatagi	
Chief Scientist	Dr. S.A. Gaddanakeri
Soil Physicist	Dr. Vijaya Kumar. C
Agril. Engineer	Dr. P. S. Kanannavar
Coimbatore + Madurai + Bhavanisagar	
Chief Scientist	Dr. V. Ravikumar
Agril Engineer (SWCE)	Dr. G. Thiyagarajan
Agril Engineer (SWCE)	Dr. M. Nagararajan
Soil Scientist/Ag Chemist	Dr. R. Indirani
Agronomy	Dr. T. Sampathkumar
Chalakudy	
Chief Scientist	Dr. Mini Abraham
S & W Engineer	Dr. Shyla Joseph
Soil Physicist	Dr. Bhindhu P. S.
Soil Scientist/Ag Chemist	Dr. Mariya Dainy M.S.
Chiplima	
Chief Scientist	Dr. A.K. Mohanty
Agril. Engineer	Dr. S. N. Bansude
Dapoli	
Chief Scientist	Dr. R.T. Thokal
Agril. Engineer	Dr. B.L. Ayare
Jr. Agronomist	Dr. M.S. Jadhav

Gayeshpur	
Chief Scientist	Dr. S.K. Patra
Agril. Engineer	Er. S. Saha
Jr. Agronomist	Dr. R. Poddar
Hisar	
Chief Scientist	Dr. Manoj K. Sharma
Agril. Engineer	Sushil Kumar Singh
Soil Physicist	Muli Devi Parihar
Jammu	
Chief Scientist	Dr. A.K. Sharma
Soil Scientist	Dr. Abhijit Samanta
Jr. Agronomist	Dr. Vijay Bharti
Jabalpur + Powarkheda	
Chief Scientist	Dr. M.K. Awasthi
Scientist SWCE	Dr. Y.K. Tiwari
Agronomist	Dr Vijay Agrawal
Jorhat	
Chief Scientist	Vacant
Soil Physicist	Dr. Bipul Deka
Agril. Engineer	Er. Kabyshree Choudhury
Junagadh	
Chief Scientist (S&W Engg)	Dr. H.D. Rank
S&W Engineer (Asst Professor)	Prof. P.B. Vekariya
Agril. Engineer (S&W Engg)	Prof. R.J. Patel
Kota	
Chief Scientist	Vacant
Asst Professor (Soil Science)	Dr. Rajendra Kumar Yadav
Asso Professor (Agronomy)	Dr. Baldev Ram

Ludhiana + Bathinda	
Chief Scientist	Dr. Rajan Aggarwal
Asst. Res. Engineer	Dr. Sanjay Satpute
Soil Physicist	Dr. K.S. Sekhon
Asst. Agronomist	Dr. Anureet Kaur
Asst. Agril. Engineer	Dr. Anurag Malik
Morena	
Chief Scientist	Dr. Y.P. Singh Dr. Bharat Singh (since 27.1.22)
Agronomist	Dr. Sandeep S. Tomar
Agril. Engineer	Er. S.K. Tiwari Dr. S.P. Shrivastava
Navsari	
Chief Scientist	Dr. J.M. Patel
Asso Professor (Soil Science)	Dr. S. L. Pawar
Assst Professor (Agril. Engg)	Er. N.G. Savani
Palampur	
Chief Scientist (Agronomy)	Dr Anil Kumar
Professor (Soil Physics)	Dr. S.K. Sandal
Pantnagar	
Chief Scientist	Dr. Yogendra Kumar
Soil Physicist	Dr. Harish Chandra
Agril. Engineer	Dr. Vinod Kumar
Agronomist	Dr. Gurvinder Singh
Agril Engineer	Dr. U.C. Lohni
Parbhani	
Chief Scientist	Dr. H.W. Awari (Additional charge)
Agronomist	Prof. G.D. Gadade
Pusa	
Chief Scientist	Dr. S.P. Gupta
Agril. Engg	Dr. S.K. Jain
Soil Scientist	Dr. A.K. Singh
Agril. Engineer	Dr. Ravish Chandra
Agronomist	Dr. Rajan Kumar

Rahuri	
Chief Scientist	Dr. A.V. Solanke
Agril Engineer	Dr. S.D. Dahiwalkar (retired on 30.6.21)
Agronomist	Prof. S.S. Tuwar (retired on 30.11.21)
Soil Scientist	Dr. C.R. Palwe
Agril Engineer (Irrigation & Drainage Engg.)	Dr. P.G. Popale
Raipur + Bilaspur	
Chief Scientist	Dr. M.P. Tripathi
Sr. Scientist (SWE)	Dr. Dhiraj Khalkho
Sr. Scientist (SWE)	Dr. Devesh Pandey
Agronomist	Dr. Geet Sharma
Soil Physicist	Sh. P.K. Keshry
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	Dr. R.P.S. Chauhan
Soil physicist	Vacant
Agronomist	Vacant
Agril. Engineer	Vacant
Jr. Agronomist	Vacant
Udaipur	
Chief Scientist (Soil & Water Engg)	Dr. P.K. Singh
Asso Professor (Soil Science)	Dr. K.K. Yadav
Asst Professor (Soil & Water Engg)	Dr. Manjeet Singh

BUDGET ALLOCATION 2021-22

Figures in ₹

S.N	Centre Name	Grant in Aid Salary	Grant in Aid General			Total General	Grant in Aid Capital		Total Capital	SCSP				G. Total
			Res.	Operational	TA		Equipment	IT		Res.	Opr.	Capital (Eqip.)	Total	
1	PAU, Ludhiana	11100000	500000	450000	25000	975000	372000	100000	472000				0	12547000
2	UAS, Dharward	10200000	350000	250000	14000	614000	125000		125000				0	10939000
3	TNAU, Coimbatore	15000000	600000	550000	40000	1190000	200000		200000	100000	120000		220000	16610000
4	IGKV, Raipur	12400000	500000	450000	16000	966000	200000	50000	250000	100000	120000		220000	13836000
5	KAU, Thrissur	6400000	550000	430000	34000	1014000	125000		125000				0	7539000
6	OUAT, Bhubaneswar	4400000	400000	250000	14000	664000	125000		125000				0	5189000
7	BSKKV, Dapoli	11000000	550000	400000	14000	964000	450000		450000	100000	120000		220000	12634000
8	NDUAT, Faizabad	7142000	400000	340000	24000	764000	125000		125000				0	8031000
9	BCKV, Kalyani Nadia	5500000	400000	250000	14000	664000	150000		150000				0	6314000
10	CCSHAU, Hissar	5300000	300000	225000	14000	539000	125000		125000				0	5964000
11	SKUAST, Jammu	9250000	500000	350000	14000	864000	125000	50000	175000	100000	120000	122000	342000	10631000
12	MPUAT, Udaipur	7000000	400000	250000	14000	664000	125000		125000	100000	120000		220000	8009000
13	AU, Kota(Raj.)	6000000	400000	250000	14000	664000	125000		125000				0	6789000
14	JAU, Junagadh	6150000	400000	250000	14000	664000	125000		125000				0	6939000
15	RVSKVV, Morena	6000000	690000	500000	24000	1214000	125000		125000				0	7339000
16	NAU, Navsari	6000000	400000	300000	14000	714000	125000		125000				0	6839000
17	CSKHPKV, Palampur	6000000	600000	500000	14000	1114000	125000		125000				0	7239000
18	GBPUAT, Pantnagar	16800000	400000	260000	23000	683000	125000		125000				0	17608000
19	VNMKV, Parbhani	5500000	400000	247000	14000	661000	125000		125000	100000	108000		208000	6494000
20	JNKVV, Jabalpur	8545000	400000	233000	14000	647000	125000		125000				0	9317000
21	MPKV, Rahuri	11720000	590000	390000	43000	1023000	125000		125000				0	12868000
22	SKRAU, Bikaner	5500000	275000	175000	14000	464000	125000		125000			0	0	6089000
23	AAU, Jorhat	8394000	500000	550000	14000	1064000	125000		125000	70000	80000	0	150000	9733000
24	Dr.RPCAU, Pusa	0	650000	400000	23000	1073000			0				0	1073000
25	ICAR-RC-NEH, Umiam	0	350000	275000	14000	639000			0			0	0	639000
26	VPKAS, Almora	0	300000	225000	13000	538000			0			0	0	538000
27	IIWM(PCU)	0	0	1400000	0	1400000			0			0	0	1400000
	Sub Total	**191301000**	11805000	10150000	489000	**22444000**	3622000	200000	**3822000**	670000	788000	122000	**1580000**	**219147000**

भाकृअनुप - भारतीय जल प्रबंधन संस्थान

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