भारत के हिमालयी क्षेत्र का भूजल परिदृश्य
Ground Water Scenario of Himalayan Region, India

संपादन/Edited by

सुशील गुप्ता
अध्यक्ष
Sushil Gupta
Chairman

केंद्रीय भूमि जलबोर्ड
Central Ground Water Board
जल संसाधन मंत्रालय
Ministry of Water Resources
भारत सरकार
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सत्यमेव जयते

प्रस्तावना

हिमालयी क्षेत्रों में अवस्थित भारत के पर्वतीय राज्य देश की मनोहर धरोहर हैं । बर्फ से ढके पर्वत, हरे घास के मैदान इन राज्यों के दुर्गम स्थानों को भी निवास योग्य बना देता है। यद्यपि इन क्षेत्रों मे जल की प्रचुरता है, परंतु पेय जल की उपलब्धता हमेशा से चिंता का विषय रहा है। झरने और भूजल विभिन्न उपयोगों के लिए जल की मांग को पूरा करने में महत्वपूर्ण भूमिका निभाते हैं। विविध विकासात्मक गतिविधियों के कारण इन जल स्रोतों के अवैज्ञानिक दोहन के परिणामस्वरूप विभिन पर्यावरीणीय समस्याएं पैदा हुई हैं तथा इन स्रोतों के स्थायित्व पर संकट आ गया है । प्रत्याशित जलवायु परिवर्तन से यह समस्या और अधिक बढ़ सकती है। इन क्षेत्रों में जल संरक्षण और झरना शेड विकास के लिए उपयुक्त कार्यनीति विकसित करना अत्यंत अनिवार्य है।

केंद्रीय भूजल बोर्ड और अन्य एजेंसियों द्वारा किए गए अध्ययनों और अन्वेषणों से व्यापक रूप में विपुल आकड़ों के उत्सर्जन मे सहायता प्राप्त हुई है जिसे एकत्रित कर हिमालयी क्षेत्रों के भूजल परिदृश्य की एक झलक प्रस्तुत करने का प्रयास किया गया है। पहाड़ी क्षेत्रों की भूजल वैज्ञानिकी संरचना अत्यंत जटिल होती है जोकि विभिन्न शैल प्रकारों से निर्मित जलभृतों द्वारा आच्छादित होता है । यहां भूजल की उपलब्धता में दिक्काल में मौलिक विविधता होती है । इन जलभृतों के पुनर्भरण का प्राथमिक स्रोत झरनें, नदियां और ग्लेशियरों से पिघला जल है। केंद्रीय भूमि जल बोर्ड द्वारा किए गए अध्ययनों को इस रिपोर्ट में संकलित किया गया है तथा आकड़ों और जानकारी को एक साझा मंच पर लाने तथा हिमालयी क्षेत्रों में झरनों और भूजल के प्रभावी प्रबंधन के लिए व्यवहार्य विकल्प का सुझाव देने का प्रयास किया गया है।

ऐसी आशा है कि यह रिपोर्ट भारत के हिमालयी राज्यों में भूजल के विकास तथा झरनो के संरक्षण में कुशल नियोजन एवं मार्गदर्शिका तैयार करने में आयोजकों को और प्रशासकों के लिए अत्यंत सहायक सिद्ध होगा ।

सुशील गुप्ता
अध्यक्ष,
केंद्रीय भूमि जल बोर्ड

Bhujal Bhawan, NH-IV, Faridabad - 121001
Tel : 0129-2419075, Fax : 0129-2412524 Email : chmn-cgwb@nic.in
Website : www.cgwb.gov.in, www.mowr.gov.in

सुशील गुप्ता
Sushil Gupta

अध्यक्ष
केन्द्रीय भूमि जल बोर्ड
भारत सरकार
जल संसाधन मंत्रालय
Chairman
Central Ground Water Board
Government of India,
Ministry of Water Resources

Preface

The Hill States of India encompassing the Himalayas are the one of the most captivating areas of the nation. The snow-clad mountains, verdant green meadows make these States tantalizing places to live. Though there is abundance of water in the form of snow and rain, access to potable water has always been a matter of concern in these areas. Springs and ground water play important role in meeting the demand for various uses. The unplanned exploitation of these water sources due to multifarious developmental activities has resulted in varying environmental problems and jeopardizing the sustainability. The anticipated climate change may further aggravate the problem. It is imperative to develop proper strategies for ground water exploration as well as conservation and spring shed development in these areas.

Studies and investigations taken up by the Central Ground Water Board and other agencies have helped generate a vast amount of data in a comprehensive manner which has been collated to provide a glimpse of ground water scenario of the Himalayan regions. The hill areas represent a complex hydrogeological set up underlain by aquifers made up of diverse rock types where the occurrence of groundwater varies radically in time and space. The primary sources of recharge for these aquifers are springs, rivers and melt water from glaciers. Studies carried out by CGWB have been compiled in this report and an attempt has been made to bring the data and information on a common platform and suggest feasible options for effective management of springs and ground water in the Himalayan regions.

It is hoped that the report would be of immense help for the planners and administrators in the Himalayan States of India for efficient planning and preparation of road map for a holistic development of ground water and conservation of springs.

Sushil Gupta
Chairman, CGWB

Bhujal Bhawan, NH-IV, Faridabad - 121001
Tel : 0129-2419075, Fax : 0129-2412524 Email : chmn-cgwb@nic.in
Website : www.cgwb.gov.in, www.mowr.gov.in

स्वच्छ सुरक्षित जल - सुन्दर खुशहाल कल

CONSERVE WATER - SAVE LIFE

भारत के हिमालयी क्षेत्र का भूजल परिदृश्य

अनुक्रमणिका

Ground Water Scenario of Himalayan Region of India

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भारत की उत्तरी सीमा के साथ लगभग 418357 वर्ग कि.मी. के विशाल क्षेत्र में फैले वक्राकार हिमालय का छः भारतीय राज्यों नामतः जम्मू और कशमीर, हिमालय प्रदेश, उत्तराखंड, पश्चिम बंगाल, सिक्किम और पश्चिम से पूर्वी अरुणाचल प्रदेश के मुख्य भागों में विस्तार है। यह क्षेत्र मनोरम ऊंची पर्वत श्रेणियों, गहरी घाटियों, निचले गिरिपद के घने उष्णकटिबंधीय वनों, ऊपरी खंडों में पर्वत शिखराय एवं उप पर्वत शिखरीय–वनस्पति तथा पूर्व में वर्षा वनों से लेकर बंजर परा हिमालय में ठंडे मरुस्थल से घिरा हुआ है। पहाड़ियों में आबादी कम और घाटियों में अधिक है।

हिमालयी क्षेत्र से सटे हुए भारत के पूर्वोत्तर भाग में असम, मेघालय, नागालैंड, मणिपुर, मिजोरम, त्रिपुरा और अरुणाचल प्रदेश के कुछ हिस्से (चांगलांग और तिरप जिले) शामिल हैं। इस क्षेत्र का भौगोलिक क्षेत्रफल 1,78,370 वर्ग किलोमीटर है, जिसमें 60% क्षेत्र पहाड़ियों से ढका हुआ है और शेष क्षेत्र में असम में ब्रह्ममपुत्र घाटी, त्रिपुरा में बराक घाटियां और मणिपुर, नागालैंड, मेघालय और मिजोरम के पहाड़ी राज्यों में तलहटी और छोटी अन्तः पर्वतीय घाटियां है।

हिमालय का भारतीय उपमहाद्वीप और तिब्बती पठार की जलवायु पर गहरा प्रभाव है। ये इस उपमहाद्वीप में दक्षिण की ओर बहने वाली शीत, शुष्क आर्कटिक हवाओं को रोकता है जिसके परिणामस्वरूप दक्षिण एशिया अन्य महाद्वीपों की तुलना में ज्यादा गर्म रहता है। यह मानसून हवाओं के अवरोध के रूप में भी कार्य करता है, तथा इन हवाओं को उत्तर की ओर बहने के कारण पहाड़ी तलहटी क्षेत्र में भारी वर्षा होती है। ऊंचाई में बदलाव के कारण हिमालयी राज्यों में जलवायु में जगह जगह बदलाव होता है। मैदानी क्षेत्रों में सुहानी और शुष्क सर्दियां तथा भीषण गर्मी के साथ उप उष्णकटिबंधीय मानसून जलवायु है। पहाड़ी क्षेत्र में, जलवायु में उप–कष्णकटिबंधीय मानसून से उष्णकटिबंधीय अपलैंड के रूप में विविधता है। हिमालय में दक्षिण परिश्चम मानसून के कारण लगभग 80% वार्षिक वर्षा होती है और पूर्वोत्तर मानसून की वजह से वार्षिक वर्षा लगभग 20% होती है। राज्यों के अधिकांश उत्तरी हिस्से पूरे वर्ष बर्फ से ढके रहते हैं।

भारत का पूर्वोत्तर भाग, हिमालय क्षेत्र से सटे होने के कारण उप उष्णकटिबंधीय आर्द्र जलवायु और दक्ष्झिण पश्चिम मानसून से प्रभावित है। इस इलाके के चेरापूंजी (सोहरा) और मेघालय में मावस्यनरम जैसे क्षेत्रों में देश में सबसे ज्यादा वर्षा होती है। चेरापूंजी में लगभग 11430 मिमी औसत वार्षिक वर्षा होती है और चेरापूंजी के पश्चिम में एक गांव, मावस्यनरम में प्रतिवर्ष लगभग 17,800 मिमी वर्षा होती है।

भू–आकृतिक रूप से, हिमालय को शिवालिक तलहटी, निम्न हिमालय, वृहत हिमालय और परा हिमालय में विभाजित किया जा सकता है। सिंधु और उसकी सहायक नदियों, अलकनंदा, भागीरथी (अंततः गंगा नदी के रूप में बहती है) और ब्रह्ममपुत्र जैसी प्रमुख नदियां इन क्षेत्रों से बहती है। भारत का पूर्वोत्तर भाग, हिमालय क्षेत्र से सटे होने के कारण इनमे पहाड़ियां, अन्तः घाटियां और ब्रह्मपुत्र और बराक घाटियां जैसी विशाल नदी घाटियां है। हिमालय में प्रोटेरोज़ोइक से चतुर्धातुक की भूवैज्ञानिक संरचनाए है। प्रोटेरोज़ोइक संरचनाए संभवतः भारतीय प्रायद्वीप में सिंधु–गंगा मैदान के दक्षिण और पश्चिम से उत्तर की ओर विस्तार कर रहा हैं। मुख्य केंद्रीय प्रणोद (एमसीटी) निम्न हिमालय के मेटा–अवसादों को केंद्रीय क्रिस्टलीय शैलों से पृथक करता है। अधिकांश शैलों में विविध विकार एवं कायान्तरण हुआ है। भारत के पूर्वोत्तर भाग में हिमालय के निकटवर्ती क्षेत्रों में, असम–मेघालय पठार के स्थाई भूभाग तथा आर्कियन नीस वाले मिशिमी मासिफ और शिलांग समूह के शैल सीनोयोजिक शान/बर्मा/मलाया कार्बनिक संचलन से प्रभावित नहीं हुए हैं। तृतीयक अवसाद भू–अभिनति में निक्षेपित है तथा इनमें लगातार पर्वतन होता रहता है। ब्रह्मपुत्र, बैराक तथा अन्तरापर्वतीय संकरी घाटियों में नवीन जलोढ़ प्राप्त हुए हैं।

जटिल संरचना सहित विविध भूवैज्ञानिक संरचना, हिमालय क्षेत्र के भूजलवैज्ञानिक परिदृश्य को नियंत्रित करता है। इस क्षेत्र में भूजल के उदगम और बहाव में भू–आकृति महत्वपूर्ण भूमिका निभाती है। क्षेत्र का बड़ा हिस्सा क्रिस्टलीय, शिस्ट, मेटा तलछटी द्वारा और मेसोज़ोइक से पूर्व केम्ब्रियन युग के ज्वालामुखी चट्टानों द्वारा आच्छादित है, जिसमे नगण्य प्राथमिक संरध्रता है अतः भूजल केवल संरचना/चट्टानों में होता है तथा माध्यमिक संरध्रता विकसित होती है उदाहरणार्थ जोड़ों, विभंग, कमजोर समतलों और समाधान गुहाएं आदि। कई स्थानों पर संभावित विभंग 70 एमबीजीएल की गहराई तक पाए गए हैं जबकि दोहन के समय, बोर कुओं से 1–5 एलपीएस जल प्राप्त हो सकता है और जिसकी अधिकतम सीमा 15 एलपीएस है। इस इलाके में मुख्यतः फैली हुई आबादी की वजह से भूजल का विकास कम और सीमित है। तृतीयक

काल की अर्धसंपीडित संरचनायें मुख्य रूप से पश्चिमी हिमालय के पश्चिमी पूर्वी भू–उपनति रेखा तथा अरुणाचल, हिमालय और समस्त हिमायली क्षेत्र में शिवालिग में उपस्थित है। यहां भूजल अपक्षीण क्षेत्रों एवं द्वितीयक संरध्रता में पाया जाता है। विभंग/युग्म/भ्रंश मंडल द्वारा सीमित संभाव्यता वाले भूजल क्षेत्रों का निर्माण होता है, जिनका बोरवेलों के माध्यम से हैंडपंप स्थापित कर विकास किया जाता है। इनकी जल उत्पादन क्षमता <1.25 एलपीएस के लगभग है। असंपीडित संरचनायें मुख्य रूप से हिमालय के दक्षिणी भाग में रेखीय बेल्ट के रूप में उपरी अत्यंत नूतन युग से नूतन युग के गिरिपद अवसादो में पायी जाती हैं। इसके अतिरिक्त यह संरचनायें वृहद/लघु घाटी भराव अवसादों तथा हिमोढ, हिमजलीय एवं सरोवली निक्षेपों में भी पाया जाता है। भावर क्षेत्र, घाटी भराव निक्षेप और अन्तरापवर्ततीय घाटियों (दून घाटी) में नलकूपों की उत्पादकता 20–60 एलपीएस के मध्य है। हिमजलीय एवं हिमोढ निक्षेपों में नलकूपों की निस्सरण क्षमता 10–28 एलपीएस के मध्य है।

अधिकांश हिमालय क्षेत्र में भूजल के पुनर्भरण का मुख्य स्रोत ग्लेशियर हैं। तलहटी पहाड़ी क्षेत्रों में, काफी उच्च वर्षा भी भू जल के लिए प्रचुर मात्रा में योगदान देता है, लेकिन उच्च राहत और ढाल चट्टानी सतह के कारण वर्षा का बड़ा अनुपात बहाव के रूप में बाहर बह जाता है जिसके परिणामस्वरूप जलभृतों में इसकी अल्प मात्रा का ही प्रवेश होता है। भूजल अनुकूल परिस्थितियों में झरनों के माध्यम से बाहर आता है जो ग्रामीण और शहरी बस्तियों की जल आपूर्ति का प्रमुख स्रोत है। झरने भी इस क्षेत्र की सतह जल निकासी नेटवर्क के लिए अतिरिक्त जल का योगदान करते हैं। भारत के पूर्वोत्तर भाग में, हिमालय क्षेत्र से सटे होने के कारण भूजल आमतौर पर, समेकित संरचनाओं में अपक्षीण अवशेषों और विभंग/जोड़ों में होता है जो असम और मेघालय पठारो, मिकीर पहाड़ियों और इन्सेल्बेर्ग में ब्रह्मपुत्र नदी के दोनों किनारो में है। सभी पूर्वोत्तर राज्यों में भूजल तृतीयक चट्टानों के अर्द्ध संपीडिय सरंध्र संरचनाओं में होता है और ब्रह्मपुत्र और बराक घाटियों और कुछ अंतरपर्वतीय घाटियों में चतुर्धातुक युग के असंपिंडित संरचनाओं के रूप में होते हैं। समपीडित क्रिस्टलों और मेटा अवसादों से भूजल नलकूपों और सीमित उत्पादन (<1 से 3 एल पीएस) के बोर कुओं के माध्यम से निकाला जा सकता है। तृतीयक युग के अल्प संपिडित में तिपाह समूह के चट्टानों के दोहन से उच्च उत्पादन (20 से 40 एल पीएस) की उम्मीद है। काफी मोटी और अत्यधिक संभावित जलभृत, असंपिंडित संरचनाओं में मुख्य रूप से ब्रह्मपुत्र घाटी में पाए जाते हैं। नलकूपों की उत्पादकता 40–55 एलपीएस के मध्य है तथा सामानतया, सीमांत क्षेत्रों के किनारे की तरफ शिलांग पठार, मिरिक घाटी और नागा–पटकाई श्रृंखला में कम उत्पादन क्षमता (15 एलपीएस) है। तलहटी (भाबर और तराई क्षेत्र) के साथ और ब्रह्मपुत्र नदी के उत्तरी किनारों के पैच में असंपीडित संरचनायें अपेक्षाकृत कम क्षमता (40 आईपीएस) की होती हैं।

समानतया, हिमालय क्षेत्र में भू जल पीने और कृषि प्रयोजनों के लिए उपयुक्त है। तथापि, गर्म झरनों से सभी रासायनिक घटकों की सांद्रता काफी अधिक और स्वीकार्य सीमा से ऊपर है। अनुमत्य सीमा (> 1 मिलीग्राम/लीटर) से अधिक भू जल में आयरन जम्मू व कश्मीर (1.1–12.2 मिलीग्राम/एल) और सिक्किम (20 मिलीग्राम/एल के रूप में उच्च) के कुछ हिस्सों में पाए गए हैं। 45 मिलीग्राम/एल की स्वीकार्य सीमा से अधिक नाइट्रेट, ज्यादातर जम्मू एवं कश्मीर, हिमालय प्रदेश और उत्तराखंड के तराई क्षेत्रों में 50–394 मिलीग्राम/एल उथले जलभृतों में पाया गया है जिस कारण नलकूपों और नलकूपों में और चारों ओर मानवीय संक्रमण की उपस्थिति है। झरना जल अपेक्षाकृत स्वच्छ होता है लेकिन इसमे भी स्वीकार्य सीमा (1.5 मिलीग्राम/लीटर) से ऊपर फ्लोराइड सांद्रता भी जम्मू एवं कश्मीर के जम्मू और लद्दाख क्षेत्र में और हिमाचल प्रदेश के शिमला, मंडी, लाहौल और स्पीति जिलों में पाया गया है। सांद्रता 1.0 से 4.0 मिलीग्राम/लीटर के मध्य है तथा लद्दाख में यह 12 मिलीग्राम/एल की उच्च सांद्रता पायी गई है। यहाँ, नलकूप में 1.0–1.60 मिलीग्राम/एल नाइट्रेट की उच्च सांद्रता है। पर्यटन व्यापार और हिमालय क्षेत्र की मैदानी भूमि पर उद्योगों के विकास के कारण भू जल की गुणवत्ता के लिए खतरा पैदा हो रहा है। जम्मू एवं कश्मीर के उद्योगों के चारों ओर किए गए अध्ययनों से पता चला है कि भूजल में भारी धातु की सांद्रता बीआईएस की अनुमत्य सीमा के नीचे है सिर्फ कठुआ जिले में उथले भूजल के डग कुएं में मैंगनीज स्वीकार्य सीमा (0.3 मिलीग्राम/गुणवत्ता अच्छी और पीने योग्य है सिर्फ इसके कुछ हिस्सों के अतिरिक्त जहां लौह सांद्रता (1 मिलीग्राम/ली. की अनुमत्य सीमा से ऊपर) फ्लोराइड (1 मिलीग्राम/ली. की अनुमत्य सीमा से ऊपर) और आर्सेनिक (0.01 मिलीग्राम/ली. की अनुमत्य सीमा से ऊपर) है। असम, मेघालय, मणिपुर और त्रिपुरा के अधिकांश जिलों में लौह सांद्रता स्वीकार्य सीमा से अधिक है। यह अभिज्ञान सीमा (बीडीएल) से कम और 14.59 मिलीग्राम/लीटर के मध्य है। कार्बी आंगलोंग, नागांव और असम के कामरूप जिलों के कुछ हिस्सों में भूजल में फ्लोराइड की मात्रा अनुमत्य

सीमा। पीपीएम से अधिक है और जिसका रेंज 4.16 पीपीएम तक है। धेमाजी जिले और जोरहाट जिले के कुछ उथले जलभृतों में 0.01 मिलीग्राम/लीटर की अनुमत सीमा से अधिक आर्सेनिक संदूषण पाया गया है। मणिपुर घाटी के थौबल और विष्णुपुर जिलों के उथले भूजल में भी अनुमत सीमा से ऊपर आर्सेनिक सांद्रता की सूचना प्राप्त हुई है। जल के नमूनों के रासायनिक विश्लेषण से 0.1776 से 0.4994 मिग्रा/लीटर के मध्य आर्सेनिक सांद्रता दर्शाता का पता चला है।

हिमालय क्षेत्र में ज्यादातर पहाड़ियां और उच्च स्थलाकृतिक ढाल वाले पहाड़ है जहां सतही बहाव हमेशा भूजल प्रवेश की तुलना में काफी अधिक है। किसी भी राज्य या देश के समग्र विकास के लिए भूजल संसाधनों का विकास एक अभिन्न भाग है, अतः यह अनिवार्य है कि महत्वपूर्ण भूजल संसाधनों के नियोजित विकास के लिए भारतीय उपमहाद्वीप में हिमालय की इन पहाड़ी राज्यों के भूजल संसाधनों पर ध्यान दिया जाए। भूजल संसाधनों का आकलन जल संसाधन मंत्रालय, भारत सरकार के द्वारा गठित भूजल आकलन समिति (जीईसी–97) द्वारा संस्तुत पद्वति के आधार पर किया गया है। भूजल आकलन समिति (जीईसी–97) के नियम के अनुसार, 20% से अधिक ढलान वाले क्षेत्रों को भूजल पुनर्भरण के लिए उपयुक्त नहीं माना जाता है। फलस्वरूप, हिमालय राज्यों का एक बहुत बड़ा हिस्सा भूजल पुनर्भरण के लिए अनुपयुक्त माना जाता है और यहां भूजल संसाधनों की गणना काफी निम्न है। मार्च 2009 की स्थिति के अनुसार, हिमालय में निवल भूजल उपलब्धता 1012288.4 एमएएच है जबकि सभी उपयोग के लिए मौजूदा सकल भूजल ड्राफ्ट 247466 एचएएम है, हिमालय में भूजल विकास का चरण अरुणाचल प्रदेश में 0.066% से उत्तराखंड में 66.33% है। हिमालय में भूजल विकास की समग्र चरण 28.80% है। भूजल क्षमता का आकलन पूर्वोत्तर राज्यों असम, त्रिपुरा, मिजोरम पूर्वोत्तर राज्यों के लिए और नागालैंड, मणिपुर और मेघालय के कुछ हिस्सों में किया गया है। नागालैंड, मणिपुर और मेघालय के अधिकांश भाग पहाड़ी इलाके की वजह से भूजल पुनर्भरण के लिए उपयुक्त नहीं हैं। सभी पूर्वोत्तर राज्यों के लिए समस्त उपयोगों के लिए निवल भूजल उपलब्धता और सकल भूजल ड्राफ्ट क्रमशः 3283810 और 620,668 एचएएम और भूजल विकास का समग्र चरण 19% है। हिमालयी बेल्ट और इसके आसपास पूर्वोत्तर राज्यों में एक संसाधन के रूप में भूजल संबंधी विषयों और इसके प्रबंधन को विशेष महत्व दिया जाना है। सदियों पुराने समय से भारत के हिमालयी राज्यों के पूरे पहाड़ी जनसंख्या टीलों और पहाड़ी ढलानों में उनकी बस्ती होने के कारण अन्य घेरेलू उपयोगों के लिए भी पेयजल के रूप में नदियों और झरने के जल पर पूरी तरह से निर्भर रहे है। तरंगित क्षेत्रों में निर्माण कठिनाईयों के कारण विभिन्न भूजल संरचनाओं का व्यवहार में नहीं लाया जाता था तथापि, वर्तमान स्थिति में बढ़ती आबादी और जलवायु विपथन के कारण, पहाड़ी इलाकों में झरने और नदियों में भूजल की उपलब्धता दिन प्रतिदिन कम होती जा रही है। इसके परिणामस्वरूप यह अनिवार्य हो गया है कि और अधिक गहरे स्रोतों से भूजल का दोहन किया जाये ताकि स्थायी जल आपूर्ति को बनाये रखने के उद्देश्य से विभिन्न वैज्ञानिक उपायों द्वारा झरनों और निचली धाराओं के स्रोतों को पर्याप्त एवं बारहमासी बनाया रखा जा सके।

इस संबंध में भारत के हिमालयी क्षेत्रों में भूजल विकास से संबंधित कुछ महत्वपूर्ण मुद्दों पर निम्नलिखित अनुच्छेदों में संक्षिप्त चर्चा की गई है।

झरनों की स्थायित्वताः ग्रामीण और शहरी क्षेत्रों में झरना स्त्रोत पेयजल की आपूर्ति प्रणाली का मुख्य आधार है। अधिक ऊंचाई में भी सिंचाई मुख्यतया झरनो अथवा लघु सरिताओं पर आश्रित हैं। झरनो का सूखना और विभिन्न मौसमों के दौरान झरनो के निर्वहन में बदलाव मानवीय हस्तक्षेप (विभिन्न भूमि उपयोग की) और जलवायु परिवर्तन के कारण होता है। इस स्थिति से निपटने के लिए उचित झरना शेड विकास की आवश्यकता है।

बिखरी हुई आबादीः हिमालय क्षेत्र में बिखरी हुई आबादी जल आपूर्ति प्रणाली की आयोजना में समस्याएं पैदा करती है। कई झरने तलहटी या छोटी घाटियों में पाये जाते हैं जबकि कई बार ऐसा देखा गया है कि आबादी पहाड़ी की चोटी पर केंद्रित होती है।

सदियों पुरानी अवैज्ञानिक खेती और चराईः कई हिमालयी राज्यों में, पहाड़ी ढलानों में, झूम/स्थानांतरण खेती सामान्य हैं जिसके लिए वनों की कटाई की जाती है। इसी प्रकार पहाड़ियों में चराई के कारण भी चरागाह और पहाड़ी ढलानों में झाड़ियां नष्ट हो रही हैं। यह झरनों के निस्सरण को प्रभावित करता है तथा मृदा कटाव को बढ़ाता है।

शहरीकरण के कारण वनों की कटाईः बढ़ती जनसंख्या और शहरी स्थापना और सड़कों के विकास के कारण वनों की कटाई हुई है जिस कारण कई धाराएं या झरना स्रोत सूख रहे है।

जल निकायो पर मानवीय प्रभावः झीलों, नदियों एवं जलाशयों के किनारे अनियोजित शहरीकरण के कारण जलस्रोत सूख रहे है। ये जल आपूर्ति के स्रोत हैं जो भूजल के पुनर्भरण के रूप में कार्य करते है। कंडी/भाबर क्षेत्र टैंक/तालाबों के सूखने के कारण भारी जल की कमी का सामना कर रहे हैं। उच्च करेवा पठार भूमि भी जल की कमी का सामना कर रहा हैं। कंडी क्षेत्र और उच्च पठार इलाकों में जल स्तर काफी नीचे चला गया है।

विभिन्न मौसमो में जल आपूर्ति प्रणाली के अवरोधः कभी—कभी, अनिश्चित और मूसलाधार वर्षा के कारण, मौसमी नालो और झरना स्रोत क्षेत्रों में अत्यधिक गाद जमा हो जाती है जिस कारण जल आपूर्ति व्यवस्था में व्यवधान पैदा होता है। इसी तरह, जल धाराओं के साथ तूफान प्रवाह से भी झरनों या नदियों से जुड़े जल आपूर्ति पाइप लाइनें टूट जाती है। सर्दियों के दौरान ऊचे स्थानों पर ठंड के कारण पाइपलाइनों का जमना भी एक बारहमासी समस्या है।

सिंचाई प्रणाली की गैर मौजूदगी की वजह से निर्धन कृषि अर्थव्यवस्थाः वर्षा आधारित सिंचाई के अलावा, जल स्रोतों को विकसित नहीं किया गया है जिस कारण हिमालयी क्षेत्रों की पहाड़ी कृषि में एक—फसल प्रणाली है। इस इलाके की अवस्थिति को भी बाधा माना जा सकता है।

जलवायु परिवर्तन और वर्षा विपथनः जलवायु परिवर्तन के कारण ग्लेशियरों की कमी से, नदियों को हिम पिघलन से प्राप्त होने वाले जल में कमी हुई है जो हिमालय में जल की उपलब्धता में एक बड़ी समस्या खड़ी कर सकता है। इसी तरह, अनियमित बारिश के कारण भी प्राकृतिक भूजल पुनर्भरण और कई बड़े तूफानी प्रवाह में कमी हुई है जिसके परिणामस्वरूप बाढ़ तथा जन आवाजाही/भूस्खलन हुए हैं।

भूजल में उच्च लौहः सिक्किम, जम्मू एवं कश्मीर और असम, त्रिपुरा, मेघालय एवं मणिपुर में पेयजल में अनुमत्य सीमा से अधिक लौह की उपस्थिति पायी गयी है।

भूजल में उच्च फ्लोराइड की मात्राः कुछ इलाकों के जलाशयों में लगे हैंड पंप नलकूपों मे पेयजल मानकों की अनुमत्य सीमा से अधिक फ्लोराइड पाए गए है इससे न केवल सतही जल उपलब्धता प्राप्त होगी बल्कि जलभृतों के पुनर्भरण में भी मदद मिलेगी।

दून घाटी में विशेष ड्रिलिंग तकनीक की आवश्यकताः दून घाटी में, बोल्डर संरचना, सामान्य स्थिति, यहां बोर होल/नलकूप निर्माण बहुत धमा एवं महंगा है। नलकूपों की स्थापना के लिए विशेष तकनीक की जरूरत है। यह देखा गया है कि बोल्डर संरचना सहित अर्धसंपीडित से असंपीडित असंरचनाओं की पहाड़ी तलहटी क्षेत्रों में संघाद—धूर्णी संयोजन (परकुशन—रोटरी रिग उपयुक्त है। इसी तरह, ओडेक्स—डीटीएच युक्त रिग बोल्डर और समेकित संरचनाओं वाली घाटियों और ढलान में उपयुक्त होगा।

पहाड़ी समुदाय के लिए जन जागरूकता और प्रशिक्षण की आवश्यकताः हिमालयी राज्यों में मौजूदा जल संबंधी मुद्दों के साथ—साथ कृत्रिम भूजल पुनर्भरण और वर्षा जल संरक्षण की स्थायित्वता के लिए आयोजित किए जा रहे जन जागरूकता कार्यक्रम पर्याप्त नहीं है।

जल संसाधनों के विकास के लिए विस्तृत सूक्ष्म स्तरीय सर्वेक्षण/जांचः हिमालय के निचले भागों तथा ऊपरी हिमालय में जल संरक्षण पर विशेष जोर देते हुए विस्तृत सूक्ष्मस्तरीय भूजल वैज्ञानिक सर्वेक्षणों की आवश्यकता है। अदृढ़ अथवा शिथिल संरचना और भूस्खलन एवं मृदा कटाव वाले संवेदनशील स्थलों की पहचान करने पर भी जोर दिया जाना चाहिए।

जल संसाधनों की रक्षा के लिए पर्यावरणीय निगरानी का अधिनियमनः समय—समय पर आगामी संरचनात्मक विकास भी इस स्थिति के उत्तरदायी होता है जिसके कारण जल निकायों के साथ—साथ मौजूदा झरना प्रवाह प्रभावित होता है। लुप्त हो जाता है। अतः सरकार के वैज्ञानिक अभिकरणों द्वारा आगामी परियोजनाओं का पर्यावरणीय मूल्यांकन एवं पुनरीक्षण होना चाहिए।

EXECUTIVE SUMMARY

The arc-shaped Himalayas extend along the entire northern boundary of India cover a vast area of about 418357 Sq.km. and span six Indian States viz. Jammu and Kashmir, Himachal Pradesh, Uttaranchal, West Bengal, Sikkim and major part of Arunachal Pradesh from west to east. The area offers a spectacular terrain having high mountain ranges, deep valleys, a fantastic variety of vegetation ranging from dense tropical forests of the lower foothills to alpine and sub-alpine vegetation in the higher reaches and from the rain forests of the east to the cold desert in the barren Trans Himalayas. The hills are sparsely populated and the population is more in valleys.

The north-eastern part of India, contiguous to Himalayan area, covers the States of Assam, Meghalaya, Nagaland, Manipur, Mizoram, Tripura and parts of Arunachal Pradesh (Changlang & Tirap districts). The Region has a geographical area of 1,78,370 sq. km., 60% of which is occupied by the hills and the rest by the Brahmaputra valley in Assam, the Barak valleys of Tripura and the foothills and small intermontane valleys in the hill states of Manipur, Nagaland, Meghalaya and Mizoram.

The Himalayas have a profound effect on the climate of the Indian subcontinent and the Tibetan plateau. They prevent frigid, dry Arctic winds blowing south into the subcontinent, which keeps South Asia much warmer than corresponding temperate regions in the other continents. It also forms a barrier for the monsoon winds, keeping them from travelling northwards, and causing heavy rainfall in the foothill region. The climate within Himalayan States changes from place to place due to variations in the altitude. The plain areas experience sub-tropical monsoon climate having mild and dry winter and hot summer. In hilly region, the climate varies from sub-tropical monsoon to tropical upland. The Tropical upland climate has mild winter, dry winter and short warm summer. Nearly 80% of annual rainfall occur in Himalayas due to southwest monsoon and nearly 20 % of annual rain fall occur in Himalayas due to Northeast monsoon. The northern most part of the state is covered by snow round the year.

The northeastern part of India, contiguous to Himalayan area, enjoys sub-tropical humid climate and experiences the South -West monsoon. The region receives highest rainfall in the country in areas like Cherrapunjee (Sohra) and Mawsynram in Meghalaya. Cherrapunji has an average annual precipitation of about 11,430 mm and in Mawsynram, a village directly west of Cherrapunji, rainfall is around 17,800 mm per year.

Geomorphologically, the Himalayas can be divided into Siwalik foothills, Lesser Himalaya, Greater Himalaya and Trans Himalaya. The major rivers like Indus & its tributaries, Alakananda, Bhagirathi (which ultimately flows as the Ganges), Brahmaputra are flowing through this Region. The north-eastern part of India, contiguous to Himalayan area, has denudational hills, intermontane valleys and the vast river valleys like Brahmaputra and Barak valleys.

In the Himalaya, geological formations range in age from the Proterozoic to Quaternary. The Proterozoic formations are possibly the northward extension of the sequences exposed in the south and west of Indo-Gangetic plain in the Indian peninsula. The Main Central Thrust (MCT) separates the low grade metasediments of Lesser Himalaya from the Central crystalline rocks. Most of the rocks have been subjected to multiple deformation and metamorphism.

In north-eastern part of India, contiguous to Himalayan area, the stable landmass of Assam-Meghalaya Plateau and the Mishimi massif containing Archaean Gneisses & Shillong Group of rocks were unaffected by Cenozoic Shan/ Burmese/ Malayan orogenic rhovement. Tertiary sediments are deposited in geosyncline and subjected to repeated orogenesis. Recent alluvial deposits are found to occur in Brahmaputra, Barak and intermontane narrow valleys.

The varied geological set up coupled with complex structures, controls the hydrogeological scenario of the Himalayan region and in addition, the morphology plays an important role on the occurrence and movement of ground water over the area. At the larger part of the area, underlain by crystalline rocks, schistose, meta-sedimentaries and volcanic rocks of Precambrian to Mesozoic age which have negligible primary porosity, the ground water occurs only in the formation/rock where the secondary porosity has developed e.g. joints, fractures, weaker planes and solution cavities etc. At places, potential fractures are encountered within 70 mbgl and while tapping, the bore wells may yield to the tune of 1-5 Ips and as high as 15 Ips. By and large the development of ground water over the terrain is low and of limited extent, mainly due to dispersed population. Here ground water in the secondary porosities/ weak zones, at places, come out as seepage through springs due to high relief and are utilized as water sources. The semi-consolidated formation of Tertiary age occupies mainly west-east trending linear tract in the Western Himalaya & Arunachal Himalaya and Siwaliks in entire Himalayan areas and ground water occurs in weathered zones and in secondary porosities. The fractures/ joints/ fault zones form moderately potential ground water zones which are developed through hand pump fitted bore wells yielding to the tune of <1-25 Ips. The unconsolidated formation occurs in Piedmont deposits belonging to Upper Pleistocene to Recent age mainly in the southern most part of the Himalayan area as a linear belt. Besides, the formation, also occurs as major/ minor/ valley fill deposits and as moranic, glacio-fluvial and lake deposits. In Bhabar zone, valley fill deposits and in intermontane valleys (Dun Valley), the tube wells may yield to the tune of 20- 60 Ips. In fluvio-glacial and moranic deposits, the tube wells may discharge 10-28 Ips.

The chief source of recharge to ground water in most of the Himalayan Region is the glaciers. In foothill areas, rainfall being quite high also contribute copious amount to ground water, but due to high relief and sloppy rocky surface, larger proportion of the precipitation flows out as over land flow resulting in a meagre amount to infiltrate to subsurface ground water bodies. Ground water comes out as seepage through springs under favourable situation and forms the major source of water supplies to rural and urban settlements. Finally the springs also contribute additional water to the surface drainage network of the area.

In north-eastern part of India, contiguous to Himalayan area, ground water generally occurs in weathered residuum and fractures/ joints in consolidated formations which occupy Assam and Meghalaya plateau, Mikir hills and inselbergs in both banks of the River Brahmaputra and in porous formations comprising semi-consolidated formations of Tertiary rocks in all the north eastern states and unconsolidated formations of Quaternary age in the Brahmaputra & Barak valleys and some intermontane valleys. Ground water in consolidated crystallines and meta-sedimentaries may be extracted through dug wells and bore wells of limited yield (<1 to 3 Ips). Amongst the semi-consolidated formation of Tertiary age, moderately higher yield (20 to 40 Ips) is expected in the tube well tapping Tipam Group of rocks. Fairly thick and highly potential aquifers are found to occur in unconsolidated formations, mainly in Brahmaputra valley and the yield of tube wells, in general, varies from 40-55 Ips with low yield prospect (about 15 Ips) in the marginal areas fringing Shillong Plateau, Mikir Hills & Naga-Patkai range. The unconsolidated formations along foothills (Bhabar &

Tarai zone) and in patches in north bank of the Brahmaputra river have comparatively less potentiality (within 40 Ips).

Ground water in Himalayan Region is in general good and potable for drinking and agricultural purposes. However, the concentrations of all the chemical constituents in hot springs are quite high and above permissible limit. Iron in ground water beyond permissible limit (>1 mg/l) is reported from some parts of Jammu & Kashmir (1.1 to 12.2 mg/l) and Sikkim (as high as 20 mg/l). Nitrate more than the acceptable limit of 45 mg/l has been observed in shallow aquifers to the tune of 50-394 mg/l mostly in valley areas of Jammu & Kashmir, Himachal Pradesh and Uttarakhand, which is attributed to anthropogenic contamination in and around the dug wells & shallow tube wells. Spring water is relatively fresh. Fluoride concentration above permissible limit (1.5 mg/l) is also observed in spring water in Jammu & Ladakh Regions of J & K State and in Simla, Mandi and Lahaul & Spiti districts in Himachal Pradesh. The concentration in general ranges from 1.0 to 4.0 mg/l and as high as 12 mg/l in Ladakh Region. Here, the tube well water is also having marginally higher concentration of nitrate to the tune of 1.0-1.60 mg/l. The development of tourist trade and growth of industries in plain lands of Himalayan region gradually pose threat to ground water quality. However, till data, ground water pollution has not been reported for the disposal of industrial waste and effluents. Studies carried out in and around the industries in J & K State showed that the concentration of heavy metal in ground water is below permissible limits of BIS, except manganese in shallow ground water in few dug wells of Kathua district where it is found more than permissible limit (0.3 mg/l).

The quality of ground water in the North Eastern States, contiguous to Himalayan Region, is found to be good and potable, except higher concentration of Iron (beyond permissible limit of I mg/l), Fluoride (beyond permissible limit of 1 mg/l) and Arsenic (above permissible limit of 0.01 mg/l) in parts of North Eastern States. Iron concentration exceeds permissible limit in most of the districts of Assam, Meghalaya, Manipur and Tripura. It ranges from below detection limit (BDL) to 14.69 mg/l. Fluoride content in ground water in parts of Karbi Anglong, Nagaon and Kamrup districts of Assam exceeds the permissible limit of 1 ppm and ranges upto 4.16 ppm. Arsenic contamination above permissible limit of 0.01 mg/l has been found to occur in shallow aquifers in parts of Dhemaji district and Majuli area of Jorhat district. The maximum concentration of 0.09 mg/l has been recorded. Arsenic concentration above permissible limit in shallow ground water has also been reported from Thoubal and Bishnupur districts of Manipur valley. Chemical analysis of water samples showed that arsenic concentration varies from 0.1776 to 0.4994 mg/l.

The Himalayan Region mostly represent the hills and mountains having higher topographical gradient where surface run off component is always much greater than the groundwater infiltration. As groundwater resources form an integral part of water resources development for an all out development of any state or country, it is obligatory to deduce the groundwater resources of these hilly mountainous states of Himalayas in Indian subcontinent for planned development of the vital groundwater resources. Ground water resources has been computed based on the methodology suggested by Groundwater Estimation Committee (GEC-97) constituted by the Ministry of Water Resources, Government of India. As per the GEC-97 norms, the areas having more than 20% slopes are not considered suitable for ground water recharge. Consequently a lion's share of the Himalayan states is considered unsuitable for ground water recharge and the groundwater resources arrived at through calculation is at the low key. As on March, 2009 the Net. Ground Water Availability in the Himalayas is 1012288.4 ham, while the existing Gross Ground Water Draft for All Uses comes upto 247466 ham. The stage of Ground Water Development in the Himalayas is varying from 0.066 in Arunachal Pradesh to 66.33% in Uttarakhand. The overall stage of groundwater development in Himalayas is 28.80%.

Assessment of Ground Water Potential as on March, 2009 has been done for the North Eastern States of Assam, Tripura, Mizoram and in parts of Nagaland, Manipur and Meghalaya. Most part of Nagaland, Manipur and Meghalaya are not suitable for ground water recharge due to hilly terrain. However, the Net Ground Water Availability and Gross Ground Water Draft for All Uses have been computed for all the north eastern states are 3283810 ham and 620668 ham respectively. The overall stage of ground water development is 19%.

Issues on groundwater as a resource and its management, in the Himalayan belt and its contiguous area in North Eastern States need to be attributed special significance. Since age old time the entire hilly population of the Himalayan states of India remained totally dependent on streams and spring water for drinking as well as for other domestic uses because of their habitation in hill tops and hill slopes. Various ground water structures were not in practice due to their constructional difficulties in, undulating terrains. But in the present situation of growing population as also due to climatic aberration, availability of groundwater in springs and streams in mountainous terrains is becoming scarce day by day. This has warranted the necessity of deciphering groundwater from further deeper sources as also to make the spring and lower order stream sources adequate and perennial adopting various scientific measures so that sustainable water supply may be continued.

In this regard, some of the important issues related to ground water development in the Himalayan areas of India have been discussed briefly in the following paragraphs.

- **Spring sustainability:** In majority of the rural as also urban areas spring sources form the backbone of drinking water supply system. Irrigation practices in the higher altitude are also mostly banking on springs or initial order streams, fed by the springs. Drying of springs and variations in discharge of spring during different seasons are being caused due to the affects of human interventions (of various land use) as also climatic change. Proper spring shed development is required to tackle the situation.

- **Dispersed population:** Scattered population in Himalayas creates problem in planning of water supply system. Many of the springs are found to occur in the hillslopes or small valleys while many times it could be seen that the population is concentrated on the hill top,

- **Unscientific age old cultivation practices and grazing:** In many of the Himalyan States, in the hill slope, Jhum/ shifting cultivation are common method of cultivation for which deforestation is being done. Similarly, grazing practices in the hills is also destroying the grassland and the bushes in the hill slopes. It affects discharge of the springs and accentuates soil erosion.

- **Deforestation due to urbanization:** The impact of deforestation to negotiate with the rise in population and development of urban establishment and roads, many streams or spring sources are being dried up.

- **Anthropogenic impact on water bodies:** Unplanned urbanization along lakes, rivers and water bodies has resulted into drying up of the water bodies. These are the sources of water supply as well as they act as the recharging bodies to ground water. Kandi/Bhabar areas are facing acute shortage of water because of drying of tanks/ponds. High Karewas plateau. lands are also facing shortage of water. Deep water levels exist in Kandi area and in high plateau table lands.

- **Disruption of water supply system in various seasons:** Some time erratic and torrential rainfalls causing high siltation in seasonal nalas and springs source areas which results into disruption in water supply system. Similarly the storm flow along the channel also breaks the long water supply pipe lines from springs or streams. In high altitude ice formation in the pipelines during winter is a perennial problem.

- **Poor agrarian economy due to non existence of irrigation system:** Other than rain-fed irrigation, water sources have not been developed adequately in the Himalayan areas causing one crop system in hill agriculture. The terrain condition may be a hindrance.

- **Climatic changes and rainfall aberration:** It has been noticed by the Scientists that due to climatic changes, evident through gradual rise in temperature resulting into recession of glaciers which in turn will retard the snow melt input to river and springs and may pose a major problem in water availability in Himalayas. Similarly erratic rainfall is also influencing reduction in natural groundwater recharge and large storm flow causing flash floods and mass movements/landslides in succession.

- **High iron in groundwater:** Presence of iron above the permissible limit of drinking standard, have been reported from Sikkim and J & K States and from Assam, Tripura, Meghalaya & Manipur.

- **Occurrence of high Fluoride in groundwater:** Fluoride more than the permissible limits for drinking Water standards, is reported from hand pump fitted tube wells in a few pockets of reservoirs will not only provide surface water availability but will also help in recharging the aquifers.

- **Need for special drilling technique in Doon Valley:** In Doon Valley, boulder formation is very common where a bore hole/tube well construction is very slow and expensive and need special techniques for installation of tube wells. It has been found that Percussion-Rotary combination rig is suitable in the foothill areas having semi-consolidated to unconsolidated formation with overlying boulder formation. Similarly ODEX-DTH combination rigs would be suitable in the intermontane valleys and hillslopes underlain by boulders and consolidated formations.

- **Need for Mass awareness and training for the Hilly people**: Public awareness programme regarding artificial recharging of ground water and rain water conservation for future sustainability including other issues existing in the Himalayan states are not being done adequately. These are required to be taken up expeditiously.

- **Detailed Micro-level survey /investigations for water resources Development:** Detailed micro level hydrogeological surveys are required in Lesser and Higher Himalayas with emphasis on water conservation. The emphasis is also required to be given on the identification of vulnerable sites prone to loose formation and susceptible to landslide and soil erosions.

- **Enacting environmental surveillance to protect water sources:** Sometimes the upcoming infrastructure developments are also the responsible factors which affect/vanish the existing spring flow as also the water bodies. Therefore, upcoming projects have to be vetted and assessed environmentally through statutory agencies of the Government.

1.0 INTRODUCTION

Himalayas, “the Abode of Snow” forms the northern international boundary of India with the neighboring country. For centuries, this mountain chain has fascinated the inhabitants of India with a mix feeling of admiration, awe and fear; and for the Hindus of India, the Himalayas are also “the Abode of God”. There are numerous pilgrim routes that have brought the Hindu pilgrims to these mountains since time immemorial. The Indian Himalayas cover a vast stretch of 418357 sq.km. between North Latitudes 29^0 15’ 00"- 36^0 58’ 00" and East Longitudes 73^0 26’ 00"- 97^0 25’ 00" along the northern frontiers of the country covering parts of five Indian States -Jammu and Kashmir (222236 sq.km), Himachal Pradesh (55673 sq.km.), Uttarakhand (53484 sq.km.), West Bengal (Darjeeling-3149 sq.km.), Sikkim (7096 sq.km.), and Arunanchal Pradesh (76719 sq.km.) (Plate-I). The State-wise brief description is as under:

1.1 JAMMU & KASHMIR

The entire Jammu & Kashmir State falls in the Himalayan region ranging from Kandi-Sirowal of Jammu Outer Plains to Trans Himalayas of Ladakh.

1.1.1 Location & Extent

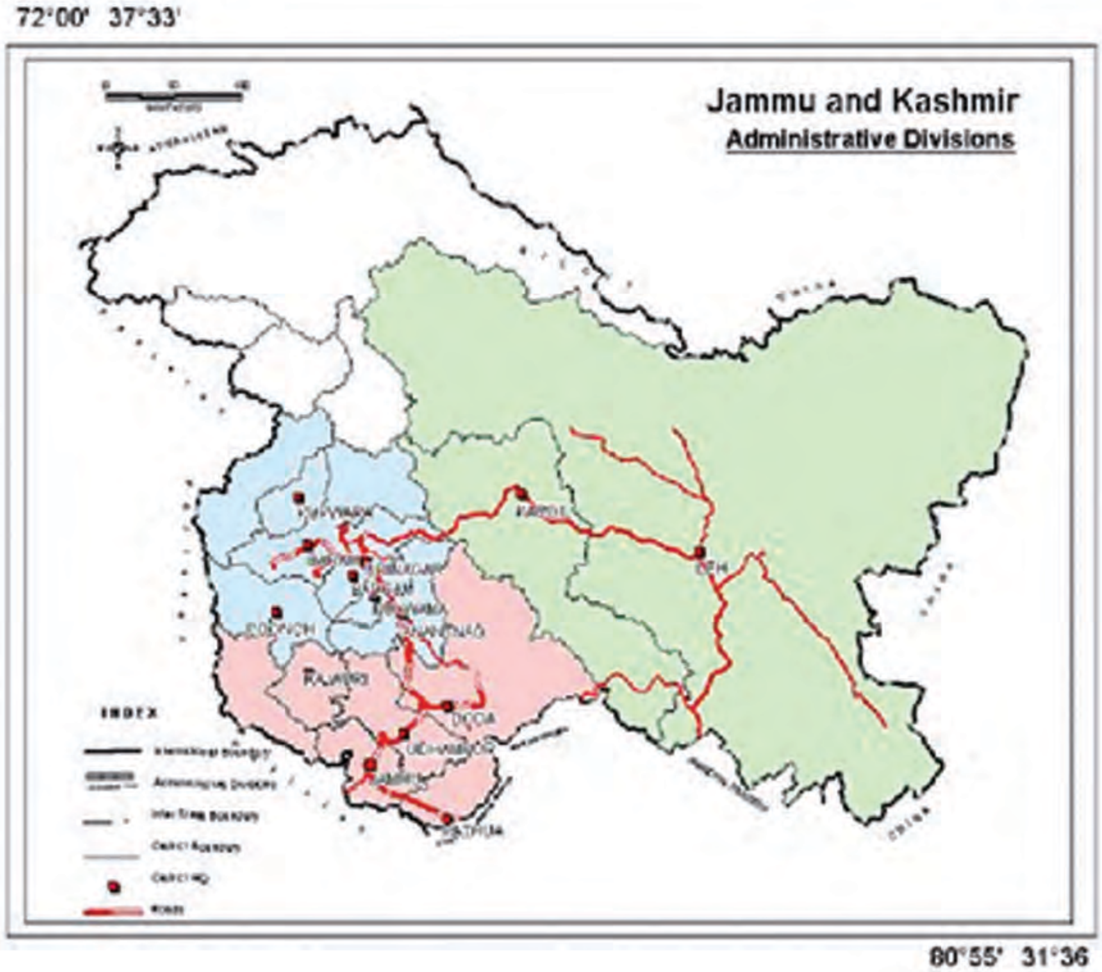
The total geographical area of the State is 2,22,236 sq.km. lying between the North Latitudes 32^o17’00" - 36^o58’00" and East Longitudes 73^o26’00" - 80^o30’00". The state has international border with China in the East and North, Afghanistan in the North-West, Tibet in the South-East and Pakistan in the West and South-West. Srinagar and Jammu are the summer and winter capital cities respectively.

1.1.2 Administrative Set up

Administratively the state is divided into two divisions Viz. Jammu and Kashmir. The Kashmir division has twelve districts i.e. Anantnag, Kulgam, Badgam, Baramula, Bandipora Kupwara, Pulwama, Shopian Srinagar, Ganderbal, Kargil and Leh. The Jammu Division has ten districts i.e. Doda, Ramban, Jammu, Samba, Kathua, Poonch, Kishtwar, Rajouri, Reasi and Udhampur. The data & boundaries of the newly created districts are not available. Therefore data presented in this report represents those of old districts only (Eight districts in Kashmir Division i.e. Anantnag, Badgam, Baramula, Kupwara, Pulwama, Srinagar, Kargil and Leh, and Six districts in Jammu Division i.e. Doda, Jammu, Kathua, Poonch, Rajouri, and Udhampur) (Fig.1.1).

1.1.3 Population

According to the 2011 census, the size of Jammu and Kashmir’s population is 1,25,48,926 i.e., 1.04 per cent of the all India figure of 1,21,01,93,422. Its geographical area is 2, 22,236 sq. km. and accounts for 6.76 per cent of the country’s size. The state has witnessed a fluctuating population growth rate since 1901. Since the size and growth of population has serious implications for development, it will be useful to have a retrospective view. The calculated growth rates reveal that throughout the period 1901-2011 population growth of the state has been quite low. The accentuated growth rate is recorded only after 1960s.



State Fig 1.1: Administrative division of Jammu & Kashmir

During 2001-2011, the average annual population growth in the state was 2.37 per cent. The districts of Kupwara, Leh, Punch, Rajouri, Ganderbal, Bandipore, Shupiyan, Pulwama, Anantnag, Doda, Ramban and Reasi had average growth rates above the state average. But it is interesting to note that, in as many as sixteen districts, viz., Kupwara, Badgam, Kargil, Leh, Punch, Kathua, Baramula, Bandipore, Srinagar, Shupiyan, Kulgam, Kishtwar, Udhampur, Reasi, Jammu and Samba, the growth rate recorded between 2001 and 2011 was was lower than that recorded between 1991 and 2001.

The district-wise population density figures show that between 1981 and 2011 all the districts recorded an increase in population density. Ganderbal and Bandipore districts have the highest population density followed by Kulgam and Shupiyan. Agglomeration of people depends on certain characteristics such as economic conditions, spatial linkages, efficacy of public and private transport and location. Conditions in the four districts are favourable for population concentration while on the other hand Leh, Kargil and Doda have very little population. The physiographic condition of these areas has prohibited population concentration. Leh district has the lowest density of 3 persons per sq. km, followed by Kargil district with 10 persons per sq. km. as per the 2011 census. District wise details of population in the state as per Census 2011 are given in Table 1.1.

Table 1.1: Population of Jammu & Kashmir - Census -2011

District	Population			% age Decadal Growth-Rate		Population Density	
	P	M	F	1991-2001	2001-2011	2001	2011
Kupwara	875564	475126	400438	39.58	34.62	273	368
Badgam	735753	390705	345048	30.11	21.18	443	537
Leh	147104	92907	54197	30.15	25.48	3	3
Kargil	143388	80791	62597	33.55	20.18	9	10
Punch	476820	252240	224580	28.17	27.97	223	285
Rajouri	619266	332424	286842	25.71	28.14	184	235
Kathua	615711	327953	287758	21.5	20.38	193	232
Baramula	1015503	542171	473332	31.28	20.34	250	305
Bandipore	385099	201531	183568	31.28	26.31	884	1117
Srinagar	1269751	675667	594084	29.51	23.56	559	703
Ganderbal	297003	158900	138103	29.59	36.30	845	1151
Pulwama	570060	297988	272072	26.39	29.18	467	598
Shupiyan	265960	136302	129658	26.39	25.85	677	852
Anantnag	1070144	552404	517740	32.77	37.48	294	375
Kulgam	422786	216672	206114	32.77	7.30	862	925
Doda	409576	213091	196485	26.84	27.89	62	79
Ramban	283313	149032	134281	26.91	31.81	162	213
Kishtwar	231037	120496	110541	26.84	21.06	103	125
Udhampur	555357	298094	257263	27.3	20.86	174	211
Reasi	314714	166392	148322	27.3	27.06	144	184
Jammu	1526406	815727	710679	29.01	12.48	526	596
Samba	318611	168948	149663	29.01	16.90	272	318
Total	**12548926**	**6665561**	**5883365**	**29.43**	**23.71**	**100**	**124**

1.1.4 Land Use

The state has 3.3% net sown area, 5.15% total cropped area, 0.38% current fallow, 0.54% pasture/ grazing land and 2.96% area under forest. The detailed land use statistics of the state is given in table 1.2.

Table 1.2: Land use pattern of Jammu & Kashmir (2009-2010)

Land Use	Area ('000 Ha)	% of geographical area of State
Total geographical area	22224	-
Forests	658	2.96
Land put to non-agriculture uses	306	1.38
Barren and uncultivable land	274	1.23
Pasture	120	0.54
Land under Misc. tree crops and groves not included in cropped area	63	0.28
Culturable waste land	149	0.67
Fallow land other than current fallows	26	0.12
Current fallows	84	0.38
Net area sown	735	3.31
Area sown more than once	409	1.84
Total cropped area	1144	5.15
Net area under irrigation	317	1.43

Source: Land Use Statistics (2009-10) – http://lus.dacnet.in

The share of agriculture and allied sectors in the gross State Domestic product is about 26.92 %. Rice, maize and wheat are the main principal crops in the State.

1.1.5 Pedology

Various types of soils are formed in different regions of the state owing to marked physiographic and climatological variations. Alluvial soils occur in parts of Jammu and Kathua districts where the land elevation is less than 300 m above mean sea level (m amsl). These soils are homogeneous and very fertile.

Brown hill soils are formed at land elevations between 300 and 1500 m amsl in the areas of moderately undulating topography. Spodo soils are developed in areas with land elevation between 1500 and 3000 m amsl experiencing relatively colder winters and higher mean annual rainfall. These soils occur in Poonch and Doda districts. Ochara-qulf soils are yellowish brown in colour and have moderately low permeability. These are developed at an elevation of about 1600 m amsl in mid upland areas of Kashmir Valley. Hapludalf soils are yellowish brown to dark brown in colour, very deep and well drained.

Skeletal soils are developed in parts of Leh and Kargil districts of Ladakh region, which vary in altitude between 2400 m and 7200 m amsl and experience severely cold and dry winter. The soils of all the regions have been described based on the physiographic units.

1.1.6 Investigations Undertaken by CGWB

CGWB has carried out ground water management surveys and extensive exploration in the state. Till date (March 2009) about 454 Exploratory Wells have been constructed in the State (289 EW in

Jammu Province, 139 EW in Kashmir Province & 26 EW in Ladakh Region). The exploratory wells are shown in the Plate – IV A. District wise exploratory wells, constructed in Jammu & Kashmir State are given in Table nos. 1.3, 1.4 & 1.5. In addition, CGWB is carrying out short term water supply investigations mainly for defence establishments for the selection of feasible sites for installation of tube wells.

Table 1.3: District wise Exploratory wells in the Jammu Division

S.No.	Name of the District	Total Geographical area (in sq.km.)	No. of Exploratory wells
1	Doda	1169	2
2	Kathua	2651	60
3	Jammu	3097	202
4	Poonch	1674	2
5	Rajouri	2630	2
6	Udhampur	4550	21
	Total		**289**

Table 1.4: District wise Exploratory wells in the Kashmir Division

District wise Exploratory wells in Kashmir Valley						
S.No.	**Name of the District**	**Total Geographical area (sq.km.)**	**Total Valley area(sq.km.)**	**No. of Tube wells**		***Total***
				Ist Phase (1973-2001)	**IInd Phase (2005-2008)**	
1	Anantnag	3984	900	10	7	17
2	Budgam	1371	850	17	5	22
3	Baramula	4558	1100	21	17	38
4	Kupwara	2379	600	18	7	25
5	Pulwama	1398	1050	11	11	22
6	Srinagar	2228	500	8	7	15
				85	***54***	***139***

1.2 HIMACHAL PRADESH

Himachal Pradesh is known for the beauty of mountains, forests, rivers and valleys. The state is a major contributor towards the water resources of the country, as major rivers like the Chandra-Bhaga, the Beas and the Ravi originate in the state and rivers such as the Satluj and the Yamuna

Table 1.5: District wise Exploratory wells in Leh and Nubra Valley

				Ist Phase (1973-2001)	IInd Phase (2005-2008)	*Total*
7	Kargil	—	—	0	1	01
8	Leh	81840	81	16	9	25
				16	***10***	***26***

pass through it. Important water reservoirs like Gobind Sagar (Satluj River), Pong dam (Beas River) and Thein dam (Ravi River) are located in the state. The northern most part of the state remains under perpetual snow cover. In spite of these huge water resources/bodies, acute water scarcity conditions are experienced during summers mainly due to physiographic set up of the state.

1.2.1 Location and Extent

The state of Himachal Pradesh lying between the North Latitudes 30° 22’ 40’’ -33° 12’ 40’’ and East Longitude 75° 45’ 55’’ -79° 04’ 20’’ covers a geographical area of 55,673 sq.km. The state has international border of Tibet in the north-east, state boundary with Jammu & Kashmir in north, Uttarakhand in south-east, Haryana in the south and Punjab in the west.

1.2.2 Administrative set up

Administratively, the state is divided into 12 districts, 76 tehsils and 75 blocks. There are 3037 Gram Panchayats and 20,118 villages (2623 un-inhabited). There are only 57 towns, 28 Nagar Panchayats and 21 Nagar Parishads including Municipal Corporations. Lahaul & Spiti (12,835 sq km) is the largest and Hamirpur (1118 sq km) is the smallest district of the state (Fig 1.2).

1.2.3 Population

The state has a population of 68, 56,509 persons (Census 2011) with an average population density of 123 persons per sq. km. The population of Himachal Pradesh has increased from 1.7 million in 1901 to 6.1 million during the year 2001 showing an increase of 258 % within 100 years. The high and rugged mountain ranges with snow and forest covered slopes are thinly populated or practically without habitation. The valley areas of Kangra, Mandi, Hamirpur, Una, Bilaspur, Solan, Sirmour and Shimla are densely populated. The Population of Himachal Pradesh is given in Table 1.6. Decennial growth rate (2001-2011) of Himachal Pradesh is maximum 15.61 in Sirmaur district and minimum -5.10 in Lahaul & Spiti district. Overall Decennial growth rate (2001-2011) of Himachal Pradesh is 12.81. Population density per Sq. Km. (2011 Census) is maximum at 406 in Hamirpur district and minimum 2 in Lahaul & Spiti district.

1.2.4 Land Use

The cultivable land in the state is very limited and is generally in the form of small holdings. Natural forests and permanent pastures form the major part of the land use pattern. Major part of the state is covered by forests, barren and unculturable land, permanent pastures etc. The details of land use statistics in the state are given in Table 1.7.

1.2.5 Pedology

Soils of the region vary according to altitude and climate. Soils are young and thin in river valleys while in the inclined hill slopes soil is very thick. The soil profile depicts topographic features of hill slope,

Fig 1.2: Administrative division of Himachal Pradesh

Table 1.6: Population of Himachal Pradesh (Census 2011)

Name	Population			Growth Rate 2001-2011	Population Density (per Sq. Km)	
	P	M	F		2001	2011
Chamba	5,18,844	2,60,848	2,57,996	+12.58	71	80
Kangra	15,07,223	7,48,559	7,58,664	+12.56	233	263
Lahaul & Spiti	31,528	16,455	15,073	-5.10	2	2
Kullu	4,37,474	2,24,320	2,13,154	+14.65	69	79
Mandi	9,99,518	4,96,787	5,02,731	+10.89	228	253
Hamirpur	4,54,293	2,16,742	2,37,551	+10.08	369	406
Una	5,21,057	2,63,541	2,57,516	+16.24	291	338
Bilaspur	3,82,056	1,92,827	1,89,229	+12.08	292	327
Solan	5,76,670	3,06,162	2,70,508	+15.21	259	298
Sirmaur	5,30,164	2,76,801	2,53,363	+15.61	162	188
Shimla	8,13,384	4,24,486	3,88,898	+12.58	141	159
Kinnaur	84,298	46,364	37,934	+07.61	12	13
Himachal Pradesh	**68,56,509**	**34,73,892**	**33,82,617**	**+12.81**	**109**	**123**

rugged surface with remnants of original topography. The Agriculture Department of Himachal Pradesh has classified five types of soils in the state on the basis of climatic conditions and altitude.

1.2.5.1 Low Hill Soil Zone

This zone extends up to an altitude of 100 m amsl. In this zone, soils are shallow and embedded with pebbles, cobbles and small stones. This zone includes Paonta valley, Nahan tehsil of Sirmour, Bilaspur, Una, Hamirpur, western part of Kangra, lower part of Chamba like Bhatiyat, Balh valley of Mandi and Kunihar valley of Solan. In this region, soil layer is not much thick. Carbon-Nitrogen ratio is 10:1. Soil is productive for the growth of paddy, wheat, barley and citrus fruits.

1.2.5.2 Mid Hill Soil Zone

This zone extends between 1000 m and 1500 m above msl. This type of soil is found in Pachhad area of Sirmour, lower part of Renuka, Solan proper, Arki, Jogindernagar, Kangra proper, Palampur and Dalhousie in Chamba district and upper Bhatiyat and Churah. Carbon – Nitrogen ratio is 10:12. These soils are neutral to acidic and are useful for potato and barley cultivation.

1.2.5.3 High Hill Soil Zone

This zone extends between 500 - 2100 m and has been developed on steep slopes with good

Table 1.7: Land use pattern of Himachal Pradesh (2008-09)

Land Use	Area ('000 Ha)	% of geographical area of State
Total geographical area	5567	-
Forests	1103	19.81
Land put to non-agriculture uses	468	8.41
Barren and unculturable land	654	11.75
Pasture	1503	27.00
Land under Misc. tree crops and groves not included in cropped area	68	1.22
Culturable waste land	135	2.43
Fallow land other than current fallows	20	0.36
Current fallows	59	1.06
Net area sown	539	9.68
Area sown more than once	407	7.31
Total cropped area	946	16.99
Net area under irrigation	108	1.94

Source: Land Use Statistics (2008-09) – http://lus.dacnet.in

drainage. Soil texture ranges from silty loam to clay loam with dark brown colour. The organic matter is also very high. Soil is acidic to neutral. This type of soil is found in the upper areas of Pachhad, Renuka of Sirmour district and covers major part of Shimla district, Chachyot in Mandi, upper part of Kangra and Chamba district. This type of soil is best suited for potato cultivation and cash crops.

1.2.5.4 Mountain Soil Zone

This type of soil is found between 2100 – 3000 m. Soil texture is silty loam to loam, with dark brown to light brown colour. Soil reaction is slightly to moderately acidic. Organic content varies from 2.5 to 3.5. These soils are not much used for agriculture purposes, but in Shimla district, apple orchards are grown on this soil.

1.2.5.5 Dry Hill Soil Zone

This type of soil is found above 3000 m particularly in Lahaul & Spiti, Pangi and Kinnaur, where monsoon rainfall is very little. Soil is very poor in organic matter.

1.2.6 Investigations Undertaken by CGWB

CGWB has carried out ground water management surveys and exploration in the state. So far 178 tube wells have been drilled in the eight districts of the State (Plate IV A) as on March 2010. District wise details of exploratory wells constructed in Himachal Pradesh are given in Table 1.8.

In addition, short term water supply investigations are taken by CGWB for Defence, Railways, IPH and other central and state agencies for drinking water supplies. The results of the investigations are highly fruitful. The agencies were advised for ground water development, management, Rain water Harvesting and Artificial recharge to ground water.

Table 1.8: District wise Exploratory wells Drilled in Himachal Pradesh

Sl. No.	District	Formation	No. of EW drilled
1.	Hamirpur	Valley Fill	6
2.	Kangra	Valley Fill	65
3.	Kulu	Valley Fill	9
4.	Mandi	Valley Fill	15
5.	Solan	Valley Fill	15
6.	Simla	Hard Rock	1
7.	Sirmour	Valley Fill	12
8	Una	Valley Fill	48
9.	Bilaspur	Valley Fill	5

1.3 UTTARAKHAND

1.3.1 Location and Extent

Uttarakhand, the twenty sixth state of Union of India, was carved out of the northern part of Uttar Pradesh State on 9th November 2000. It is bounded by North Latitudes $28^0$43'00" to $31^0$28'00" and East Longitudes $77^0$32'00" to 81^0 00'00". The state is surrounded by Himachal Pradesh in the west, Uttar Pradesh in the south, Nepal in the east and China in the north. The state is spread in an area of 53, 484 sq.km. It is well connected with the National Capital Delhi by road and railways.

Fig 1.3: Administrative division with Isohyets of Uttarakhand

1.3.2 Administrative Set-up

Uttarakhand is divided into two divisions viz. Garhwal and Kumaon. Garhwal and Kumaon divisions are divided into seven and six districts respectively; these districts are Chamoli, Dehradun, Pauri, Haridwar, Rudraprayag, Tehri Garhwal, Uttarkashi, Almora, Bageshwar, Champawat, Nainital, Pithoragarh and Udham Singh Nagar. The disposition of these districts is shown in Fig 1.3. The state has 49 tehsils, 95 community development blocks and 16,414 villages.

1.3.3 Population

The total population of Uttarakhand state is 10116752 persons out of which 5154178 and 4962574 are males and females respectively (Census: 2011). The district wise details of the population are given in Table 1.9.

Uttarakhand is a sparsely populated state with a population density of 189 persons per sq.km. which is fairly less in comparison to the population density of the country that is 364 persons per

Table 1.9: Population of Uttarakhand (Census 2011)

District	Population			% age Decadal Growth-Rate		Population Density	
	P	M	F	1991-2001	2001-2011	2001	2011
Uttarkashi	329686	**168335**	161351	**23.07**	**11.75**	**37**	**41**
Chamoli	391114	193572	197542	13.87	5.60	46	49
Rudraprayag	236857	111747	125110	13.43	4.14	115	119
Tehri Garhwal	616409	296604	319805	16.24	1.93	166	169
Dehradun	1698560	893222	805338	25.00	32.48	415	550
Garhwal	686527	326406	360121	3.91	-1.51	131	129
Pithoragarh	485993	240427	245566	10.95	5.13	65	69
Bageshwar	259840	124121	135719	9.28	5.13	110	116
Almora	621927	290414	331513	3.67	-1.73	201	198
Champavat	259315	130881	128434	17.60	15.49	127	147
Nainital	955128	494115	461013	32.72	25.20	179	225
Udhamsingh Nagar	1648367	858906	789461	33.60	33.40	486	648
Haridwar	1927029	1025428	901601	28.70	33.16	613	817
Uttarakhand	10116752	5154178	4962574	20.41	19.17	159	189

sq.km. The population density is the highest in Haridwar district, whereas it is the lowest in Uttarkashi district. Decadal growth rate during 2001-2011 has decreased in all the districts except Dehradun and Haridwar when compared with that during 1991-2001.

1.3.4 Land Use

Physiography, temperature, rainfall and its distribution in time and space and soil type are the main natural factors, which govern the land use of a place or state. Uttarakhand may broadly be divided into two physiographic units viz. (1) Plain area and (2) Hilly area. Most of the plain area is confined to Dehradun, Haridwar and Udham Singh Nagar districts. Here the main land use is agriculture, which is supported by Canal irrigation. The hilly area exhibits very uneven topography, which is mainly covered by forests, pasture land, bushes, barren land, fallow land, etc.

Out of total geographical area of the state of 5348300 hectares, 34,84,803 hectares is covered by forests. These figures reveal that 65% of the state's area is under forests. The maximum and minimum forest covered areas fall in Uttarkashi (721664 hectares) and Haridwar (84537 hectares) districts respectively. The net sown area is 736581 hectares, which is only 14% of the total geographical area. The maximum and minimum net sown areas fall in districts of Udham Singh Nagar (142548 hectares) and Champawat (18058 hectares) respectively.

Table 1.10: Land Use Pattern of Uttarakhand (2009-10)

Land Use	Area ('000 Ha)	% of geographical area of State
Total geographical area	5348	-
Forests	3485	65.16
Land put to non-agriculture uses	216	4.04
Barren and unculturable land	225	4.21
Pasture	198	3.70
Land under Misc. tree crops and groves not included in cropped area	383	7.16
Culturable waste land	309	5.78
Fallow land other than current fallows	82	1.53
Current fallows	37	0.007
Net area sown	737	13.78
Area sown more than once	430	8.04
Total cropped area	1167	21.80
Net area under irrigation	338	6.32

Source: Land Use Statistics (2009-10) – http://lus.dacnet.in

1.3.5 Pedology

General

The soils are natural, dynamic, heterogeneous, non-renewable, which support plant and animal life. It is the most precious basic resource for the very existence of mankind since they cater to their basic needs by producing food, fiber and timber. For sustainable utilisation of soil resource, it is imperative to know the nature, characteristics and extent of distribution of different soils, their qualities, productive potentials and suitability for optimum land uses.

The Soils of Uttarakhand Himalayas are sub-divided into three categories viz. (1) Soils of Greater Himalayas, (2) Soils of Lesser Himalayas and (3) Soils of Siwaliks (the outer Himalayas).

1.3.5.1 Soils of Greater Himalayas

Greater Himalayas represent a highly rugged topography and occupy the northern most part of Uttarakhand and cover an area of 1.14 million hectares. This is dominantly a zone of glaciers and rock outcrops.

- **Soils of Summits, Ridge Tops and Mountain Glaciers**

Soils of summits, ridge tops and mountain glaciers cover an area of about 237588 hectares of which 85% area is under glaciers and rest under rock outcrops. In general, this tract is devoid of soils and vegetation due to Arctic conditions.

- **Soils of Side slopes**

These soils cover an area of 831480 hectares. Very steep to steep hills are dominantly occupied with very shallow to moderately shallow, excessively drained, sandy-skeletal to loamy-skeletal, neutral to slightly acidic with low available water capacity (AWC) soils (without soils development) in association with rock outcrops. They are severely eroded and moderate to strongly stony. They have been classified as Lithic/Typic Cryorthents. These soils in general are under sparse vegetation.

- **Soils of Upper Glacio-Fluvial Valleys**

These soils cover an area of 29163 hectares. The soils of glacio-fluvial valleys with moderate slopes are occupied with moderately shallow, neutral to slightly acidic, moderately eroded and strongly stony with low available water capacity (AWC) soils in association with rock outcrops. They have been classified as Typic Cryorthents.

- **Soils of Cliffs**

Cliffs are dominantly occupied with rock outcrops in association with very shallow, excessively drained, sandy-skeletal, neutral, severely eroded and strongly stony with low available water capacity (AWC) soils, Lithic Cryorthents. These soils occupy an area of 48675 hectares.

1.3.5.2 Soils of Lesser Himalayas

These soils cover an area of about 3.02 million hectares. Lesser Himalayas have a massive mountainous tract and tangled mass of series of ridges divided from each other by deep valleys. The ranges are mainly composed of highly compressed and altered rocks like granite, phyllite, quartzite etc.

- **Soils of Summits and Ridge Tops**

Soils encountered at summits and ridge tops are shallow to moderately shallow, excessively drained and sandy to loamy. These soils cover an area of 490550 hectares. They are classified as Lithic/

Typic Udorthents. However, the other soil formations are moderately shallow, somewhat excessively drained, fine-loamy/ coarse-loamy, with slight to moderate erosion. The soils are slightly to moderately acidic in nature.

- **Soils of Side slopes**

The soils occurring on very steep slopes are very shallow to shallow, excessively drained sandy to loamy without soil development with lithic contact within 50 cm of the surface (Lithic Udorthents). These soils cover an area of 2220211 hectares. They are slight to moderately acidic, very severely eroded and strongly stony with low available water capacity. At places they are associated with rock outcrops. Moderately to steeply sloping hills consist of moderately shallow to moderately deep excessively drained, coarse to loamy soils. They are slightly to moderately acidic, moderately eroded and moderate to strongly stony with low available water capacity. The terrace slopes, at places exhibit the development of cambric horizon in the soils. They are moderately deep to deep, somewhat excessively drained, fine loamy, slight to moderately acidic with slight to moderate erosion. At places, these are also associated with moderately shallow, well-drained, fine-loamy, moderately acidic soils

1.3.5.3 Soils of Siwaliks/ Outer Himalayas

- **Soils of Piedmont Plain (Bhabar)**

The soils of Piedmont plain are deep, well drained, neutral to slightly alkaline, coarse-loamy/fine-loam. These soils, Udic Haplustepts, occur in association with deep, well drained, neutral, and slightly acidic coarse-loamy, over fragmented and fine-loamy or over sandy soils and are at places deep and excessively drained.

- **Soils of Tarai**

In Tarai region, soils are very deep, well drained, slightly alkaline, coarse-loamy/fine-loamy, Udic Haplustolls. The other soils are coarse-loamy (Calcareous), Udic Haplustepts and fine loamy over sandy-skeletal, Udifluventic Haplustepts. These soils are rich in organic matter, plant nutrients and have fairly good water holding capacity.

1.3.6 Investigations Undertaken by CGWB

CGWB has carried out ground water management surveys and exploration in the state. So far 70 tube wells have been drilled in the six districts of the State (Plate IV A). District wise details of exploratory wells constructed in Uttarakhand are given in Table 1.11.

Table 1.11: District wise Exploratory wells Drilled in Uttarakhand

Sl.No	District	Formation	No. of EW drilled
1.	Dehra Dun	Dun Valley	21
2.	Hardwar	Siwaliks/ Alluvium	9
3.	Udham Singh Nagar	Alluvium (Terai)	13
4.	Nainital	Alluvium (Bhabar)	17
5.	Champawat	Alluvium (Bhabar)	06
6.	Pauri Garwal	Alluvium (Bhabar)	04

In addition, short-term investigations are taken by CGWB for Defence, Railways, IPH and other central, state agencies for drinking water supplies.

1.4 WEST BENGAL (DARJEELING) AND SIKKIM

1.4.1 Location and Extent

Small landlocked mountainous state of Sikkim is bounded within 27°00’46" and 28°07’48" North Latitudes and 88° 00' 58" and 88° 55' 25" East Longitudes while the contiguous part of Darjeeling Himalaya falls within the geographical coordinates of $87^{0}59^{'}$ to $88^{0}53^{'}$ E Longitudes and $26^{0}31^{'}$ to $27^{0}13^{'}$ N Latitudes (Plate-1). The Sikkim state occupies a geographical area of 7096 sq.km., while the West Bengal part of Himalayan territory is incorporated in Darjeeling District having a geo-graphical area of 3149 sq.km. including the Terai belt comprising the Siliguri subdivision.

1.4.2 Administrative Set up

The state of Sikkim is constituted by four administrative districts viz. Gangtok, Geyzing, Mangan and Namchi with State capital at Gangtok. Darjeeling District is the lone district of West Bengal falling in Eastern Himalayas (Fig 1.4).

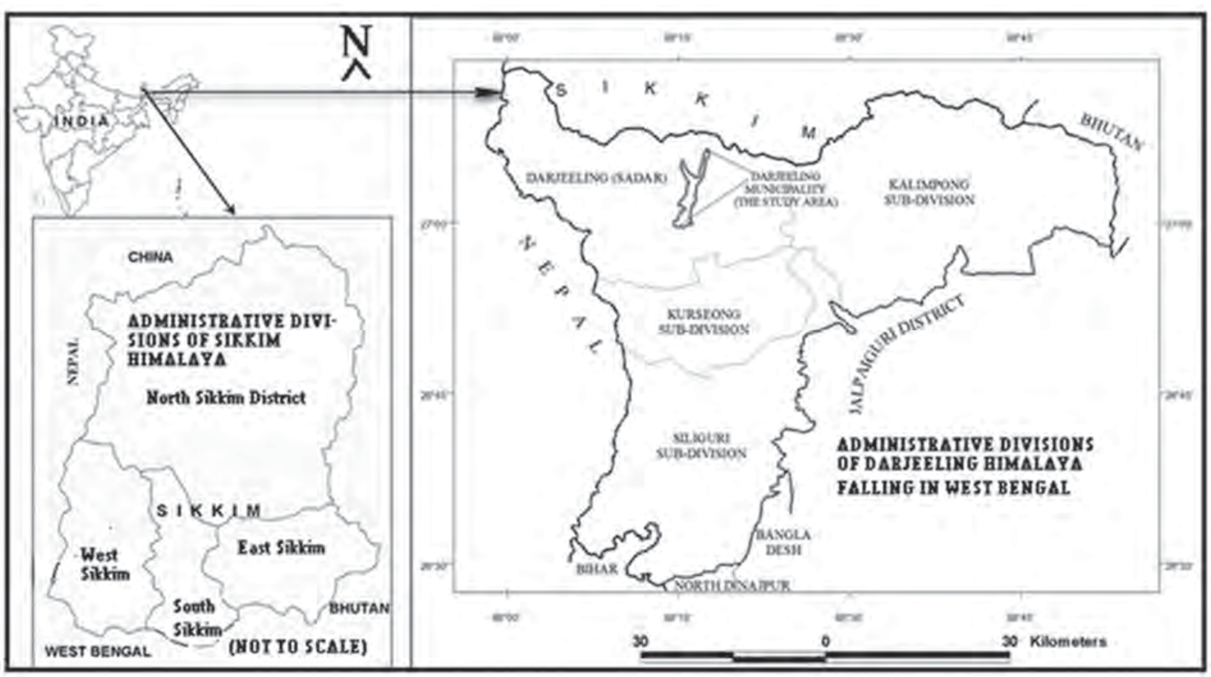


Fig 1.4 Administrative division of Darjeeling district of West Bengal & Sikkim State

1.4.3 Population

During 2001 census the population of Sikkim was 540493 persons. Density of population during the census period was 76 while it was 57 during 1991 census. Total population of Sikkim as per 2011 census has increased to the tune of 607688. The population density during 2011 has been observed to be 86. During the decade of 1991-2001 the population growth rate of Sikkim was 33.07% which has reduced to 12.36% during 2001-2011. The population of Darjeeling District is 1842034 with population density of 585 as per 2011 census. District wise details of population of Sikkim and that of Darjeeling district of West Bengal are given in Table 1.12.

Table 1.12: Population of Sikkim and Darjeeling (Census 2011)

District	Population			% age Decadal Growth-Rate		Population Density	
	P	M	F	1991-2001	2001-2011	2001	2011
North District	43354	24513	18841	31.34	5.67	10	10
West District	136299	70225	66074	25.57	10.59	106	117
South District	146742	76663	70079	33.39	11.57	175	196
East District	281293	150260	131033	37.32	14.80	256	295
SIKKIM	**607688**	**321661**	**286027**	**33.07**	**12.36**	**76**	**86**
Darjeeling	1842034	934796	907238	23.79	14.47	511	585
West Bengal	**91347736**	**46927389**	**44420347**	**17.77**	**13.93**	**903**	**1029**

1.4.4 Land use

Nearly 56% (3995 sq.km) of the total geographical area of the state of Sikkim lying above tree line at around 3800 metres above mean sea level goes under alpine climate. Around 84% of the land area is classified as forest land while the remaining 16% is privately owned. Average size of land holdings is 1.3 hectare. Although the Himalayan state is having good forestry, still loss of forest area has been reported from East Sikkim due to encroachment problem. However, improvement in forest area has been reported from South and West Sikkim with the regeneration of Shorea robusta and plantation of Cryptomeria Japonic respectively.

Average slope of the area is 45^0 and only 11% of the land is available for agricultural use in Sikkim. Access to rivers in the valley bottom is very difficult due to the steepness of the slopes and land-slides are very common. Most of the farmers are involved in agricultural and horticultural activities as well as animal husbandry. The people of rural Sikkim are almost entirely dependent on springs for their livelihood.

Total available land for agriculture in Sikkim is 109000 hectares, which is 15.4% of the total geo-graphical area of the state. Paddy and Maize are the main crops. The other crops grown on the hill slopes are vegetables, cardamom, potato, ginger etc. However, as a cash crop orange is also grown in the state.

There is a tea garden at Temi in South Sikkim. However, tea gardening is not as popularized as it is in Darjeeling Hills. In Darjeeling district, forest area is mostly restricted to the Himalayas. As per Forest Statistics, the net forest area of the district was 1142.76 sq.km during 1988-89 while in 2007 it was 1245.76 sq.km. An area of 1001.29 sq.km is under tea plantation. The net cultivable area in the district is 143860 hectares.

1.4.5 Pedology

Soils in Sikkim are generally sandy loam in character and acidic to very acidic in nature. In Darjeeling district, the soil types vary from sandy loam to podozol. Brown forest soils are seen in the hilly areas.

1.4.6 Investigations Undertaken by CGWB

The geological surveys in Sikkim and Darjeeling Himalaya were undertaken by various officers of Geological survey of India (Ghosh, 1953; Roy, 1971; Sinha Roy, 1972; Acharya, 1972). However, systematic hydrogeological surveys including geophysical surveys in Darjeeling Himalayas and in Sikkim were undertaken by the officers of Central Ground water Board. The Board has also undertaken groundwater exploration in Darjeeling district of West Bengal and South & East Sikkim (Plate - IVB). Scientiific data generated and analysed during the course of hydrogeological/ geophysical/ Remote Sensing/ Hydrochemical/ Special studies & Ground water exploration has been compiled in the form of reports. The hydrogeological reports brought out so far, contain relatively good field data generated during various scientific activities carried out in South and east districts of Sikkim. However, extensive hydrogeological surveys are yet to be carried out in West and North Sikkim as data availability is sparse.

Hydrogeological data has been generated through short-term water supply investigations carried out for Defence establishments, Railways and Tea gardens in the Darjeeling district of West Bengal.

1.5 ARUNACHAL PRADESH

1.5.1 Location & Extent

The Eastern Himalayas constitute the eastern most part of the Greater Himalayas, referred to as the Arunachal Himalayas (formerly NEFA Himalaya) and occurs as a “gigantic crescent” with its convex side towards south. It rises abruptly from Brahmaputra alluvial plain at a general elevation of 100 m above mean sea level to the dizzy height of 7089 m merging with the Tibetan Plateau in the north. It extends from the eastern border of Bhutan in the west to Dibang and Lohit Valleys in the east abutting against the Myanmar (Burmese) Arakan ranges forming the Mishmi Hills, which is the northern continuation of the Proterozoic succession of northern Myanmar, containing elements of Cretaceous and Neogene plutonism apparently similar to that of Ladakh. Mishmi Hills abut against the Naga- Patkoi ranges of Arakan Youma Mountains to the south. The region is underlain by rocks ranging in age from Proterozoic to Quaternary, and has attained the present height during different pulses of Himalayan Orogeny, the last being during Middle Pleistocene period.

Arunachal Pradesh attained its statehood on 20th February 1987. It covers an area of 83743 sq. km. area and is the largest state area-wise in the north-east region, even larger than Assam which is the most populous. It is situated between latitude 26° 30' N and 29° 30' N and longitude 91° 30’ E and 97° 30' E.

1.5.2 Administrative Set Up

The Arunachal Himalaya covers almost all the districts of Arunachal Pradesh, except Changlang & Tirap districts (Fig 1.5). The region is divided into 16 districts. The Arunachal Himalayan region has 36 sub-divisions, 57 blocks, 3360 villages and 16 towns.

1.5.3 Population Details

As per 2011, Census Arunachal Himalaya has a population of 1382611 consisting of 720232 males and 662379 females, with density of population of 17 persons per sq.km. Decadal growth rate has declined from 27% during 1991- 2001 to 25.92% during 2001-2011. Demographic details are depicted in Table 1.13

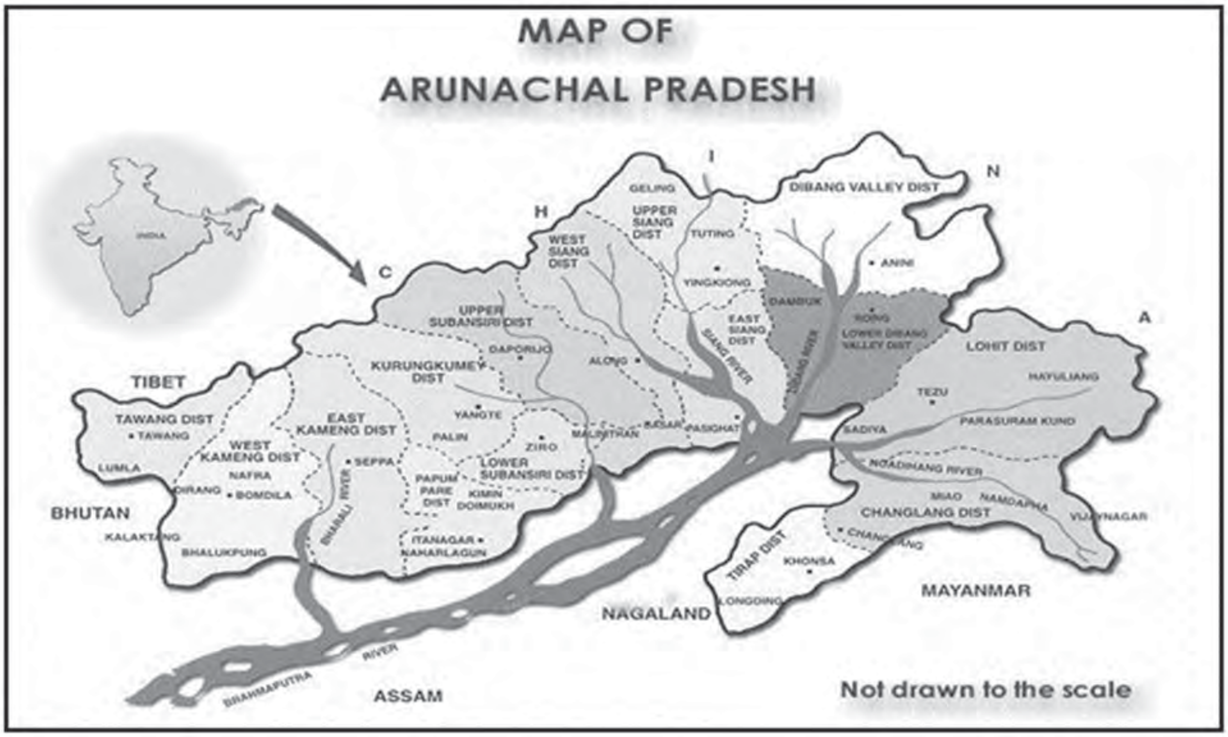


Fig 1.5: Administrative division of Arunachal Pradesh

Table 1.13: Demographic details of Arunachal Himalaya (2011 census)

District	Population			% age Decadal Growth-Rate		Population Density	
	P	M	F	1991-2001	2001-2011	2001	2011
Tawang	49950	29361	20589	37.60	28.33	18	23
West Kameng	87013	49568	37445	32.22	16.64	10	12
East Kameng	78413	38974	39439	13.46	37.14	14	19
Papumpare	176385	90447	85938	67.56	44.57	35	51
Upper Subansiri	83205	41974	41231	10.50	50.34	8	12
West Siang	112272	58589	53683	15.55	8.04	12	13
East Siang	99019	50467	48552	21.61	13.30	24	27
Upper Siang	35289	18657	16632	20.10	5.77	5	5
Changlang	147951	77289	70662	31.29	17.96	27	32
Tirap	111997	57992	54005	17.33	11.63	42	47
Lower Subansiri	82839	41935	40904	29.15	48.65	16	24
Kurung Kumey	89717	44226	45491	6.24	111.01	7	15
Dibang Valley	7948	4396	3552	17.65	9.30	1	1
Lower Dibang Valley	53986	28127	25859	36.76	7.01	13	14
Lohit	145538	76544	68994	35.10	16.44	24	28
Anjaw	21089	11686	9403	7.84	13.77	3	3
Arunachal Pradesh	**1382611**	**720232**	**662379**	**27.00**	**25.92**	**13**	**17**

1.5.4 Land Use

Vegetation of Arunachal Himalayas can be classified in five broad forest types with sixth type of secondary forests. These are tropical forests, subtropical forests, pine forests, temperate forests and alpine forests. The reserve forests constitute nearly 37.32% of the total forest area of Arunachal Pradesh, which is much less than all India average of 52.2%. There is a vast area known as unclassified state forest for which both state and local people claim rights. Land use pattern of the Arunachal Himalayas is presented in Table. 1.14.

Table 1.14: Land use pattern of Arunachal Pradesh (2009-2010)

Land Use	Area ('000 Ha)	% of geographical area of State
Total geographical area	8374	-
Forests	5154	61.55
Land put to non-agriculture uses	26	0.003
Barren and unculturable land	38	0.005
Pasture	18	0.002
Land under Misc. tree crops and groves not included in cropped area	38	0.005
Culturable waste land	64	0.008
Fallow land other than current fallows	70	0.008
Current fallows	40	0.005
Net area sown	212	2.53
Area sown more than once	276	3.30
Total cropped area	64	0.008
Net area under irrigation	56	0.007

Source: Land Use Statistics (2009-10) – http://lus.dacnet.in

1.5.5 Pedology

The soils of Arunachal Pradesh are broadly classified into two categories viz., soils of the higher region and soils of the lower region:

- Soils of higher region are developed from high grade metamorphics comprising of schists, gneisses, biotite granite, granodiorite, mica schist, hornblende, sandstones, conglomerates, shales, phyllites, quartzites, etc. Soils are dark brown to dark yellowish brown in colour and are coarse to medium textured. They are coarse loamy sand to sandy loam with loam to clay loam sub-soil.

- Soils developed on the alluvium deposited by the rivers and colluvial fans gliding down the slope are carried away by runoff. These soils belong to the orders of Entisols, Inceptisols and Altisols tentatively.

Almost entire soils in Arunachal Pradesh are low in available phosphorus and high in organic carbon content.

1.5.6 Investigations Undertaken by CGWB

Ground water Management Studies were carried out in parts of Arunachal Pradesh. Ground water exploration activity in the valley and foothill areas of the Arunachal Himalaya, namely, Papum Pare, Lohit, East Kameng and West Kameng districts has been undertaken by Central Ground Water Board. So far 18 exploratory wells have been constructed in these districts (Plate – IVB). District wise numbers of exploratory wells constructed in the area are given in Table 1.15.

Table 1.15: District wise Exploratory wells Drilled in Arunachal Himalayan Region

Sl.No	District	Formation	No. of EW drilled
1.	Papum Pare	Alluvium	11
2.	Lohit	Alluvium	5
3.	East Kameng	Alluvium	1
4.	Wet Kameng	Alluvium	1

In addition, short term investigations are taken by CGWB for Defence, and other central, state agencies for drinking water supplies.

1.6 NORTH-EASTERN STATES CONTIGUOUS TO HIMALAYAN AREA

1.6.1 Location & Extent

The north-eastern part of India, contiguous to Himalayan area, covers the States of Assam, Meghalaya, Nagaland, Manipur, Mizoram and parts of Arunachal Pradesh (Changlang &Tirap districts). The Region has a geographical area of 1,78,370 sq. km., 60% of which is occupied by hills. The region has two principal drainage systems viz. Brahmaputra and Meghna. Even though the region receives the highest rainfall in the country and experiences high floods during monsoon, there is acute shortage of drinking water in many hilly terrains. The entire Brahmaputra valley in Assam, the synclinal valleys of Tripura and foothills and small intermontane valleys in the hilly states of Manipur, Nagaland, Meghalaya and Mizoram hold good potential for ground water development, but the utilization of ground water in the region is yet to pick up the required momentum.

1.6.2 Administrative Set Up

The State wise administrative division is given in the Table No. 1.16.

Table 1.16: Administrative Set Up of North Eastern States (except Arunachal Pradesh)

Sl. No.	State	Geographical Area (in sq. km.)	No. of districts	Name of State Capital
1.	Assam	78438	27	Dispur
2.	Meghalaya	22429	7	Shillong
3.	Nagaland	16579	11	Kohima
4.	Tripura	10492	4	Agartala
5.	Manipur	22327	9	Imphal
6.	Mizoram	21081	8	Aizwal

Apart from the above states, two districts, namely, Changlang and Tirap of Arunachal Pradesh, covering an area of 7024 sq.km, come under this Region.

1.6.3 Population Details

As per 2011 Census, the North Eastern states including Arunachal Pradesh have a population of 44980301 with density of population of 176 persons per sq.km. Demographic details are depicted in Table 1.17.

Table 1.17: Demography (as per Census 2011), North Eastern States (except Arunachal Pradesh)

Sl. No.	Name of State	Population (as per 2001 Census)	Population Density (per sq.km.)
1.	Assam	31169279	397
2.	Meghalaya	2964007	132
3.	Nagaland	1980602	119
4.	Tripura	3671032	350
5.	Manipur	2721756	122
6.	Mizoram	1091014	52

The population (2011) of Tirap and Changlang districts of Arunachal Pradesh, falling in the region, is 259948.

1.6.4 Land Use

The land utilization pattern has positive correlation with geomorphic setting of the north eastern region. The hilly terrain including inselbergs and high altitude areas are characterized by mixed forests, extremely scattered homesteads, restricted cultivation along slopes, hard rock quarries for concrete aggregates and road metals.

The low level Sub-Recent terraces have forests with extensive sal and very limited teak plantations. The area is highly suitable for tea plantation. The terrain is completely immune to floods but susceptible to erosion by gullies and creeks.

The Recent alluvial plains are mainly farmlands with orchards and very minor tea gardens. Sal forests are generally absent. It also has limited use of lakes as fisheries.

The regional pattern of land use is, however, a result of chance adoption rather than planned growth. With the fast diminishing land-man ratio and increasing demand of foodgrains, it has been imperative to enhance productivity by switching over to planned growth from the present stage of chance growth.

Details of land use pattern of the northeastern states are given in Table 1.18.

1.6.5 Pedology

The North Eastern Region, which treasures geological formations of a wide range right from Archaean to Recent, has undergone diversified pedogenesis depending upon the composition of the parent materials, palaeogeographical conditions and climatic conditions to which it was subjected. However, a brief description of soil groups which have got strategic significance in present day land utilization is given below:

- Forest and hilly lateritic soil, deep reddish in colour, developed over the geological formations belonging to Archaean, Precambrian and Upper Tertiary age. The soil is acidic and characterized by low nitrogen, low phosphate and medium to high potash.

- Low-level terrace, red and yellow soil, restricted mainly on the northern bank of River Brahmaputra, formed due to lateritisation process of Upper Pleistocene fluvial sediments under favourable climatic conditions. The soil is having clayey plastic latosol with sedimentary structures and textures totally obliterated in the solum. Formation of pedogenic clay minerals due to high alteration of alluvium is very intensive. Mottling and incipient development of ferruginous nodules at places are quite common.
- Alluvial Plains soil developed along the vast expanses of the River Brahmaputra banks and along other major rivers in the Region is light grey to dark grey in colour and is practically unaltered alluvium representing a broad spectrum of sand, silt and bog clay (humus rich) depending on landform component. Mineral weathering and geochemical changes are minimal, but incipient changes in the top clay layer have been noticed due to biological activity. Soil pH is generally feebly alkaline excepting bog soils.

Table 1.18: Land Use Pattern of North Eastern States (except Arunachal Pradesh)

S No.	State.	Forest area	Land not available for cultivation	Other uncultivated land	fallow land Fallow land excluding current	Net area sown	Total cropped area	Area sown more than	Land Use Statistics once
Report									
1.	Assam	1853260	2625545	432439	128164	2810597	4099462	1288865	2009-10
2.	Meghalaya	946318	230525	555840	213292	282939	336416	53477	2009-10
3.	Nagaland	862930	89168	149581	160293	360746	486406	125660	2009-10
4.	Tripura	606168	133500	27751	1750	280000	4	279996	1998-99
5.	Manipur	-	7365	5575	200	208500	208500	-	2000-01
6.	Mizoram	1585305	94962	50600	246823	122865	122865	-	2009-10
7.	Arunachal Pradesh (Tirap & Changlang districts)	Not Available	26375	32952	39367	28374	38827	10453	2009-10

1.6.6 Investigations Undertaken by CGWB

CGWB has carried out Ground water Management Studies in most parts of North Eastern States. Ground water exploration activities are restricted in the valleys and foothill areas of the Region due to inapproachability of drilling rigs in hilly tracts. State wise number of exploratory wells constructed so far in the area are given in Table 1.19.

Table 1.19: State wise & Formation wise number of Exploratory wells constructed in North Eastern States

S.No.	State	Number of Exploratory wells in different Formations		
		Unconsolidated Formation	Semi-consolidated Formation	Consolidated Formation
1.	Assam	234	32	37
2.	Meghalaya	14	16	53
3.	Nagaland	-	9	-
4.	Manipur	-	22	-
5.	Mizoram	-	3	-
6.	Tripura	-	50	-
7.	Arunachal Pradesh (Tirap & Changlang districts)	7	2	-

2.0 HYDROMETEOROLOGY

The Himalayas have a profound effect on the climate of the Indian subcontinent and the Tibetan plateau. They prevent frigid, dry Arctic winds blowing south into the subcontinent, thus keeping South Asia much warmer than corresponding temperate regions in the other continents. It also forms a barrier for the monsoon winds, keeping them from traveling northwards, thus causing heavy rainfall in the foothill region. The climate in Himalayan States changes from place to place due to variations in the altitude. The plain areas experience sub-tropical monsoon climate having mild and dry winter and hot summer. In the hilly region, the climate varies from sub-tropical monsoon to tropical upland. The Tropical upland climate has mild and dry winter and short warm summer.

2.1 Climate of the Himalayan region and Indian sub-continent

In winter, an extensive high pressure system prevails over central Asia and the northern part of India. There then exists a low pressure over the seas and the ocean south of India. As winter passes, the landmass becomes warm quickly and by about late March and April, a low pressure is built up over northern India. The air mass over the ocean getting heated up slowly, there prevails a relatively high pressure over the seas and the ocean. With the northward migration of the sun, the land mass becomes very hot in April and May and the pressure gradient between north India and the southern seas becomes very steep. A low-pressure system thus envelops the lower altitudes of north Indian region. The winds then begin to blow from the south and south-west of the region bringing about a significant change in the weather condition of this region. Such a condition results in occurrence of thunder showers, squalls and occasional rains. The Mediterranean lows, which reach the upper Indus valley and the upper Gangetic plain in winter cause overcast sky, drizzle and rain.

2.1.1 Southwest Monsoon

The southwestern summer monsoons occur from June through September. The Thar Desert and adjoining areas of the northern and central Indian subcontinent heat up considerably during the hot summers, causing a low pressure area over the northern and central Indian subcontinent. To fill the void, the moisture-laden winds from the Indian Ocean rush in to the subcontinent. These winds, rich in moisture, are drawn towards the Himalayas, creating winds blowing storm clouds towards the subcontinent. The Himalayas act like a high wall blocking the winds from passing into central Asia, thus forcing them to rise. With the gain in altitude of the clouds, the temperature drops and precipitation occurs. Nearly 80% of annual rainfall in Himalayas occurs due to south-west monsoon.

2.1.2 Northeast Monsoon

Around September, with the Sun fast retreating south, the northern land mass of the Indian sub-continent begins to cool off rapidly. With this, air pressure begins to build over northern India, while the Indian Ocean and its surrounding atmosphere still holds its heat. This causes the cold wind to sweep down from the Himalayas and Indo-Gangetic Plains towards the vast spans or Retreating Monsoon. While traveling towards the Indian Ocean, the dry cold wind picks up some moisture from the Bay of Bengal and pours it over peninsular India. City like Chennai, which receives less rain from the Southwest Monsoon, receives rain from this Monsoon. Nearly 20 % of annual rainfall in Himalayas occurs due to Northeast monsoon.

2.1.3 Factors Influencing the Climate of Himalayan Mountain

The presence of a precipitous Himalayan Mountain that thwarts the course of the incoming south-west monsoon winds, has rendered the climate of Himalayan region somewhat different from that of the other parts of India. The factors influencing the climate of the region may be listed as follows:

1. Situation and alignment of hills and mountains.
2. Tropical oceanic (south-west monsoon) air masses that blow over this region.
3. Occasional visit of the westerly (Mediterranean) lows in winter.
4. Presence of mountain and valley winds.
5. Presence of extensive forests and development of local cyclones.

The state-wise details of the climate are described as under:

2.2 Jammu & Kashmir

2.2.1 Temperatures

The atmospheric temperature component of the climate of Jammu and Kashmir varies greatly owing to its rugged topography. In the hot season, during May and June, Jammu city is very hot and the temperature reaches up to 40 ^{0}C. The Climate of Jammu region is sub-humid to sub-tropical. The temperature in plain areas of Jammu region goes up to 45^{0}C during summer and drops to as low as 3^{0}C during winter season. Kashmir region experiences Temperate-cum-Mediterranean type of climate. The mercury drops between -8^{0}C and -12^{0}C during winter and attains a moderate temperature of around 35^0 C during summer.

Climate of Ladakh region is 'Cold Continental' arid type. This region is almost above 3000 meters (9750 ft) above sea level and thus experiences extremely cold winters. In Zanskar, the average January temperature is -20^0 C with extremes as low as -40^0 C. All the rivers freeze over and locals actually do river crossings during this period because their high levels from glacier melt in summer inhibit crossing. In summer in Ladakh and Zanskar, days are typically warm with temperature at 20^{0}C but with the low humidity and thin air, nights can still be cold. The temperature falls down to -7^{0}C during winter. Dras, the second coldest inhabited place in the world falls in this region.

2.2.2 Rainfall Distribution

On the basis of rainfall distribution, the climate of J&K state is typically monsoonal. The state receives average 40 to 50 mm (1.6 to 2 inches) of rain per month between January and March while in July and August, very heavy though erratic rainfall occurs with monthly extremes up to 650 mm. In September, rainfall declines, and by October conditions are hot but extremely dry, with minimal rainfall and temperatures of around 29°C (Fig 2.1).

In the Kashmir region, average annual precipitation is 660 mm. About 65% of the precipitation occurs in the form of snow during winter season, i.e. December to February. March and April are the months of rainfall. May to September are relatively dry months.

Beyond the Pir Panjal range, the South West monsoon is no longer a factor. Srinagar receives as much as 635 mm of rain from western disturbances, the wettest months being March to May with around 85 mm rainfall per month. Across the main Himalayan Range, even the southwest cloud bands break up and the climate of Ladakh and Zanskar is extremely dry and cold. Annual precipitation is only around 100 mm per year and humidity is very low.

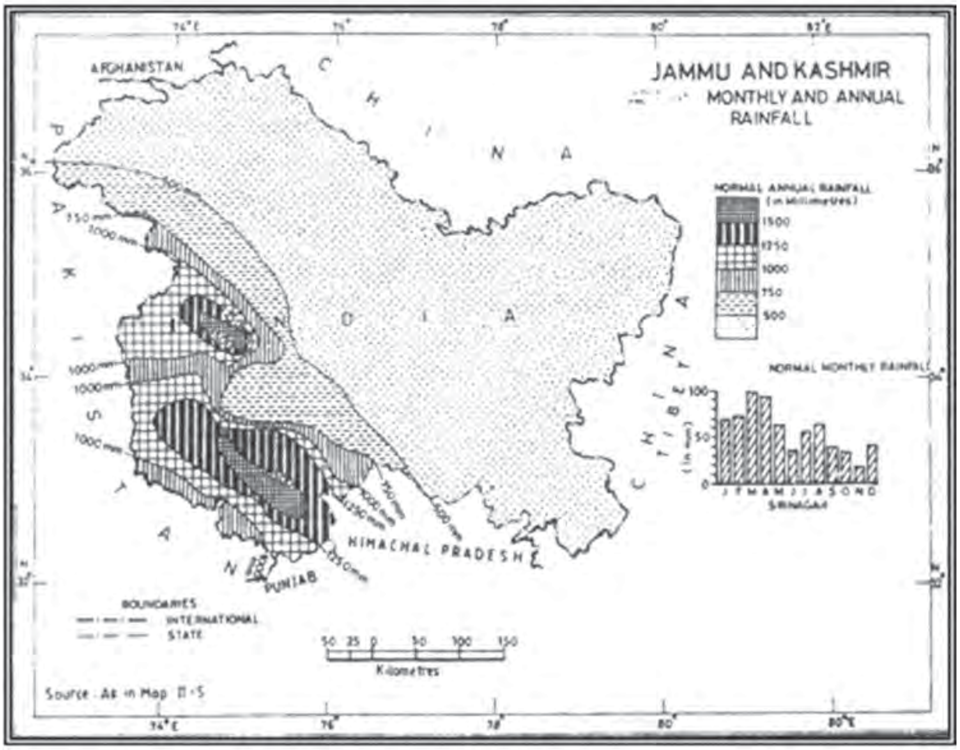


Fig 2.1: Rainfall distribution in J & K State

Jammu region receives an average annual precipitation of 1070 mm mainly in the form of rainfall. Snowfall occurs in high mountainous parts. South-west monsoon from July to September contributes about 80% of the total rainfall. Average number of annual rainy days in Jammu region is 59 days. Mean monthly rainfall and temperature in all the three regions are given in Table 2.1.

Table 2.1: Mean monthly rainfall & temperature in Ladakh, Kashmir and Jammu regions

Month	Mean Rainfall (mm)			Mean Temperature ^{o}C		
	Ladakh Region	Kashmir Valley	Jammu Region	Ladakh Region	Kashmir Valley	Jammu Region
January	10	74	58	-7.0	1.2	13.6
February	8	72	62	-5.7	2.7	15.5
March	7	92	52	0.4	8.3	20.0
April	6	93	33	6.1	12.9	26.4
May	6	60	24	10.2	17.6	32.1
June	5	36	71	14.2	21.9	33.6
July	12	59	325	17.4	24.5	30.8
August	15	61	299	17.1	23.9	29.3
September	7	39	84	13.2	20.3	28.9
October	3	30	19	6.9	14.0	25.4
November	1	11	17	0.9	8.5	19.5
December	5	34	32	-4.4	3.6	14.4

In the moderate and high altitude areas of Jammu region covering Doda, Poonch, Rajouri and Udhampur districts, the intermediate climate is experienced which marks the most last north-eastern limit of the south-western monsoon in summer and north-western disturbance in winter. From October to June, the precipitation and temperature patterns resemble closely the valley temperature zones. However, the summer rainfall and temperature resemble the precipitation pattern in the sub-tropical zone.

2.2.3 Snow Fall

The snow fall data of last few years is given in the Table 2.2.

Table 2.2: Yearly total snowfall (J&K sector)

Station Name	2005-06	2006-07	2007-08
Banihal Top (Jammu)	466 cm	577 cm	958 cm
Gulmarg (Kashmir)	737 cm	766 cm	629 cm
Haddan Taj	1010 cm	1044 cm	800 cm
Pharkian	1148 cm	1076 cm	968 cm
Z-Gali	1269 cm	944 cm	1215 cm
Stage-II	1022 cm	1257 cm	995 cm
Kanzalwan	1130 cm	973 cm	957 cm

2.2 Himachal Pradesh

There is a great variation in the climatic conditions of Himachal Pradesh due to varied elevation and topography. In general, however the various climatic zones range from sub tropical (450-900 m amsl) to warm temperate (900-1800 m amsl), cool temperate (1800-2000 m amsl), cold high mountain (2000-4000 m amsl) and snowy and frigid (above 4000 m amsl). Variations in altitude and topography result in local variation in conditions which are sometimes so conspicuous that statistical averages made at selected stations are not helpful. There are two rainy seasons in the state.

2.3.1 Rainfall Distribution

Himachal Pradesh receives rainfall both from southwestern monsoon and winter cyclonic rainfall. About 25% of precipitation occurs during December to March and 75% during the monsoon months of June end to September. Average annual rainfall is 1,134 mm. Generally rainfall increases from south to north. Western disturbances also shower rainfall during winter. Beyond Kullu, towards Lahaul & Spiti and Kinnaur, rainfall decreases due to rain shadow effect. Spiti is the driest area with 50 mm rainfall because it is enclosed by high mountains from all sides. Dharamshala receives the highest rainfall (> 3000 mm). Shimla receives 1600 mm rainfall annually. Kangra, Palampur and Jogindernagar receive more than 2000 mm rainfall. Kullu receives about 900 mm rainfall. There is a gradual decrease in rainfall towards Mandi, Rampur, Kullu, Kalpa and Keylong. About 70% of the annual rainfall is received during July to September and about 20% from October to March and 10% from April to June.

2.3.2 Snow Fall

Precipitation in the form of snow is received down to an elevation of about 1500 m amsl but the snow does not remain for long periods below 2500 m amsl. At an elevation of about 3000 m amsl the average snowfall is about 3 m which remains for four months (December to March) while above 4500 m amsl, there is almost perpetual snow cover. Differences in elevation gives rise to microclimates. The climate of Lahaul & Spiti and Kinnaur is semiarid highland type.

2.4 Uttarakhand

In general, Uttarakhand experiences humid and cold climate. The northern most part of the state is covered by snow round the year. The summer season starts from April and continues upto June. The southern part of the state is hot whereas the middle part is pleasant. The northern most part is cold in the summer season too. The rainy season starts from middle of June and continues upto October. The winter season is from November to March. January is the coldest month. Fog is very common is December and January. There are winter rains as well in the state.

The mean annual wind speed ranges from 3.2 to 12.2 km/hour and the wind speed is higher in hilly areas in comparison to the plain areas. The temperature and relative humidity show wide variations from month to month and place to place.

2.4.1 Rainfall Distribution

Covered mainly by hilly areas, the State receives rainfall in plenty. The southwest monsoons bring the rains in the state. The mean annual rainfall in the State ranges between 972.7 and 2,592.3 mm, with mean annual rainfall of 1545 mm. About 85% of the rainfall occurs from June to October when southwest monsoon sets in. The winter rains occur between December and January. The mean monthly and mean annual rainfall along with the number of rainy days for stations spread over the state are given in Table 2.3 and Isohyetal map showing rainfall distribution in the State is given in Fig 1.3. The rainfall distribution doesn't form any pattern in the state. This is because of sudden changes of high magnitude in the topography.

2.5 West Bengal (Darjeeling) and Sikkim

The area enjoys tropical, temperate to alpine type of climate. Mean temperature in Sikkim ranges between 4.6-24.8^{0}C in East District, 4.9-28.7^{0}C in West and 9.5^{0}C to 29.2^{0}C in South District. Relative humidity varies from 45% to 89%. In Darjeeling, maximum and minimum temperature varies from 1^{0}C to 21^{0}C.

2.5.1 Rainfall Distribution

Sikkim and Darjeeling Himalaya receive high monsoon rainfall. Average annual rainfall of Sikkim is 3250 mm while in Darjeeling Himalaya, the annual downpour goes to the tune of 2841 mm. Monsoon generally sets in during May and continues to October. The southwest monsoon is the most active during the months of July to September and is responsible for 80% of the total annual rainfall in the area. However, due to interception of the monsoon clouds by the high hill ranges, the rainfall is not uniform in Sikkim (Fig 2.2). A lot of precipitation takes place in the south and east districts of Sikkim while it gradually reduces towards west and north. The normal annual rainfall of Gangtok in the East is 3494 mm at altitude of 1818 m amsl, while at Thangu in North Sikkim(3812 m amsl), the normal annual rainfall is 821 mm. even in two sides of the hill ranges , significant deviation of rainfall is seen. Thus in the rain shadow side very less rainfall is received. This consequently influences ground water recharge as also spring perenniality. There are numerous such pockets all along the state where severe scarcity of drinking water is felt in summer.

Table 2.3: Mean Monthly & Annual Rainfall (mm), Uttarakhand (1901-1980)

District	Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Dehradun	Mussoorie	a	79.3	89.7	66.8	37.1	54.9	208.3	782.3	800.0	329.4	41.1	12.5	36.1	2537.8
				b	4.9	5.2	4.4	3.4	4.2	9.7	23.0	23.6	12.5	2.1	0.7 2.1
95.8															
Dehradun	Mussoorie	a	79.6	89.5	57.8	36.0	51.8	211.0	797.4	818.2	355.6	44.3	9.3	41.8	2592.3
	(obsy)	b	4.9	5.5	4.2	3.3	4.2	9.3	23.2	23.9	13.1	2.4	0.7	2.2	96.9
Nainital	Nainital	a	69.9	73.1	52.6	38.1	84.1	390.9	769.4	750.1	362.7	61.0	12.9	25.4	2690.2
		b	3.1	3.6	3.0	2.3	4.9	12.9	22.6	22.7	12.4	2.2	0.7	1.4	91.8
Nainital	Mukteshwar	a	56.9	62.0	48.5	36.3	56.4	176.0	516.0	306.3	201.7	43.4	8.9	24.6	1337.0
	(obsy)	b	3.7	4.5	4.1	3.2	5.0	9.7	17.9	17.8	10.4	2.3	0.6	1.7	80.9
	(Kumaun)														
Almora	Almora	a	42.9	49.3	42.2	27.9	48.3	143.8	264.9	234.2	130.3	32.3	7.4	21.3	1044.8
		b	3.3	3.9	3.8	2.7	4.5	8.2	15.1	14.2	7.6	1.9	0.6	1.8	67.6
Champawat	Champawat	a	67.6	75.9	49.3	30.2	62.0	194.8	339.1	287.8	198.1	43.9	12.7	25.4	1386.8
		b	3.4	4.5	3.7	2.7	5.3	10.2	17.1	16.1	8.3	1.7	0.7	1.6	75.3
Almora	Ranikhet	a	54.1	62.0	46.2	31.0	50.0	144.0	331.5	344.4	165.9	33.5	7.4	22.9	1292.9
		b	3.7	4.2	3.6	2.8	4.4	8.6	17.6	18.2	9.0	1.8	0.5	1.9	76.3
Pithoragarh	Pithoragarh	a	44.2	56.4	40.4	28.2	72.6	182.9	299.7	287.3	149.3	33.3	6.9	21.8	1223.0
		b	3.1	4.0	3.8	3.1	5.8	10.4	17.2	16.1	8.7	2.1	0.6	1.6	76.5
Pithoragarh	Askote	a	36.8	54.9	30.2	29.7	73.4	215.1	453.9	419.9	190.3	36.1	3.3	21.8	1565.4
		b	3.2	3.9	3.1	3.4	6.5	12.1	20.6	19.9	12.3	3.1	0.4	2.0	90.5
	Chaukuri	a	44.7	53.9	48.8	32.0	76.7	317.7	674.6	669.5	313.7	53.9	8.1	18.0	2311.6
		b	3.3	4.4	4.3	3.1	6.2	13.6	23.3	23.8	14.3	3.3	0.5	1.5	101.6
Pithoragarh	Berinag	a	57.9	62.7	55.6	39.1	85.3	272.0	520.9	507.0	228.6	43.2	9.4	25.7	1907.4

		b	3.6	4.2	4.3	3.6	6.2	12.4	20.5	19.5	11.5	2.6	0.6	1.8	90.8
Bageshwar	Kausanie	a	58.7	71.4	62.5	45.7	86.4	226.6	420.1	375.2	185.2	43.9	9.1	26.2	1611.0
		b	3.9	4.5	4.3	3.9	6.5	11.7	19.7	18.9	9.4	2.3	0.8	1.7	87.6
Pauri	Pauri	a	60.7	66.8	55.1	32.0	51.6	132.3	326.1	359.9	148.3	33.8	8.1	28.2	1302.9
		b	4.4	4.5	4.1	2.9	5.0	8.3	16.9	17.2	8.4	1.8	0.7	1.8	76.0
Rudraprayag	Okhimath	a	66.0	67.8	52.6	40.9	73.4	196.3	524.3	570.0	232.4	36.6	6.1	22.1	1888.5
		b	4.2	4.7	4.3	4.0	6.4	11.0	22.6	23.5	13.1	2.6	0.6	1.5	98.5
Chamoli	Joshimath	a	65.8	92.7	98.5	54.4	35.1	88.9	176.3	184.7	108.5	28.2	12.2	27.4	972.7
		b	4.4	5.6	6.6	4.5	3.8	7.6	15.5	16.2	8.8	2.0	0.9	2.0	78.1
Pauri	Bironkhal	a	63.0	71.6	43.9	30.5	63.0	165.9	315.5	263.9	131.6	36.6	5.1	27.2	1217.8
		b	3.7	4.1	3.2	2.5	4.3	9.0	15.5	15.0	6.6	1.7	0.4	1.6	67.6
Pauri	Lansdowne	a	66.8	73.1	45.0	28.5	53.1	201.9	626.4	627.9	316.0	44.5	6.1	27.2	2116.5
		b	3.5	3.9	3.4	2.3	3.7	8.7	21.4	21.7	11.4	1.6	0.5	1.5	83.6
	Somerford	a	58.4	76.7	54.6	39.1	56.6	214.1	380.7	371.1	224.3	46.0	12.5	32.3	1566.4
	Orchard	b	3.6	4.1	3.8	3.1	4.5	9.9	17.5	17.5	9.8	1.7	0.8	1.8	78.1
Chamoli	Badrinath	a	—	—	—	—	—	43.0	182.9	138.5	64.9	26.2	—	—	—
		b	—	—	—	—	—	6.7	18.8	15.2	6.3	2.2	—	—	—
Pithoragarh	Tijjim	a	97.5	89.9	139.0	59.1	54.4	136.6	381.9	408.6	233.9	63.1	21.3	35.6	1720.9
		b	5.2	5.6	7.9	5.3	5.4	13.2	25.6	24.3	14.8	3.9	1.5	1.6	114.3
Pithoragarh	Munsyari	a	79.1	35.5	130.7	83.2	106.3	229.9	784.8	661.0	350.3	41.2	33.8	63.6	2599.4
		b	5.0	3.0	8.2	7.5	7.6	13.8	26.3	25.8	16.7	3.3	2.6	2.0	121.8
Uttarkashi	Uttarkashi	a	69.5	36.5	67.7	30.5	41.5	97.6	387.6	419.9	347.5	20.1	7.7	26.7	1552.8
		b	4.0	3.2	6.3	3.3	4.2	10.0	20.5	21.7	14.8	2.2	0.8	1.5	92.5
Uttarkashi	Rajgarhi	a	62.7	50.6	79.1	31.2	79.5	132.4	421.4	326.4	360.8	23.4	28.9	34.8	1631.2

		b	4.7	5.0	6.5	4.8	6.0	8.8	19.4	18.8	10.4	1.8	2.0	1.8	90.0
	Jamunachetty	a	94.5	60.3	93.8	35.0	64.7	192.2	498.3	514.6	244.6	71.2	19.6	28.7	1917.5
		b	5.7	3.8	6.1	3.5	5.3	10.0	19.5	20.6	13.2	3.5	1.1	1.7	94.0
Uttarkashi	Rana	a	132.4	58.2	119.1	64.8	96.2	161.6	424.5	511.12	260.0	53.3	28.0	39.3	1948..5
		b	6.7	4.4	7.8	5.8	7.8	11.0	22.0	22.2	14.0	3.7	1.6	2.3	109.3
Uttarkashi	Kharsali	a	157.1	89.2	135.2	91.7	101.0	147.1	413.9	600.9	358.7	85.9	18.7	50.6	2092.9
		b	6.3	5.5	8.5	7.0	7.8	9.6	22.1	23.4	13.9	4.7	1.6	3.3	113.7
Tehri	Mukhim (obsy)	a	69.3	56.3	73.7	43.6	75.7	151.7	431.9	348.2	251.16	6.4	15.7	42.0	1625.6
Garhwal		b	4.2	4.2	5.6	4.6	5.4	9.3	19.8	18.4	12.5	3.7	1.1	2.1	90.9
Tehri	Dhanolti	a	48.2	51.6	56.2	25.7	55.4	139.4	518.2	473.0	301.7	41.9	33.1	27.8	1772.2
Garhwal		b	4.4	3.3	4.7	3.0	4.0	7.9	20.9	20.6	11.6	3.9	1.4	1.7	87.4
	Ghuttu	a	91.2	82.1	109.5	73.2	75.7	417.0	757.12	695.4	427.9	59.8	17.5	42.7	2849.1
		b	5.3	3.7	5.9	5.5	5.2	14.5	4.9	23.3	14.1	2.9	1.3	1.9	108.5
Pauri	Kotdwara	ab	41.9	46.0	21.6	15.5	25.4	172.5	557.0	541.8	249.7	37.1	6.3	15.2	1730.0
			2.6	2.9	2.0	1.5	2.0	7.3	18.2	17.5	9.0	1.4	0.4	1.1	65.9
Nainital	Nainital (obsy)	ab	117.5	44.0	53.7	24.7	75.5	273.3	769.4	560.7	330.8	305.2	7.4	35.3	2597.5
			6.5	2.4	4.1	2.0	3.5	11.4	23.6	22.9	12.5	5.5	0.5	1.1	96.0
Haridwar	Haridwar	ab	47.2	48.8	26.2	11.2	23.6	116.3	345.2	390.9	194.6	25.1	5.3	16.5	1250.9
			3.0	3.0	1.8	0.9	1.9	5.8	14.2	14.8	7.6	1.1	0.4	1.3	55.8
							Hill of U.P. West								
Nainital		ab	36.6	40.3	16.9	10.4	27.3	190.0	485.6	468.3	242.4	31.5	3.0	13.6	1565.9
			2.1	2.6	1.5	0.9	2.0	7.2	16.1	16.2	9.0	1.3	0.2	1.0	60.1
Dehradun		ab	60.5	63.0	36.3	19.8	32.9	184.9	707.8	775.8	328.0	39.9	7.5	25.3	2281.7
			3.8	3.6	2.8	1.8	2.7	8.3	20.3	21.1	11.1	1.8	0.5	1.6	79.4

a- Mean Rainfall (mm)b-Average number of Raining Days (with Rainfall of 2.5 mm or more)

Fig 2.2 Rainfall Distribution in Sikkim

2.5.2 Snow fall

Snow fall is very common feature in many places of North Sikkim and West Sikkim as also in the Tsomgo (Chhangu) Lake area near Nathula Pass. In these areas, snowmelt water forms a potential source of groundwater recharge beside rainfall. However, during extreme cold, snow fall may also occur in other parts of Sikkim, like Gangtok as also in Darjeeling and Kalimpong areas of West Bengal state.

2.6 Arunachal Pradesh

The wide altitudinal difference along with physiography contributes to great climatic variations in the Arunachal Himalaya. Based on altitude, rainfall patterns, temperature variations, topography, soil, etc., five agro-climatic zones have been identified in the area. These are:

1. Alpine Zone: Gorichen, Upper Tawang, Tulungla, Bumla, Shela Pass area of Tawang and West Kameng district, Jidu and adjoining areas of Upper Siang.
2. Temperate and subalpine zone: Tawang, Dirang, Bomdila, Shergaon areas of Tawang and West Kameng district, northern part of East Siang, Upper Subansiri district, part of Dibang valley district around Anini and north eastern part of Lohit district.,
3. Subtropical hill zone: Basar area of Siang district.
4. Mid Tropical hill zone: Southern part of Lower Subansiri district, i.e., Papum Pare district.
5. Mid tropical plain zone: Lower part of Lohit district.

The climate of the major part of the state falls under humid subtropical with wet summer and winter and the remaining part falls under cold humid with wet summer and winter.

2.6.1 Rainfall

The pre-monsoon season starts from January and continues up to March. April/ May to September constitute the monsoon season and the post-monsoon season starts from October and continues up to December. Highest rainfall occurs in the months of June and July/ August.

2.6.2 Temperature

The average maximum and minimum temperatures in humid subtropical region are 31.87 and 14.99^{0}C and in cold humid region are 19.4 and 3.84^{0}C respectively.

2.6.3 Humidity

Humidity is more in the mid-tropical hill and plains than in alpine zone. In general average humidity during rainy season is more than 80%. In the alpine region, the average humidity varies from 64 to 68%.

2.7 Hydrometeorology of North Eastern States contiguous to Himalayan Region

2.7.1 Assam

The state of Assam enjoys sub-tropical humid climate with maximum temperature ranging from 27^0 to 38^0 C and minimum winter temperature varying between 3.4^0 to 11^{0}C. Humidity is very high ranging from 74 to 87%. Assam experiences the phenomenal influence of the southwest tropical monsoon which persists from April to October, with occasional winter showers. The normal annual rainfall of the state is recorded to be 2408.6 mm with little variation. In the extreme southern parts of Karbi Anglong and Nagaon districts, rain-shadow area receives relatively low rainfall having average annual rainfall of less than 1500 mm.

2.7.2 Meghalaya

High altitude areas of the region have temperate climate and low altitude areas have tropical to sub-tropical climate. Generally, the central hill area experiences an ambient annual temperature of 20^0 C; elsewhere the temperature exceeds 20^{0}C. The summer temperature is as high as 25^0 C and mean winter temperature ranges from 2^{0}C to 9^{0}C with periodic deviation upto below the freezing point, marked by the appearance of ground frost in the early morning. Meghalaya experiences a remarkably high rainfall profile during the southwest monsoon, which usually starts from the middle of May and declines towards mid October. There are four seasons in Meghalaya namely summer, monsoon or rainy, autumn and winter. The summer season extends from end of March to Mid May, which is characterized by relatively high temperature, occasional thunderstorm, and high wind velocities. The rainy season commences with the onset of southwest monsoon in April and lasts up to October that encourages a lot of wet cultivation in the state. This is followed by short autumn from mid October to November. The winter season extends from December to the end of March. This is the coldest season of the year with sharp decline in temperature. During winter, some high altitude areas of the state experience very cold nights with mercury dipping to –1^{0}C to –2^{0}C. Winter is basically dry with reducing diurnal range of temperature. Rainfall in the state is abundant. Rainfall during the monsoon season varies from 100 cm in the west central part to over 1000 cm in the south and southeast. Average rainy days during the season vary from 60 in the west-central part to over 100 days in the southeastern part. Heavy precipitation occurs in areas like Cherrapunji (Sohra) and Mawsynram. Mawsynram and Cherrapunji in the East Khasi Hills district are geographically considered as the rainiest places in the World. Cherrapunji has an average annual precipitation of about 11,430 mm (450 inches) and Mawsynram is a village directly west of Cherrapunji, where rainfall of around 17,800 mm (700 inches) per year has been recorded. On an average, the area receives rainfall for 161 days in a year.

2.7.3 Mizoram

The state of Mizoram enjoys sub-tropical humid climate. It is generally cool in summer and not very cold in winter. During winter, the temperature varies from 11^0C to 24^0C and in summer it varies between 20^0C to 29^0C. The State experiences the phenomenal influence of the South West Tropical monsoon which persists from May to October, with occasional winter showers. The average annual rainfall of the state is recorded to be 2794 mm with little variation within the state. The average monsoon rainfall is 1761 mm (63%) and non-monsoon rainfall is 1033 mm (37%). The Relative humidity is high throughout the year, but it reaches more than 85 percent during the months of January, March, April, May, June, July, October, November and December.

2.7.4 Nagaland

The state of Nagaland enjoys sub-tropical humid climate with maximum temperature upto 38^0C and minimum winter temperature goes down to 2.2^0C. Humidity is very high ranging from 74 to 87%. Nagaland experiences the phenomenon influence of the South West Tropical monsoon which persists from May to September, with occasional winter showers. The average annual rainfall of the state is recorded to be 1715 mm, with districts of Wokha and Zunebhoto receiving more than (2000 to 2250 mm) average rainfall and Mokokchang and Phek districts receiving less than (1170 to 1300 mm) average rainfall of the state. The average number of rainy days in the state is around 135 days.

2.7.5 Tripura

Climate of the state is characterized by moderate temperature and high humid atmosphere. Winter sets in November and lasts till the end of February. Summer season starts from March and lasts upto May and is followed by Southwest monsoon lasting till September. Generally, the maximum summer temperature ranges from 35^0C to 40^0C and average minimum temperature in winter nights is recorded at 6^0C.

The state receives rainfall from Southwest Monsoon. The average annual rainfall over the state is 2403 mm. The intensity of rainfall increases from SW to NE in the state. In West Tripura district, the normal monsoon rainfall is 1733 mm and normal annual rainfall is 2324 mm. In South Tripura district, normal monsoon rainfall is 1364 mm and normal annual rainfall is 2026 mm. In North Tripura district, normal monsoon rainfall is 1370 mm and normal annual rainfall is 2439 mm. In Dhalai district normal monsoon rainfall is 1394 mm and normal annual rainfall is 2320 mm.

2.7.6 Manipur

The State of Manipur has sub-tropical to temperate climate depending upon the elevation. The temperature varies from 0^0 C to 39^0 C. Manipur experiences the phenomenal influence of the South West Tropical monsoon. The maximum rainfall of monsoon period occurs between May and August. The Average annual rainfall of 22 years (1986 to 2007) in the State is 1465.95 mm of which 808.16 mm is monsoon rainfall and 652.07 mm is non-monsoon rainfall.

3.0 GEOMORPHOLOGY

The geomorphological features of the Himalayas are distinctive in nature based on the topographic and physiographic landscapes (Plate-II). A generalized description of major land forms in the Himalayan region is furnished below.

- **Siwalik Foothills**: These are below 900 m in elevation and are comprised of sedimentary rocks that are unconsolidated in nature deposited in a lake formed after collision of plates. These ranges are fossiliferous and are relatively endowed with water due to their partially consolidated nature of sediments. Springs are common and wells re observed in a few areas.

- **Lesser Himalaya**: These unfossiliferous ranges have elevation in the range of 900 – 3000 m and are comprised of slightly metamorphosed sedimentary rocks such as quartzites, slates, phyllites and limestones. Springs are the main source of water. Reducing discharge of springs is a major concern in these ranges.

- **Greater Himalaya**: These are high snow-capped peaks above 3000 m and are comprised of sedimentary, metamorphic and igneous rocks. Sediments and high grade metamorphic rocks are intruded by granites of different ages. These are the water-scarce regions and are dependent on springs.

- **Trans Himalaya**: These ranges lie beyond the Greater Himalayas and have altitudes between 3000 – 5000 m. Major rivers originate in the Trans Himalayas. These are comprised of sedimentary, metamorphic and igneous rocks. These areas are traditionally dependant on springs.

State-wise details of geomorphological features have been described as under:

3.1 JAMMU & KASHMIR

The Jammu & Kashmir region consists of four mountain ranges of Himalayas.

- Karakoram Range
- Ladakh Range
- Zanskar Range
- Pir Panjal Range

Between these ranges, there are several WNW- ESE to NW- SE trending longitudinal valleys viz. the Gilgit, the Shyok, the Indus and the Jhelum. In the south of the Pir Panjal Range, is the Siwalik Range, comparatively much lower in elevation and comprising the Jammu hills. Further south, there is a narrow strip of foothill plains (25 km wide) merging into Punjab plains. The state can be divided into three physiographic units. They are:

1. Lesser and Outer Himalaya: These can be subdivided into:-

a. Plains / the Outer Plains

b. Siwaliks

c. Sub Himalayas

2. Higher or Greater Himalayas

3. Trans Himalayas (Ladakh and Karakoram Himalaya)

3.1.1 Lesser and Outer Himalaya

3.1.1.1 Plains / Outer Plains

The narrow strip of north west - south east trending plains bounded by Chenab river in the north-west and Ravi river in the south-east is situated in the south-western part of Jammu and Kashmir where it marks the border with Pakistan. Alluvial deposits of the sloping plains below the foothills of the Himalaya consist of thick permeable beds of cobbles, pebbles, coarse sands, and minor clay bands. This plain has further been subdivided into two geomorphologically distinct belts, which are locally known as

A. Kandi belt and

B. Sirowal belt

A. Kandi belt:

The submontane tract lying in the outer Himalayas of Jammu Division between Chenab in the north-west and Ravi river in the south east is mostly ravine, locally known as Kandi area of Jammu and Kashmir. This unit is an extension of the Kandi belt in the states of Himachal Pradesh and Punjab, and Haryana and Uttarakhand where this northwest-southeast trending belt at places is also known as *Bhabar Zone*. The upper portion of Kandi belt consists of low hills covered by shrubs and forests, and the lower terrain has cultivated lands and gully beds. It has an undulating topography, steep and irregular slopes, erodable and low water retentive soils and badly dissected terrain forming numerous gullies.

B. Sirowal belt

The Kandi and Sirowal deposits being contemporaneous, it is difficult to demarcate precisely the line between the two belts. However, the 'spring line' broadly marks the boundary of Kandi and Sirowal. Sediments of Sirowal comprise of clay, silt and sand. The flood plains and the associated features (channel bars) of Chenab and Ravi rivers and those of their major tributaries, alluvial lowland, alluvial upland and piedmont alluvial plains are the main geomorphic units in the zone. In general, the ground slope is towards south-west and is dissected by tributaries of Chenab and Ravi rivers. The extension of this belt in Uttarakhand is also known as *Tarai Belt.*

3.1.1.2 Siwaliks

This zone is characterized by structural and denudational hills comprising WNW-ESE to NW-SE trending ridges separated by sub-latitudinal flat-bottomed valleys called 'Duns'. The elevation of the hills ranges between 600 m and 1200 m. Siwaliks have a maximum width of about 50 km in Jammu area. The width of the Siwaliks gradually decreases eastwards to get completely eliminated for a stretch of about 80 km but further eastwards, they reappear as a narrow strip in the southern Arunachal Pradesh. The erosional and depositional terraces of Chenab river and its major tributary, Tawi river are the other geomorphic features of the zone.

3.1.1.3 Sub Himalayas

This zone, like the Siwaliks, is also characterized by structural and denudational hills but with higher elevations ranging from 3500 to 5000 m. Pir Panjal range and its offshoot and northerly trending Saribal range are parts of this zone. These ranges are characterized by deeply cut valleys and precipitous gorges. The zone is dissected by Chenab river which has developed cyclic and non-cyclic terraces. The range lies between the Greater Himalayas in the north and Siwâliks, in the south. Also called, Ratanpir Range in Jammu and Kashmir, the Lesser Himalayas is a prominent range at elevation of 2,000 to 3,000 m amsl (6,600 to 9,800 ft) formed along the **Main Boundary Thrust** with a steep southern face and gentler northern slopes. The Lesser Himalayan Ranges are drained by rivers originating in the northern Tethyan Himalayan Zone, which cut across the Higher Himalayan and Lesser Himalayan Ranges in a number of deep gorges and ultimately flow into the great alluvial flood plains of the Indo- Gangetic Plains.

3.1.2 Higher or Greater Himalayas

North of the *Main Central Thrust* (MCT), the highest ranges rise abruptly as much as 4,000 m above mean sea level (13,000 ft) into the realm of perpetual snow and ice. As the Himalayan system becomes wider from east to west, the number of parallel high ranges increases.

Greater Himalayan zone including the well known Zanskar range with snowy peaks and average height exceeding 6000 m above mean sea level is higher, steeper and more rugged than the Lesser Himalayan Zone. Nanga Parbat attaining an elevation of 8126 m above mean sea level is its highest peak. Rising steeply like a wall from lesser Himalaya, the whole of this zone with the exception of the deep river ravines lies above the perpetual snow line. Kashmir valley with its fresh water and riverine lakes is located between Pir Panjal (Lesser Himalayan) and Greater Himalayan ranges.

3.1.3 Trans-Himalayan zone (Ladakh and Karakoram Himalayas)

This zone also contains WNW- ESE to NW-SE trending mountain ranges**. Ladakh and Karakoram ranges are located in this zone**. These ranges have almost flat crests and glaciers and streams draining their flanks have cut very deep valleys, which subsequently got filled with glacial moraines.These are prominent ranges in the trans-Himalayan region, with peaks ranging from 6000 to 7000 m amsl, but some exceed 8000 m amsl. The Ladakh range is situated between Indus and Shyok rivers.

Indus valley located between Zanskar range in the south and Ladakh range in the north is a broad flat valley with its valley floor elevation varying from 3195 m at Leh to 3395 m at Upshi. Bajada (Piedmont fan surface), erosional and depositional terraces, recent flood plains with associated bars of Indus river, palaeo-lake and aeolian surfaces are the main geomorphic features of Indus valley. South-flowing rivers form valleys in this region, which have often semi-arid climate due to rain shadow effect. These valleys hold some of the highest permanent villages on earth.

3.1.4 Mountains and their Passes

Mountains have a special geographical importance to the State of Jammu and Kashmir. Kashmir valley is enclosed by high mountain-chains on all sides except for certain passes and a narrow gorge at Baramulla. There are Siwalik hills towards the south and very lofty mountains in the north, the peaks of which always remain covered with snow. There are volcanic mountains too in the State. They have caused havoc in Kashmir in the past. Some of the famous mountains and their passes are:

3.1.4.1. Karakoram (8615.17 M) and Kyunlun Ranges

Both these mountains lie to the north and north-east of the State and separate it from Russian Turkistan and Tibet. In the north-west, Hindukush range continues towards Karakoram range, where K2 peak, the second highest peak of the world, is situated. Two lofty peaks of Gashorbram (8570 metres) and Masharbram (7827 metres) also lie there. People of Ladakh pass through Karakoram pass (5352 metres) and Nubra pass (5800 metres) while going to China, Turkistan and Khattan. One can reach Tibet from Ladakh via Khardungla pass (5557 metres) and Changla pass (5609 metres).

3.1.4.2 Zanskar Range

It is about 600 m amsl and separates Indus valley from the valley of Kashmir. It prevents south-west cold winds from reaching Kashmir. Ladakh region terminates at Zojila pass (3529 metres) from where begins the valley of Kashmir. Poat pass (5716 metres) is also a famous pass in this range.

3.1.4.3 Nun Kun Range

It lies between Ladakh and Kashmir border. It is 7055 m amsl. To its south-east is situated Kullu and to its north-west is situated Kargil tehsil of Ladakh. One has to pass through Bawalocha pass (4891 metres) to reach Leh (Ladakh) from Kullu.

3.1.4.4 Nanga Parbat Range

This range spreads in Gilgit. Its height is 8107.68 m amsl and is utterly devoid of vegetation. It was conquered by the Italian mountaineers in 1954.

3.1.4.5 Harmukh Mountain

This range of the Himalayas is situated at a height of 5141.3 m amsl towards Bandipore between the rivers Jhelum and Kishan Ganga valley.

3.1.4.6. Burzil Mountain

It lies between Kashmir and Ladakh on which Burzil pass is situated at a height of 3200 m amsl.

3.1.4.7 Amarnath Mountain

This mountain famous for its holy Amarnath Cave, is at a height of 5372 m amsl, which thousands of pilgrims visit every year on Rakshabandhan. They have to pass Mahagunas pass (1475 metres) on their way to Shri Amarnathji. Gwasharan (5450 metres) is situated in the Liddar valley towards Pahalgam; on which lies the famous glacier Kolahi. Shaeshnag Mountain also spreads in this valley. It is called Shaeshnag as its peaks resemble the heads of seven big snakes.

3.1.4.8 Toshmaidan

Toshmaidan (4270 metres) and Kajinag (3700 metres) mountains lie in the Inner Himalayas. They remain clad with snow throughout the year, but during summer when the snow melts, water flows down into the Jhelum river.

3.1.4.9 Afarwat

This mountain spreads through the Gulmarg valley. The famous spring Alpathar lies on its peak, from which Nullah Nagal comes out and flows down into the Wullar lake.

3.1.4.10 Pir Panjal Range

It separates Kashmir valley from the outer Himalayas and is about 2621 km in length and 50 km in breadth. Famous Banihal pass (2832 metres) lies in the shape of a tunnel on its peak; it remains covered with snow during winter making it impassable. Now at a height of 2200 m amsl a new tunnel 'Jawahar Tunnel' has been constructed. On the other end of this range lie Baramulla pass (1582 metres) and Hajipir pass (2750 metres).

3.1.4.11 Volcanic mountains

There are two volcanic peaks viz. 'Soyamji' (1860 metres) situated in North Machhipura (Handwara) and 'Kharewa' that lies in Tehsil Pehalgam. The former volcano continued eruption of lava for about l3 months during 1934, while the latter is passive. Many sulphur springs are found at the foot of the hill. These volcanic mountains are the cause of earthquakes in Kashmir. So far twelve devastating earthquakes have occurred in Kashmir.

3.1.5 Glaciers

In order to comprehend the drainage system in the Himalayas, description of glaciers**,** the origin of many important rivers of Asia, require a special mention. Jammu and Kashmir glaciers and glaciers of Ladakh are of different types. But the most important is the Siachen glacier, which is the largest glacier outside the Polar Regions. Some of the important glaciers in Jammu and Kashmir are as follows:

- Siachen Glacier
- Baltoro Glacier
- Biafo Glacier
- Nubra Glacier
- Hispur Glacier

3.1.5.1 Siachen Glacier

Siachen glacier is located in the extreme north-central part of Jammu and Kashmir near the Indo - Tibet border. Stretching to a length of about 72 km, it is the largest glacier in the world outside the Polar Regions. Siachen is situated on the north-facing slopes of Karakoram Range. It is the source of the Mutzgah or Shaksgam River that flows parallel to Karakoram Range before it enters Tibet. Central part of Siachen glacier is a vast snow field. It mainly lies in a vast trough, which is about 2 km wide and scattered with rocks and boulders on its sides. Large tributary glaciers like the Mamostang and Shelkar Chorten open into the main glacier from both sides of its trough. Numbers of icefalls are formed at the meeting point of trunk glacier and small valley glaciers. A group of three glaciers i.e. North, Central and South lies to the east of Siachen. It is known as the Rimo glacier group. The altitude of this glacier is between 6,000 and 7,000 m above mean sea level. Siachen glacier can be travelled via Skardu in Ladakh.

3.1.5.2 Baltoro Glacier

Baltoro glacier is located in Jammu and Kashmir in an area called Baltistan on the southern slopes of central Karakoram Range. It stretches to a length of 62 km. It is the second largest glacier in the Himalayan region. Shigar River, which is a tributary of the Indus River, originates from this glacier. Other large tributary glaciers join the main Baltoro glacier. The central part has a vast snowfield and the trough of this glacier is very wide. This glacier can be accessed via Skardu in Ladakh.

3.1.5.3 Biafo Glacier

Biafo glacier is located in Ladakh in an area called Baltistan on the southern slopes of the Karakoram Range. It stretches to a length of 60 km. The main stream, which originates from Biafo glacier flows into a tributary of the Indus River called the Shigar River. In this area, there is no vegetative cover.

3.1.5.4 Hispar Glacier

In the Himalayan region, Hispar glacier is the third largest glacier. It is located in Ladakh, Jammu and Kashmir on southern slopes of Karakoram Range. It stretches to a length of 60 km. There is no vegetation of any kind in this area. Many small glaciers join the main glacier on both sides. The central part of the glacier is a vast snow field while its sides contain debris eroded by the huge body of moving ice.

3.1.5.5 Nubra Glacier

Nubra glacier is also located in Ladakh on the southern slopes of Karakoram Range. Nubra River originates from this glacier and flows into the Shyok River. Just like other glaciers, central portion of the glacier forms a vast snow field. Vegetation is totally absent in this area as it lies above the snow line. The place can be accessed via Leh in Ladakh.

3.2 HIMACHAL PRADESH

Himachal region presents an intricate mosaic of mountain ranges, hills and valleys with altitude ranging from 350 m to more than 6500 m amsl (Plate II). The Dhauladhar range looks in supreme majesty over the Kangra valley while the Pir Panjal, the Great Himalayas and the Zanskar keep a guard over Chamba, Lahaul & Spiti, Kullu and Kinnaur. The mountain slopes are covered with forests and meadows. The valleys below are interspersed with numerous streams and agricultural fields. There is general increase in elevation from east to west and from south to north. The physiographic divisions from south to north are as follows:

3.2.1 Outer Himalayas / Siwaliks (350 to 1500 m amsl)

Outer Himalayas or the Siwaliks is the southern most zone consisting of low hills of Siwaliks varying in altitude from 350 m to 1500 m amsl. The conspicuous feature is longitudinal depressions or “Valleys” formed between these ranges. They maintain almost uniformity from river Ravi in the west to the Yamuna in the east. Siwaliks have been highly deforested and eroded. Nurpur, Indaura, Una, Nalagarh and Paonta are the important valleys in the area.

3.2.2 The Lesser Himalayan Range (1500-5000 m amsl)

The Lesser Himalayan range is marked by a gradual rise in elevation towards the Dhauladhar and Pir Panjal ranges. In the south, the rise is more abrupt near Shimla. Series of parallel ranges are divided by longitudinal valleys. The only exception being Kullu valley that runs transverse to the main alignment. Near the plains, the features of hills and valleys are somewhat distinct. Kangra valley is a longitudinal trough at the foot of the Dhauladhar ranges. Various streams and rivers have carved out valleys. Dhauladhar ranges are intersected by the Ravi river in Chamba district and the northern flank impinges against the southern flank of the Pir Panjal range (average peak elevation 4600 m amsl). The mean elevation of Dhauladhar is about 4500 m amsl.

3.2.3 The Pir Panjal Range

The Pir Panjal range is the largest of the lesser Himalayan ranges. It is a bifurcation from the Great Himalayan range, near the bank of the Satluj forming the water parting between the Chenab on one side and the Beas and the Ravi on the other. Rohtang Pass (3978 m amsl) and several other passes lie over it. Lahaul valley lies between the Pir Panjal and the Great Himalayan range.

3.2.4 The Great Himalayan Range (5000 – 6000 m amsl)

The Great Himalayan range runs along the eastern boundary and is cut by the river Satluj. The range separates the drainage of the Spiti river from the Beas. There are number of famous passes on this range such as Zkangla (5248 m amsl), Parang (6548 m amsl), Bara Lacha (4512 m amsl) and Pin Parbati (4802 m amsl). Spiti and Kinnaur valleys lie between the Great Himalayan and the Zanskar range.

3.2.5 The Zanskar Range

The Zanskar range is the eastern most range and separates Spiti and Kinnaur from Tibet. It has peaks of over 6500 m amsl in altitude. The Zanskar range is cut by the Satluj. There are many glaciers on the Zanskar and the Great Himalayan range.

3.3 UTTARAKHAND

Himalayas in Uttarakhand extend from the Kali River which defines the India – Nepal border in the east, to the Tons – Dabar valleys demarcating the eastern border of Himachal Pradesh. It comprises the districts of Pithoragarh, Almora, Bageshwar, Nainital, Pauri, Chamoli, Uttarkashi, Tehri, Dehradun Udhamsingh Nagar, Champawat and Haridwar

3.3.1 Physiographic belts

The Uttarakhand Himalayas fall into five well defined physiographic belts, each being a distinct geological unit.

1. Bhabar & Terai
2. Siwalik
3. Lesser Himalayas
4. Great Himalaya
5. Tethys or Tibetan Himalayas

3.3.1.1 Bhabar and Terai

The NW-SE trending foothill zone, immediately south of Himalayan region forms a distinct physiographic unit, known as Bhabar. The Bhabar sub-unit is formed by lateral coalescence of alluvial fans designated as piedmont deposits. The piedmont deposits form a zone of high permeability in which the streams descending from north are sub-merged and again emerge on its southern extremity as spring line. The drainage is almost absent in this physiographic sub-unit. The NW-SE trending area between Bhabar and Central Ganga plains forms a physiographic unit of varying width, which is known as Terai. The northern limit of Terai is demarcated by spring line and significant difference in topographic slope. Terai unit is confined to Udham Singh Nagar district.

3.3.1.2 Siwaliks

The outer Himalayan Siwalik range 900 – 1500 m in height, built up of Late Tertiary Sedimentaries, exhibits a rugged and restive topography characterized by steep hill slopes and deep valleys with crumbling walls scarred with landslides. This youthful mountain range seems to be tectonically active and is presumably still rising.

3.3.1.3 Lesser Himalaya

Krol Thrust (Main Boundary Fault) separates Siwalik and Lesser Himalayas (1500 to 2500 m). Topography with gentle slopes and deeply dissected valleys suggests that the rivers and streams are still furiously at work. The highest peaks of this central belt of the Precambrian-Palaeozoic sedimentary and granite injected metamorphics are Dudhatoli (3114 m) east Pauri and Nag – Tibba (3022 m) north Mussoorie.

3.3.1.4 Great Himalaya

The northern belt of Great Himalaya with its peak soaring 6500 to 7200 m height is characterized by precipitous scarps and vertical walled gorgeous valleys and tub trembling and foaming rivers. This belt of youthful topography is tectonically still active and is comprised of the oldest rocks of Himalayas, the Precambrian metamorphics and granitic-gneisses.

3.3.2.5 Tethys or Tibetan Himalayas

To the north of formidable Great Himalayas lies the vast expanse of what is known as the Tethys or Tibetan Himalaya made up of sedimentary rocks ranging in age from the late Precambrian to Cretaceous. This extremely rugged vegetation less and sparsely populated zone of frigid climatic conditions evinces comparatively milder tectonic instability.

These sub-ranges are shown in Plate-II. The Great Himalayan range and Tethys or Tibetan Himalayas are at places covered by snow.

3.3.2 Geomorphic Units

Geomorphologically, the area is divided into seven units viz., high relief forming glaciated area, structural hills, denudational hills, area of mass wasting, high level dissected fans, river terraces and present day flood plains of major rivers and its tributaries. These units are developed in response of lithology to erosional and depositional activities and tectonics in which they are embedded. Each unit is characterized by distinct erosional and depositional activities, drainage, diagnostic geomorphic landform elements and features, photo-element and morphogenetic expression. Other geomorphic features and land element identified in the area are point-bar, channel-bar, alluvial fan, talus cone, rock-cut terraces, fan-cut terraces, abandoned channel, epigenetic gorges, strandline landslides, rockfall, scree and scree slopes, retreating escarp, abandoned cirque, arêtes, threshold hornpeaks and glacial lakes.

3.3.2.1 Glacial Terraces

The glacial terraces are high level terraces and are restricted above an average elevation of 0710.50 m amsl in the upstream of Nandprayag around Chamoli, Pipalkot, Marwari, Pandukesar, Hanumanchatti and Badrinath. The glacial terraces are characterized by heterogeneous assemblage of sub-angular to angular, unsorted and unstratified fragments ranging from big boulders to small pebbles in size predominantly of gneiss, granite, quartzite and highly weathered biotite muscovite and chlorite schist in the matrix of very coarse to fine sand, silt and clay. These rock clastics are largely angular, very poorly sorted and display isotropic imbrication pattern.

3.3.2.2 Fluvio-Glacial Terraces

The fluvio-glacial terraces are identified at an average elevation of 975 m amsl. These terraces are sandwiched between the glacial and fluvial terraces as these terraces abut against the glacial terraces on the upstream side and fluvial terraces on the downstream side and represent the transitional phase of sediments.

These are characterized by sub-angular to sub-rounded boulders, cobbles and pebbles of quartzites, gneisses, granites, slates and decomposed highly weathered biotite, muscovite and chlorite schist in the matrix of coarse to fine sand, silt and clay. Although the sediments of these terraces are similar in texture to that of glacial terraces, these exhibit entire different order of sedimentary pattern and sediment character. In contrast to the glacial terraces, these sediments display moderate degree of sphericity, roundness and sorting and preferred orientation pattern. The ill preserved sedimentary features and long interval cyclic development of bedding is also conspicuous. Associated diagnostic sediment character, sedimentary features and deposition of these deposits indicate an intermittent and rapid reworking of the sediments from glaciers subsequent to melting of glaciers during the Late Pleistocene time.

3.3.2.3 Fluvial Terraces

The fluvial terraces are alluvial topographic benches from the prominent Quaternary landscape in valley breaking the monotony of vast rugged hilly tracts. These terraces were formed by combined intermittent processes of aggradation and degradation in the valley associated with different phases of sedimentation of fluvial domain. As such these are the abandoned flood plains of the rivers representing the erstwhile levels of valley floors and were formed due to tectonic, eustatic and climatic changes during Holocene period.

These terraces are characterized by sub-rounded to well rounded boulders, cobbles and pebbles predominantly of quartzite-gneiss, granite-schist, slate, phyllite, limestone etc. embedded in the matrix of very coarse to very fine sand with subordinate amount of silt and clay.

Alaknanda is the trunk stream and has formed six prominent regional terraces. Each of these terraces are separated by scarp facing towards the river. These terraces are both erosional and depositional in nature and display divergence and convergence in their relative disposition. The erosional terraces are generally seen as isolated pockets and lenses over the country rock along the higher parts of valley flanks, representing the former level of valley floors. The occurrence of these terraces and associated feature in the higher part of valley indicates the incision of valley floors due to relatively rapid and sudden uplift of watershed region of Alaknanda during early Holocene. The complete sequence of terraces in the valley is very rare and is seen at a very few places viz. around Srinagar, Nagrasu, Gauchar, Langasu and Bamoth; which give complete account of tectonic and climatic changes in the area.

The **Bhagirathi** River has developed five fluvial terraces. These terraces are mostly cut and fill type and both are erosional and depositional in nature. The older terraces are elongated and rectangular in shape and have paired equivalent on both the flanks of valley, whereas younger terraces are semicircular and crescent shaped, irregular deposits. Full development of these terraces is seen at places in the valley viz. Uttarkashi, Dunda, Bhinayalisaur, Chamb and Tehri.

The other rivers like Bhilangana, Nandakini, Mandakini, Pindar and Balganga embraces five, four, four, three and three terraces respectively.

3.4 WEST BENGAL (DARJEELING) & SIKKIM

The Himalayan state of Sikkim is the second smallest state in India after Goa. It possesses the highest and steepest landscape in the country with an elevation ranging between 300 to 8598 meters (Fig 3.1).

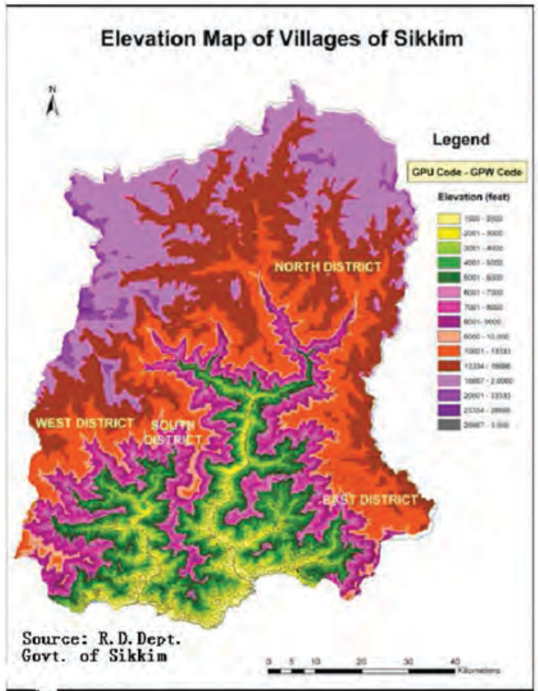


Fig. 3.1: Elevation map of Sikkim

3.4.1. Lower/Outer/Sub-Himalaya

Sikkim and contiguous Darjeeling district of West Bengal within the Central Himalayan Zone form a part of Eastern Himalayas, and are characterized by rugged topography with series of ridges and valleys. Tista and Mahananda plains are followed by Siwaliks (Tertiary) which form the Sub-Himalayan zone (Fig 3.2).

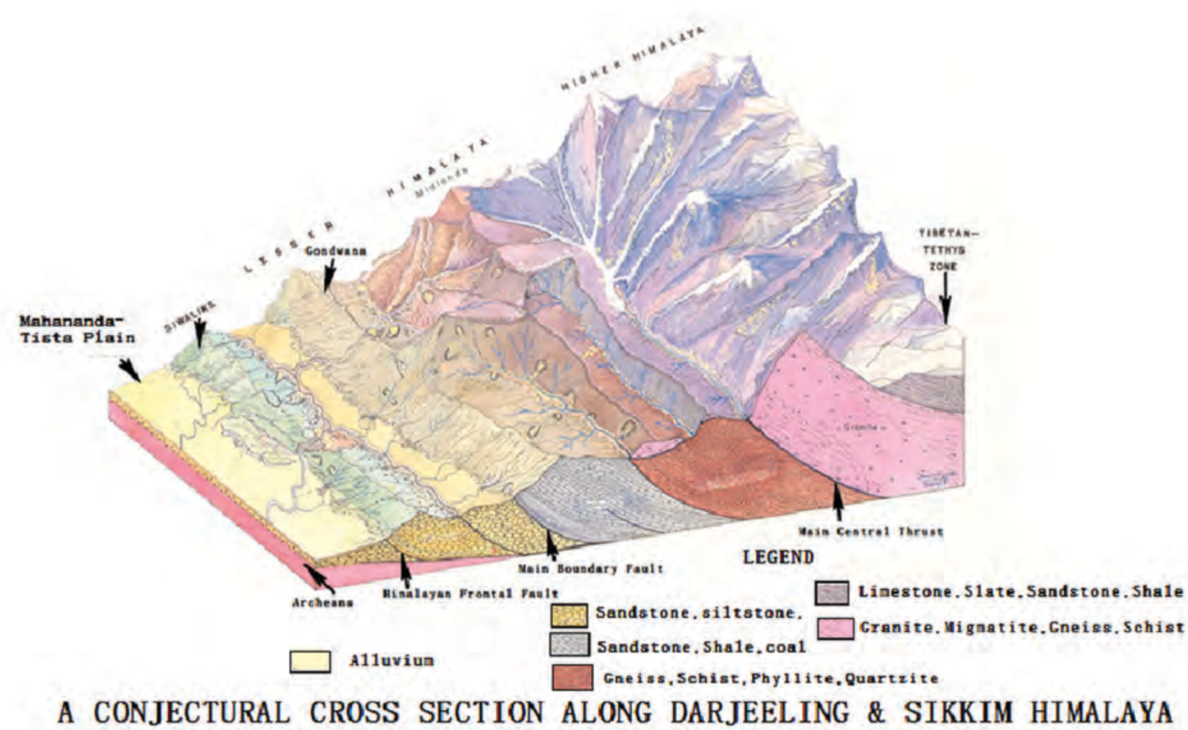


Fig 3.2: Conjectural cross section along Darjeeling and Sikkim Himalaya

3.4.2 Middle Himalaya or Lesser Himalaya

After the Sub-Himalaya, the Damuda Formation (Gondwana) and Daling Schists crop out in Lesser Himalayas with increase in steepness (Fig 3.2).

3.4.3 Higher Himalaya

North and West Sikkim form part of Higher Himalaya (Fig 3.2). The northern part of the area is characterized by high mountain ranges capped by many glaciers. In general the ridges are aligned in NE - SW direction. The altitude of the entire Himalayan tract in Sikkim-Darjeeling part varies from 230 to 8598 meter above mean sea level. The entire area can be divided into ten distinct physiographical divisions as under:

1. Summit and ridge
2. Escarpment
3. Very Steep Slope (>50%)
4. Steep Slope (30-50%)
5. Moderately Steep Slope (20 – 30%)
6. Valleys
7. Cliff and Precipitous Slope
8. Glacial drifts/ Moraine/ Boulder
9. High Mountains with Perpetual snow
10. Foothill areas (Bhabar).

3.4.4 Drainage

3.4.4.1 Basin

The entire Darjeeling-Sikkim tract is drained by the rivers of two major basins viz. Brahmaputra and Padma (Ganga).

3.4.4.2 Sub-basin

The Sikkim State is drained by Tista and Rangit rivers and their tributaries (Fig. 3.3) mainly falling in Tista Sub-basin of Brahmaputra Basin.

Drainage of the area is tectonically controlled. The types of drainages are sub-parallel, rectangular, trellis and radial. The perennial Tista and Rangit rivers along with their tributaries flow along very deep gorges. The Tista River traverses through high mountain ranges often with perpetual snowline Glacier (Tista Khangsee Glacier). The Tista and its tributaries have vast catchments and drain larger part of the area. The rivers are snow fed and perennial. The Rangit river, originates from west Sikkim. In general six orders of streams are present in the area.

The hilly tracts of Darjeeling district are drained by Mechi, Mahananda,Balason, Jaldhaka and the Tista rivers and their tributaries. Mainly they form part of Mahananda and Tista sub basins. The former takes a westward turn and meets the Padma river in Bangladesh forming a part of Ganga(Padma) basin while the latter forms a part of Brahmaputra basin.

Fig 3.3: Drainage map of Sikkim

3.5 ARUNANCHAL PRADESH

The east-west trending Himalayan segment forms the eastern most part of the Himalayan mobile belt. The northern limit of the area is Indus-Tsangpo Suture which is not exposed in Arunachal Pradesh while the southern contact of the area with the Shillong Group of rocks is concealed beneath the thick cover of Quaternary alluvium. In the east, it is assumed that the mountain chain takes a south-easterly trending orographic bend. From north to south, the Arunachal Himalaya has been subdivided into following divisions (Fig. 3.4):

i) Higher Himalayas

ii) Lesser Himalayas

iii) Outer Himalayas

iv) Mishmi Hills

3.5.1 Higher Himalayas

This linear Northeast-Southwest trending Great Himalayan Range having altitude more than 4000 m abuts against the Tibetan Plateau in the North and Lesser Himalaya in the South. The southern limit is generally defined by the Main Central Thrust. It comprises high grade metamorphic rocks of the Proterozoic age and the Phanerozoic metasediments, besides basic volcanics and intrusive granite.

3.5.2 Lesser Himalayas

These hill ranges, lying between the Higher Himalaya to the north and Outer Himalaya to the south, are of lesser height with elevation ranging between 2,500 and 4,000m. The zone is much wider than the Higher Himalaya, about 80-90 km and trends east-west in the western part close to Bhu-

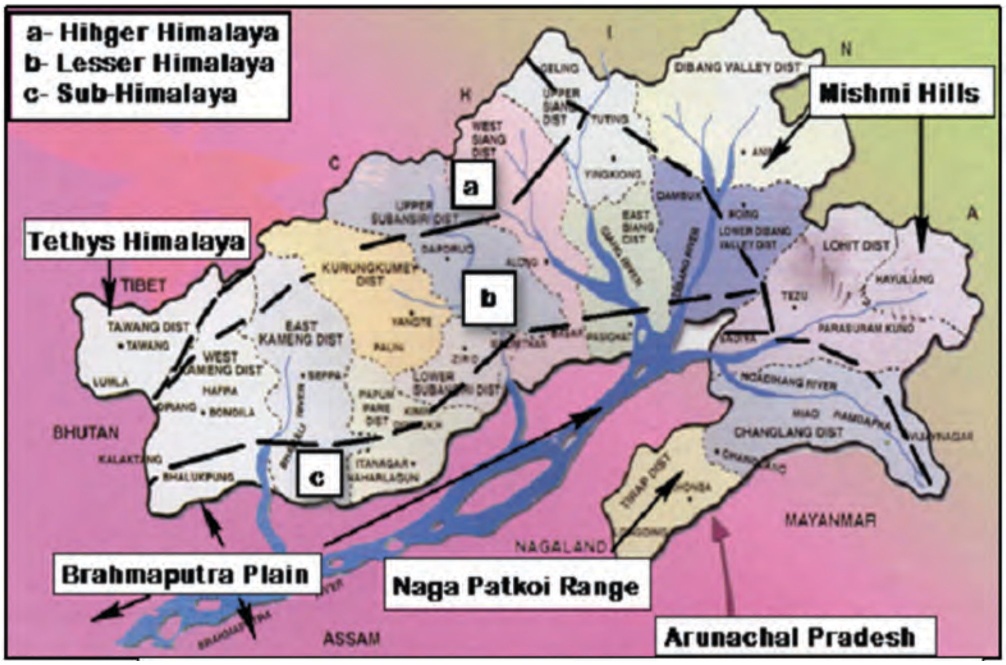


Fig. 3.4 Map showing Physiographic divisions in Arunachal Himalaya

tan but assumes a northeasterly trend before taking a syntaxial bend to the southeast and abutting against the Mishmi Hills along the Tidding Suture in the eastern part. The southern limit with Outer Himalayan ranges is defined by the Main Boundary Fault.

3.5.3 Outer Himalayas

These form the outer or the southernmost hill ranges abruptly rising from Brahmaputra (Assam) Plain along another tectonic plane - the Himalayan Frontal Fault (Singh, 2007), which is mostly concealed under Newer Alluvium. This zone which extends from the border with Bhutan in the west to Pasighat is about 10-20 km wide but further east it is much narrow, about 1-2 km wide and ends up against the Roing Fault at Roing in Lr.Dibang Valley. These hill ranges are made up of Neogene - Early Quaternary sediments and are characterized by strike ridges with steep obsequent escarp-ments and gentler dip-slopes and support luxuriant vegetation.

3.5.4 Mishmi Hills

The Himalaya at its eastern end gets terminated along the Tidding Suture and meets another chain of mountains-the Mishmi Hills. These mountain ranges trending northwest-southeast, are in con-tinuation of the hill ranges of northern Mayanmer (Burma), but are also considered to be in continu-ation of the Ladakh ranges lying to the north of the Indus-Tsangpo Suture . These are made of meta-sediments - the Lohit Granodiorite Complex of the Precambrian age with younger mafic and acid intrusive. These mountain ranges attain elevations of between 2,500 and 6,000 m, and are drained by the Lohit, Dibang and Siang rivers of the Brahmaputra drainage system. The Mishmi Hills abut against the Naga- Patkoi ranges of Arakan Youma Mountains to the south along another tectonic plane - the Mishmi Thrust.

3.5.5 DRAINAGE

The rivers draining Arunachal Himalaya form part of the mighty Brahmaputra river which originates on the northern slopes of Himalaya and Tibet. The Bhareli or Kameng and the Subansiri rivers are its principal north bank tributaries draining the Himalayan ranges, while the Dibang (Sikang) and the Lohit drain the Mishmi Hills and join the Brahmaputra from the east. The rivers form the sub-basins of the Brahmaputra basin (Plate-II) and follow the structurally weak planes and generally exhibit dendritic to trellis drainage pattern. The rivers often cause devastating floods on receipt of massive downpour in its catchment. The intermontane valleys along the drainage course even in the higher course of the rivers are often flooded. However, the flash flood water recedes quickly after cessation of the rainfall in the catchment. In the foothills, the flood hazard is quite common.

3.5.5.1 Brahmaputra

The Brahmaputra river rises in glacier covered northernmost chain of Himalaya - the Kailash range at an elevation of 5,150 m amsl, and east of Mansarovar (Konggyo Tsho) Lake in Tibet. Here the river is known as **Tsangpo**. It flows along the depression of Indus-Tsangpo Suture for about 1135 km running parallel to the general trend of the Himalayan ranges in Tibet and takes a turn to the northeast near Pe at an altitude of 3000m. After taking a sudden U-turn around Namche Barwa (7,756m), it assumes a southwesterly course and enters Arunachal Pradesh where it gets the name **Dihang or Siang**. It takes another right angled turn to the southeast near Singing and cuts through the Lesser Himalaya and Sub-Himalaya. It enters into the Assam plain at Passighat at an elevation of 170m. In the Lesser Himalaya, depending upon the physical character of the rocks, the river has carved V-shaped broad valley with development of river terraces or narrow river valley where development of terraces is either insignificant or absent.

3.5.5.2 Bhareli

Of the principal tributaries of Brahmaputra, draining the Arunachal Himalaya, the Bhareli (Kameng) river in the western part covers an area of about 9,860 sq.km through its network of smaller streams like Tenga, Bichom and Papu. Originating from the southeastern slope of Higher Himalaya, Kameng drains the Dafla hill in Lesser Himalaya and after cutting a deep gorge through the Outer Himalayan ranges, it enters Brahmaputra Plain near Bhalukpong and further downstream gets the name Jia Bhareli. In the Himalayan sector, the Bhareli river and its tributaries are transverse rivers with V-shape profile except over small stretches where it is subsequent to structural features such as Main Boundary Fault.

The other rivers draining Western Arunachal Pradesh are of smaller dimensions. These are the Nyamjang and the Tawang Chhu in Tawang district draining into the Manas Basin of Eastern Bhutan, and the Kalaktang river, a tributary of southeasterly flowing Dhansiri river of Western Bhutan joins the Dhansiri river near Amatulla. The river Dhansiri has a straight course and it is subsequent to a cross fault trending NNW-SSE.

3.5.5.3 Subansiri

The Subansiri river is another principal tributary of the Brahmaputra river which originates in Tibet at Tsari Chhu and cuts through the Higher Himalaya. It drains about 30,000 sq.km. area in the Lesser Himalayan and Outer Himalayan part of Miri and western part of Abor Hills. It debouches near Dulangmukh in Assam at an elevation of 152 m. In the Himalayan sector, it is having a length of about 208 km and the river bed falls from a height of 4206 m in Higher Himalaya to 152 m at Dulangmukh. The Kamala river, its main tributary rises in Higher Himalaya and flows southeast, running almost parallel to Subansiri river and joins Subansiri river near Leling at an elevation of about 660m. In addition, there are two other large tributaries, viz, the Ranga Nadi and the Dikrang, which originates in the Dafla Hill of the Lesser Himalaya, the former debouches into Brahmaputra plain near Jaihing Tea Estate and the latter near Doimukh in Arunachal Pradesh. The Subansiri river and its tributaries in the plain have straight braided to highly meandering course, the sinuosity ratio varying from 1.10 close to foothills to 1.90 near the confluence with Brahmaputra.

3.5.5.4 Dibang and Lohit

In the eastern part of Arunachal Himalaya, the Dibang and Lohit are the two main rivers draining the Mishmi Hills. Both the rivers originating on either side of the northwest-southeast trending range forming the international border with Yunnan province of China.

The Dibang river drains the southwestern slope covering an area of about 11,100 sq.km. It originates in the southern slopes of peak at 5355 m as Adzon chhu and flows southwards almost in a straight course and debouches into Brahmaputra Plain at Nizamaghat and is known as Dibang or Sikang river. Further downstream it has a straight braided course till it joins the Brahmaputra river near Sadiya. In the mountainous region, it is joined by several tributaries as Emra and Ahui, draining the western side of the valley and Dri and Ange on the eastern side. The streams of the western side are mostly subsequent to the strike of the rock formation and trend northwest-southeast while that of the eastern side are transverse. In the Plains, the Sesseri or Sesar river is the main west bank tributary of the Dibang river draining about 1140 sq.km. area of the Himalayas in between the Siang and Dibang rivers.

The Lohit (Luhit) river originates in the northwest-southeast trending Nyimo Chomo mountain ranges in the adjoining part of the Yunan province of China as Rangto Chhu. It flows southeastwards and runs parallel to the ranges. It swings southwards before cutting through the ranges and after entering India north of Kahao, it gets the name of Tellu river. After taking a sharp northwesterly turn near Changwinty and southwesterly turn near Hayuliang, it leaves the mountain at Brahmakund where it is known as Lohit River. Total length of the river is 650 km of which about 500 km is in Arunachal Pradesh, draining about 11,200 sq.km. of Indian territory. In the Mishmi Hill region, it is joined by several smaller streams such as Deleri at Hayuliang and Tidding at Tidding. The Digaru Paya originates in the Lesser Himalaya and forms the north bank tributary. The Nao Dihing and Belang are the south bank streams which drain part of Mishmi Hill and part of Naga-Patkoi ranges originating along the southern and northern slopes of Dapha Bum. In the plains, Lohit river has a wide straight meandering course and joins the Brahmaputra near Sadiya.

3.6 NORTH EASTERN STATES CONTIGUOUS TO HIMALAYAN AREA

Geomorphologically, the North Eastern Region (except Arunachal Himalaya) consists of hill ranges, plateau and valleys. State wise description is as under:

3.6.1 Assam

Geomorphologically, the State can be divided into following three divisions:

- The vast plains of Brahmaputra, stretching in roughly east-west direction and bounded on the north, east and south-east by Himalayas and on the south by the Shillong Plateau.
- The south Central High lands of Karbi Anglong and Dima Hasao (N.C.Hills) rising to an average elevation of 1000 m.
- The hilly and alluvial terrain in the south of Dima Haso (N.C.Hills).

The Brahmaputra and Barak are the two important river systems in the State.

3.6.2 Manipur

Manipur is hilly terrain, the hills form north-south parallel ranges with altitudes ranging from 760 to 3050 m. Central Manipur is in the form of a valley which is flat, elongated and tapering towards south with isolated hills. The drainage of the region is from north to south. Manipur (Imphal) and Barak are the two important rivers draining the State.

3.6.3 Mizoram

Physiographically, the State constitutes N-S trending steep, mostly anticlinal, longitudinal parallel hill ranges and synclinal narrow valleys. The difference of elevation between valley floors and hill tops greatly varies from west to east (200-600 m). The steep hill ranges are more towards east than in the west. There are numerous rivers and streams in the State. The Tlawng (Dhaleswari), the Tuirail (Sonai) and the Tuivawl rivers flowing north join the Barak river in Cachar district of Assam.

3.6.4 Nagaland

Nagaland consists of a narrow strip of hilly terrain running from north east to south west and facing Assam plains to its north and north west. The foothill areas have undulating topography.

3.6.5 Tripura

Physiographically, Tripura is a hilly terrain. The major geomorphic elements observed are N-S running parallel hill ranges and intervening broad and flat valleys. The hill ranges coincide with the anticlinal folds whereas the areas of lower elevation represent the synclinal valleys. The major rivers are Gomti, Haora, Khowai, Dhalai etc. which form a part of Meghna basin.

3.6.5 Meghalaya

The state can be classified into the following geomorphic units:

- **Alluvial plain**: It is exposed in the southern and northwestern parts of the state comprising fluviatile sediments.
- **Denudational low and high hills**: These occupy the major part of the state comprising of hard rocks like granite and gneisses. They are moderately dissected by fractures and joints forming a good number of narrow, intermontane valleys.
- **Dissected Plateau:** In the eastern part of Jaintia hills and south of Khasi hills lies the dissected plateau comprising of soft and friable rocks like shales, sandstones and quartzites.
- **Dissected mounds:** They are of limited extent and occur in south and southwestern parts of the state. They comprise of older alluvium, clay-sandstone-conglomerate sequence.
- **Structural hills:** These are exposed in the southern part of Khasi hills comprising of Tertiary rocks like sandstones, shales and limestones.

4.0 HYDROLOGY & SURFACE WATER UTILISATION

Facilitated by the glaciers and snowmelt water in the Himalayas as also from the overall high rainfall down poured in major parts of the tract, many perennial rivers from west to east like Indus, Jhelum, Beas, Sutlej, Ravi, Ganga, Jamuna, Kosi, Tista, Mahananda, Jaldhaka, Brahmaputra and their numerous tributaries originate from the Himalayas. These rivers drain India and the adjoining countries like Pakistan, Nepal, China, Bhutan and Bangladesh. Besides, the preponderance of perennial rivers and streams, other surface water bodies like lakes of various origins are also ubiquitous in the Himalayan Region. Hence, hydrological information and development of these surface water resources is of prime importance for water resources development in the high altitude terrain. In the following paragraphs, the hydrology and surface water utilization in various Himalayan States are discussed.

4.1 Jammu and Kashmir

4.1.1 Rivers, tributaries and canals

The main surface water bodies in the tract are Rivers, Lakes, and Glaciers. Jhelum and its tributaries like Vishav, Romushi, Dudhganga and Liddar drain along the area. In some parts, the river Jhelum is navigable. Srinagar, the capital town of Jammu and Kashmir, is situated on either side of it.

The Ferozpore Nullah is an important water-way in the western mountains of Baramulla-Gulmarg area. It collects water from many mountain streams, small lakes and springs. The mountainous part of the drainage remains frozen even in summers.

The **Sind Nullah** has its source in the Inner Himalayas at Dras and is fed by the Gangabal lake lying at Harmukh Mountain having altitude of 5150 m. It joins the Jhelum at Shadipur. Its water is used for irrigation purposes .The 'Sind Valley Hydroelectric Power Project uses its water at Ganderbal to produce electric power. It is navigable from Ganderbal downwards.

The **Flood Spill Channel** was constructed in 1904 to relieve the strain on the city of Srinagar by Jhelum. Through withdrawal of a lion share of the total flow in the river, it helps the river Jhelum to regulate its water level while crossing Srinagar.

4.1.2 Lakes

The **Wular Lake (Fig 4.1)** in Kashmir is the largest fresh water lake in India. It is about 16 km long and 9.6 km wide with ill-defined shores. This lake lies between Bandipore and Sopore at a distance of 75 km from Srinagar. The Jhelum enters this lake from the south-east and leaves it in the west. Storms rise in the lake everyday during afternoon. The deepest part of the lake is at Watlab towards the hill called Baba Sukhuruddin in the north-west. Many small streams, Harbuji, Aarah, Erin and Pohru join this lake.

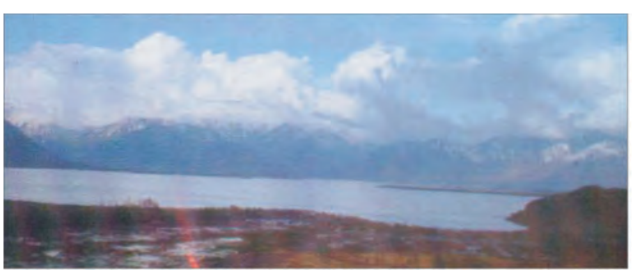


Fig 4.1 Wular Lake

Fig 4.2 Dal Lake

The **Dal Lake** (Fig.4.2) is a beautiful lake in Srinagar. It is 8 km long and 6.4 km wide. It is the flood-lung of the Jhelum. The famous Mughal gardens are situated around it. The lake is an ideal place for swimming and sailing in Shikaras and motorboats. Floating gardens are found in this lake where a large variety of vegetables are grown. The Dal lake has two parts, the small Dal and the big Dal, separated by a swampy bund. The road around the lake, is called Boulevard. There are two artificial islands in the lake, viz. Rupalank and Sonalank, built by Mughal Emperors. Nehru Park is the western terminus of the lake.

The **Mansbal Lake** is located at a distance of 29 km from Srinagar in Tehsil Ganderbal. It is 5 km long and one km wide. It is connected to the river Jhelum by a canal near Sumbal. Mughal Emperors have built a summer palace on its bank.

Other important lakes are Anchar Lake, Harvan Lake, Hokarsar Lake, Konsarnag or Vishno Pad Lake, Gangabal Lake, Shaeshnag Lake etc.

4.1.3 Hydro Power Projects

Since the rivers are endowed with copious quantity of snowmelt water and are generally perennial in nature, many hydropower projects are established in the area. Many of the projects are constructed on river Chenab. As such there are twelve such projects available in the area.

4.1.4 Surface Water Schemes

Good irrigation practices have been developed in the state utilizing various canals connected to the perennial rivers. There are seventeen such major irrigation canals available in Kashmir valley. Table 4.1 gives an account of irrigation practices in the Kashmir Valley using surface water sources.

Table 4.1: Status of surface water irrigation

Type of Irrigation	Net Irrigated Area ('000 ha)
Canal Irrigation	284.42
Tanks & Other Irrigation	24.14
Total	308.56

Source: Fertiliser Association of India, 2001-02

Besides these, there are a few other small canals in the valley that irrigate about 6.07 Thousand hectares of land in the surrounding areas. In Jammu Region, canal irrigation is also in practice tapping the perennial flow of river Ravi. Altogether there are 13 irrigation canals in Jammu with command area of 269.80 thousand hectares.

4. 2 Himachal Pradesh

4.2.1 Surface Water Bodies

Himachal Pradesh forms a part of the Indus and the Ganga river basins. Major rivers of Indus river basin are the Chenab, the Ravi, the Beas and the Satluj. River Yamuna is the only river contributing water to Ganga basin. The catchments of these rivers are fed by snow and rainfall, and are protected by extensive cover of natural vegetation.

4.2.2 Hydropower Projects

Himachal Pradesh is well known for its vast surface water resources. The state is a major contributor of water resources of our country. Water from major rivers of the country passing through the state is mostly utilised for hydroelectric power generation. Altogether there are 111 small, medium and large hydroelectric power stations in the state falling in Satluj, Chenab, Beas, Ravi and Yamuna river basins. These projects are likely to generate nearly 19673.12 MW of electricity. Among these 30 projects are already under operation, of which Bhakra Dam (1200 MW) and Nathpa Jhakri (1500 MW) are important.

4.2.3 Surface Water Based Schemes

4.2.3.1 Irrigation

In Himachal Pradesh, very limited area is available for agricultural practices. Therefore, majority of the irrigation is concentrated in valley areas. There are about 1614 irrigation schemes in the state including 531 lift irrigation schemes and 1079 flow irrigation schemes.

4.2.3.2 Drinking Water Supply

Drinking water is supplied through 7935 water supply schemes, out of which 6180 schemes are under gravity flow while 1526 are lift based schemes. Only 229 water supply schemes are based on Tube wells.

4.3 Uttarakhand

4.3.1 Development of Surface water resources

Uttarakhand state is endowed with rich surface water resources. Irrigation is in practice utilizing the surface water potential besides the groundwater resources. The main sources of irrigation are Canals, tanks, ponds and lakes. The major irrigation projects have contributed extensively in the plain areas falling in the districts of Haridwar and Dehradun. The details of major irrigation projects are given in Table 4.2 and area irrigated by surface and ground water sources in the state are given in Table 4.3.

Table 4.2 Major Irrigation Projects in Uttarakhand

Sr. No.	Name	Location (km)	Length of main Canal (Cumec)	Head Discharge d (M.hec.)	Total Comman	Districts irrigated
1	Upper Ganga Canal	Haridwar	230	312	1.45	Haridwar
2	Kisau	On Tons river in Dehradun	-	Hydro -electrical (600 Mega Watt)	0.27	Dehradun,Sahaspur, Meerut and Muzaffarnagar
3	Sarda System	Banbasa Nainital	-	-	0.60	South-eastern part of Uttarakhand and Central U.P.
4	Ramganga System	Kaulagarh, Pauri	82 Km feeder system at Garh	151	-	To supply additional water to lower Ganga

Table 4.3 Area Irrigated by Surface and Groundwater sources, Uttarakhand

Sr. No.	District	Net Irrigated	Canals Area	Govt. Tubewells	Private Tubewells	Other Sources
1	Uttarkashi	5242	3690	-	-	1552
2	Chamoli	1782	525	-	-	1257
3	Tehri Garhwal	8506	756	-	-	7750
4	Dehradun	24246	14079	2294	256	7617
5	Pauri Garhwal	7667	4311	464	-	2892
6	Rudraprayag	2413	1555	-	-	858
7	Haridwar	101400	15273	4457	79842	1828
8	Pithoragarh	4662	1300	-	-	3362
9	Almora	6915	2416	-	-	4499
10	Nainital	29655	23963	3600	1598	494
11	Udham Singh Nagar	145703	30265	11411	89625	14402
12	Champawat	2553	607	-	-	1946
13	Bageshwar	6070	4235	-	-	1835
	Total	**346814**	**102975**	**22226**	**171321**	**50292**

Source: Statistical Diary, 2002-2003

4.4 Sikkim and Darjeeling District of West Bengal

4.4.1 Rivers

Facilitated by the glaciers and stupendous rainfall in the Sikkim-Darjeeling Himalayas, many perennial rivers like Tista, Rangit, Jaldhaka etc. emerge from the tract and drain the State of Sikkim and Darjeeling district of West Bengal.

4.4.2 Surface water bodies

The State of Sikkim is endowed with numerous lakes (wetlands) situated at high altitude. These lakes are mostly fed by snowmelt water and are generally perennial in nature. The lakes are formed in the natural valleys or depressions. In many cases, such depressions are of tectonic origin. These water bodies form potential recharge sources to the spring's catchments. A sum total of 227 lakes are available in the Sikkim State. Table 4.4 & 4.5 show details of Wetlands (Lakes) in Sikkim. In Darjeeling, the most important wetland is available at Mirik. The most important lakes in Sikkim and Darjeeling are described below.

Table 4.4 Details of Wetlands of Sikkim

Wetland category	Wetland Class	No. of Wetlands	Wetland area (Hectare)	Water Spread area	
				Post monsoon	Pre-monsoon
Natural	Lake/Pond	160	1985.00	1985.00	1479.50
<2.25 Ha	-	67	-	-	-
Total	-	227	1985.00	1985.00	1479.50

Source: Wetlands of India, Nationwide Mapping unit, sponsored by MOEF, Space Application Centre (ISRO, Ahmedabad,1998)

Table 4.5 District wise Wetlands of Sikkim

District	Wetland Class	No. of Wetlands	Wetland area (Hectare)	Water Spread area	
				Post monsoon	Pre-monsoon
East Sikkim	Lake/Pond <2.25 Ha	160	120.75	120.75	100.70
West Sikkim	Lakes/Ponds	67	56.50	56.50	56.50
North Sikkim	Lakes/Ponds <2.25 ha	227	1807.75	807.75	1592.25
South Sikkim	-	-	-	-	-

Source: Wetlands of India, Nationwide Mapping unit, sponsored by MOEF, Space Application Centre (ISRO, Ahmedabad,1998)

Fig 4.3 Gururdongmar Lake during summer

Fig 4.4 Khecheopalri Lake

Gurudongmar Lake or Gurudogmar Lake is one of the highest lakes (Fig. 4.3) in the world, located at an altitude of 17,100 ft (5,210 m). It lies in North Sikkim district and is situated only 5 km south of China border. This fresh-water lake is located northeast of the Kanchenjunga range in a high plateau area connected with the Tibetan Plateau. Gurudongmar lake provides one of the source streams of the Teesta River. The source of Teesta, the Tso Lhamo Lake, lies around 5 km to the east. The lake remains completely frozen in the winter months from November to Mid-May.

Khecheopalri Lake (Fig.4.4) originally known as Kha-Chot-Palri (meaning the heaven, being a wish fulfilling lake). It is located near Khecheopalri village, 147 km west of Gangtok and 34 km to the northwest of Pelling town in the West Sikkim district. The popularly known name of the lake, considering its location is Khecheopalri Lake, ensconced in the midst of the Khechoedpalri hill, which is also considered a sacred hill. The Khecheopalri Lake is also a part of Buddhist religious pilgrimage. The formation of the lake is estimated to be 3500 years old. The lake is situated amidst pristine forest at an altitude of 1,700 feet (520 m) near Tsozo village. The lake drains the catchment area of the Ramam watershed (Ramam mountain gives its name to the valley) and has a drainage area of 12 sq km (including area of bog of 70,100 sq m). In addition, during the monsoon season two streams are also diverted temporarily into the lake to supplement its storage capacity. The geological formations in the lake and its surrounding hills consist of granites, gneisses, schists and phyllites.

Chhangu/ Tsomgo Lake: It is literally known as “source of the lake” in Bhutia language. This serene lake (Fig 4.5) is situated at an altitude of 12,000 ft on the Gangtok - Nathu La highway, about 40 km away from Gangtok, the capital of the state. The lake is about 1 km long, oval in shape, 15 m deep and is considered sacred by the local people. It is also a home of brahminy ducks. This placid lake remains frozen during the winter months up to the middle of May.

Fig 4.5 Chhangu/Tsomgo Lake Fig 4.6 Samiti Lake Fig 4.7 Mirik (Sumendu) Lake

Samiti Lake: While climbing towards Gochala Pass, the view of transparent turquoise Samiti lake, a glacial lake in the Onglathang valley could be observed (Fig.4.6). It is a lake of tectonic origin.

Mirik (Fig.4.7) is a picturesque tourist spot nestled in the serene hills of Darjeeling district in West Bengal. The name *Mirik* comes from the Lepcha words *Mir-Yok* meaning “place burnt by fire”. Mirik has become a tourist destination for its climate, natural beauty and accessibility. The centre of all attraction is the lake surrounded by a garden on one side and pine trees on the other. This place is 5,800 feet above the sea level and has very thin population of 10,000 people. The water in Mirik is reportedly polluted.

4.4.3 Hydro-power projects

This part of Himalaya has bountiful surface water resources as the rivers like Tista, Rangit, Jaldhaka, Mahananda etc. are mainly fed by snowmelt water from the glaciers in the northern part which mostly fall in the permafrost horizon.

Utilizing the slope of drainage basins and abundant availability of snowmelt water throughout the year, the areas are important and feasible tracts for hydropower generation. Already there are a number of mega hydro-power projects like Jaldhaka project in Darjeeling District, Rangit project in West Sikkim etc. In addition, one mega hydel power plant has been under construction on Tista river near Gangtok. The rural electricity is generated through a number of micro-hydro power plants spread all over the state of Sikkim. Currently, many hydro-power developers are working in the area to construct a number of small and medium power plants. A recent report revealed that out of the total hydropower potential of Sikkim of 8000 MW, the total installed capacity as on March 31, 2010 is only 610.7 MW. The State government has awarded 24 hydropower projects at a total estimated installed capacity of around 4,694 MW to various developers, which are expected to be commissioned within the 12th Plan period. In its recommendations, immediate structural changes in the State’s power sector for its efficient management coupled with the need to manage a quantum jump in the development of hydropower resources from the existing level of about 200 MW to 8000 MW have been called for.

4.4.4 Surface water based schemes

Irrigation projects could not be taken up in Sikkim and Darjeeling, utilizing the river water which is flowing along steep gorge like river courses situated more than 150-200m or even more depth below the habitations or the cultivated areas along the hill slopes. However, spring water or the water coming from lower order streams at much higher topographical levels is diverted and brought to the terraces for irrigation.

Because of the steepness of the terrain and high altitudinal difference between the river/stream courses and the habitation, drinking water supply arrangements could not be done tapping the river water. However, near Gangtok, Tista river water is being pumped to the filtration tank for piped water supply.

4.5 Arunachal Pradesh

4.5.1 Rivers

The Eastern Himalaya, i.e. Arunachal Himalaya is represented by wealth of surface water sources represented by the mighty Brahmaputra River, which originates in the Himalayas. The Bhareli or Kameng and the Subansiri rivers are its principal north bank tributaries draining the Himalayan ranges, while the Dibang (Sikang) and the Lohit drain partly along the Mishmi Hills and the eastern most part of the Himalayas in Arunachal to join the Brahmaputra. The rivers form the sub-basins of the Brahmaputra basin. Along their mountainous courses, many times the rivers flow along deep gorges and form spectacular water falls (Fig. 4.8). The rivers often cause devastating floods on receipt of massive downpour in their catchments. The intermontane valleys along the drainage courses even in the higher course of the rivers are recurrently flooded. However, the flash flood water recedes quickly after cessation of the rainfall in the catchment. In the foothills, the flood hazard is quite common.

Fig. 4.8 Waterfalls along river course

Fig. 4.9 Frozen Lake in Tawang

4.5.2 Surface water bodies

Besides the running surface water resources, the state of Arunachal Pradesh is blessed with good number of perennial Lakes. Lakes are mostly located in high altitude fed by the snowmelt water. Most of the Lakes are located in Tawang (Fig 4.9 to 4.11) and Mechhuka area of West Siang District. However, perennial lakes also could be seen in the Foothills or Sub-Himalayan and Lesser Himalayan parts of Arunachal Pradesh. The Mayodia Lake in Lower Dibang valley district and Ganga Lake in Papumpare District are the examples of structurally controlled lakes in such geomorphic settings. The Ganga Lake (Fig 4.15) in Itanagar is formed in the structural depressions of Siwaliks and receives copious quantity of rainfall water as also base flow from the groundwater. Majority of the lakes are of tectonic origin. The Shungetser Lake popularly known as Madhuri Lake is a glaring example of Tectonic Depression lake, which was developed during the devastating Assam earth-quake in 1950. The dead trees still remain inside the lake (Fig 4.13 & 4.14). The Se La lake, (Fig. 4.12) located in West Kameng District, is situated at the highest altitude of 4152m amsl in the State. Reportedly, there are more than 250 lakes of various sizes in Arunachal Pradesh of which 180 or so are located only in Tawang district. In these lakes, Department of Fisheries, Government of Arunachal Pradesh grows a type of cold water fish (Trout). Besides the lakes, with the initiative of Fisheries Department, more than 400 ponds have been created in the foothills as also in the valley areas in the uphills of the state for Pisciculture. These ponds act as rainwater harvesting as also groundwater recharging bodies.

Fig. 4.10 **Fig. 4.11** **Fig. 4.12**

Fig 4.10 & 4.11 Two Lakes in different seasons in Tawang, Fig 4.12 A view of Se La Lake

Fig. 4.13 **Fig. 4.14** **Fig. 4.15**

Fig. 4.13 & 4.14 Shungetser (Madhuri) Lake in various seasons

Fig. 4.15 Ganga Lake at Itanagar

4.5.3 Hydro-power projects

Like Himachal Pradesh, there are vast prospects of development of hydropower in Arunachal Pradesh. According to a report, Arunachal Pradesh has a hydropower potential of more than 50,000 MW, but till date only 400MW could be developed. Government of Arunachal Pradesh has awarded contracts of three projects with a total generation capacity of 5,600 MW. This includes 2000 MW Lower Subansiri Project under construction by NHPC. The project is likely to be completed by 2014.

4.5.4 Surface water based schemes

Inspite of vast available surface water resources and availability of irrigable lands in the foothills, irrigation potential developed in the State is insignificant. Only 3589 hectares of land incorporated in the Himalayan part of Arunachal Pradesh has been brought under irrigation. In major part of the state in the mountainous tract having slope more than 70-80% or more, irrigation facility is unavailable. However, springs or lower order streams are tapped at various topographical levels and water is diverted to the terraces for irrigation.

Because of the steepness of the terrain and high altitudinal difference between the river/stream courses and the habitation, drinking water supply arrangements could not be done tapping the river water barring a few places in the valleys or in the foothills. Construction of surface water based water supply system in Itanagar - Naharlagun township is underway.

5.0 GEOLOGY AND TECTONICS

5.1 Stratigraphic Succession

In the Himalayas, geological formations range in age from the Proterozoic to Quaternary. The Proterozoic formations are possibly the northward extension of the sequences exposed in the south and west of Indo-Gangetic plain in the Indian peninsula. The Main Central Thrust (MCT) separates the low grade metasediments of Lesser Himalaya from the Central crystalline rocks. Most of the rocks have been subjected to multiple deformation and metamorphism often rendering it difficult to decipher the stratigraphy and structure. Based on the extensive studies carried out by various workers of Geological Survey of India viz. Acharya et al., 1979, Auden,1934, the ages and tectonic features along with lithostratigraphy of the Himalayas in Indian subcontinent have been well established from which the main lithostratigraphic units are well correlated (Table 5.1). Description of the broad rock formations in various Himalayan units right from Western to Eastern Himalayas are described in the following paragraphs and the Geology of Himalayas is presented in Plates- III A & B.

5.1.1 Northwestern Himalayas (Jammu and Kashmir, Himachal Pradesh and Uttarakhand States)

The old rocks of the northwestern Himalayas are variously designated as the Nanga Parbat Crystallines, Tso-Morari Complex, Suru Crystallines , and Salkhala Formation in Jammu & Kashmir, the Salkhala, and Vaikrita sequences in Himachal Pradesh and the Central Crystallines in Uttarakhand State. In addition to these, the Jutogh Group, Almora Crystalline, Ramgarh Formation, Askot, Baijnath, and Dudhatoli Crystallines in Uttarakhand exposed to the south of MCT are probably overthrusted slices of Central Crystallines. These sequences comprise Kyanite schist, garnet mica schist, quartzite, migmatised biotite gneiss, augen gneiss, streaky gneiss, porphyroblastic granite gneiss, calc-silicate rock, marble etc. with minor basic sills. At places, inverted metamorphism is also observed. Isotopic age data indicate several phases of granite intrusions and migmatisation, the oldest being 2200± 125 Ma.

The next litho-package includes a thick sequence of quartzites often with penecontemporaneous basic flows and overlying carbonate rocks and is characterized by low grade metamorphism of green schist to lower amphibolite facies. These rocks are included under the Sirban Group of Jammu and Kashmir, Sundernagar Group and Shali Group of Himachal Pradesh, the Dharagad Formation and Deoban Group of Himachal Pradesh and the Bhimtal Formation and Garhwal Group of Uttarakhand. The meta-sediments exposed in Kishtwar Window in Jammu and Kashmir and the Rampur window in Himachal Pradesh and also those referred to as Agastmuni and Bhilangana Formations in Mandakini valley of Uttarakhand, though tentatively included in the Central Crystallines, possibly form the base for these rocks. This sequence was deposited under unstable platform condition with associated intercontinental rifting and volcanism. The sediments of this stack ended with a phase (1000±100 Ma) of granitic intrusions. The epigenic uraninite in the Manikaran Quartzite (Rampur Group) has been dated as 1232±120 Ma (Bhalla et al.,1979), which along with the Stromatolite assemblage in the carbonate rocks suggests a Middle Proterozoic age ranging between 1600 and 1000 Ma. These rocks together with high grade metamorphic rocks were uplifted and became provenance for the next phase of sedimentation.

TABLE 5.1: CORRELATION OF DIFFERENT ROCK FORMATIONS/ GROUP OF NORTH-WEST HIMALAYA, DARJEELING (WB) – SIKKIM & ARUNACHAL HIMALAYA

Geological Time		North-Western Himalaya	Darjeeling (WB)-Sikkim	Arunachal Pradesh
Holocene		Alluvium, river terraces, glacial deposits	Alluvium, river terraces	Alluvium, glacial depositsHapoli Fm
Pleistocene	Upper			
	Middle			
	Lower			
		Upper Siwalik, Karewa Fm	Upper Siwalik	Upper Siwalik
Pliocene		Middle Siwalik	Middle Siwalik	Middle Siwalik
Miocene		Lower Siwalik	Lower Siwalik	Lower Siwalik
		Murree Gp, Dharamsala Gp, Kasauli Fm, Dagshai Fm		
Oligocene				
Eocene		Nummulitic Fm, Subathu/ Krol Fm,, Kanji GpPunch-Mandi		Yinkiong Fm
		& Rajpura Fm		
Palaeocene				
		Manikot Shell Limestone, Sangchamalla Fm, Gimual Fm,		
Cretaceous		Chikkim Fm,		
Jurassic		Wumuh Fm, Spiti Fm, Burtsa Fm (L & K)Lilang Gp,		
Triassic		Chocolate, Kalapani, Kuti, Kioto & Lapthal Fms		
		Bishot & Kalhel Fms, Tso Lhama Fm, Vihi Gp, Zewan Fm,		
Permian		Tandi Gp, Mamal Fm, gamgul Fm, Kuling Fm	Damuda Gp, Rangit Pebble Slate	Bhareli Fm, Bichom Fm,
		Agglomeratic Slate- Nishatbagh beds , Boulder Slate,		Garu Fm
		Syringothyris & Fenestella Fm, Lipak & Po Fm,		Miri Fm
Carboniferous			Lachi fm	
Devonian		Pungmur La Fm, Muth Fm		
Silurian		Variegated Fm		

Ordovician	Garbyang, Ralam, Shiala Fms	Everest Limestone	
Cambrian	Rockchung Fm, Lolab & Karihul Fm, Kunzamla Fm, Tal Fm		
Proterozoic	Bhimdasa Fm, Sincha Fm, Krol Fm, Ramsu Fm, Machhal Fm Undifferentiated Gamir & Belia Fms, Ramban Fm, Simla Gp, Jaunsar Gp, Betalghat Fm, Morar Chakrata Fm, Amri Fm, Bijni Fm, Banali Setangal Fm, Manjir Fm, Katargali Fm, Chamba/Bhaderwah Fm, Batal Fm, Martoli FmTanawal Fm, Kulu GpSirban Gp, Sundar Nagar Gp, Shali Gp, Dharagarh Fm, Deoban Gp, Bhimtal Fm, Garwal Gp, Larji Fm, Rampur Gp		
Undifferentiated Proterozoic (Sedimentaries/ Low Grade Metamorphites)	Undifferentiated Dogra Gp, Undifferentiated Kibar, Lopara & Dul Fms	Gorubathan Fm, Reyang Fm, Buxa Fm, Everest Pelite	Potin Fm, Tenga Fm, Reyang Fm, Lumla Fm, Dirang Schist, Khetabari Fm, Tidding Fm, Nuimi Fm, Dedja Fm
Undifferentiated Proterozoic (Crystallines/ High Grade Metamorphites)	Jutogh Gp, Almora-Dudatoli Crystallines, Ramgarh Fm, Undifferentiated Askot & Baijnath Crystallines, Salkhala Fm, Vaikrita Gp, Undifferentiated Nanga Parbat Crystallines, Suru Crystallines, Tso Morari Gneissic Complex, Central Crystallines, Agastmuni Fm, Bhilangana Fm,	Kanchenjungha Gneiss, Darjeeling Gneiss, Chungthang Fm	Sela Fm & Undifferentiated Granitic Gneisses

Formations of Ladakh & Karakoram Area and igneous activities have not been included in the above table.

The deposition of the younger sediments of Pre-Vendian to Late Proterozoic age commenced with the accumulation of conglomerate beds under the shallow marine environment in many parts of Western Himalayas. These sediments are variously described as the Simla and Jaunsar Groups, Ramban Formation, undifferentiated Gamir and Baila Formation, Betalghat, Morar-Chakrata, Bijni, Amri and Banali-Setangal Formations in Lesser Himalayas. The Higher Himalayan Formations include Tanawal Formation, Kulu Group (excluding the mylonitised granodiorite gneiss), Manjir, Katrigali, Chamba, Bhaderwah, Betal and Martoli Formation. The sequence is typical of stable platform deposits, comprising essentially arenaceous - argillaceous sediments with minor bands of stromatolite bearing carbonates. The medium to coarse grained quartzite occasionally with quartzite-pebble conglomerate in upper part is suggestive of a gradual regressive phase and uplift in the provenance area. In some parts of Jammu and Kashmir, gypsum is also associated with these rocks. Two phases (55±0100 Ma. and 30±050 Ma.) of granite intrusions have been recorded in these sediments. The stratigraphy suggests a tentative age of ca.1000 to 670Ma.

The overlying sequence commences with a diamictite representing a widespread unconformity throughout the Lesser Himalayas. This sequence includes the Bhimdasa and Sincha Formations of Jammu and Kashmir, the Blaini, Infrakrol, Krol and Tal Formations of Himachal Pradesh and Uttarakhand in Lesser Himalayas; and the Ramsu, Machhal, Lolab, and Karihul Formations of Kashmir and Kunzam La Formation of Himachal Pradesh in Higher Himalayas. These sediments are best exposed in the Krol belt of Uttarakhand and Himachal Pradesh. It has been assigned a Late Proterozoic to Cambrian age. The Krol Formation is essentially a carbonate sequence with evaporite beds in the middle section, whereas the overlying Tal Formation is argillaceous with phosphorite at its base. The Sedimentation terminated during the Late Cambrian time due to withdrawal of Sea from this part of the Tal, Lolab and Kunzam La Formations and elsewhere in the upper part of the Martoli Formation.

The deposition of marine sedimentary pile resumed in the Higher Himalayan Tethyan basins with an angular unconformity over the older sequence in parts of Kashmir, Spiti - Zanskar and Kumaon - Garhwal. These are referred to as the Ralam (mostly pebbly quartzite and conglomerates), Garbyang (carbonates), and Shiala (Siliceous-calcareous) Formations of Ordovician age, and variegated Series (calcareous-arenaceous) of Silurian age in Kumaon basin. In the Kashmir basin, these are designated as Margan, Muth and Aishmuqam (Siliceous-clastic) Formations of Ordovician-Devonian age and the Syringothyris (carbonates) and Fenetella (areno-argillaceous-calcareous) Formations of Carboniferous age. These rocks in the Spiti-Zanskar basin are named as Thango, Takche, Muth Formations and Taglang La Formations of Ordovician - Devonian age and the Kanawar Group of Carboniferous age. The entire stretch of Lesser Himalayas possibly remained a positive area during this period. The inter-tonguing of marine and continental facies reflects periodic fluctuation of sea level and total regression of sea took place towards the Early Carboniferous. These rocks are overlain by the Late Carboniferous to Early Jurassic Tethyan sequences, in the Higher Himalayas. These sequences in Kashmir include the Agglomeratic Slate (Siltstone with marine fossils), mamal (Carbonaceous shale with plant fossils, purple shale, limestone), Zewan (fossiliferous limestone with minor sandstone and siltstone), and the Vihi Group (shale and limestone) with penecontemporaneous Early Permian Panjal Volcanics (Andesitic basalts). These are referred to as the Gamgul Salooni Formation in the Chamba-Bhaderwa basin, and predominantly carbonate with minor shale bearing chocolate, Kalapani, Kuti, Kioto, and the Lapthal Formations in the Kumaon basin. The sedimentation of this litho-pack in general, commenced with arenaceous rocks and diamictite enclosing marine fossils and was followed by a continental facies made up of feldspathic sandstone, grit and carbonaceous shale containing a Lower Gondwana Gangamopterisglossopteris flora in the Lesser Himalayas. However, only the early Permian sediments are observed in Garhwal, Kumaon and further east.

A significant litho-assemblage in this sequence is the thick limestone sequence of the Triassic age deposited under stable platform environment, which has in its basal part the Permo-Triassic boundary. The Early Jurassic period is characterized by temporary withdrawal of Sea. The marine transgression during Late Jurassic which persisted till Early Cretaceous resulted in deposition of the Spiti Shale-Giumal sandstone sequence overlain by the Chikkim Limestone of Himachal Pradesh and Uttarakhand. This stack in Kashmir is represented by Wumuh Limestone of Jurassic age.

The Middle Cretaceous to Middle Eocene sediments contain record of perhaps the most significant part of the history of the Himalayan orogeny and the sedimentary as well as the magmato-tectonic history of this period differs considerably in different parts of the Himalayas.

The Indus-Tsangpo suture zone saw emplacement of ophiolites and formation of mélange during Middle to Late Cretaceous time. North of this suture zone, deposition of marine sediments (Indus Formation) comprising green conglomerate, grit, sandstone with minor shale and limestone along with marine fauna continued over the Ladakh Plutonic complex until Early Eocene time after which complete regression of sea took place. Further north in the Shyok valley, ophiolites and associated volcano-sedimentary rocks of the Shyok Group of Cretaceous to Eocene age are observed. A large part of the Lesser Himalayas remained a positive area from Cambrian onward except for a short marine interlude during the Permian. Transgression by a shallow sea again took place in Late Cretaceous which resulted in deposition of the Shell Limestone over the Tal Formation. During Palaeocene and Early Eocene a thin cover of marine beds (Subathu Formation) once formed over the Tal Formation and Shell Limestone. At the same time, a continental facies developed in Jammu region, where coal beds are found inter-layered with the marine Subathu. The Palaeocene- Eocene Sea covered much wider area in the Lesser Himalayas as well as in the developing sag of frontal zone to the south. Consequently, Nummulitic/ Subathu Formation unconformably overlies diverse basements such as the Shell Limestone, Punch Mandi Formation, Krol and Blaini Formation, Simla Group, Riasi Limestone, Sataun Limestone etc. Sea again withdrew from the entire Himalayas saving the frontal zone in the Late Eocene, which marked the end of sedimentation of this stack and initiation of large scale orogenic movements and uplift. This may be regarded as the beginning of the Himalayan orogeny. Isotopic data indicate that the period from ca.42 to 50 Ma. witnessed a phase of intense syntectonic magmatism and associated thermal events.

After a brief hiatus, deposition of next stack of sediments (Uppermost Eocene-Oligocene) commenced in the newly formed foredeep. These included the Murree/ Dharamsala Group/ Dagshai and Kasauli Formations comprising thick pile of essentially brackish water sandstone and red shale alternation. These sequences are restricted in the north by the Main Boundary Thrust (MBT). During Early Miocene, next phase of Himalayan uplift and folding took place along with the emplacement of granite bodies in the Higher Himalayas resetting the isotopic clock of the older metamorphic sequences to ca. 20 Ma. As a result of this movement, the foredeep to the south of rising Himalaya shifted further southward where fluvial condition prevailed and a thick pile of Siwalik Molasse was deposited. The main centre of deposition in Siwalik period was in general, limited to the north of what is presently known as the Main Boundary Fault/thrust (MBF/MBT).

Further to the north, between rising Himalaya and the Ladakh Range, another basin developed in the Indus suture zone where deposition of moderately thick (250m-800m) fluvial sequence similar to Siwaliks continued till Pleistocene (Kargil Molasse and Lyan Formation in the Indus valley and Kailash conglomerate in Tibet/Nepal). A major uplift in the Pir Panjal Range took place during Early Pliocene which initiated accumulation of lacustrine deposits (Karewa Formation) in the Kashmir valley (Bhatt, 1989) simultaneously with the Upper Siwaliks. Mineral ages of some granites, aplites and Pegmatites in the range of ca.3.5 Ma may be related to this orogenic episode. The fourth uplift of the Himalayas took place in the Early Pleistocene, which saw the end of the Siwalik sedimentation and development between the Lower and Upper Karewa Formation. The uplift of Himalayas continued during Late Pleistocene and Holocene due to isostatic adjustments and related epeirogenic movements. The fluvioglacial deposits, loess, lacustrine clay and river terraces/alluvium constitute the youngest stack of sediments in this sector.

5.1.2 Sikkim-Darjeeling Himalayas (Sikkim and Darjeeling District of West Bengal State)

The high grade metamorphic rocks in Sikkim-Darjeeling including rocks of the Darjeeling and Kanchanjanga gneiss are represented by Sillimanite-Kyanite bearing magmatic gneiss with an enclave of Calc-Silicate rocks and mica schist. These tectonically overlie the Chungthang Formation comprising sheared quartzite, marble, graphite-schist and amphibolite gneiss, also of undifferentiated Proterozoic age. The Everest Pelite consisting of phyllite and phyllitic quartzite, and quartzite-biotite schist intruded by leucogranite and pegmatite is exposed exclusively in the Higher Himalayan region (and extends down to even foothill region on the Everest Pelite). It is possibly slightly younger undifferentiated Proterozoic stack, which acted as a basement for the Phanerozoic Tethyan sediments.

The other undifferentiated Proterozoic sequences occurring mostly in the Lesser Himalayas are the Gorubathan, Riang and Buxa Formations. The Gorubathan Formation comprising thick assemblage of green slate, chlorite schist and epidiorite occurs over a large tract in south central part. It tectonically lies over the Siwaliks and occurs generally as elongated outcrops. The Rangit Window exposes the rocks of Buxa and Gondwana Formations. The Buxa Formation consists of dolomite, pyrite-slate and cherty quartzite. The Lingtse mylonitised gneiss, occurring within the Gorubathan Formation is considered to be a basement slice. The Gondwana sequence of the Permian age consisting of the Rangit Pebble Slate and the overlying Damuda Formation occurs in the Foothill region. In the Rangit Window these unconformably overlie the Buxa Formation and are tectonically underlain by the Gorubathan Formation. Further south, a long narrow strip of the Gondwana rocks overrides the Siwaliks along the MBT and is, in turn, tectonically overlain by the rocks of Gorubathan Formation. Rangit Pebble Slates essentially consist of pebbly and gritty slate, lithicwacke with minor non-pebbly argillite, feldspathic and calcareous quartzite, carbonaceous bed and lenses of impure limestone and marl. Eurydesma and products of other marine bivalves of the Lower Permian age (Asselian-Sakmarian) have been reported from the pebble slates. The Damuda Formation comprises feldspathic micaceous sandstone, carbonaceous shale and crushed coal seams. The shales and sandstones have preserved remains of Permian plants Viz. Glossopteris cf indica, vertebraria and stems, indicating continental environment of deposition.

The Siwalik rocks occur as narrow discontinuous outcrops in the foothill region overridden by the Permian Gondwana rocks or the Proterozoic Gorubathan Formation. They are comprised of micaceous sandstone, siltstone, shale and conglomerate with lenses of lignite and are assigned Miocene to Lower Pleistocene age. In the southern belt, the Siwaliks dip north with homoclinal structure whereas the northern belt shows folded sequence. The Quaternary sediments include fluvio-glacial deposits in the Higher Himalayas and alluvium in the foothill region. A few raised river terraces are also reported.

5.1.3 Arunachal Himalayas (Arunachal Pradesh)

Sela Formation and undifferentiated granitoids consisting of high grade gneiss, migmatite, calc-silicate, marble, quartzite with amphibolites are considered to be the extension of the Thimphu Formation of Bhutan and are possibly the oldest rocks in Arunachal Pradesh. These occupy a large part of the state from the Higher Himalayas down to Sub-Himalayas along the Gondwana/ Siwalik belt, with a prominent thrust in between. These rocks have been assigned an undifferentiated Proterozoic age. The next younger stack of undifferentiated Proterozoic rocks comprises of Dirang, Tenga, Potin, Reyang, Khetabari, Buxa, Tidding, Nuimi, Dedja and Lumla Formations, which are medium to low grade meta sediments mainly orthoquartzite with or without penecontemporaneous basic volcanic rocks, carbonate rocks, and graphitic phyllites. The extensively occurring Dirang Formation consists of schistose quartzite, chlorite, phyllite, garnet-mica schist, para-amphibolite and marble. The outcrops of the Potin, Tenga and Reyang Formations are observed within the Dirang Formation. The Potin Formation consists of Schist with garnet and staurolite, subordinate quartzite as well as gneissic or granitic rock. The Reyang Formation is exposed over a small area near Bomdila with a thrust contact with Dirang. The Tenga Formation, which is considered equivalent to the Potin occurs mainly as elongated outcrops tectonically juxtaposed against the Sela, Dirang and sometimes Bichom Formations. The Dedja Formation (Nuimi Formation of East Arunachal Pradesh) occurs as a long narrow strip overriding the Permian Bichom Formation and tectonically underlying the Dirang Formation. A small outcrop of the Dedja rocks with conformable contact is also seen within the Tenga Formation.

In the central part of the state, an arcuate thrust slice of the Tenga Formation is seen in a window like structure, underlain by the Bichom and overlain by Sela Formations. A number of tectonic wedges of granitoid gneiss occur within the low grade metasediments in central and western parts. Low grade metasediments, such as the Reyang, Buxa and Tidding Formations occur as long, narrow, thrust slices in association with the Sela Formation in the east and turn around the Siang flexure containing eastern orographic bend of the Himalayas.

The Tidding Formation consists mainly of green chlorite-quartzite phyllite, actinolite schist, crystalline limestone, granodiorite and concordant as well as discordant bodies of serpentinite. In the east, they abut against the Lohit granitoid, diorite, hornblendite, pink potash feldspar bearing hornblende granite, olivine norite, gabbro, anorthosite etc., along a prominent thrust plane. In the west, the Tidding rocks are juxtaposed against the Sela group along a thrust plane which is considered by some workers as the Tidding suture equivalent to the Indus suture of western Himalayas and the LGC equivalent to the Ladakh Granite Complex. The metasediments of the Kameng district were earlier divided into two groups viz. the Bomdila Group of Lesser Himalaya and Sela Group of Higher Himalaya but at many places these two are difficult to be differentiated. The Potin and Khetabari Formation represent the Lesser Himalayan metamorphites of Subansiri District, which are regionally occurring units within Arunachal Pradesh. The contact between the gneissic rocks of the Sela Group and the low grade schist of Dirang area was tentatively marked by the earlier workers as a thrust plane equivalent to Main Central Thrust (MCT), but its extension all across Arunachal Pradesh is doubted by many.

The Palaeozoic (Lower Permian) Miri Formation of the central Arunachal Pradesh comprising purple to white feldspathic sandstone with thick bands of diamictite, overlies the Siwaliks along the MBT in the south and underlie the Sela and undifferentiated Potin and Khetabari or Buxa rocks. Further east, these rocks overlie the Permian Bichom and the Proterozoic Reyang, Sela or Tidding Formation.

The Gondwana rocks of the Lower Permian age constituted by Bichom, Garu and Bhareli Formations are thrusted over the Siwaliks along MBT in the south and tectonically overlain by the Proterozoic rocks and the Miri Formation in the north. The Lower part of the Bichom/ Garu Formation comprises of diamictite, carbonaceous shale with calcareous or cherty nodule, slate Carbon-phyllite, greenish shale and siltstone with marine fossils like Conularia, Laskeri, Chonetes, Productus, Spirifer, Crinoid etc. and are better exposed in the east. The upper part (Bhareli Formation) comprising Feldspathic sandstone, carbonaceous shale, siltstone and coal seams, with plant fossils such as Glossopteris indica, Vertebraria indica, Sphenophyllum and Speciosum, Noeggerathiopsis hislopi, etc., represent the continental facies and are better exposed in the west.

The Mesozoic sequences are not observed in this sector, but, LGC may represent this period. The Eocene Yinkiong Formation is exposed in the southeast as silvers of marine rocks comprising gray greenish or purple shale with plant fossils and foraminifera- bearing limestone along the MBT and in the northeastern part near the orographic bend, in a large tract underlying the Permian and older rocks.

The Neogene Siwalik rocks occurring as a narrow strip along the northern fringe of the Assam plains from Bhutan border to Siang District, widen in the east and are juxtaposed with Pre Tertiary rocks along the Main Boundary Thrust (MBT). The Siwaliks comprise hard, grey and brownish pebbly sandstone, subordinate clay or siltstone and boulder bed. Some dicot leaf impressions and fragmentary plant remains and lenses of lignite have also been observed in these rocks.

The Quaternary deposits in Arunachal Pradesh mainly include alluvium, river terraces and glacial deposits. The lacustrine Hapoli Formation, resting over the Sela Formation in Lesser Himalayas occupies a small area in central part of the state.

5.2 Structure and Tectonic History

The Himalayan Orogen with Ladakh and Karakoram in the west and Mishmi hills in the east, can be subdivided into four almost east-west trending lithostratigraphic belts, each characterized by distinct geological attributes. These belts take a turn towards south-west in the 'western syntaxis' and similarly assumed southeasterly trend as orographic bend in the east. From north to south, the belts are identified as below.

NORTH
Karakoram Belt (KB)
……………...Shyok Suture……….
Indus Shyok Belt (ISB) and Lohit Granitoid complex belt (LGCB)
———— Indus Tsangpo/ Tidding suture…………….
Main Himalayan Belt (MHB)
…….. Main Boundary Thrust…………….
Frontal Fold Belt (FFB)
……. Foothill Thrust……………….
Alluvium
SOUTH

The data of the folds of various scales is insufficient to arrive at a comprehensive picture of the folding of the Himalayan rocks, it is evident that multiple deformation occurs within this belt. The deformation associated with the Main Himalayan Orogeny is so pervasive that the structures developed during the earlier tectonic phases, got superimposed and modified to the extent that at places, it is difficult to map the earlier structural elements. It has also reset the mineral ages to Tertiary. The regional folds trend NW-SE in the western, E-W in the central and NE-SW in the eastern sector. The youngest phase with NE-SW to N-S trending open warps has affected all the earlier structures and is apparently the youngest.

The southern most fold belt i.e. the Frontal Fold Belt (FFB) is made up essentially of Tertiary and Quaternary sediments i.e. Subathus, Murrees, Siwaliks and Quaternary sediments in the Western Himalaya and Siwaliks and alluvium in other sectors. It is limited in the north by Pre-Tertiary rock of Main Himalayan Belt (MHB) along a prominent north dipping tectonic plane designated as Murree Thrust in Jammu, Krol thrust in eastern part of Himachal Pradesh and Main Boundary thrust/Fault in other places, and in the south by the Foothill Thrust against alluvium. In the Western Himalayas, the FFB can be divided into three broad zones. The southern zone, with Older Alluvium beds either homoclinally dipping towards north or having rolling dips and delimited in the north by the foothill thrust against the alluvium. The central zone consists of Siwalik rocks whereas the northern zone has largely the Palaeogene rocks. These zones are limited northward by the main boundary fault and the main boundary thrust respectively and have open and low plunging folds with axial trace parallel to the Himalayan trend. The intensity of folding increases towards north where the folds sometimes are tight and limbs are even inverted. In Jammu and Himachal Pradesh sector, several detached outcrops of the Proterozoic rocks comprising dolostone, quartzite, slate etc. are observed in Riasi - Bilaspur - Sataun belt which may be the slices of basement rocks emplaced along high angle reverse fault or may represent basement topography.

The MHB is bound between the Main Boundary Fault (MBF) in the south and the Indus suture in the north and contains rocks ranging from Proterozoic to Quaternary in age. Towards west, it extends into Pakistan while in the east it abuts against the Lohit Granitoid Complex along the Tidding Suture. The most important tectonic plane within this belt is the Main Central Thrust (MCT), which is northerly dipping and separates the Low-grade metamorphic rocks of the Lesser Himalayas from the High grade rocks or the Central Crystallines. In Western Himalayas, the MCT defines the contact between the Garhwal Group and its equivalent rocks and the Central Crystallines. It is traceable, towards west, upto south of Rohtang Pass in Himachal Pradesh. Further west in Kashmir, its extension is cut-off by the N-S trending Kishtwar Fault. In Kishenganga valley, it marks the boundary between the Kashmir basin (Dogra Slates) and the Nanga Parbat metamorphites. East of Garhwal, in Nepal, the MCT is traced in similar tectonic position, but further east in Sikkim-Darjeeling, the MCT is not clearly decipherable. The other tectonic planes sub-parallel to the Himalayan trend are the North Almora Thrust and South Almora Thrust (possibly the trace of MCT), Tons Thrust, Duwakhar Fault, Singtali Fault (Garhwal Thrust of Auden,1934), Panjal Thrust, Giri Thrust etc.

Kumar et al. (1972) recognized a tectonic plane, the Dar Martoli Fault, at the northern boundary of the central crystallines, which was later referred to as the Malari Fault or as Trans-Himadri Thrust by Valdiya (1988). Profuse Tertiary tourmaline granite and aplite bodies are present all along this tectonic plane. Besides these, there are a number of cross faults, trending in NNW-SSE to NNE-SSW direction e.g., the Kishtwar Fault in Jammu & Kashmir, Sundernagar Fault in Himachal Pradesh, Dwarahat Fault in Kumaon, the Bame Fault in Arunachal Pradesh, etc. Several active faults have also been recorded in the FFB.

The Indus-Shyok Belt lies between the Karakoram belt in the north and the MHB in the south. It is essentially composed of Cretaceous and Tertiary sediments and associated magmatic rock. On the basis of lithology, sedimentation pattern and magmatism, this belt can be divided into three zones, each separated from the other by a tectonic plane.

North
Karakoram Belt
………………………..Karakoram Fault……………………
Zone III Shyok Suture Zone
………………. Fault………………..
Zone II Ladakh Granitoid complex unconformably overlain
By the Indus Group and Khardung Volcanics
———— Pashkyum Thrust…………….
Zone I Indus suture Zone
…….. Zanskar Thrust (Zildat Fault)…………….
Main Himalayan Belt
South

The Indus suture and Shyok Suture zones have more or less similar lithologic associations of magmatic and volcano-sedimentary rocks. The emplacement of ophiolites in this belt (Zone I and III) has been a subject of debate. Zone I was regarded by many workers as an ophiolitic mélange. However, Srikantia and Rajdan (1980) suggested that the Ophiolites are tectonically emplaced within the sediments of the Sangeluma Group.

The data on structures of Karakoram Belt (KB) is very scanty but the available information suggests that there are three generations of folds in the Pangong Formation. The F_1 folds are isoclinals with NE-SW trend whereas the F_2 folds are open and either coaxial or at places at a low angle to F_1.The F_3 folds are observed only in the Upper Palaeozoic and younger sequences. There are a number of NW-SE trending faults.

5.3 GEOLOGY OF NORTH EASTERN STATES CONTIGUOUS TO HIMALAYAN AREA

The northeastern region can structurally be classified into five major Geotectonic Provinces (Fig. 5.1). These are as follows.

Shield area/ Cratons: The stable landmass of Assam-Meghalaya Plateau and the Mishmi massif form the shield area which were unaffected by orogenic movements. The shield area is separated from the other tectonic provinces by deep fractures in all sides.

Platform area: The areas bordering the shield area are termed as platform area. This zone was also unaffected by Cenozoic orogenic movement. However, late Mesozoic and Cenozoic marine and fluviatile sediments were deposited on this. The Upper Assam valley extending from Mishmi hills to Karbi Anglong, its southern margin and the northern margin of Cachar and N.C. Hills form the platform area, which is the eastern extension of Bengal platform. The Platform is constituted of Precambrian and Palaeozoic rocks. The southern limit of the Platform is marked by the Naga thrust that continues from the Mishmi massif to Halflong, while Dauki fault limits the northern extension of the Platform at north of Cachar and further west of it.

Shelf area: The narrow southern margin bordering the Shield area is known as shelf area. The sediments on the southern fringe of Assam-Meghalaya plateau are recognized to have been deposited on the continental shelf of Assam-Meghalaya shield. A shelf region bordering the Upper Assam platform and the Naga Hills mobile belt has also been identified and is suggested to have been the continuation of the Assam-Meghalaya shield shelf. The shelf sediments, deposited during mid-Oligocene, took part in the Naga-Patkoi orogenesis.

Mobile belt: Pascoe (1914) recognised two lateral movements in the North East India- the Himalayan from north to south (described earlier in the report) and the Shan, Burmese or Malayan from east to west. He also opined that both the upheavals took place more or less at the same time, prior to Tertiary period and also that for the most part of the thrust, movements from north and east must have proceeded simultaneously. He was of the opinion that development of Patkai-Naga-Manipur-Mizo hills started during late Palaeozoic-early Mesozoic period.

Foredeeps: The depressions in the northern and south-eastern margins of the platform are known as foredeeps. These foredeeps are covered by thick pile of molassic sediments derived from still rising mountains of mobile belt. The foredeeps were developed only after the thrust sheets from the mobile belts overrode the platform at different places.

In between two mobile belts, Himalaya & Assam-Arakan Range, there exists an east-west trending wide valley of Brahmaputra river having thick Recent Alluvial deposits.

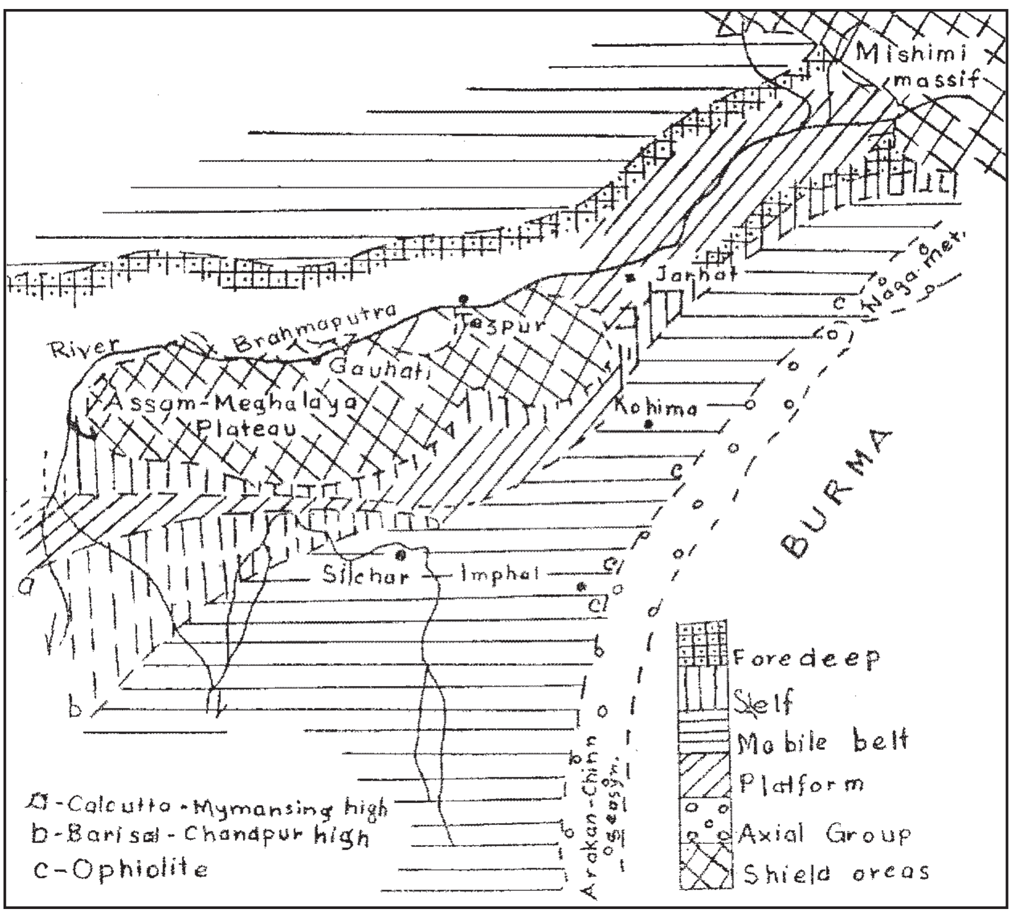


Fig. 5.1: Geotectonic Provinces in North Eastern Region

Geological Formations encountered, in the area, range in age from Archaean to Recent (Plate – IIIB). The generalised Geological succession of the Region is shown in Table 5.2.

Table 5.2: Generalised Geological Succession in North Eastern India

Age	Group/ Formations		Lithology
Recent	Newer Alluvium		Clay, Silt, Sand as beds and lenses.
~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~~			
Pleistocene	Older Alluvium der deposits as beds and lenses.		Clay, coarse Sand, Shingle, Gravel & Boul
~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~~			
Pliocene	Dihing Formation Grit and Sandstone.		Pebble beds, soft Sandy clay, conglomerate,
~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~~			
Mio-Pliocene	Dupi Tila Formation (Surma Valley)Namsang Formation (Upper Assam)		
Sandstone, Mottled clay, Grit and Conglomerate with beds of coal at places			
~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~~			
	Tipam Group	Girujan Clay	Mottled clay, Sandy shale, Grity sand Sandstone Conglomerate
		Tipam Sandstone	
Miocene	Surma Group	Bokabil Fm	Shale, Sandy shale, Siltstone, Mudstone, Ferruginous sandstone
		Bhuban Fm	Alternations of sandstone, sandy shale & conglomerates
~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~~			
Oligocene	Barail Group		Massive sandstone, Shale, Sandy shale etc.
Eocene	Disang Group (geosynclinal) / Jaintia Group (Shelf facies)		Shale, Sandstone, Marl, Limestone etc.
Upper Cretaceous	Khasi Group		Conglomerate, Arkose, Sandstone – Con glomerate alternations
Cretaceous to Palaeocene	Alkali Complex (Sung valley of Meghalaya)/ Ophiolites (Nagaland)		Serpentinites, pyroxenite, carbonatite also common/ Basalts, Slates, Phyllites, radiolarian cherts, pockets of limestone
~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~~			
Cretaceous/ Jurassic (?)	Sylhet Trap		Basalt, Rhyolite, acid Tuff as flows and Lenses.
~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~~			
Carboniferous-Permian	Lower Gondwana		Basal tillites, conglomerate, sandstone, shale and siltstone
~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~~			
Proterozoic	Shillong Group with igneous rocks of Mylliem Granites/ South Khasi Batholiths and Khasi Greenstone/ Naga metamorphic		Schist, Carbonaceous Slate/ Phyllite, Quartzite, Conglomerate, Porphyritic and coarse Granite, Pegmatite, Dolerite, Basalt.
~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~~			
Archaean (?)- Proterozoic (Undifferentiated)	Gneissic Complex		Biotite-gneiss, Biotite-hornblende-Gneiss, Gran ite, Ilmenite-quartz- schist, Mica-Schist etc.

The **Archaean gneissic complex** covers the northern and central parts of the Mikir Hills in Karbi Anglong and Dima Hasao (N.C.Hills) districts of Assam, major portion of Meghalaya covering parts of East and West Garo Hills, West Khasi Hills and parts of Ri-Bhoi districts and adjacent parts of Assam and is also scattered along the north and south banks of Brahmaputra river as isolated inselbergs in the districts of Goalpara, Dhubri, Kokrajhar, Kamrup, Darrang, Sonitpur and Nagaon in Assam. The Archaean Gneissic Complex is made up of para and ortho gneisses, migmatite, meta-sedimentary bands like Biotite gneiss, augen gneiss, mica schist, chlorite schist, granulite with xenoliths of amphibolite. Rarely preserved Banded Iron formation (BIF) in the form of banded magnetite is also found. They are intruded by numerous bands of basic rocks like ortho-amphibolite, meta-dolerite, meta-pyroxenite with concordant or partly discordant relation with the associated gneiss. The grade of metamorphism of the gneissic complex varies from green schist to amphibolite facies and occasionally upto granulite facies. The structural alignment is NE-SW to ENE –WSW.

Subsequent to the cratonization of the gneissic complex, a shallow basin was developed in an intra-cratonic setting in the eastern and central part of Meghalaya plateau. The meta-sediments deposited unconformably over the basement rocks comprise of the **Shillong Group** of rocks, which are exposed in the central and eastern part of Meghalaya plateau in the district of East Khasi Hills and parts of Ri-Bhoi districts and are restricted to small areas over the western flanks of the Mikir Hills and the northern part of Dima Hasao (N.C. Hills) of Assam. It consists of thick arenaceous and argillaceous meta- sediments. Shillong group is divided into two types of formations namely- Tyrsad and Shillong formation. The older Tyrsad formation of Lower Proterozoic age comprises of argillaceous metasediments comprising of mica schist, chlorite schist, carbonaceous slate/ phyllite, quartzite, garnetiferous slate, quartz sericite schist and phyllite. The younger Shillong formation of Middle Proterozoic age comprises of phyllite, graded and sheared conglomerate, ferruginous quartzite with structures like ripple marks and cross bedding suggesting less metamorphism than Tyrsad formation. They have a strike direction of NE-SW. The Shillong Group has been affected by two major episodes of igneous activity. The first is in the form of basic dykes and sills known as **Khasi greenstones**. Probably in the later part of middle of Proterozoic, a number of discordant granitic plutons like **Mylliem granite, South Khasi batholith, Kalang pluton** etc. containing anomalous uranium intruded the basement rocks as well as meta-sediments of Shillong Group.

Lower Gondwana rocks occur as patches in Singrimari area of West Garo hills. They are represented by Talchir and Karharbari formation. The Talchir formation unconformably overlies the Gneissic Complex and Granitoids comprising of the basal tillites, conglomerate, sandstone, shale and siltstone. This is conformably overlain by Karharbari formation consisting of coarse-grained sandstone, conglomerate, siltstone, shale and coal. Coal lenses and fossils like *vertebraria indica* are found to be present.

Sylhet Traps are a type of plateau basalt being exposed in the southern margin of the Meghalaya plateau. They are a product of Cretaceous-Jurassic type of volcanism and are associated with Dawki and Raibah fault trending in E-W direction, which are about 80 km long and 4 km wide. They have a maximum thickness of about 550-600m. They are overlain by eroded Precambrian basement complex, which is in turn overlain by the Cretaceous-Tertiary sediments. They comprise predominantly of basalts, with minor amount of alkali basalt (nepheline tephrite), rhyolites and acid tuffs. The basalts are micro porphyritic with phenocrysts of labradorite and augite. Petrochemically, the Sylhet basalt belongs to calc-alkaline volcanic suite with minor acid and alkaline differentiates. Structures like flow breccias, layering and flow folding are common in basaltic rocks.

Alkali Complex rocks like pyroxenite, serpentinite, umcompahgrite (melilite pyroxene rock), ijolite, syenite, and carbonatite occur in small isolated round bodies along a NE trending zone in Sung valley. This ultramafic carbonatite body cuts the Shillong Group of rocks with the development of fenitic contact. These rocks suggest a small-scale mantle melting through deep-seated fractures under tensional regime.

The **Cenozoic rocks** of the Region were laid over a basement comprising Precambrian and Lower Gondwana sediments. The basement in the core of Arakan Mountains is believed to be low grade politic-psammitic and carbonaceous sequence of mica-schist, granitoid gneiss, feldspathic metagreywacke of Mesozoic/ Proterozoic (?) age, known as **Naga Metamorphics**, occupied the eastern fringe of India (Nagaland) and Myanmar. It is overlain by the **Nimi Formation** consisting of phyllites, quartzites and quartz-sericite schists. This sequence is unfossiliferous. However, the oldest fossiliferous magmatic, metamorphic and marine sediments of Jurassic-Cretaceous age identified in the eastern part of Nagaland & Manipur are **Ophiolite suites** consisting of marine sediments like slates, phyllites, greywackes, cherts, limestones containing radiolaria, volcanic rocks like basalts, magmatic rocks such as peridotites, pyroxenites, anorthosites, serpentinites, etc. It marks the beginning of a marine transgression covering Assam-Arakan region. The Assam-Arakan geosynclinal basin, containing the ultramafic igneous rocks in association with the sediments deposited in it, has been subjected to continuous orogenesis. Deposition of thick (about 3000 m) pile of monotonous shaly flysch type of sediments designated as **Disang Group** started in Jurassic-Cretaceous Period and continued upto early Eocene. The provenance of these sediments was presumably located in Mishmi Hills or Myanmar (erstwhile Burma). In the western and central parts, the Group is composed of splintery shales with thin bands of hard flaggy sandstones. Eastwards, the rocks progressively became metamorphosed into slates, phyllites and schists with intrusives of ultrabasics and serpentinous rocks, limestones, etc. The Upper Cretaceous sediments occurring on the southern fringe of the Assam-Meghalaya plateau and below the alluvium in upper Assam were deposited under shallow marine environments at the shelf of the geosynclines. The sediments are thick and extensive. They are divided into **Khasi Group** and **Jaintia Group**.

The **Khasi Group** is further divided into Jadukata and Mahadek formations. Jadukata formation consists of alternate beds of sandstone and gritty /pebbly sandstones with *inoceramus* fossil.   The Mahadek formation is divided into two parts namely Lower and Upper Mahadek. The Lower Mahadek formation consists of medium to very coarse grained /pebbly feldspathic to arkosic sandstone with carbonaceous matter and bottom conglomerate. The Upper Mahadek is an oxidized arenaceous facies.

The **Jaintia Group** of Palaeocene to Eocene age unconformably overlies the Mahadek formation in southern parts of Meghalaya/ Shillong plateau. They consist of siltstone and sandstone with alternation of sandstone, limestone, calcareous sandstone etc. The limestone –sandstone succession of Jaintia Group is also called Sylhet limestone. The Jaintia group of rocks also extend along the southern flanks of Karbi Anglong and the western parts of Dima Hasao (N.C.Hills). In Karbi Anglong, the Sylhet limestone of Jaintia Group of rocks is underlain by a typical transgressive sequence of sandstones and shales with coal beds known as Kopili Formation.

The **Disang/ Jaintia Group** is conformably overlain by about 1200 m thick succession of alternating hard sandstones and shales of **Barail Group**. It represents shelf facies. The succession in 'Kohima Synclinorium' in the south comprises of interbedded shales and sandstones containing some thick coal seams in the upper part of the succession. The same rock type occupying the south-western part of Meghalaya, known as **Simsang formation**, is conformably overlain by **Baghmara formation** of Miocene age comprising of feldspathic sandstone, conglomerate & clay, followed by **Chengapara formation** of Mio-Pliocene age containing sandstone, siltstone, clay, marl.

Deep sea conditions continued till Oligocene time, when shallowing of the basin started. Emergence of geanticlines known as Arakan Chin Hills marked separation of Indian part of geosynclines from that of Myanmar. The emergence also caused subsidence of the marginal areas of geanticlines both in geosynclines and shelf areas, initiating perhaps the development of the foredeep on the earlier margin of Assam valley platform. This stage continued from Eocene to Middle Miocene with prevalence of flysch. A hiatus between Barail & Surma showed the beginning of a next stage from flysch to molasses stage. A major uplift during Mid-Miocene period experienced overthrusting of the platform from SE and NW. The foredeep that already existed from Middle Oligocene period got more deepening where thick molasses were deposited from mountain ranges of mobile belt bordering foredeep. **Surma & Tipam** groups of rocks were deposited. This succession is exposed in a large area extending southwards from the centre of Kohima Syncline through Surma valley, Tripura to Arakan mountains of Myanmar. **Surma Group** ranging in thickness from 2900 to more than 4000m comprises a succession of alternating sandstones and shales and has yielded shallow brackish water micro faunal assemblages. The **Tipam Group** that conformably overlies **Surma Group** consists of 3000 to 4000 m thick succession of massive sandstones with subordinate clays and shales, known as **Tipam sandstone**, overlain by **Girujan clay** comprising variegated & mottled clays. Away from mobile belt, compression forces caused folding and faulting and promoted series of block thrusting. Thus the belt of Schuppen having 4 to 5 thrust slices were formed between Disang thrust limiting SE extension of belt of Schuppen and Naga thrust limiting NW extension of Schuppen.

During Mio-Pliocene period, **Dupi Tila and Dihing** group of sediments were deposited above Tipam Group over an unconformity. Sedimentation in this period was almost entirely fresh water (fluviatile). **Dupi Tila** group of sediments are exposed in the northern Cachar district of Assam and consist of sandstones and conglomerate with mottled clays. In Langting and Dihing valleys of Upper Assam, Girujan clay is unconformably overlain by a sequence of mottled clay, sandstone and conglomerates, known as **Namsang beds**, which reflect a fresh phase of uplift in Naga-Patkoi range. The Namsang beds are unconformably overlain by a succession of well rounded boulder and pebble beds with interspersed lenses of soft sands & clays, best exposed in Dihing valley as **Dihing Group**. The succession has been unconformably overlain by the **Quaternary formation** described variously as Terrace Deposits/ Unstratified Drifts/ Older or High Level Alluvium etc. of Pliestocene to Holocene age. The Brahmaputra valley is covered by recent alluvial deposits grouped as Newer/ Recent formation with variable thickness of approximately 200-300 m.

6. HYDROGEOLOGY

Varied geological set up coupled with complex structures, controls the hydrogeological scenario of the Himalayan region. As the larger part of the area is underlain by crystalline rocks, which have negligible primary porosity, ground water occurs only in the formations/rocks where the secondary porosity has developed e.g. joints, fractures, weaker planes, solution cavities etc. The development of secondary porosity in different rock units in the area is the result and effect of various stress and strain situations through which these litho-units have undergone during geological past. Hence it is the structure of the area which controls occurrence of ground water over the Himalayan Region. Besides, the rock formations in Himalayan Region are continuously undergoing disintegration through glacio-fluvial action. A considerable part of this region remains under snow cover throughout the year. Landforms such as moraines, varves and terraces are common, which occasionally extend over several kilometers and have thickness upto 50 m. In the localized intermontane valleys, where reasonable alluvial thickness is available, ground water occurs in the primary porosity. Ground water over the area is localized and occurs as disconnected bodies under favourable geomorphological and structural conditions.

Chief source of recharge to ground water in most of the Himalayan Region is the glaciers. In foothill areas, rainfall being quite high also contributes copious amount to ground water, but due to high relief and slope of rock surface, larger proportion of the precipitation flows out as overland flow resulting in a meagre amount to infiltrate to subsurface ground water bodies. Ground water comes out as seepage through springs under favourable situation. Finally, the springs also contribute additional water to the surface drainage network of the area.

6.1 Occurrence & movement of ground water

Groundwater occurs in all types of formations depending upon the depositional sequence and structural set up, porosity, degree of weathering and topographic locations. Various formations forming potential aquifers may be classified as under:

- Consolidated formation
- Semi-consolidated formation
- Unconsolidated formation

A brief description of ground water potential and feasible ground water abstraction structures in different formations is given in Table-6.1 and Hydrogeology of Himalayan area is presented in the Plate – IV A & B.

Table 6.1: Formation wise summarized ground water potentiality and feasible abstraction structures in Himalayan area

FORMATION	AGE	TYPE OF ROCKS	GROUND WATER POTENTIALITY & FEASIBLE ABSTRACTION STRUCTURES
CONSOLIDATED FORMATION	Proterozoic (Crystallines/ Sedimentaries/ High & Low Grade	Granite, Gneisses, phyllite, schist, Migmatite, calc-silicate, marble, quartzite, amphibolites carbonate rocks	Ground water is restricted in weathered residuum, frac tures, joints, etc. Exploration at some places has revealed moderately potential fractures within 70 mbgl & bore well in the depth span of 10-70 mbgl yielding 1-5 lps & as high as 15 lps.

	Metamorphites)		**Ground water abstraction structures feasible**· ● Bore well ● Dug well in weathered residuum.· ● Percolation/ collection wells ● Harnessing of springs **Rig suitable for drilling:** DTH rig
	Mesozoic-Palaeozoic	Quartzite, Dolomitic Limestone, Sandstone, slate, carbon, phyllite, carbonaceous shale, siltstone, conglomerate with coal seam	Ground water is restricted in weathered residuum, as well as in secondary porosities like fractures, joints, etc. upto 100 mbgl.Exploration has revealed potential frac. tures in limestone in Jammu in the depth span of 27-65 mbgl and in Gondwana sedimentaries in Sikkim down to 70 mbgl. Bore wells in limestone have yielded 5-15 lps & in Gondwana formation 0.12-8 lps. **Ground water abstraction structures feasible**· ● Dug well tapping weathered zone· ● Bore well· ● Harnessing of springs **Rig suitable for drilling:** DTH rig & DTH with ODEX combination in highly fractured formations.
	Tertiary-Proterozoic	Igneous Intrusive	Ground water is expected to be available in fractures/ joints in Ladakh Granitoid in Ladakh Region. **Ground water abstraction structures feasible**· ● Hand pump fitted tube wells in the depth span of 15-73 mbgl may yield 0.5-3 lps.· ● Springs may be harnessed for water supply. **Rig suitable for drilling:** DTH rig & DTH with ODEX combination in highly fractured formations.
		Igneous Extrusive	Ground water is restricted in weathered residuum, frac tures, joints, etc. Exploration in Panjal trap (Permian age) in Kashmir valley & Dras volcanics of Ladakh Region shows potential fractures within 76 mbgl. Bore wells (in Panjal Trap) discharge to the tune of 6.3-19 lps **Ground water abstraction structures feasible**· ● Bore wells· ● Springs **Rig suitable for drilling:** DTH rig & DTH with ODEX combination in highly fractured formations.
SEMI-CONSOLIDATED FORMATION	*Tertiary*	Pebbly sandstone (friable), subordinate clay, siltstone, Shale & limestone	Ground water occurs under unconfined to semi-confined condition down to the depth of 25-200 mbgl & bore wells yield to the tune of <1-25 lps with drawdown of 19-25m. **Ground water abstraction structures feasible**· ● Large diameter dug wells· ● Hand pump fitted tube wells· ● Harnessing of springs **Rig suitable for drilling:** DTH with ODEX combination in highly fractured formations/ Percussion rig.
UNCONSOLIDATED FORMATION	*Quaternary Holocene -Lower*	Bhabhar zone (Kandi in J & K) comprising	Ground water generally occurs under unconfined condi tions. Discharge of exploratory wells down to depth of

	Pleistocene	boulders, cobbles, pebbles, coarse sand & little clay	26 - 200 mbgl, varies from 10 - 30 lps (as high as 75 lps in Uttarakhand State) with drawdown ranging from 4 to 44 m. Transmissivity values range between 150 & 1980 m^2/day (also reported 15810 m^2/day in Uttarakhand). **Ground water abstraction structures feasible**· ● Tube wells· ● Harnessing of springs **Rig suitable for drilling:** Percussion rig.
values dition with wells may yield estimated, ranges		Terai zone (Sirowal in J & K) comprising of clay & sands	Ground water generally occurs under unconfined to confined conditions. Discharge of exploratory wells down to the depth of about 60 mbgl varies from 20-55 lps with drawdown ranging from 5 to 10 m. Transmissivity range between 110 & 2785 m^2/day. Autoflow con- prevails in deeper aquifers down to 84-433 mbgl head as high as 8.69 magl. Here tube about 57 lps. Transmissivity value, as between 825-12274 m^2/day. **Ground water abstraction structures feasible**· ● Tube wells· ● Dug wells **Rig suitable for drilling:** Rotary rig.
m^2/ Dun val with pi Here tube		Valley fills of intermontane valleys & Dun Valley	Ground water generally occurs under unconfined to semi-confined conditions. Highly potential aquifers oc cur within 100 mbgl. The discharge of exploratory wells down to the depth of about 100 mbgl, varies from 5-60 lps with drawdown ranging from 5 to 20 m. In general, yield of the tube wells is less in Arunachal Pradesh (about 5 lps) and maximum in Dun valley of Uttarakhand. Transmissivity values range between 500 & 3336 day and as high as 8242 m^2/day, reported from ley area. Autoflow condition prevails in the area ezometric head varying from 0.93 – 1.45 magl. wells may yield about 4-15 lps. **Ground water abstraction structures feasible**· ● Tube wells· ● Dug wells **Rig suitable for drilling:** Percussion/ Rotary rig.
ley & tion in and water as tory wells 12-19 The 'T' Potential cial de		Fluvio - glacial & Morainic deposits	The deposits are found to occur in Kashmir & Ladakh regions of J & K State, Kangra-Palampur valley in Himachal Pradesh and Kali Valley, Alaknanda Val- Saraswati valley in Uttarakhand. Karewa forma- Kashmir valley consists of a huge pile of sand, silt clay interspersed by glacial boulder beds. Ground in this formation occurs under unconfined as well confined conditions. The discharge of explora- down to the depth of 15 m to 355 m varies from lps with drawdown ranging from 0.4 to 40.0 m. Values range from 39 m^2/day to 2983 m^2/ day. aquifers are encountered in morainic & fluvio-gla- posits of Leh Plain, Nubra valley & Siachen in

Ladakh Plain, ex lps for tween fers have yielded with T un first time. Tubewells drawdown T value its in Pradesh, explora and the tube Transmissivity			Region. Exploration has revealed that:i) In Leh ploratory wells down to 54-70 mbgl yielded 10-27 drawdown of 3-16.57 m with T value ranging be- 204 & 2136 m^2/d.ii) In Nubra valley, potential aqui- occur within 60 mbgl & exploratory wells 25-38 lps for very low drawdown (0.16-0.47 m) varying from 3068-6947 m^2/d. iii) Exploration was dertaken by CGWB at Siachen for the have yielded high discharge of 18-28 lps for of 0.77-2.07 m down to the depth of 44 mbgl. The ranges from 3862-28465 m^2/d.In morainic depos- Kangra-Palampur area of Himachal tion was conducted down to 50-80 mbgl wells yielded to the tune of 3-22 lps. The values vary from 48-673 m^2/day. **Ground water abstraction structures feasible**· ● Tube wells· ● Dug wells· ● Springs **Rig suitable for drilling:** Percussion/ Rotary rig.

Formation wise detailed description of hydrogeological condition of Himalayan area is given as under:

6.1.1 Consolidated Formation

Consolidated formations of Precambrian to Mesozoic age occupy most of the areas of Himalayan Region (Plate-IV A & B). In these formations, ground water occurs in secondary porosities, such as joints, fractures, weathered zones in various lithological units namely, gneisses, phyllites, schists, quartzites, marbles, hard traps, etc. The possibility of ground water occurrence in volcanic rocks and limestones is moderate. Besides, potential fractures are also encountered in gneissic, schistose and sedimentary rocks within 70 mbgl and bore wells tapping these fracture zones may yield to the tune of 1-5 lps and as high as 15 lps. However, detailed hydrogeological and geophysical surveys are required for deciphering the potential secondary porosities and their extension. By and large the development of ground water over the terrain is low and of limited extent, mainly due to dispersed population. At places, water comes out as seepage through springs due to high relief, which are utilized as water sources.

The State wise details are as under:

6.1.1.1 Jammu & Kashmir

Jammu Region

About 15000 sq km area in hilly terrain of Jammu region is occupied by consolidated formations like gneisses, schists, quartzites, crystalline limestones, slates, etc. with hard traps of Precambrian to Mesozoic age. In these formations, ground water occurs in weathered residuum and in fractures & joints and is developed through dug wells / hand pump fitted bore wells. Potential fractures are encountered in the depth span of 27-65 mbgl in limestone and the bore wells tapping these fractures yield to the tune of 5-15 lps.

Kashmir Region

In Kashmir valley, consolidated formations comprise of gneissic, schistose, quartzitic and calc-silicate rocks of Proterozoic age, shale, limestone, siltstone of Palaeozoic-Mesozoic age with Panjal traps of Permian age. Here the Panjal trap is highly potential and the exploratory bore wells, constructed down to the depth of 37.50 - 76.0 m, have yielded to the tune of 6.30-19 lps, with a maximum discharge of 50 lps, at draw down ranging from 0.74 m to 12.00 m. The Transmissivity values range between 60 and 1620 m^2/day.

Ladakh Region

Granitoids of Ladakh formation and basic volcanics of Dras Formation, mélange and older metamorphics constitute the consolidated formations of the region. Ground water occurs under unconfined condition in the weathered residuum and under unconfined to confined condition in the secondary porosities of the formation. State Govt. has constructed a number of hand pumps to mitigate the drinking needs of villages. Depth of these hand pumps varies from 15 to 73 m having water level ranging from 4.57 to 15.24 m bgl and as deep as 60 mbgl. The discharge varies from 0.5 to 3.0 lps. Apart from the existing hand pumps, springs are a significant source to meet the drinking water needs.

6.1.1.2 Himachal Pradesh

The consolidated formations of Precambrian to Mesozoic are represented by granites, gneisses, schists, phyllites, dolomites, quartzites, limestones and shales. Fracture zones and joints form the aquifers in the low topographic areas with poor to moderate yields (< 1-10 lps). Exploration by CGWB down to 300 mbgl in parts of Shimla district has helped in delineating potential fractures yielding to the tune of 20 lps. The Transmissivity value is to the tune of 70.39 m^2/day. Groundwater is either developed through hand pump fitted bore wells with discharge about 2 lps or springs. Springs, sometimes yield more than 40 lps and are utilized both for drinking and irrigation purposes. Weathered mantle in low topographical areas also forms poor aquifers. In some areas, percolation wells are also constructed. *Bowris* are also constructed in oozing spring zones, for collecting water to fulfill the domestic water needs.

6.1.1.3 Uttarakhand

Consolidated formations belonging to Pre-Cambrian - Mesozoic age occupy most of the area of the region and comprise predominantly of gneisses, schists, quartzites, phyllites, dolomites, marbles, etc. In the north-eastern part, where deposits of marine sediments occur over the older sequences in the Higher Himalayan Tethyan basins, carbonate rocks are predominant. These rocks are devoid of primary porosity and ground water occurs in the weathered mantle and along the weaker planes like fractures and joints. Geomorphic conditions do not permit development of ground water through tube wells. However, hand pump fitted tube wells tapping fractures are being used in some places for drinking purpose. Spring waters usually help in meeting the need of water of the area.

6.1.1.4 West Bengal - Sikkim

The northern part of Darjeeling district of West Bengal and Sikkim State constitute the Eastern Himalaya. Almost entire part of Eastern Himalaya, except a narrow discontinuous outcrop of Siwaliks and alluvium in the southern most part, is occupied by consolidated formations. Ground water occurs under favourable hydrogeological locales like joints, fractures, weathered zones in phyllites, schists, gneisses, quartzites, marbles of Proterozoic age and sedimentary formations of Gondwana sequences comprising sandstones, slates and carbonaceous beds. Ground water in the weathered zones occurs under unconfined condition and in the deeper fractured horizon generally under semi-confined to confined conditions.

Ground water exploration in parts of Darjeeling district of West Bengal reveals that the water bearing fractures exist down to 70 mbgl and bore wells tapping fractures may yield to the tune of 8 lps.

In Sikkim, during the course of ground water exploration in gneissic & schistose rocks and in Gondwana sedimentaries in South and East Sikkim, fractures have been encountered in the depth range of 10 - 70 m bgl. Discharge of bore wells ranges from 0.12-8 lps in Gondwana formation, 5-15 lps in Daling Schists and 15 lps (in one well) in Darjeeling Gneiss. Transmissivity values vary from 16 m^2/day to 181 m^2/day in schistose rocks of Daling Group and 5.32 m^2/day to 316 m^2/day in Gondwana rocks.

Exploratory drilling in the area reveals that fractures are interconnected and steeply dipping at an angle of 50^0 to 60^0 which act as the pathway for ground water oozing as springs in the localities at various altitudes. The yield of a few such springs ceased while the ground water was intercepted by a bore well at Namchi area, South Sikkim. To avoid such a situation, it is essential that a thorough survey of the geological structures and human settlements down below along the dip direction of fractures is undertaken before selecting sites for the boreholes. A few high discharging boreholes are still under utilization for water supply in Namchi District headquarters area. However, bore well water supply could not gain popularity in Sikkim as local people have a belief that spring water is the best and sacred water. Hence considering its popularity, spring water is considered as the best source in the entire State especially in rural areas.

6.1.1.5 Arunachal Pradesh

The consolidated formation occupies nearly 90% of the Arunachal Himalaya. The Sela Group and the low-grade meta-sediments, consisting of gneisses, phyllites, schists, slates, quartzites with intrusives, act basically as run-off zone and have little importance from the ground water point of view. The occurrence of ground water in such terrain is mainly restricted to weak zones, such as fractures, lineaments and weathered residuum. The secondary porosities and thick weathered rocks may yield good amount of ground water to the tune of <1- 4 lps at precisely located areas supported by geophysical resistivity survey.

In the area, the tectonic elements create seepage conduits, which are sources of springs. These springs are utilized as the main source of water supply to the populace. The existing water supply for drinking purposes is mainly from springs tapped through gravity drainage.

6.1.2 Semi-consolidated Formation

The semi-consolidated formation of Tertiary age occupies mainly west-east trending linear tract comprising rocks of Murree Group, Dharamshala Group, Dagshai Formation, Kasauli Formation, Subathu Formation in the Western Himalaya, Yinkiong Formation in Arunachal Himalaya and Siwaliks in entire Himalayan areas (Plate-IV). In this formation, ground water occurs in weathered zones and in secondary porosities, such as, joints, fractures, in sandstone (friable), siltstone, Shale & limestone. The fractures/ joints/ fault zones form moderately potential ground water zones which are developed through hand pump fitted bore wells. The State wise details are as under:

6.1.2.1 Jammu & Kashmir

Murees and Middle- Lower Siwaliks comprising of soft or friable Sandstones, Clays, Shales, Conglomerates constitute the semi-consolidated rocks in the area. In this terrain, ground water occurs mainly either in the weathered mantle or in joints or cracks of these rocks. Friable Siwalik sandstones do possess primary porosity, but are not very potential aquifers. Exploratory wells constructed in parts of Rajouri and Udhampur districts in Jammu down to the depth of 23.50 -193.77m, yielded less than 1 lps to 25 lps discharge with drawdown ranging from 0.13 m to 22.80 m. Transmissivity values range between 9.23 m^2/day & 1760 m^2/day.

6.1.2.2 Himachal Pradesh

The semi-consolidated rocks in the State are constituted by Tertiary formations, namely, Siwaliks, Dagshai and Dharamshala formations consisting of mainly Limestones, Sandstones, Shales and Clays. The fracture/ fault zones form the potential ground water zones with yield varying from 18-20 lps. Hand pump fitted bore wells are being used for domestic water supply.

6.1.2.3 Uttarakhand

The Lower & Middle Siwaliks, constituting the semi-consolidated formations in the State, are exposed in the foothill region. These mainly consist of sandstones and shales. About 70 gravitational type springs have been reported which have varying discharge <1 lps. Ground water mainly occurs under water table condition in the fractured and jointed portions and is utilised through hand pump fitted bore wells.

6.1.2.4 West Bengal & Sikkim

Occurrence of semi-consolidated formations in Darjeeling area of West Bengal and Sikkim is very limited and discontinuous.

6.1.2.5 Arunachal Pradesh

Tertiary Group of rocks represented by the Siwaliks and Yinkiong formations are semi-consolidated formations in the State. Loosely cemented boulders, shales, siltstone, sandstone, interbedded with coal seams and limestone occur towards south and south-eastern part of the State and show gradual decrease in altitude and therefore behave as run-off as well as infiltration zone. The Siwaliks act as a good recharge zone, because of their highly permeable nature. The tube wells in the area may yield <1 to 5 lps with high drawdown of about 19-25 m. Large diameter dug wells of 2 to 3 m diameter and 10 to 12 m deep in the weathered sandstone beds are expected to yield good discharge of around 7.0 to 8.3 lps.

Ground water in semi-consolidated formations is mainly manifested as springs. But the development of springs is limited and surface runoff is less compared to that in the consolidated formations. Discharge of springs oozing out of the contact of boulder horizon and silty/ clayey layer is in the range of 0.43 to 2 lps (during Pre monsoon) and 0.02 to 2.4 lps (during Post monsoon). Most of the springs become dry during dry season because of low water holding capacity of the highly permeable fractured/ jointed formation.

6.1.3 Unconsolidated Formations

The unconsolidated formations occur as a linear belt in piedmont deposits belonging to Upper Pleistocene to Recent age mainly in the southernmost part of the Himalayan area. These formations also occur as major/ minor/ valley fill deposits and as morainic, glacio-fluvial and lake deposits. The State wise description is as under:

6.1.3.1 Jammu & Kashmir

Jammu Region

The unconsolidated formation comprises piedmont deposits belonging to Upper Pleistocene to Recent age. In Jammu region, these sediments occurring in the form of terraces and coalescent alluvial fans, developed by the streams debauching out of Siwalik Hills, extend between Munnawar Tawi in the west and River Ravi in the east. The sediments consist of coarse clastics ranging in size from boulder to gravel in loose clay matrix and occasionally alternating bands of clay of varying thickness. Kankar is also intercalated with these sediments at different intervals and in variable quantity.

These deposits are graded into finer sediments from north to south. Down south, these are comprised of alternate bands of sands of all grades and clay with sub-ordinate pecks of gravels and pebbles.

Kandi Formation

Typical Kandi formation comprises of very coarse material with little clay but in Jammu & Kashmir State, the typical Kandi formations are not seen. Instead, they comprise of boulders, gravels, pebbles and coarse sand with substantial amount of clay, sometimes hard and sticky of varying thickness. The clay proportion increases towards southwest. Occurrence of perched water bodies is a common phenomenon in the Kandi belt of Jammu & Kashmir state. Ground water generally occurs under unconfined conditions. Discharge of exploratory wells constructed in this formation down to the depth of 26 - 367 mbgl, varies from 5- 7.56 lps (maximum of 23 lps at B.K.Bari) with drawdown ranging from 0.1 m to 43.95 m. Transmissivity values range between 367 m^2/day & 1280 m^2/day.

The **Section along Naran – Kootah –Mela – Dhano from west to east in Kathua** (Fig. 6.1) drawn connecting the bore holes in Kandi and Siwaliks brings out the pre-Kandi Siwalik topography. The ground water elevation ranges from 322 m amsl at Naran to 559.0 m amsl at Dhano. The Siwaliks are exposed near Dhano, but at Kootah, Upper Siwaliks are struck at 130 m bgl i.e. at an elevation of 255 m amsl. Thick sandy clay occurs from ground level to 32.0 m bgl followed by 10 m thick clay at Naran before thin granular zone is encountered below it. The sediments change from sandy clay to bouldery clay at the top from Naran to Mela. The thick clay occurring below the sandy clay at Naran extends towards Kootah occurring below a band of sand body and further extending towards Mela occurring just below sand-boulder zone before abutting against the Siwalik bed. Number of granular zones are encountered below the first clay at Naran but at Kootah and Mela this clay is divided by two bouldery zones, lower more clayey in nature directly overlying the Siwaliks. Depth to water level is recorded as 10 m bgl at Naran where as at Mela & Dhanu the water level are observed at 36.0 and 24.25 m bgl respectively. Free flowing condition with a discharge of 5 lps has been obtained in Kootah well. It appears that the Siwalik boulder zone tapped in this well is under high pressure and has created flowing condition.

Sirowal Formation

The Kandi formation coalesces into Sirowal formation in the south, which is finer outwash of Siwalik debris, brought by streams. Ground water occurs under both unconfined as well as confined conditions. At the junction of Kandi and Sirowal formations, ground water oozes out along the spring line where water table intersects the ground level and creates marshy conditions. The spring line has undergone changes due to decline of water table resulting from development of ground water in Sirowal area. However, the base flows are found to occur in streams south of this line in the Sirowal formation. The boreholes drilled in Sirowal range between 60 & 350 mbgl. Clastic sediments

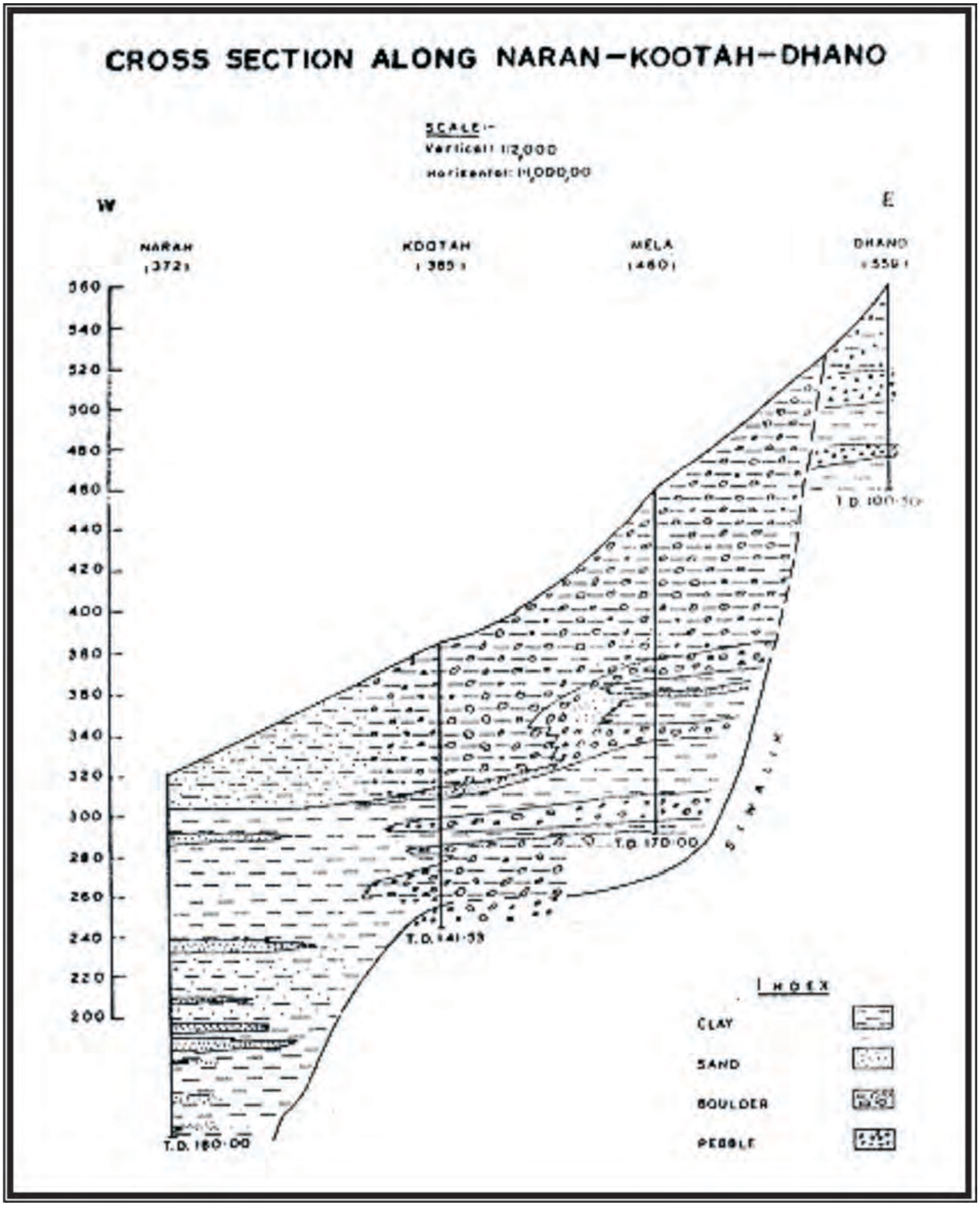


Fig. 6.1

ranging from clay, silt, sand, gravel and pebble form the bulk of lithology with boulders occurring at places. Depth to water level in general rests at 10.0 m bgl. Flowing conditions have been noticed at Quadrechak and Pakhri sites, potentiometric height attaining more than 2.0 m agl with a free flow discharge of more than 3.33 lps. The discharge of exploratory wells, constructed in this formation, is recorded more than 25 lps and as high as 63 lps for moderate drawdown. Transmissivity values ranges from 272-1197 m^2/day.

The sub-surface geological section **Ratnu Chak-B.K.Bari-Sachani-Mela-Imala-Nannan running along northwest-southeast in Jammu-Kathua area** (Fig. 6.2) shows characteristics of Kandi

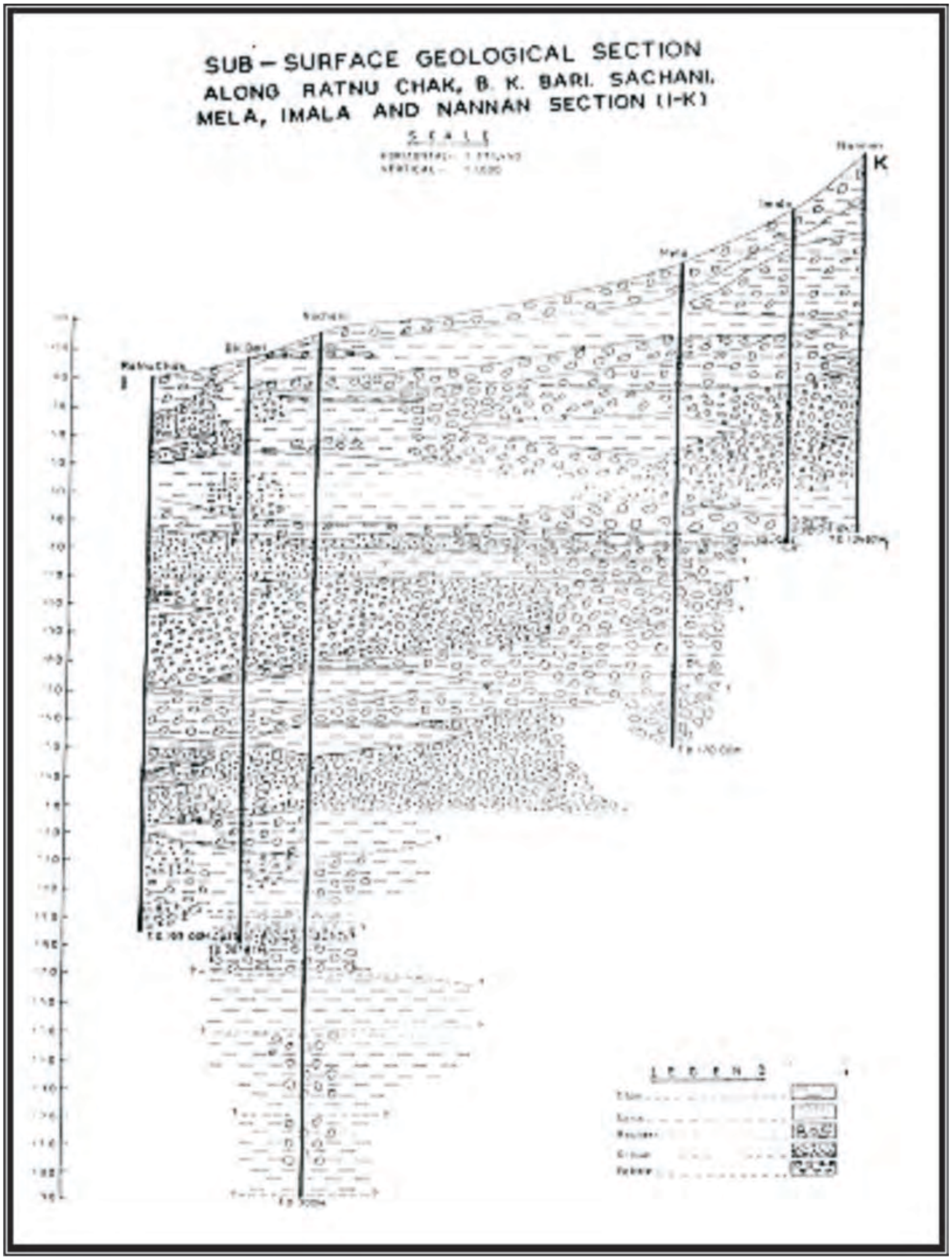


Fig: 6.2

and Sirowal formations. The section reveals that Kandi formation is encountered at Ratnu Chak & B.K.Bari wells and upper Siwalik sediments are encountered below the Kandi formation at the depth of 62 mbgl and 102 mbgl in these boreholes respectively. At B.K.Bari at least three horizons of Kandi boulders are encountered above the Siwaliks and these form potential aquifers. Deep water level at B.K.Bari charactrerises the Kandi aquifers. Other boreholes southwards pierce through the Sirowals. Several granular zones comprised of sand, gravel and boulders with intervening clays are encountered in these boreholes and appear to extend laterally to a long distance. The sandy-gravelly-bouldery aquifer material of Sirowal has better homogeneity than Kandi or Siwalik group of aquifers. This is evidenced by higher discharge in wells located in Sirowals as compared to those locatd in Kandi or Siwaliks.

The Dun Belt separates the Siwalik hills in the middle Himalayas and runs as a series of river terraces between Basholi (32°30', 76°49’30") in the east & Riasi (33°05', 74°50') and beyond in the west. The sediments are in the form of isolated sub-recent to recent valley fill deposits ranging in thickness between a few meters to a few tens of meters. These deposits are often dissected as a result of the present day drainage pattern. The deposits comprise of coarse clastics such as boulders, cobbles and pebbles etc. interbedded with lenticular clays.

There exist a number of isolated valleys in middle Himalayas where ground water occurs in valley fill deposits comprising lacustrine to fluvio-glacial sediments. A few meters thick layer of wind-blown loess overlies these deposits. Ground water in such valleys generally occurs under confined conditions. One of the prominent isolated valleys in middle Himalayas is Kishtwar valley in Doda district of Jammu region where exploratory wells down to the depth of 90 mbgl in the valley yielded very low.

Kashmir Range

Kashmir valley, covering an area of 5600 sq.km, is occupied by unconsolidated formations comprising alluvium and Karewa formation which consists of a huge pile of alternating bands of sand, silt and clay interspersed by glacial boulder beds. The sands are mostly fine to very fine grained and very rarely they are medium to coarse grained. There is considerable lateral facies variation in the nature of the sediments. The aggregate thickness of these sediments is of the order of 1300 m.

The **section along Badampura – Gadura- Illahibagh – Pantha Chowk and Zewan in Srinagar** area (Fig. 6.3) shows the sub-surface extension of aquifers. The section covers almost the entire North – South length of the district. A top silty clay layer persists from Badampur to Pantha Chowk turning clayey sand towards Zewan. One or two sequences of granular zones are encountered within the top clay. Below the top clay, two aquifer zones having considerable thickness at Badampur laterally extending towards Illahibagh and thicker towards Zewan are seen occurring below 1500 m amsl elevation. Except Badampur and Illahibagh artesian conditions have been met with at all other sites.

Ground water in Alluvium and Karewa formations of Kashmir valley occurs under unconfined to confined conditions. Discharge of exploratory wells constructed in these formations, down to the depth of 15 to 355 m varies from 13 to 20 lps with drawdown ranging from <1 to 40 m. However, at Badampur the exploratory well yielded about 50 lps with a drawdown of 7.13 m. The ‘T’ Value, in general, ranges from 39 to 2983 m^2/ day.

Ladakh Region

In Ladakh Region, unconsolidated formations are restricted along the valleys and terraces along

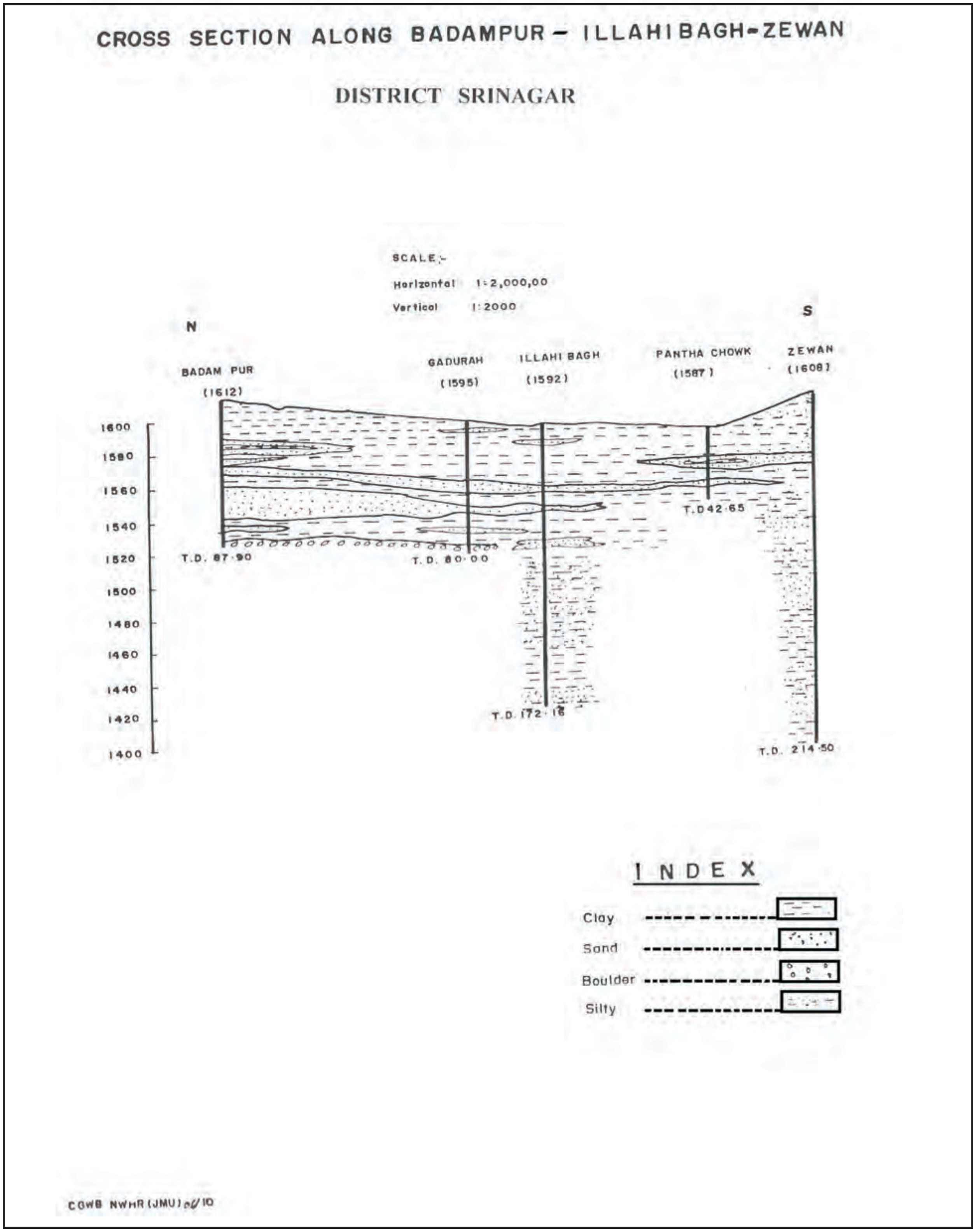


Fig: 6.3

the river Indus and its tributaries like Shyok, Zanskar and Nyuma. The sediments consist of alluvium, morainic deposits (scree and talus deposits) and fluvio-glacial boulders, cobbles underlain by lacustrine deposits consisting of clay and silt. Sustainable ground water development is possible in these formations. Apart from these, sand dunes are also found along southern side of Shyok river near Disket and Hunder. This is also the promising zone for ground water development.

Ground water generally occurs under unconfined conditions. Ground water exploration was carried out in Leh Plain and Nubra valley in Leh district. The discharge of exploratory wells, constructed in these formations, down to the depth of 54-70 m in Leh plains is to the tune of 10-27 lps with drawdown of 3-16.57 m and that of Nubra valley down to 60 mbgl is 25-38 lps for drawdown of 0.16-0.47 m. The Transmissivity values range between 204 and 2136 m^2/day in Leh plains and 3068-6947 m^2/d in Nubra valley. PHE has constructed a number of hand pump fitted tube wells of 60-70 m depth in this formation to supply drinking water in villages. **Ground water exploration was also carried out in the forward areas of Siachen down to 44 mbgl and the exploratory wells yielded to the tune of 18-28 lps for drawdown of 0.77-2.07 m. The T value ranges from 3862-28465 m^2/d.**

The results of the exploration carried out in unconsolidated formation in Jammu & Kashmir State are tabulated below in Table 6.2. The location of the exploratory wells is shown in Plate-IV A.

Table 6.2: District wise summarised results of exploration undertaken by CGWB in unconsolidated formation of Jammu & Kashmir State

Sl. No.	Region	Formation	Depth drilled (mbgl)	Depth of wells (m)	SWL (mbgl)	Discharge (lps)	Drawdown (m)	Transmissivity (m2/d)
1.	**Jammu**	**Clay, sand, boulder, cobbles, pebbles**	**80-350**	**45-300**	**1.94-9.33 mbgl** 10-35 mbgl	**30-45** 3-20	**5-20 (Occasionally as high as 50 m)**	**10-1280 (at places 2437)**
2.	**Kashmir**	**Alluvium & Karewa formation**	**355**	**70-200**	**2.50 magl -10 mbgl**	**8.33-33 (69.40 reported in Baramula area)**	**5-40**	**14.30-693 (calculated to be 2983 in Baramula area)**
3.	**Leh**	**Clay, sand, boulder of Morainic & fluvio-glacial deposits**	**87**	**54-70**	**0.16 magl – 16.57 mbgl (at places 43.76 mbgl)**	**10-38**	**0.77-13.24**	**204-6947 (maximum of 28465 at Siachen)**

6.1.3.2 Himachal Pradesh

The unconsolidated sediments occur either as major/ minor valleys/ piedmont deposits. The sediments consist of valley fills, morainic and fluvio-glacial deposits. The major valley fills are Nurpur – Jawali – Nagrota Surian, Pragpur – Dadasiba, Palampur – Kangra valley fills in Kangra district, Shathlai and Sirkhad in Hamirpur district, Balh valley in Mandi district, Una valley in Una district, Nalagarh valley in Solan district, Paonta valley in Sirmour district, Spiti valley in Lahaul & Spiti district. Ground water occurs under phreatic to semi-confined conditions in these deposits. In some of the valleys like Indaura – Nurpur valley in Kangra district, Balh valley in Mandi district and Una valley in Una district, confined aquifers are also encountered.

Thickness of valley fills in Paonta, Una, Nalagarh, Nurpur and Indaura terrace is generally more than 100 m whereas in other valley fills it is less than 100 m. Ground water occurs under unconfined conditions in shallow valley fill areas, developed along the river/ streams as discontinuous aquifers in Kangra, Hamirpur, Sirmour, Kulu, Mandi, Una and Solan districts, where depth to water level in general varies from 5 to 20 m bgl.

The ***Mohtli-Gagwal-Barota section*****,** runing along the NW-SE direction ***in Indaura valley in Kangra district*** (Fig. 6.4), shows the disposition of two major aquifers having sand, gravel, pebbles and cobbles. The top sand zone along with gravels, pebbles and cobbles, 10-30 m in thickness forms the phreatic aquifer and is underlain by thick clay beds, the thickness of which decreases towards Southeast. The thickness of confined aquifers which are intercepted by numbers of thick clay lenses towards Northwest at Kursain, Chanaur, Kathgarh etc. increases towards Southeast at Barota and seasonal artesian flow conditions prevail during and after the rainy season in the area. Depth to water level, in general, varies from 5 to 25 mbgl. In this tract, Central Ground Water Board has constructed many exploratory tube wells ranging in depth from 145 m to 432 m. Yield of these tube wells ranges between 15 and 57 lps. State Government has also constructed many tube wells for irrigation and domestic purposes. The discharge of these tube wells varies from 15 lps to 35 lps for a drawdown of 6 m to 10 m.

In valley area of Nalagarh in the district of Solan, ground water occurs in porous unconsolidated alluvial formation. Ground water occurs both under phreatic & confined conditions. The section ***Bagheri-Rajpura-Barotiwala*** (Fig. 6.5) along the NW-SE direction ***in Nalagarh valley, Solan district*** reveals two major aquifers consisting boulders and sand. The upper aquifer of 10-60 m thickness, overlain by clay bed (of 10- 40 m thick) in the north-western part at Bagheri, becomes phreatic aquifer in the central part of the section (Rajpura area). The clay bed (5-10 m thick) reappears above the upper sand zone towards south-east near Barotiwala. The deeper aquifers having boulders and sands, separated from the upper aquifer with a thick consistent clay layer, become more thick (to the tune of 40-60 m) at the central part and gradually pinch out in the south-eastern part at Barotiwala. Ground water of shallow aquifers is developed by dug, dug-cum-bore well and shallow tube wells. Depth of these wells ranges from 4 - 60 m bgl wherein depth to water level varies from near ground surface to more than 35 m bgl. Yield of shallow aquifer is moderate with well discharge up to 10 lps. The deeper semi-confined to confined aquifers are being developed by tube wells ranging in depth from 65 to 120 m tapping 25-35 m granular zones. The well discharge varies from about 10 to 30 lps. CGWB has constructed 12 exploratory wells in the valley area in the depth range of 65 to 300 m bgl. Static water level of the tube wells ranges from 2.20 to 43.20 mbgl and discharge ranges from 7 – 33 lps for draw-down of 2 to 24 m.

In Paonta valley of Sirmaur district (Fig. 6.6), two sections – AA' along Khaddar-Singhpura-Akalgarh section and BB' along Paonta-Bhungarni-Nariwala section are considered to show the disposition of clay, sand, gravels etc. in valley fill areas.

The AA' section (Fig. 6.7) runs along the NW-SE direction in Paonta valley and incorporates borehole at Khaddar, Singhpura and Akalgarh. It reveals the presence of 4-5 thick permeable granular zones down to the depth of 150 m bgl. The top soil cover is thin and varies from 0-3 m bgl in the area. The first aquifer forms the water table aquifer and occurs up to 15-25m bgl. It consists of sand, gravel, pebbles and cobbles. At Singhpura second and third aquifers consist of sand, gravels, pebbles and cobbles.

The BB' section (Fig. 6.8) runs along the NE-SW direction in Paonta valley and incorporates boreholes at Paonta Sahib, Bhungarni and Nariwala. This section reveals two prominent aquifers. Both the aquifers consist of fine to coarse grained sand with gravels and pebbles at all places.

In general, ground water is developed through shallow and deep tube wells in most of the valley areas of Himachal Pradesh. The discharge of the tube wells, in general, varies from 15 to 25 lps

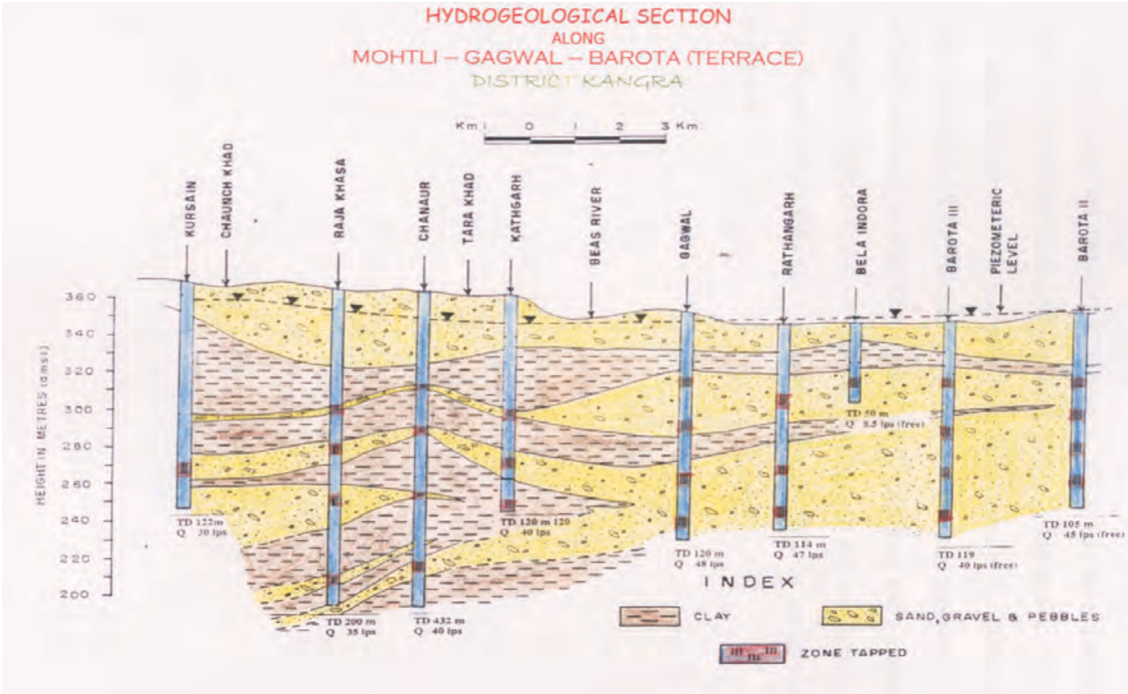

HYDROGEOLOGICAL SECTION
ALONG
MOHTLI – GAGWAL – BAROTA (TERRACE)
DISTRICT KANGRA
Km 1 0 1 2 3 Km
KURSAIN
CHAUNCH KHAD
RAJA KHASA
CHANAUR
TARA KHAD
KATHGARH
BEAS RIVER
GAGWAL
RATHANGARH
BELA INDORA
BAROTA III
PIEZOMETERIC LEVEL
BAROTA II
HEIGHT IN METRES (amsl)
360
340
320
300
280
260
240
220
200
INDEX
CLAY
SAND, GRAVEL & PEBBLES
ZONE TAPPED

Fig. 6.4

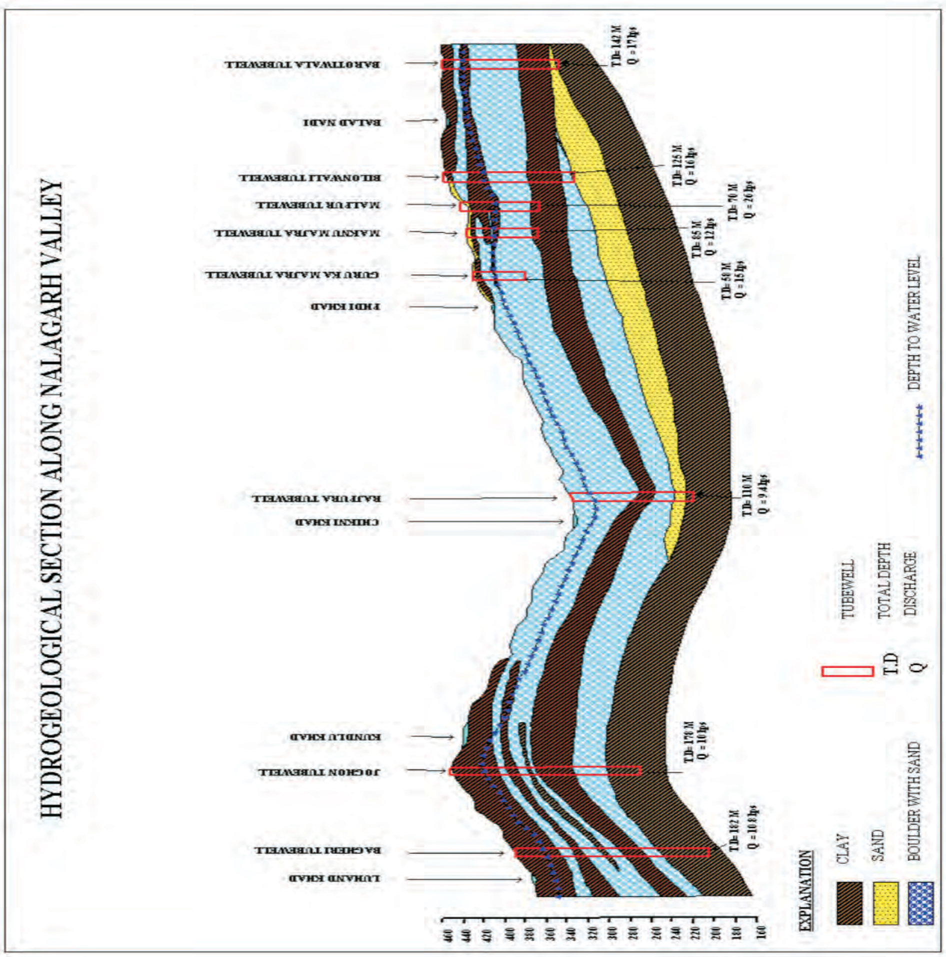

HYDROGEOLOGICAL SECTION ALONG NALAGARH VALLEY
EXPLANATION
CLAY
SAND
BOULDER WITH SAND
TUBEWELL
T.D TOTAL DEPTH
Q DISCHARGE
DEPTH TO WATER LEVEL

Fig: 6.5

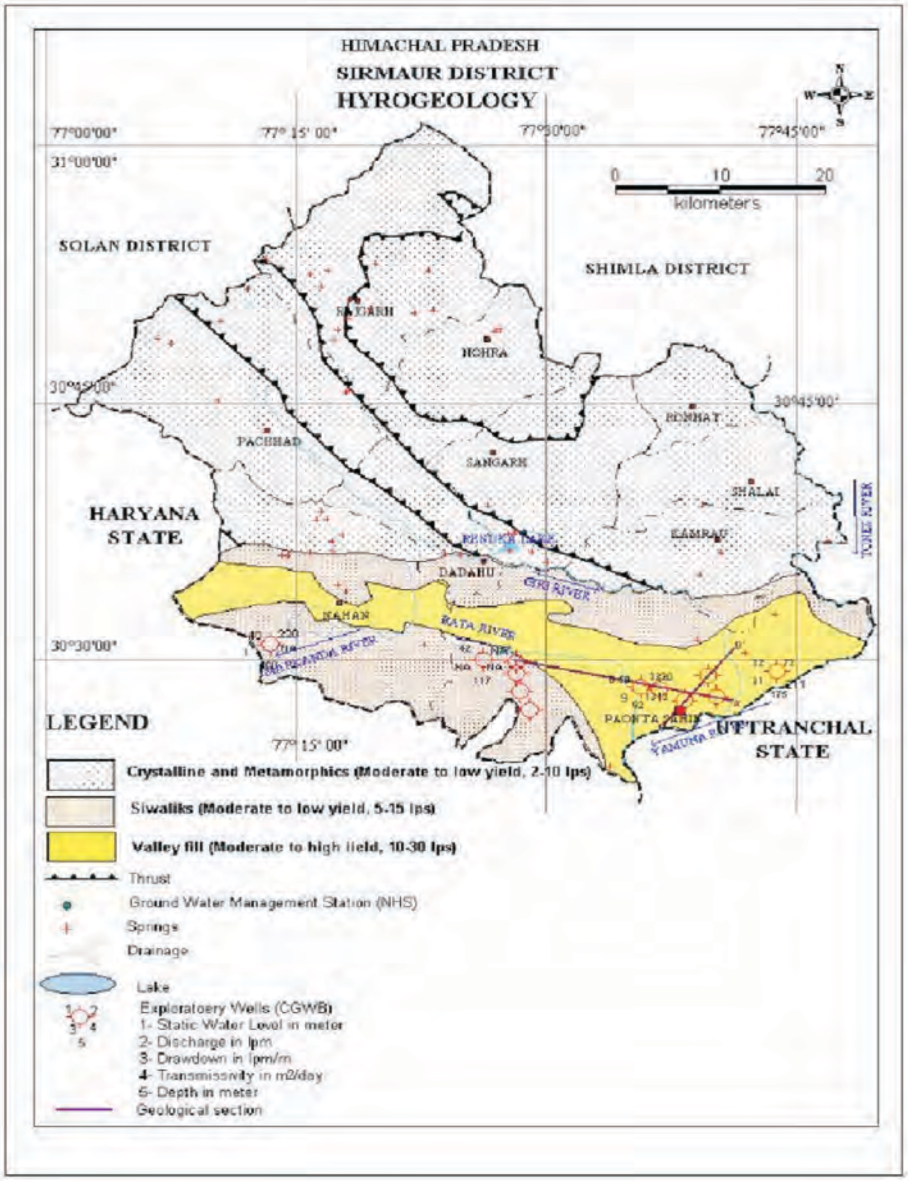


Fig. 6.6

with drawdown to the tune of 3-24 m. The maximum discharge of 54-60 lps has been observed in exploratory wells in Una, Kangra and Sirmour district. The Transmissivity values vary from 7.61-3336 m^2/day. The exploration in Una district showed that the confined aquifers occur in the depth span of 50-90 and 160-194 mbgl and the tube wells tapping the aquifers yield to the tune of 19-60 lps and 20-55 lps with drawdown ranging from 3.71-19 m and 30-40 m respectively. Artesian flowing condition was found to occur in lower and central part of Una valley with discharge of 15 lps and a head of 1.45 magl.

In morainic deposits in Kangra-Palampur area, exploration has been conducted down to 50-80 mbgl and the tube wells have yielded to the tune of 3-22 lps. The Transmissivity values vary from 48-673 m^2/day.

The exploration so far conducted in the Himachal Pradesh is shown in Plate- IV A and district wise and formation wise summarized results of exploration in the State are given in Table 6.3.

Table 6.3: District wise summarised results of exploration undertaken by CGWB in unconsolidated formation of Himachal Pradesh

S.No	District	Formation	Drilled Depth	Discharge (lps)	Transmissivity Range (m bgl)	Rigs Employed (m^2/day)
1.	Hamirpur	Valley Fill	40-82	<1 - 18	7.61-712	Percussion
2.	Kangra	Valley Fill	145-432	15 - 57	8.35-1971	Percussion/Rotary
		Morainic deposit	52 - 80	3 - 22	48 - 673	DTH-ODEX
3.	Kulu	Valley Fill	39-62	20		DTH-ODEX
4.	Mandi	Valley Fill	55-135	<1 - 13	25-820	Percussion/ DTH-ODEX
5.	Solan	Valley Fill	65-301	7 - 33	11-1480	Percussion/Rotary
6.	Sirmaur	Valley Fill	90-139	1.2 - 54	1098-3336	Percussion/Rotary
7.	Una	Valley Fill	51-220	6 - 60	85-2566	Percussion /Rotary
8.	Bilaspur	Valley fill	42-115	14 - 21	21.39-1218.21	Percussion

There are about 10,000 tube wells, dug wells, percolation wells including exploratory wells of CGWB in the valley fill deposits, both for drinking and irrigation purpose. A large number of boreholes with hand pumps also exist in the state.

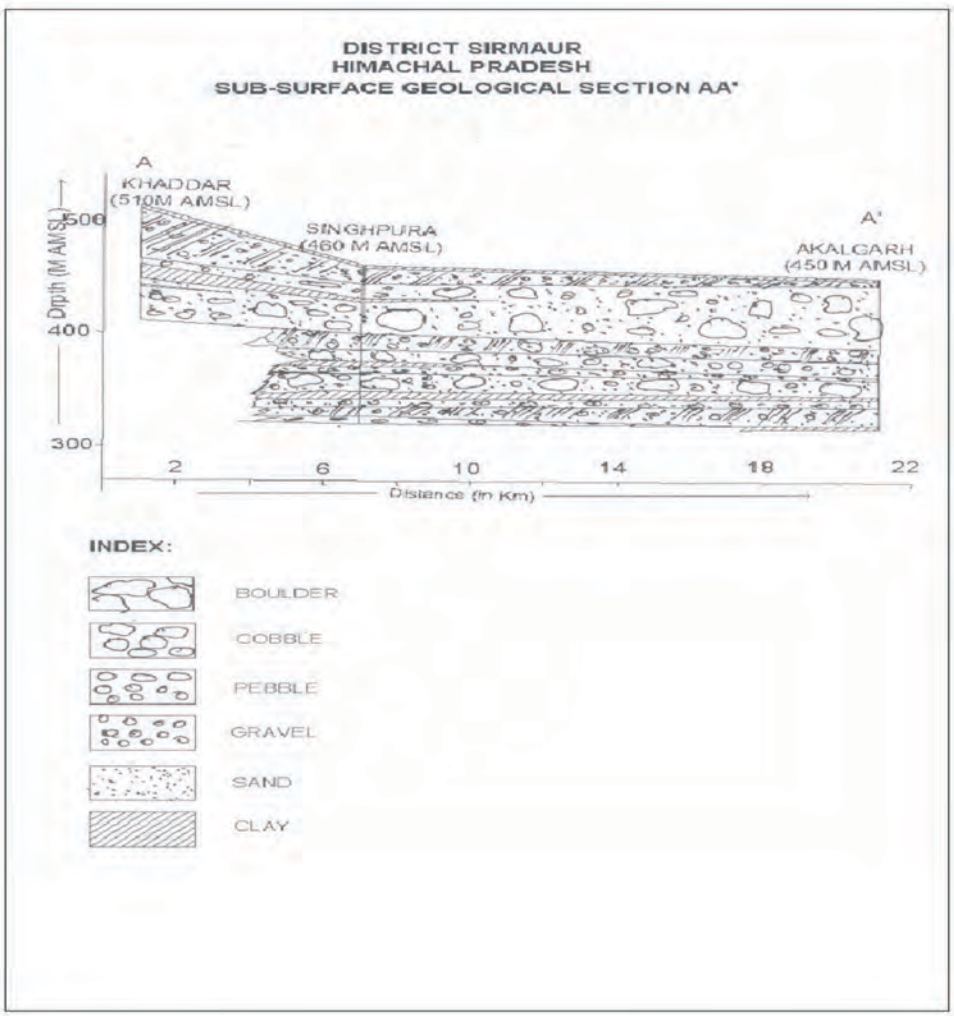


Fig. 6.7

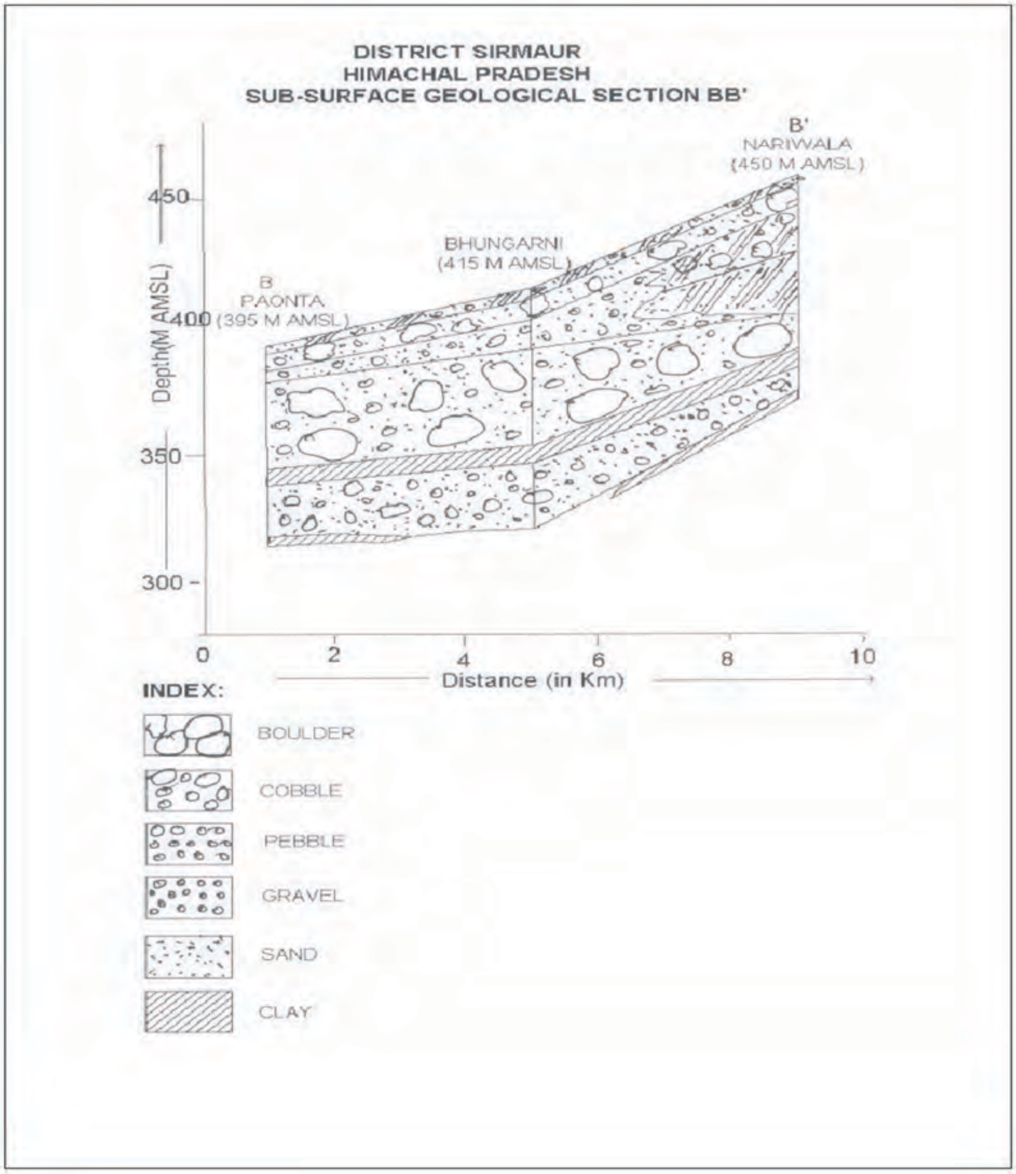


Fig. 6.8

6.1.3.3 Uttarakhand

The unconsolidated formations occur as piedmont deposits and alluvial deposits in the intermontane valleys and river terraces and as morainic, glacio-fluvial and lake deposits generally occurring as terraces of weathered unconsolidated material. These Quaternary sediments are the sole formations which may hold ground water repository over the area.

The piedmont deposits consist of numerous coalescent fans in the narrow tract, 10 to 20 km in width along the foothill region, south of Sub-Himalayan zone. The Bhabhar belt has a southerly slope of 10-20 m/km and merges with Terai belt in the south. The fans have been formed by accumulation of debris brought down by heavily charged streams descending from higher altitudes. The fans consist of poorly sorted material of all sizes. The percentage of granular material is higher in the northern part whereas clay content increases towards south. The presence of thick clay layer over coarser sediments with abrupt reduction of slopes marks the southern limit of Bhabhar zone.

Tarai zone occupies a narrow belt, south of Bhabhar and its contact with Bhabhar is well marked by a spring line. The southern limit of Terai belt is not well defined but is generally taken where flowing conditions cease to exist and it imperceptibly merges with Central Ganga plains. This zone is characterized by moist, water logged area, which is gently sloping southwards (2.5 m/km). The zone is traversed by numerous perennial, sluggish channels rendering the area swampy. Luxuriant growth of dense forest is the characteristic feature. Artesian conditions are restricted to the Terai zone. In this zone, confining conditions result due to intercalation of permeable materials like sand and gravel with impervious clay horizons. The difference in elevation of Bhabhar and Terai, together with the regional slope of the strata, appears to build the artesian head in the aquifers. Permeability of the Terai aquifers is less than that of Bhabhar, thereby playing a vital role in developing the pressure, as it impedes ground water flow.

The Terai formations are exposed in Udham Singh Nagar and Haridwar districts, and in parts along the southern boundary of Nainital district juxtaposed with the northern boundary of Udham Singh Nagar district. Central Ground Water Board has constructed thirteen exploratory wells in Udham Singh Nagar district and five in Haridwar district including three deposit wells at Jwalapur.Two observation wells and one piezometer were also constructed at Landhaura and Roorkee respectively.

The section along ***Haldwani – Nagla alignment in Nainital/ Udham Singh Nagar districts*** (Fig. 6.9) is considered as the type section of Terai - Bhabhar in the entire explored region for the following reasons:

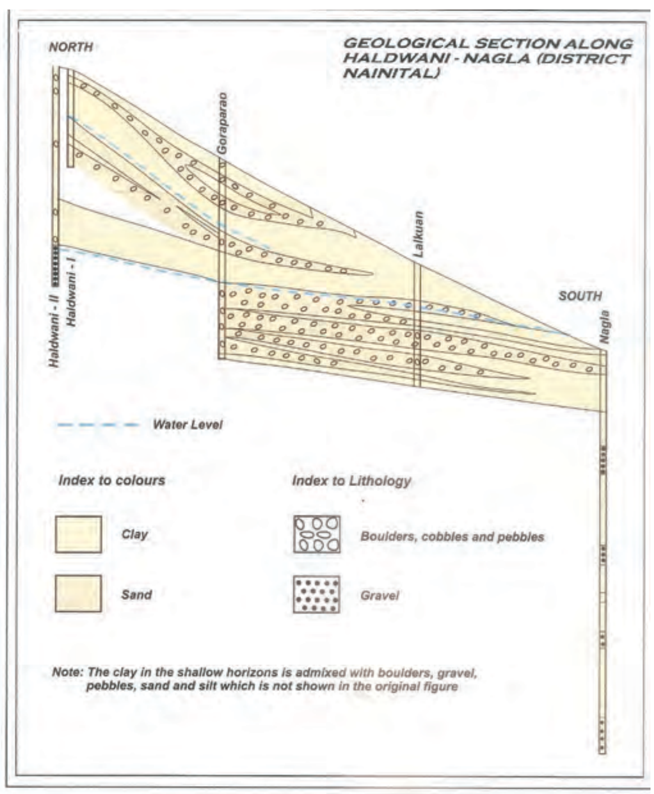


Fig. 6.9

1. The Terai – Bhabhar belt is the widest along this section, the width of Bhabhar alone being of the order 19 to 21 km.

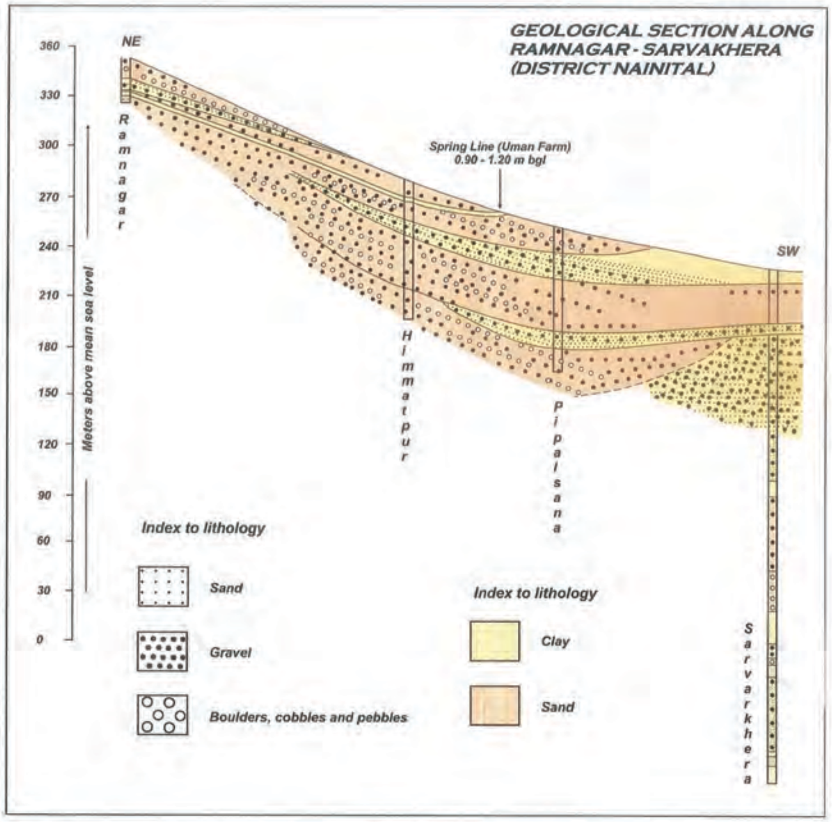


Fig. 6.10

2. The section furnishes maximum information regarding the inter-relationship (geological and hydrological) of the Terai formations with those of Bhabhar in the region.

3. The maximum depth to water table in the Bhabhar formation was also encountered in this section in Goraparao well. The correlation based on the drilling data has confirmed the hitherto believed presumption that the Terai aquifers are interfringing with the Bhabhar formations; and that the thickness of the clay and clayey sand beds increases towards the Terai belt i.e. towards south. It is also noteworthy to mention that the well drilled at Nagla Dairy Farm has piezometric head above the ground level resulting in free flowing conditions.

The section a*long* ***Ramnagar - Sarvarkhera in Nainital*** **district** (Fig. 6.10) forms the western extremity of the Terai – Bhabhar belt. The wells at Himmatpur and Pipalsana are of special significance in their location as they define precisely the Terai – Bhabhar boundary in the area, also the latter provided information on the artesian pressure head and the nature of strata close to spring zone. The alignment of the exploratory well is roughly NE – SW. Himmatpur and Pipalsana are closely spaced where as Sarvarkhera well is located 9 km away from Pipalsana. The endeavor to drill an exploratory well at Sarvarkhera is to know the information regarding deeper artesian aquifers below 152.4 m bgl.

The subsurface correlation brings out clearly the interrelationship between the Terai and the Bhabhar aquifers close to the spring zone. The disposition of the beds close to the northern fringe of the Terai belt points out the existence of a depression in the general topography at the time of deposition of the sediments. The thickness of the clay beds in the Bhabhar zone is not significant as the depth increases.

Drilling down to a depth of 304.8 m bgl at Sarvarkhera revealed that greater numbers of artesian aquifers exist in the depth zone of 152.4 – 304.8 m than that within 152.4 m depth below ground level and the aquifers below 198.12 m bgl are of limited thickness.

Ground water occurs under unconfined condition in Bhabhar zone. Water table is generally deep to the tune of 45 - 135 mbgl and as deep as 173.71 mbgl at Haldwani (Bhotia Parao).

The elevation of water table varies from 250-300 m above msl. The hydraulic gradient is around 3 m/km. The yield of the tube wells is observed to the tune of 12.50-75 lps at a drawdown of 1.34 to 8.83 m with transmissivity values ranging between 1980 & 15810 m^2/day. The hydraulic conductivity, as deciphered from pumping tests, ranges between 25 and 300 m/day.

In Tarai zone, the tube wells tapping confined aquifers with non-flowing conditions have yielded to the tune of 16 - 55 lps and as high as 92 lps for drawdown of 5.0 to 10.0 m. The coefficient of permeability ranges between 17 and 108 m/day and transmissivity values range between 298 & 2785 m^2/day. More than 2000 artesian wells exist in Kashipur, Bazpur, Gadarpur, Rudrapur and Sitargunj blocks. Central Ground Water Board has constructed artesian wells at Basai, Kashipur, Bazpur, Nagla and Rudrapur. The drilled depth ranges from 84.4 to 433.0 m bgl, with free flowing head upto 8.69 m above ground level. These wells have yielded upto 57 lps, with drawdown 5.39 to 10.69 m. The Transmissivity values range from 825 to 12274 m^2/day, and the hydraulic conductivity ranges from 16.17 to 245.50 m/day.

The pressure head of the artesian aquifers has drastically reduced over the two decades and some of the shallow depth wells have lost artesian conditions. The causes of reduction in discharge of artesian wells may be attributed to

i) Over exploitation of groundwater due to industrialization
ii) Reduction in recharge area due to developmental activities in Bhabhar zone
iii) Over exploitation of confined artesian aquifer
iv) Interlinking of confined and unconfined aquifers due to increased number of tube wells
v) Choking of wells
vi) Continuous free flow of artesian water in the absence of efforts to arrest the auto-flow.

The intermontane valleys and river terraces form prospective ground water repositories. The intermontane valleys are extensive having thick alluvial deposits comprising assorted material. These are strike valleys running parallel to hills or short transverse erosion valleys. The former are Duns, prominent being Dehradun, Patli Dun and Kota Dun. The transverse valleys are seen at Kalsi, Haridwar, Kalagarh, Ramnagar and Rambagh. River terraces, fans and colluvial deposits are found along the flanks of such valleys.

The fence diagram of Dun valley, based on the data obtained from exploratory drilling, shows the disposition and inter-relationship of granular zones in the ***Bhaniawala – Laltappar – Rishikesh – Joligrant – Ranipokhri tract*** (Fig. 6.11). A study of the fence diagram reveals the presence of numerous clay bands (sticky and plastic) within a depth of 110.00 m bgl at Bhaniawala. The clay horizons fringes out towards Gumaniwala and are absent in Rishikesh. The thickness of gravel and boulder beds also increases towards Rishikesh, thus confirming fluvial deposition. Clay hori-

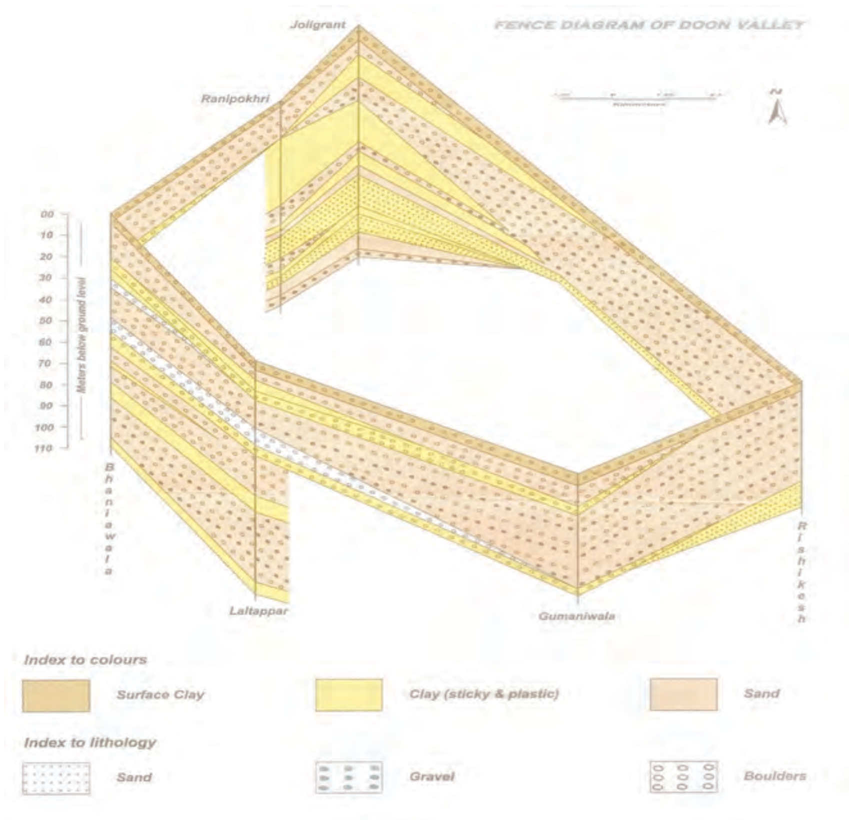


Fig. 6.11

zons attain maximum thickness (30 m) at Ranipokhri – Joligrant and pinch out towards Rishikesh. The boulders are admixed with gravel throughout the region making the area highly potential for ground water exploration.

The maximum thickness of the Dun alluvial fill so far recorded is 141.73 m (at Ranipokhri site). Seasonal fluctuation in the water table in the eastern part of the valley is heavy. The maximum fluctuation is recorded at Ranipokhri site as 44.80 m bgl. This is attributed to the proximity of the region to the highly disturbed zone of local faults and Krol thrust axis, which is hardly one km from the sites.

Table 6.4: District wise summarised results of exploration undertaken by CGWB in unconsolidated formation of Uttarakhand

Sl. No.	District	Formation	Depth drilled (mbgl)	Zones tapped in depth span of (mbgl)	SWL (mbgl)	Discharge (lps)	Drawdown (m)	Transmissivity (m^2/d)
1.	Dehradun	Dun Gravel	164	30-138	30-72	27-53	1.5-8.43	1023-8242
		Dun Gravel/ Siwaliks	85	41-76	19.66-27.30	30	6.58	528
2.	Hardwar	Terai/ Siwaliks	225	36-222	16-20.60	16-38	1.71-8.83	298-19850
3.	Udham Singh Nagar	Terai	433	Thick sediment upto 433	8.69 magl – 8.70 mbgl (Most of the wells are auto flowing)	16-55 (maximum of 92)	5.50-10	825-2785

4.	Champawat	Bhabhar	88	Within 65 (However aquifers exist beyond 88 mbgl)	5.24-8.08	45-52	3.94-9.68	7484-14140
5.	Nainital	Bhabhar/Terai	100	30-100	6.63 magl – 45 mbgl	37-75	2.04-5.60	3885-23860
		Bhabhar	300	100-300	62-173	22-60	1.75-7.48	3700-15810
6.	Pauri Garwal	Bhabhar	196	90-191	102-135	12.50-19.30	1.34-8.83	298-1980

In these areas, ground water occurs mostly under unconfined conditions and sometimes under semi-confined conditions. The ground water exploration work carried out, down to a depth of 200 mbgl, in Dehradun area has shown that water level lies at a depth ranging between 20 and 76 mbgl. The tube well, constructed by tapping the aquifers, is capable of yielding between 27 & 53 lps of fresh water at the draw down ranging between 1.5 and 8.43 m. Transmissivity values range from 528-8242 m^2/day and the coefficient of permeability varies between 20 and 250 m/day.

The exploratory wells, constructed by CGWB in piedmont zones and Dun valley in the State, are shown in Plate – IV A. The district wise summarised results are given below:

Morainic, glacio-fluvial and lake deposits generally occur as terraces of weathered unconsolidated material. The significant moraines are Malpa (Kali Valley), Pandukeshwar (Alaknanda Valley) and Gangotri (Bhagirthi Valley). The thick lake deposits, comprising basal gravel, sandy loam and moraine deposits occurring near Malpa and Garbyang in Kali Valley; Gona, Hanumanchatti and Bamaini in Alaknanda Valley and Ghatsoli in Saraswati valley have reasonable prospects for ground water. Further studies would be required to establish the hydrogeological conditions.

6.1.3.4 West Bengal & Sikkim

Unconsolidated Formations occur along the narrow river valleys and river terraces in Sikkim & Darjeeling District of West Bengal. Bhabhar zone at the foothills consists of alluvial deposits of assorted boulders, pebbles and sands. The subsurface lithological characteristics are deciphered from the lithologs of several boreholes sunk in the unconsolidated formations (both Bhabhar and Terai) in the foothill Himalayas of Siliguri Subdivision. The maximum depth for which this information is available is about 300m. Sediments in the piedmont zone consist of boulders, pebbles, gravels and coarse sand mixed with clay lenses. The sediments are poorly sorted but the degree of assortment improves slightly towards south. Several cycles of deposition took place, each of which is marked by gravel to coarse sand at the bottom and clay at the top. The subsurface correlation in Siliguri subdivision based on available lithologs is shown in Fig. 6.12.

Ground water exploration carried out down to a depth of 300 mbgl (Plate – IVB), has shown that moderately potential aquifers exist in the depth span of 50-180 mbgl and a suitably constructed tube well, tapping the aquifers, is capable of yielding between 15 & 30 lps at the draw down to the tune of 4 -12 m. The transmissivity values range from 59-150 m^2/day.

6.1.3.5 Arunachal Pradesh

The unconsolidated Quaternary sediments occupy the valley areas including piedmont plains,

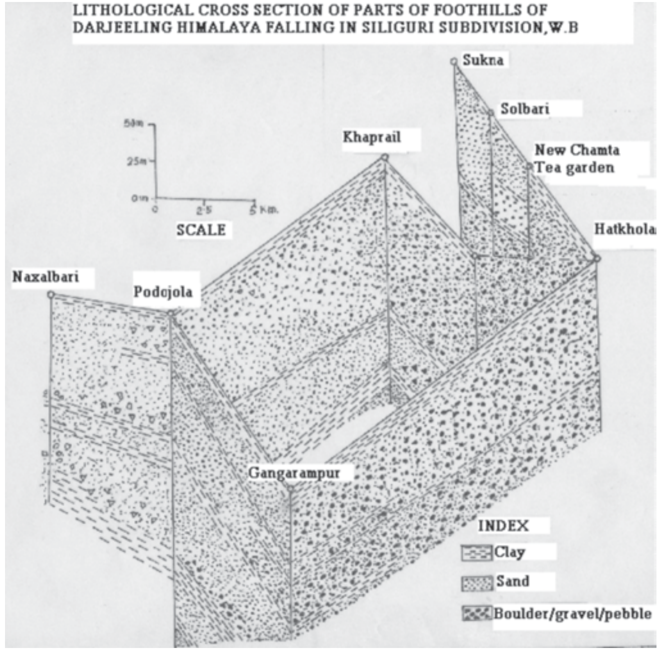


Fig. 6.12

intermontane valleys, and extension of Brahmaputra alluvial plains. The intermontane valleys are narrow and linear occurring between high hill ranges and are comparatively very small in areal extent ranging from 2 to 10 sq km only. The piedmont plains and alluvial plains occur towards southern and south-western parts of the state bordering Assam. Open and wide valleys are found in Dibang valley, Lohit and in East Siang districts.

In the piedmont plains, sedimentation pattern is not uniform all over. It depends on variable fluvial energy head and sediment load. Deposition pattern is mostly in a flash and as such, poor in sorting and in distribution of grains. The rate of infiltration depends on physical geometry and matrix of the formation. Terrace type deposits are found in and along the foothill zone. It is commonly referred to as Bhabhar belt comprised of sand, gravels, pebbles and boulders. The zone contains one or more aquifers which have fair to good ground water potential. The aquifers at depth tend to be artesian in nature when extended in lower zones.

Unconsolidated alluvial sediments in valley areas act as good repositories for ground water development. Valleys adjoining Assam are most promising where thick granular aquifer zones exist. However, physical parameters of heterogeneous aquifer sediments with variable matrix play an important role in determining permeability, transmissibility and specific capacity of aquifer zones. Intervening clay layers found with arenaceous sediments indicate leaky aquifer system. Autoflow conditions, observed at places, occur due to high hydraulic head. In the intermontane valleys, thickness of alluvium and weathered residuum are important factors. Sediment column of even small thickness holds good prospects for ground water development by shallow abstraction structures.

In Papum Pare, Lohit and East Kameng districts, both shallow as well as deeper aquifers are found to occur in foot hill zones and river valleys, surrounded by hills, constituting the sand of various grades, pebbles, cobbles and boulders, which act as the recharge zone. The presence of sand, pebbles and gravels within a depth of 10 to 20 m bgl and thin to thick clay or sandy clay layer up to a depth of 50 to 60 m bgl is a common phenomenon almost all along the foothill or valley areas.

Ground water level in Bhabhar belt is deep varying from 10-22 m bgl while in shallow zones of Terai area, it varies from 6-10 m bgl and in flood plain areas it ranges between 1.5 & 6 m bgl. The shallow aquifers, occurring within a depth of 50 m bgl are developed through dug and shallow tube wells. Dug wells are 6-7 m deep in the valleys with yield prospects of 42-63 m^3/day for 3-5 hours of pumping in a day. Exploration conducted by Central Ground Water Board reveals that the shallow tube wells constructed down to a depth of 50 m, tapping 12 – 15 m of aquifer, give discharge to the tune of 5 lps for a drawdown of 15 m. Deeper aquifers down to a maximum drilling depth of 133 m bgl occur under semi-confined to confined conditions. Development of ground water from this aquifer is both for drinking and irrigation purposes. The deeper aquifers when tapped give a discharge of 3.50 (free flow) – 15 lps for a drawdown of 3.90 – 20.93 m. The transmissibility values range from 35 to 1732 m^2/day.

The exploratory wells, constructed in Himalayan area of Arunachal Pradesh by CGWB, are shown in Plate - IVB and the district wise results are given below:

Table 6.5: District wise summarised results of exploration undertaken by CGWB in unconsolidated formation of Arunachal Pradesh

Sl. No.	District	Formation	Depth drilled (mbgl)	Zones tapped in depth span of (mbgl)	SWL (mbgl)	Discharge (lps)	Drawdown (m)	Transmi-ssivity (m^2/d)
1.	Papum Pare	Tertiary Alluvium & Tertiary	56 133	38-53 30-75 78-127	6.75 0.93 magl-14 mbgl	<1.0 3.50-10.50	18.73 3.90-21	9.92 35-44 (maximum of 667)
2.	Lohit	Alluvium	74	29-53	3.0-3.30	9.85-15	4.20-21	33-1732
3.	East Kameng	Alluvium	71	38-65	5.80	4.50	26	

In Lower & Upper Subansiri, West and Upper Siang districts, in general, the alluvial cover in intermontane valleys is very thin. Even small thickness of these sediments has good prospects for ground water development by shallow ground water structures. The surrounding hilly terrain recharges these valleys by the runoff and through the fractures, fissures and weak plains beneath their covers. An average thickness of 3-4 m of alluvial veneer could be seen in the valleys while average thickness of weathering in the underlain consolidated formations may vary from 5-10m. Dug wells of 5-6m depth are feasible throughout the valley and are expected to yield about 1.40 lps. The shallow tube wells of 25 to 30m depth in the alluvium around Ziro and east of Hapoli town in Lower Subansiri district are expected to yield more than 5.55 lps.

In East Siang District, the piedmont plain area consists of unconsolidated formation and occupies the southern part of the district. The north-south flowing Siang River divides the entire piedmont plain. Broadly two levels of terraces are found in this area. The upper level terrace along the foothills consists mainly of boulders. All the rivers are dried up during lean period which indicates high permeability of the underlying formation. Depth to water ranges from 10 mbgl to even 20 mbgl and discharge of the tube wells ranges from 8-12 lps. The lower level terrace is important for ground water availability and it acts as discharge zone. The lower level terrace deposit consists of medium to fine sand down to 6.0 to 12.0m and below which gravels are encountered. The depth to water varies from 0.83 to 3.65 mbgl. Discharge varies from 13 to 25 lps.

6.2 Behaviour of Water level

CGWB has established Ground Water Monitoring Stations (GWMS) to monitor water level and quality of ground water. The monitoring is being carried out four times in a year i.e. in the months of March/ May, August, November and January. Since, most of the area of Himalayan Region falls under hilly tract/ inaccessible, the monitoring stations (296 nos) are confined to the alluvial/ valley fill areas (Plate IV A & B).

6.2.1 Jammu & Kashmir

Ground water monitoring is being done from GWMS in Kandi belt, Sirowal area and in the valleys including Dun Belt. The depth to water level during pre-monsoon for most wells of Jammu and Kashmir lies within the range of 2-5 mbgl and 5-10 mbgl. During post-monsoon, the water level ranges from 0-2 mbgl and 2-5 mbgl. A comparison of water level of May 2012 with the mean water level for the period of May 2002-2011 shows a fall in water level in 63 % wells mostly in the range of 0-2 mbgl.

6.2.2 Himachal Pradesh

Ground water monitoring is being done from GWMS in the alluvium and valleys. Depth to water level for pre-monsoon and post-monsoon falls in the range of 2-5 and 5-10 mbgl. A comparison of water level of May 2012 with the mean water level for the period of May 2002-2011 shows a fall and rise in water level in 61 % and 38 % of wells respectively. Out of the total, 56 % wells depict a fall in water level ranging from 0-2 m and 33 % wells shows a rise within 0-2m.

6.2.3 Uttarakhand

Depth to water level is monitored from the Ground Water Monitoring Stations located in alluvial areas of river valleys and piedmont areas of the districts of Dehradun, Haridwar, Udham Singh Nagar and Nainital. During pre-monsoon, the depth to water level ranges from 2-5 mbgl and 5-10 mbgl. However, deeper water levels within 10-20 mbgl are also recorded constituting 27 % of the total number of wells. The post-monsoon analysis reveals an increase in water level in 26 % wells within 0-2 mbgl where this percentage was only 2 % during pre-monsoon. A comparison of water level of May 2012 with mean water level for the period of May 2002-2011, shows a fall in 72% wells mostly in the range of 0-2m.

6.2.4 West Bengal & Sikkim

Ground water level monitoring is being done from the Ground Water Monitoring Stations located in alluvial areas of Darjeeling district. There is no monitoring station in Sikkim as the State is in hilly tract. During pre-monsoon period, depth to water level in major parts lies in the range of 2-5 (53%) & 5-10 (33%) mbgl. Deeper water levels of 10 mbgl have been recorded in Siliguri area. During post-monsoon period, depth to water level lies in the range of 0-2 (40%) & 2-5 (40%) m bgl. Long term trend of water level of pre & post-monsoon for the period 1999-2009 shows no significant rise or fall, except at Siliguri area, where decline of water level to the tune of 30 cm/year has been observed.

6.2.5 Arunachal Pradesh

Since major part of the state is hilly, monitoring stations are located along the southern boundary. Depth to water level during the pre-monsoon period is generally within 5 mbgl with maximum at 10 mbgl. In the post monsoon period also the depth to water level has been found within 10m. At places, post-monsoon declining trend of water level has been found 20cm/year, but as a whole no significant decline has been observed.

6.3 Occurrence of Ground Water as springs

Springs are localised natural discharge of ground water issuing on the land surface through well-defined outlets. The discharge may vary from a trickle to a stream. If water merely oozes out on the surface without distinct outlets, the discharge is termed as a seep. Springs occur in many forms and have been classified based on cause of their formation, rock structure, lithological character of aquifers, discharge, temperature, and variability.

In Himalayan Region, ground water mainly manifests in the form of springs. The springs are formed mainly either along the fault or other structurally week zones. Springs formed along the major thrust/ fault zones yield higher discharge and are being developed for both domestic and irrigation purposes. Recently the discharge of the springs has started decreasing during peak summer and most of the minor springs go dry. In some of the areas, the spring lines are disappearing. This is being experienced in snow bound areas also. The reduction in discharge and longevity during the year may be attributed to degradation of forest cover, land erosion and retreating snow line. There is an urgent need to rehabilitate these sources of water supplies by adopting proper management practices for recharging.

The State wise details are as under:

6.3.1 Jammu & Kashmir

Discharge of the springs varies from one place to another depending on rock types.

In **Jammu Region**, the discharges of springs are given below:

- In alluvium: average discharge is 4-5 lpm
- In Siwaliks: average discharge is 1-3 lpm with higher discharges of the order of 20-30 lpm
- In Murrees: average discharge is <0.5 lpm with higher discharges of the order of 2-6 lpm in Kathua and Jammu region whereas in Rajauri & Poonch areas average discharge is 15 lpm with higher discharges of 200-500 lpm.

In **Kashmir region**, the discharges of springs are higher and details are given below:

- In Karewas: average discharge is 60-300 lpm with higher discharges of 600-1200 lpm.
- Dras Volcanics: average discharge is 120 lpm with higher discharges of the order of 300-400 lpm.
- Panjal Traps: average discharge is 200 lpm with higher discharges of the order of 500 lpm.

Kashmir valley abounds in numerous springs of which Verinag (source of the Jhelum), Martand (Anantnag), Achhabal (Anantnag), Kukarnag (Anantnag), Chashma Shahi (famous for its fresh and digestive water, situated near Srinagar on one side of the Boulevard road), need special mention.

In **Ladakh region**, the springs are found to occur in fractures and joints developed in various geological formations as well as in the contact of two rock units. However, most of the springs are fracture springs. A study carried out by CGWB on springs in parts of Leh district has revealed that the discharge of springs varies depending on the type of host rocks. The details of discharge of the springs of different host rocks are given in Table 6.6.

The temperature of spring water, in general, varies from 5^0 to 70^0C. As per Meinzer classification based on spring discharge, most of the springs are fourth, fifth and sixth order.

Table 6.6: Details of discharge of the springs in different formations in Ladakh Region

Sl. No.	Host Rock	Range of discharge of springs (lpm)	Average discharge of springs (lpm)
1.	Quaternary Alluvium	6-1296	354
2.	Indus Group	54-1575	595.2
3.	Ladakh Plutonic Complex	6-1800	493
4.	Puga Formation	12-2700	1356
5.	Volcanics	36-540	219.6
6.	Ultra Basics	1650-4500	3075

In Shyok and Nubra valley, springs are the prominent seepage zone which receive their recharge from glaciers located at higher altitude. These springs are present at the contact of valley fill deposits with the older formations and also along week zones, such as fractures, faults and thrust zones. These springs normally are being used for domestic as well as irrigation purposes. Hot water springs are located near Panamic and Changlum along the thrust zones. These springs yield about 9-20 lps having temperature about 95^0C at the source point which indicates that the ground water is oozing from the deep seated granite along thrust zone.

Geothermal Fields of Puga-Chhumathang, Jammu & Kashmir

Puga and Chhumathang geothermal fields are located at altitudes of 4000 and 4400 m in Ladakh district, Jammu & Kashmir. Thermal manifestations of Chhumathang and Puga geothermal fields have been observed in the form of geyser, hot springs and hot water pools along the Indus river and Puga nala respectively. Present day thermal spring deposits/fossil deposits are found as carbonate/travertine material. The area lies in the vicinity of Indian and Asian Plate suture zone where basic-ultrabasic volcanism took place in Upper Cretaceous age. Later, several phases of acid igneous activity took place in the Upper Cretaceous to Tertiary times during the Himalayan Orogeny. These magmatic bodies are considered to be the sources of heat at shallow level. In Puga Geothermal belt, the thermal manifestations are in the temperature range of 22°C to 84°C spread over an area of 4 sq km and the rock types are gneiss, quartz-biotite schist and garnetiferous schist of Puga Formation (Proterozoic age). Several Tertiary granites, quartz and pegmatite have intruded the above rock units. The Puga valley is filled up with glacial deposits.

A total of 35 shallow holes have been drilled by GSI in the Puga Valley to depths of 28.5 to 200.0 m. The hydrochemistry of Puga has indicated that the thermal water from springs and drill holes are neutral to alkaline. Water is mainly bicarbonate and NaCl-HCO_3 type. The Cl/B atomic ratio of springs and drill holes are constant 0.08 to 0.10, which indicates a common reservoir for springs and drill holes.

6.3.2 Himachal Pradesh

In Himachal Pradesh, major source of water supplies to rural and urban settlements are springs.

Table 6.7: District & formation wise discharge of springs in Himachal Pradesh

District	Formation	Discharge of spring during Pre-monsoon (in lpm)	Temperature (^{0}C)
Mandi	Sandstone	Seepage-7.50	17-22
	Quartzite	18.0	17-21
Kinnaur	Granite & Gneiss/ Augen Gneiss (Talus Materials)	1.0-600	10-46

	Phyllites, Quartzite & Slate (Talus Material)	Dry-30	14-48
Simla	Phyllite	Seepage-183	6-19
	Mica Schist	Seepage-60	5-19
	Shale	2	12-14
	Granite	4.30-40	9-20
	Quartzite	8-12	5-20
	Limestone	1.33-9	10-18
Sirmour	Slate/Phyllite/Limestone	Seepage-120	17-23
	Sandstone/ Slate/ Quartzite/ Boulders & Conglomerates	Seepage-36	13-25
	Granite Gneiss	0.6	12-16

These springs are formed mainly either along the fault or other structurally week zones in Granite Gneiss, Phyllites, Quartzite, Slates etc.. Discharge of these springs varies from seepages to 40 lps with maximum discharge of 600 lpm, specially along the major thrust/ fault zones and are being developed for both domestic and irrigation purposes depending on the discharge. The district & formation wise discharge of springs is given in Table 6.7

Geothermal Springs

Majority of thermal springs are located between the Main Central Thrust and Central Himalayan Axis. Important thermal springs in the Satluj valley, have temperatures ranging between 23° to 73° C (Jhakhri & Jeori), in Spiti valley between 23° to 59° C (Chuza and Sumdo), Parbati valley between 12° to 95° C (Manikaran) and in Beas valley between 30° to 57°C (Vashist and Kalath). Lukewarm thermal springs, generally occur along the outer margin of the Himalayas. These springs, are developed for domestic / irrigation and recreational purposes.

Spring in Sumdo area in Spiti valley has temperature of 46^{0}C and is rich in Sulphur with pungent smell. The saline nature of this hot spring is due to evaporite rocks associated with Lower Carboniferous Lipak formation.

6.3.3 Uttarakhand

Eighty five percent of the area of Uttarakhand State is mountainous. Himalayan watersheds harbour a wealth of water sources which are utilized by the inhabitants for various purposes. People live at the places where the mountain slopes are locally less. The rivers are the main source of water which is usually far away from the dwelling places of the local populace. Springs emerging on the slopes are developed to provide water to the inhabitants of mountainous terrain.

The springs are both hot and cold. The hot water springs are generally found in crystalline and are structurally controlled. About 25 hot springs are reported in the state. The temperature ranges

Table 6.8: District wise details of springs in Uttarakhand

Sl. No	District	No. of springs inventoried	Discharge range of spring in (LPM)		Geology	Range of Temp. (^{o}C)	Remarks
			Pre-monsoon	Post-monsoon			
1	Bageshwar		Jan-45	19-29	Quartzite, Schist, Granitic-Gneisses	15-28	

2	Rudraprayag	57	02-Dec	Mar-80	Quartzite, Schist, Granitic-Gneisses	17-24	
3	Tehri	60	0.70-150		Phyllites, Schist, CalcareousRock, Gneiss	21-24	
4	Pauri	200	Oct-30		Phyll.Slates , Quartz, Gr-Gneisses	Nov-23	
5	Champawat	13	02-Dec	Mar-15	Phyllites, Slates , Quartzite etc.		
6	Nainithal		Feb-36		Dolomatic-limestone, Volcanics,Quartzt, Phyll.	15-36	
7	Dehradun	13	1.10-122		Calcareous rock, Boulder bed etc.	—	Generally higher discharge found in Cal-rocks.
8	Pithoragarh	145	2-210		Qrtzt,Gr-gneisses, slates, volcanics , Calc-rocks	16-22	Generally higher discharge found in Cal-rocks.
9	Almora	106	6-900		Qrtzt,Gr-gneisses, slates, volcanics , Calc-rocks	Dec-32	Generally higher discharge found in Cal-rocks.
10	Chamoli	91	1-300		Qrtzt,Gr-gneisses, slates, volcanics , Calc-rocks	Sep-22	Temp. of hot springs-50-65 ^{0}C
11	Uttarkashi		2-216	5-232	Qrtzt,Gr-gneisses, slates, Phyll, Calc-rocks	25	Temp. of hot springs 64 ^{0}C

Table 6.9: Status of spring based Rural Drinking Water Supply Schemes in Uttarakhand

District	Total schemes	Functional	Percentage	Partially Functional	Percentage	Defunct	Percentage
Udham Singh Nagar and Nainital	325	109	33.54	152	46.77	64	19.69
Almora and Bageshwar	1333	608	45.61	368	27.60	357	26.78
Pithoragarh and Champawat	1097	779	71.01	201	18.32	117	10.67
Dehradun	284	239	84.15	14	4.93	31	10.92
Pauri Garhwal	852	447	52.46	209	24.53	196	23.0
Chamoli and Rudraprayag	742	534	71.97	172	23.18	36	4.85
Tehri Garhwal	736	603	81.93	88	11.96	45	6.11
Uttarkashi	431	392	90.95	28	6.5	11	2.55
Total	5804	3711		1232		861	
Percentage	100	64		21		15	

between 32^{0}C and 90^{0}C. The discharge of the springs ranges from 1 to 10 lps. Out of 600 cold springs, 330 are located in crystallines, 180 in quartzites, 50 in shales/slates and 40 in carbonate rocks. The discharge of cold springs ranges from <1 lps to 30 lps. District wise details of the springs, as per studies undertaken by CGWB, are given in Table 6.8 & Table 6.9

State Government has developed about 5804 springs to supply water, out of which only 3711 (64%) are functional (Table 6.11). The number of partially functional and dried up springs are 1232 (21.22%) and 861 (14.83%). The partially functional schemes are not due to broken supply line or any mechanical failure but due to the declining discharge of the springs. The number of defunct schemes is on the rise since human activities are going on thoughtlessly in the Himalayas.

6.3.4 West Bengal - Sikkim

Gravity springs, depression springs, contact springs are common in Sikkim and Darjeeling area. Fracture springs are also encountered in the crystalline metamorphics represented by Daling Formation & Darjeeling gneiss.

In hilly area of Darjeeling district of West Bengal, ground water abstraction structures are not feasible and water supply is generally done through development of springs. Here number of springs is available, but the quantum of discharge of the springs fluctuates between wide ranges in different seasons. In Darjeeling town area, water supply from springs during lean and no-lean period is 3.24 MLD and 8.18 MLD respectively. In Kurseong Municipality area, springs are mainly perennial yielding 2.04 MLD during lean period. In Kalimpong Municipality area, 2.27 MLD water is being supplied from springs during lean period which caters about half the present demand of water during lean period. In Mirik Municipality area, water supply to the tune of 0.35 MLD is being catered from springs to the present residential population and about 0.225 MLD is used for water supply to the tourist population during lean period.

In Sikkim, existing 1361 perennial springs cater to the drinking water needs, which are categorised as Critical, Semicritical and Normal depending on the distance of source and the number of beneficiaries.

The occurrence of springs and discharge of the springs varies with the formation and altitude and the average discharge of the springs varies to the tune of 1-150 lpm during lean period with maximum discharge of 1800 lpm during monsoon. Formation and altitude wise discharge of the springs are given Table 6.10.

Table 6.10: Formation wise discharges of springs in Sikkim

Formation	Altitude (mamsl)	Discharge (lpm)
Darjeeling Granite gneiss	500-1000	3-100
Darjeeling mica schist	1000-1500	2-60
	1500-2000	1-60
	2000-2500	3-30
Daling Phyllite, Quartzite	300-500	4-24
	500-1000	1-180
	1000-1500	1-120
	1500-2000	1-1800
	2000-2500	15-1800
Buxas Phyllite, Dolomite, Quartzite	500-1000	1-120
Gondwanas including pebbly horizon	1000-1500	1-100
	1500-2000	1-8

The springs discharge fall in fourth to seventh category of Meinzer. However, during rainy season the spring discharge is elevated to first to fifth category.

Geothermal springs

Sikkim has many hot springs known for their medicinal value. The most important are those located at Reshi, Yumthang and Ralang. Water of these springs has medicinal value as it contains sulphur and can cure a few skin diseases.

6.3.5 Arunachal Pradesh

Since the area has varied geology and geomorphic set up and is endowed with copious annual rainfall and snow capped areas, consequently potential springs are formed having various modes of origin (Fig. 6.13). The discharge of the springs during pre-monsoon varies from <5 m^3/day to >10 m^3/day. Springs in the state are both perennial and ephemeral in nature. All the springs are fractures and joints oriented. In general, discharges of the springs are meagre in high altitudes, which progressively increase down slope. Chemical analysis data of the springs have revealed that the springs yield very good quality water, which can be utilized for all purposes. The chemical data indicates that the spring water belongs to Ca-Mg-HCO_3 type and is of recent origin. Hilly people, especially in rural areas, feel at ease with spring water usage while the Arunachal Pradesh Public Health Engineering Department (PHED) also promotes water supply from spring sources through gravity drainage, as it involves no power consumption.

The discharge of springs in gneissic rocks was found to be 32 to 64m^3/day in Kurung Kumey district. In the schistose rocks, the discharge was found to be 14 to 17m^3/day and in quartzites, 10 to 43m^3/day. The discharge of the main water supplying springs in Upper Subansiri district varies from 10.29 m^3/d to 34.60 m^3/d. The springs reported to emanate through the weathered horizon have been observed to yield high discharge than those oozing through fractures. Spring discharge in gneissic rocks was found to be more due to presence of more fractures and joints. However, perennial springs flow throughout the year but their yields decreases during dry season (March to April). In Papum Pare district, the meta-sediments of Paleo-Proterozoic age and Lower Gondwana Group of rocks are intensely folded, fractured and jointed. Ground water emerges out in the form of springs along the fractures at lower points. The springs dry up during lean period and during post monsoon period yield discharge ranging from 9 to more than 78 m^3/d. Construction of large diameter dug well in weathered zone in selected sites is feasible. In East Siang district, the discharge of the springs issuing from consolidated formation varies from 15 to 28m^3/day.

The Tidding suture is made up of basic volcanics, schists, foliated quartzites and crystalline marble. The NW-SE trending Lohit Plutonic Complex is made up of diorite, tonalite, granodiorite, hornblende granite, pegmatites, gneiss, schist, marble bands. In the vicinity of the thrust zone, the rocks are highly sheared, strongly foliated, highly jointed and fractured. Ground water in this unit occurs under water table and semi confined to confined condition and is manifested in the form of springs with discharge varying from 14-112 m^3/day. The movement of ground water is towards areas of lesser altitude and makes conduit through interconnected secondary or planar porosity features like fractures and fissures.

Study on spring hydrogeology in Papum Pare district has shown that in general most of the springs oozing out at the contact of the Siwalik Group and Older Alluvium can be classified as stratigraphic or contact spring. Contact springs are also observed in the northern part of the district, i.e., near

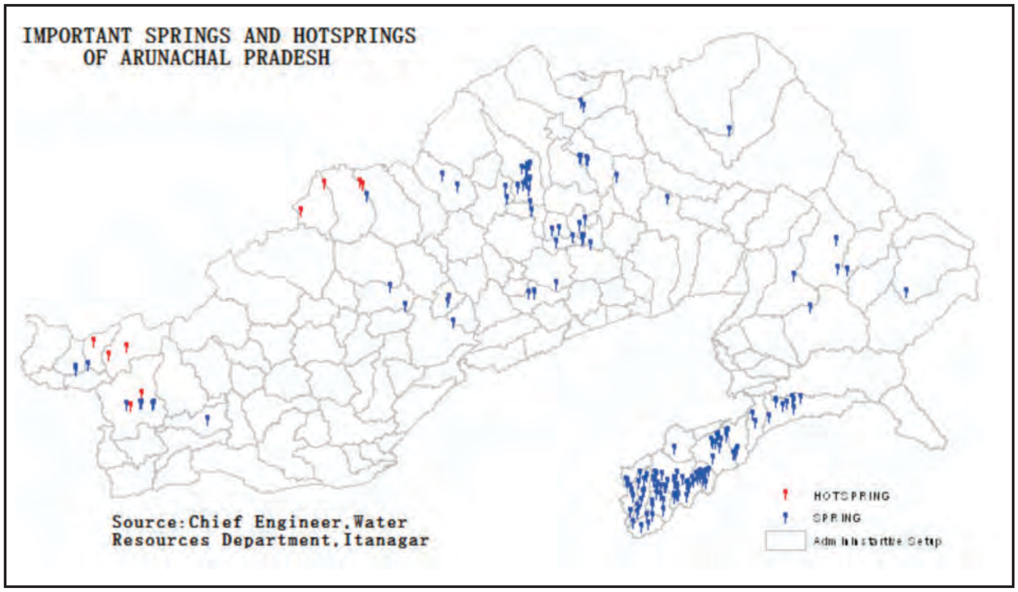


Fig 6.13 Important springs in Arunachal Pradesh

Sagalee where granite/granite gneiss underlain the Older Alluvium. A few fracture springs are also observed in the Siwalik Group and in the

fractured Precambrian Bomdila Group near Kimin. Spring near Gumtu can be classified as topographic in nature.

As per the yield classification of Meinzer, the springs of Arunachal Himalaya could be classified under each first to eighth class. However, the yield of the springs are mostly considered during the lean period otherwise the same class of springs as mentioned above may yield very high during the rainy season.

During a case study in Papum Pare district, it was found that out of 60 inventoried springs, 40 are perennial with discharge varying from 406.74 to 1,68,804 LPD. The discharge vs. precipitation graphs of the springs indicate that spring discharge is entirely dependent on precipitation. It was observed that although spring water is extensively used in the district, users do not take adequate measures to tap and conserve the spring. Traditional practice of split bamboo channels still are in use to tap and convey water up to the village/hamlet for drinking purpose. Spring box construction practices are negligible. However, in a few areas, spring water is collected in reservoir and water supply to the household is achieved through gravity. Another practice observed in Naharlagun area is that the earlier spring source along the bank of Pachin River and the foothill area near the Pachin River is tapped by construction of dug wells. During monsoon some of the perennial springs are covered with the debris of landslide.

From the study it has been observed that the perennial springs of Papum Pare district can cater drinking water to a considerable population. If the present norms of 40 litre per day water per person is taken into account, then with the present condition 8 perennial springs in the Itanagar-Naharlagun section can cater water to 3114 numbers of people, 4 perennial springs along Itanagar-Holangi section can cater water to 1701 numbers of people, in the Doimukh-Sagalee section of 24 perennial springs can cater water to 16,875 numbers of people, along Kimin-Lichi section 5 perennial springs can cater water to 4603 people and along Naharlagun-Yupia section one spring fed 3rd order stream can cater water to 2287 people. Although majority of the springs are rain-fed and this hilly district is blessed with copious precipitation, discharge of the springs is not prolific. Since the spring sources are not properly developed and maintained, the spring discharge is less compared to the surface run-off and during lean period spring discharge dwindles significantly.

6.4 Hydrogeology of North Eastern States Contiguous to Himalayan Area

In north-eastern part of India, contiguous to Himalayan area, ground water generally occurs in weathered residuum and fractures/ joints in consolidated formations which occupy Assam and Meghalaya plateau, Mikir hills and inselbergs in both banks of the River Brahmaputra and in porous formations comprising semi-consolidated formations of Tertiary rocks in all the north eastern states and unconsolidated formations of Quaternary age in the Brahmaputra & Barak valleys and some intermontane valleys (Plate – IV B). State wise description is given below:

6.4.1 Assam

The consolidated formations occupy mainly the Mikir Hills in Karbi-Anglong, Kamrup, Morigaon, Goalpara, Dhubri, Nagaon districts and consist of crystalline rocks of gneissic complex. The Precambrian gneisses, quartzites, schists and granites occupy the major part of Karbi Anglong district and parts of the districts of Kamrup, Morigaon, Goalpara, Dhubri, Nagaon as extension of Shillong plateau and as inselbergs in the alluvial plain. In consolidated formations, ground water occurs in weathered zone and can be extracted through large diameter dug wells of 5-15 m deep yielding about 8-10 m^3/day. The bore wells by tapping fracture/ joints within about 200 m bgl are also feasible at suitable sites and can yield within 5 lps. CGWB has constructed bore wells down to maximum depth of 91 mbgl. The yield of the bore wells varies from <1 to 3 lps for reasonable drawdown of 30 m.

The semi-consolidated formations belonging to Cenozoic Group comprise siltstone, claystone, grit, sandstone, shale and conglomerates. These are found in the Brahmaputra valley covering southern fringe of Dibrugarh, Tinsukia, Sibsagar, Jorhat, Golaghat and Dima Hasao (North Cachar Hills) districts as also in the southern part of Mikir Hills of Karbi Anglong district, where preponderance of clay with very thin bands of sandy clay is noticed down to the explored depth of 300 m. The area has restricted lenticular aquifers with low yield prospects (< 15 lps for higher drawdown).

The Barak valley of Cachar, Karimganj and Hailakandi districts is a synclinal valley. Here, semi-consolidated sandstone of Tipam Series forms the principal aquifers in the area. The sedimentation during this period was affected by numerous faults and as a result the granular sandy zones get affected and become discontinuous. The granular zones in Silchar valley are fine to medium grained, but in Hailakandi and Karimganj valleys towards west the sediments become relatively coarser. Five to seven major granular zones including potential shallow aquifers within 50 mbgl have been identified down to the drilled depths of 200-241 m. The cumulative thickness of granular zones varies from 85-120 m. The tube well in the area may yield 10-30 lps for high drawdown of upto 20 m or even more.

The Brahmaputra valley is underlain by unconsolidated formation of Quaternary age consisting of sands of various grades, gravels, pebbles, cobbles and boulders with thin intercalations of clay and silt. In northern bank of Brahmaputra river, the thick continuous alluvium having coarser fractions forms the productive aquifers and the bed rock has not even been encountered within the drilled depth of 300 mbgl in the western part of the State, except in close vicinity of inselbergs. The panel diagram showing disposition of aquifer materials in Brahmaputra valley is given in Fig.6.14. Fairly thick and regionally extensive aquifers down to the explored depth of 300 m have large yield prospect and a tube well tapping the aquifer may yield to the tune of 45 - 55 lps for drawdown within 8 m. The transmissivity ranges from 2000 m^2/day to more than 4000 m^2/day and permeability varies from 20 m/day to 60 m/day.

On the south bank of Brahmaputra river covering parts of Goalpara, Dhubri, Kamrup, Morigaon, Nagaon, Golaghat, Karbi Anglong, Jorhat, Sibsagar, Dibrugarh and Tinsukia districts, the granular zones are encountered at different depths. Coarser fractions are, in general, restricted in the flood plain areas and clays dominate over sand horizons in the vicinity of Shillong plateau, Mikir Hills and Naga-Patkai hills. The bed rock is generally encountered at depth of about 100 m. However, in the eastern part of the State, at places granular zones are found to occur even down to the depth of 200 m, but the thickness of granular zones encountered within 50 m depth constitutes over 50% of the total granular zones. Moderately thick (generally exceeds 50 m) aquifer has good yield prospects and tube wells may yield upto 150 m^3/hr for drawdown within 6 m.

Depth to Water Level:

In Assam there are 305 numbers of Ground Water Monitoring Stations (GWMS). The change in water level is monitored periodically four times a year, i.e. during March (pre-monsoon), August (peak monsoon), November (post monsoon) & January. Water samples are being collected once a year in the month of March for chemical analysis.

Analysis of water level data during March' 09 shows that the general depth to water level (DTW) lies in 2-5 mbgl (62%). Around 14% stations has recorded water level within 2 mbgl, mostly recorded in Barak valley of Cachar, Karimganj and Hailakandi districts. DTW in rest of the stations (23%) ranges between 5 & 10 mbgl , in the western part of the state adjacent to Bhutan (Bhabar-Terai belt) and in the inselberg areas of Karbi Anglong district, except at 3 stations water level rests in the range of 10-20 mbgl in the inselberg areas of Dhubri district.

Analysis of water level data during November' 09 shows that the depth to water level (DTW) lies within 5 mbgl in 90% of the stations, out of which in 36% of stations water level was recorded <2 mbgl. Water level in rest of the stations, most of which are located near the inselbergs, was recorded in the range of 5-10 mbgl. Shallow water level (within 2.00 mbgl) was observed in the Brahmaputra valley, mostly adjacent to the river, and iIn the Barak Valley of Cachar, Hailakandi and Karimganj districts.

Water level trends for the period 2000-09, as analysed, reveal that the significant decline is not observed anywhere in the State. Maximum stations show a rise or fall in water level in the range of 0 to 10 cm/yr. However, at isolated places of the districts of Kamrup, Darrang, Sibsagar, Lakhimpur, Karbi Anglong, decline of water level >20 cm/year has been observed.

6.4.2 Meghalaya

The Meghalaya Plateau is the northeastern extension of the Indian Peninsular shield. Ground water occurs in consolidated, semi-consolidated and unconsolidated formations deposited as the narrow belt in the western part of Garo Hills.

The consolidated formations comprise of Archaean Gneissic Complex, quartzites and phyllites of Shillong Group, acid and basic intrusives, sandstones and shales of Lower Gondwana rocks. These formations lack primary porosity and the movement and occurrence of ground water is controlled by secondary porosities like joints, faults, lineament etc. Groundwater occurs under confined condition in secondary pore spaces and in unconfined condition in the weathered residuum.

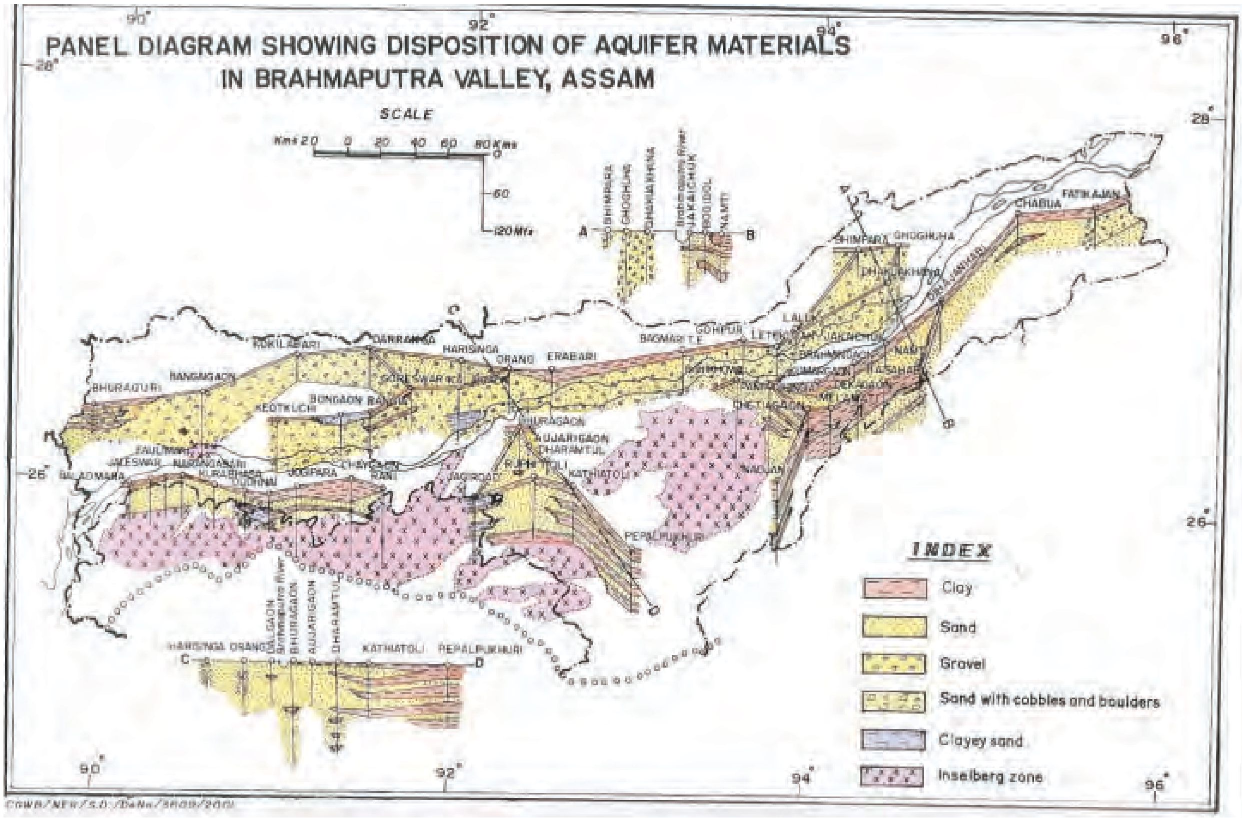


Fig. 6.14

The bore wells drilled down to depth of about 80 -150 m below ground level in this formation may yield a good discharge of <1 - 4 lps in Archaean and Shillong Group of rocks whereas the acid and basic counterparts have a discharge of 1-3 lps. The valley areas are found to be favourable for construction of dug wells and bore wells in other areas.

The semi-consolidated formations include limestones, sandstones and shales. Aquifers developed in limestone can be granular/ porous, fissure/fracture and conduit/ cavernous, which can be confined, unconfined or perched. Sandstones with limited porosity yield water through secondary fissures like joints.

The Khasi and Jaintia Group of rocks of Meghalaya comprise the semi-consolidated formations. Limestones of Jaintia hills are cavernous and hold good potential for ground water occurrence in comparison to Cherrapunjee area. This can be attributed to the local geomorphological conditions. Wells drilled in limestone terrain have yielded 5 lps with nominal draw down. Dupitala and Chengapara sandstones make excellent aquifers as wells drilled down to 250 m below ground level have a discharge of 45 lps and shallow tube wells of 50 m have a discharge of 7 lps. These areas are favourable for construction of shallow and deep tube wells.

The unconsolidated formations deposited in the western part of Garo Hills comprise alternating layers of coarse sand and clay, which are highly productive in nature. Productive aquifer of thickness ranging from 10-15 m occurs extensively in this area. Ground water development can be taken up through shallow tubewells in this area.

Exploration in all the districts was conducted and the district wise summarized results are given in Table 6.11.

Table 6.11. District-wise findings of Exploration conducted in Meghalaya State

District	Depth range (m bgl) explored	Findings of exploration
East Khasi Hills	60-240	Potential fractures are mainly encountered in gneisses and quartzites with intrusives of pegmatite and quartz veins. Cumulative thickness of fractures varies from 10 to 15 m. within 125 mbgl. Exploratory wells yielded <1 – 10 lps with drawdown ranging from 2 to 40 m. T is 7.26-86.87 m^2/d. Generally, poor yield is expected in cavernous limestone. The exploration in cavernous lime stone has shown that the yield is poor & water from the top zone gets seeped into the zones below and escapes without building piezometric head in the wells drilled. The result is that the water level is also observed at deeper levels.
West Khasi Hills	24-80	Exploration conducted in gneisses & quartzites shows that bore well by tapping fractures within 80 mbgl may yield to the tune of <1 – 3 lps with a maximum draw down of 15 m.
Jaintia Hills	74-120	Exploration in quartzite, limestone, shale having secondary porosities reveals that 4 to 5 sets of fractures exist within the depth range of 85 m bgl. The exploratory wells yielded <1 – 5 lps with drawdown from 8.1 to 39.55 m. Transmissivity is in the range of 1.0 to 3.65 m^2/d.,
East Garo Hills	14-214	Exploration conducted in granite gneiss showed low yield. Potential fractures may be obtained in quartzite & intrusives.
West Garo Hills	37-300	Exploration conducted in hard rock as well as alluvium. In Alluvium, prominent aquifer zones encountered within 263 mbgl. The wells, constructed within this depth, yielded to the tune of 5 – 45 lps with drawdown ranging from 2.4 to 19 m. Transmissivity value varies from 15-1595 m^2/d.· Water bearing fractures have been identified in granite gneiss down to the drilled depth of 85 m. Bore hole tapping the fractures yielded to the tune of 1 – 5 lps with drawdown ranging from 1.5-12 m. T value ranges between 5 and 20 m^2/d.
South Garo Hills	Maximum depth explored 142 m bgl	Exploration down to 142 mbgl in Quaternary alluvium and Tertiary sediments reveals presence of moderately potential aquifers within 138 mbgl and tube wells yielded to the tune of 8 – 15 lps with drawdown of about 9 m. T value is around 60 m^2/d.
Ri-Bhoi	124-204	Exploration in granite gneiss delineated highly potential fractures in the depth span of 30-180 mbgl. Bore wells, constructed by tapping the fractures, yielded 3 – 10 lps (& as high as 18 lps) with drawdown about 6-20 m. T value varies from 3-29 m^2/d. Free flow wells encountered in Barapani area.

At present, in Meghalaya, ground water is generally extracted through dug wells (or seepage wells in valley areas/topographic depressions) and bore wells. Apart from this, tubewells are in use in West Garo Hills district. Dug wells are generally shallow in depth varying from a meter to 6 mbgl. Bore wells are drilled up to 200 mbgl. However, the majority of them are shallow in the depth range of 40 to 80 mbgl.

Depth to Water Level:

In Meghalaya, there are about 36 Ground Water Monitoring Stations (GWMS). The change in water level is monitored periodically four times a year, i.e. during 1st to 10th January, 20th to 30th April (pre-monsoon), 20th to 30th August (peak monsoon) and 1st to 10th November (post monsoon). Water sample are being collected once a year in the month of April for both Partial and Iron analysis.

Analysis of water level data during March' 10, collected from valley parts of the state, indicates that depth to water levels lie between 0.80 and 8.06 m bgl. Water level in most of the areas lies within 5 mbgl. Water level measured from only14% stations was recorded between 5 to 10 mbgl. Around 61% stations mostly covering East & West Garo Hills districts and in pockets in Ri-bhoi and Jaintia Hills districts, show depth to water levels between 2 to 5 m bgl.

Water level trends for the period 2000-09, as analysed, reveal that most of the rising and declining trend has been restricted below 10cm/year. Decline in the range of 10 to 1 cm/year is only found in 4 stations of South Garo Hills & West Garo Hills districts.

Occurrence of ground water as springs:

Springs play a major role in managing the water resources of Meghalaya. They serve as a major source of water supply for drinking water and other uses. Spring discharge is controlled by rainfall, land use, vegetation, and geomorphology of the recharge zone. Geologically, the springs monitored in the area are of gravity type.

Springs in Shillong area:

Spring plays a major role for the water requirement of the people in Shillong. The discharge of springs in dry period (Jan-Mar) varies from 8100 lpd (at Laban) to 51,840 lpd (at Umkdait) and in wet period (Nov-Dec) from 11293 lpd (at Mawpat) to 187488 lpd (at Umkdait). The summarized details of discharge of the springs monitored are given in **Table 6.12.**

Table 6.12: SUMMARISED DETAILS OF SPRINGS IN SHILLONG

Sl. .No.	Village/ Area	Discharge (LPD)			Population covered for water supply (approximate)
		May-Jun-04	Nov-Dec-04	Jan-Mar-05	
1	Nongthymmai	32400	39877	28780	110
2	Mawlai	74057	51840	32400	250
3	Umkdait	106272	187488	51840	350
4	Mawpat	17280	11293	8640	60
5	Lengkarding	129600	31708	23563	110
6	Pynther	77760	151200	32400	260
7	Madanrting	86400	64800	28800	100
8	Lawsep (Pohkseh)	46656	49989	23563	160
9	Laban	28880	11520	8100	30

Springs in Ri-Bhoi district:

The study of springs in Ri-Bhoi district shows that the location of the springs is mainly restricted to foothills and intermontane valleys. 26 springs in the district have been studied to ascertain the characteristics and type of springs. It has been observed that the discharge of springs is mostly within 25,000 lpd during both pre and post monsoon season. The highest discharge has been recorded as 100800 lpd during post-monsoon period in Mawlasnai. The summarized details of discharge of the springs monitored are given in **Table 6.13.**

Table 6.13: SUMMARISED DETAILS OF SPRINGS IN RI-BHOI DISTRICT

Sl. No.	Village	Discharge (Litres Per Day)			Population covered for water supply (approximate)
		May 06 - June 06	Nov 06 – Dec 06	Feb 07 - March 07	
1	Barapani	11275	17280	19929	40
2	Laban Saro	8640	14400	10368	30
3	Bhoilymbong	25920	51840	32400	90
4	Umpowin	37022	12960	51840	120
5	Mawlasnai	86400	100800	86400	200
6	Umsning-I	15235	28800	18504	50
7	Nongiri	5184	10368	7401	20
8	Tadoh Umsiang	2347	86400	37022	10
9	Mawdiengngang	10368	25920	17280	40
10	Mawhati	50400	86400	14400	150
11	Sonidan	19929	12960	5760	70
12	Mawlaho-I	8092	18504	8640	30
13	Mawlaho-II	2592	5184	2160	10
14	Umlapar	10368	8640	5760	40
15	Iewmawlong	9604	17280	7401	30
16	Margar	5400	32400	6408	20
17	Mawlong	2721	3700	2592	10
18	Umran dairy	3801	64800	6019	20
19	Umsning-II	9244	17280	16368	30
20	Sumer	7401	9604	11772	25
21	Mawlendep-I	21600	25920	21600	70
22	Mawlendep-II	19920	32400	20160	70
23	Patharkammah-II	12960	7401	7848	40
24	New Jirang	86400	14400	12960	200
25	Umling	21600	23040	DRY	20
26	Umeit	8640	11520	9964	30

Chemical analysis of water samples shows that the spring water is of excellent quality and is suitable for drinking purposes as per BIS standard.

6.4.3 Nagaland

Hydrogeological condition of the State is mainly controlled by two distinct formations – semi-consolidated & unconsolidated formations. Consolidated formations comprising of metamorphic, metasedimentaries, ultrabasic and basic rocks occupy the south-eastern border with very less extent.

The semi-consolidated rocks belong to Tertiary age ranging from Eocene to Pleistocene. The Lower Tertiary formation is confined to south-central part and occupies moderate to high hills and adjoining narrow valleys along the strike direction of hills. These form run-off zone and infiltration to ground water is low to moderate. The Upper Tertiary group of rocks, i.e. Surma, Tipam & Dihing Groups, are exposed mainly in the northern part of the State and form low to moderate altitude hill ranges with structural valleys following the strike of the hill. The rocks are less consolidated than the Lower Tertiaries. This zone is also basically a run-off zone with moderate to low infiltration. The formations have moderate potential and can sustain deep tubewells having yield prospects varying from 2.8 to 5.55 lps. The valleys underlain by Tipam sandstones form good aquifers with yield prospects varying from 8.33 to 22 lps.

The structural valleys comprise unconsolidated sediments with variable thickness which show moderate to high infiltration, less run-off and recharge condition. The valleys with considerable extent are Dimapur, Ghaspani-Jalukie, Baghti, Disoi, Longnak, Naginimora, Tiru and Tizit in the districts of Dimapur, Peren, Kohima, Mokokchung and Mon respectively. The total valley area is 22.75% of the total State area. The valley formations are seen mainly in the north of Disang thrust zone and are aligned almost parallel to strike of structural hills formed due to prevalent effect of Schuppen zone. Ground water development potentiality in valley fills and alluvial deposits are restricted to construction of open wells having depth of 15 to 20 metres and deep tubewells down to 100 m depth which can give yield ranging from 10 m^3/day to 45 m^3/day with more than 5 m drawdown. Autoflow zones have also been identified in some parts of the state. Exploration carried out by CGWB infers that yield potential of deep tubewells in the valley fill and alluvial formations ranges from <1 to 17 lps for considerable drawdown. The transmissivity ranges from 9 m^2/day to more than 300 m^2/day and permeability varies from 0.4 m/day to 5 m/day.

In the hilly areas, ground water emerges as perennial springs at different contour levels. The springs are the main source of water supply for domestic needs in the state. The springs are found to develop in 1st and 2nd order streams. High discharge springs are also common.

Depth to water level

Under Ground water regime monitoring studies, CGWB and Directorate of Geology and Mining Department, Govt. of Nagaland, has established 19 monitoring stations in valley areas of five districts of Nagaland.

The pre-monsoon water level in the shallow zones in Dimapur valley ranges from 1.86-10.25 mbgl and the piezometric level varies from 5.20-19.09 mbgl. In Kohima, depth to water level ranges between 4.41 & 7.22 mbgl. In Workha, it varies from 3.08-6.87 mbgl.

During post-monsoon, the depth to water level in Dimapur, in general, varies from 1.75-5.70 mbgl and the piezometric level ranges between 4.49 & 17.92 mbgl.

6.4.4 Manipur

Ground water is restricted to secondary porosity in joints, fissures, fractures and weathered residuum of consolidated and semi-consolidated rocks and inter-granular pore spaces of alluvial deposit.

Hydrogeological studies in Central Manipur valley showed that the area is underlain by superficial thickness of alluvial deposit which is largely clayey in nature, underlain by rocks of Tertiary age mainly Barail Group of rocks. Sandy and silty clay forms the principal water bearing formations in the upper stratum, i.e. the zone where open wells are constructed. The open wells have very poor yield. In the deeper zones, soft sandstones of Tertiary age are encountered where ground water occurs under confined conditions.

Exploration carried out by CGWB indicates that in Imphal valley, aquifer thickness ranges from 10 to 20 m where the peizometric head varies from 2.50 to 4.30 m below ground level. The transmissivity of the aquifer formation ranges from 4.3 to 89 m^2/day and hydraulic conductivity from 0.67 to 16 m/day respectively. The discharges of tube wells constructed are about 2.8 to 8.33 lps at 10 to 15 m drawdown.

6.4.5 Mizoram

Hydrogeologically, the various rock types found in Mizoram can be grouped into two categories i.e. semi-consolidated formations and unconsolidated formations. The unconsolidated formations with limited alluvial thickness are restricted along streams and rivers. Semi-consolidated formations have developed secondary porosity due to tectonic disturbances. As the state is entirely occupied by hills with slopes mostly more than 20%, most of the rainwater flows out as surface runoff. In this type of terrain, the scope for ground water storage is limited to mostly secondary porosity and structural controls in the higher elevation aquifers. Ground water is confined only to valley fill areas. Ground water stored in the hill slopes emanates in the form of springs, which are being used as a source for water supply.

Ground water exploration carried out by CGWB indicates that yield potential of deep tubewells within the depth range of 200 m tapping Tertiary sandstone ranges from 2 to 5.5 lps for drawdown of 13 to 20 m.

It was found that only springs are easily accessible source for water. A large number of springs are noticed which are found al all places and altitudes. But discharge varies from place to place. Maximum discharge in post monsoon period was found to be 80 m^3/day. Springs have been found in good numbers having enough discharge in Sairang-Kawnpui Road.

Ground Water Level Conditions:

As on date, there is no hydrograph monitoring well in the State due to non availability of representative dug wells. Ground Water Management Studies, carried out so far, indicate that depth to water level varies widely from hilly areas to plain areas.

6.4.6 Tripura

The semi-consolidated Tertiary formations form the main hydrogeological units in the State. Other small deposits of alluvial formations of Recent age also constitute local hydrogeological units along major river courses. Ground water occurs in semi-consolidated formations of Tipam and Dupitila Groups and in unconsolidated formation of Recent alluvium.

The Tipam Group of rocks are mainly soft, massive and friable sandstones and alternate layers of shales and are exposed throughout the State along the outer flanks of anticlinal hills with moderate dips and also occupy the synclinal valleys. Tipam sandstones (about 400 m thick) form the principal and only productive aquifer system in the State.

The formations belonging to Dupitila Group are mainly clay and silt with some thin intercalations of gritty and ferruginous sandstones. The thickness of this group is limited to 10-30 m and is prominent in the western portion of the State. The storage capacity and the permeability of the formations are very low due to the occurrence of clay layers.

There are five broad longitudinal valleys namely : i) Agartala-Udaipur-Sabroom, ii) Khowai-Teliamura-Amarpur, iii) Kamalpur-Ambassa-Gondacherra, iv) Kailasahar-Kumarghat-Chawmanu and v) Dharmanagar-Panisagar-Kanchanpur valleys, located between N-S trending parallel to sub-parallel antiformal hill ranges. Hydrogeological surveys, aided by exploratory drilling and deposit well programmes carried out by Central Ground Water Board so far have revealed that there are 3 to 4 major aquifers within 250 m depth in the synclinal valleys of the State. The thickness of the aquifers and its potentiality vary from valley to valley and decrease considerably in the northern valleys of the state, namely, Kamalpur, Kailasahar & Dharmanagar valleys. The sub-surface configuration in Kamalpur-Ambassa-Gondacherra valley reveals high variation in the lithofacies laterally as well as vertically (Fig. 6.15). Clay is dominating in northern portion as compared to southern part of the valley. There are 4 granular zones down to the depth of 300 mbgl occurring at the depths of (i) 5-30 mbgl, (ii) 50-65 mbgl, (iii) 80-120 mbgl and (iv) 130-240 mbgl. The third and fourth aquifers are confined and exhibit artesian condition around Abhanga and Ambassa. In western part of the State, the aquifers are of good potential in comparison to northeastern parts.

Ground water occurs under unconfined condition in Dupitila formation, Recent formation & in Tipam formation. Besides it also occur under confined to semi-confined conditions in Tipam formation at considerable depth. Recharge areas for the deeper aquifer lies in the adjacent anticlinal hills.

On the basis of drilling, the aquifer zones down to the explored depth of 250m, can be divided into two groups, viz., (1) a shallow aquifer zone within 40m depth from surface & (2) a deeper aquifer zone below 40m depth. The study of sub-surface geology through lithological logs has revealed that- the aquifers are discontinuous in nature even within the same valley. Exploration in the state has established that the deep tube wells, constructed down to 150-250 m depth in the central part of the valley, may yield to the tune of 22 to 42 lps with drawdown ranging from 15-20 m. The yield decreases and the drawdown increases in the tube wells towards the foothill zone. The transmissibility of the aquifers in the central part of the valleys varies from 500-1500 m^2/day, whereas the same ranges from 57-90 m^2/day in foot hill zones. The storage co-efficient ranges from 2.25 X 10^5 to 2.20 X 10^{-3} showing confined nature of the aquifer.

The artesian flowing conditions have been found to occur in the valleys. In fact, the geology as well as geomorphology of the State is favourable for such artesian conditions within synclinal valleys. The artesian flowing conditions occur in patches both at shallow depth and at deeper depth. The auto discharge of the flowing wells in the State ranges from <1 to 1.66 lps. The maximum auto discharge from deep tube well to the extent of 15 lps has been found in Khowai valley near Khowai town, where the piezometric head rose up to 7m above ground level.

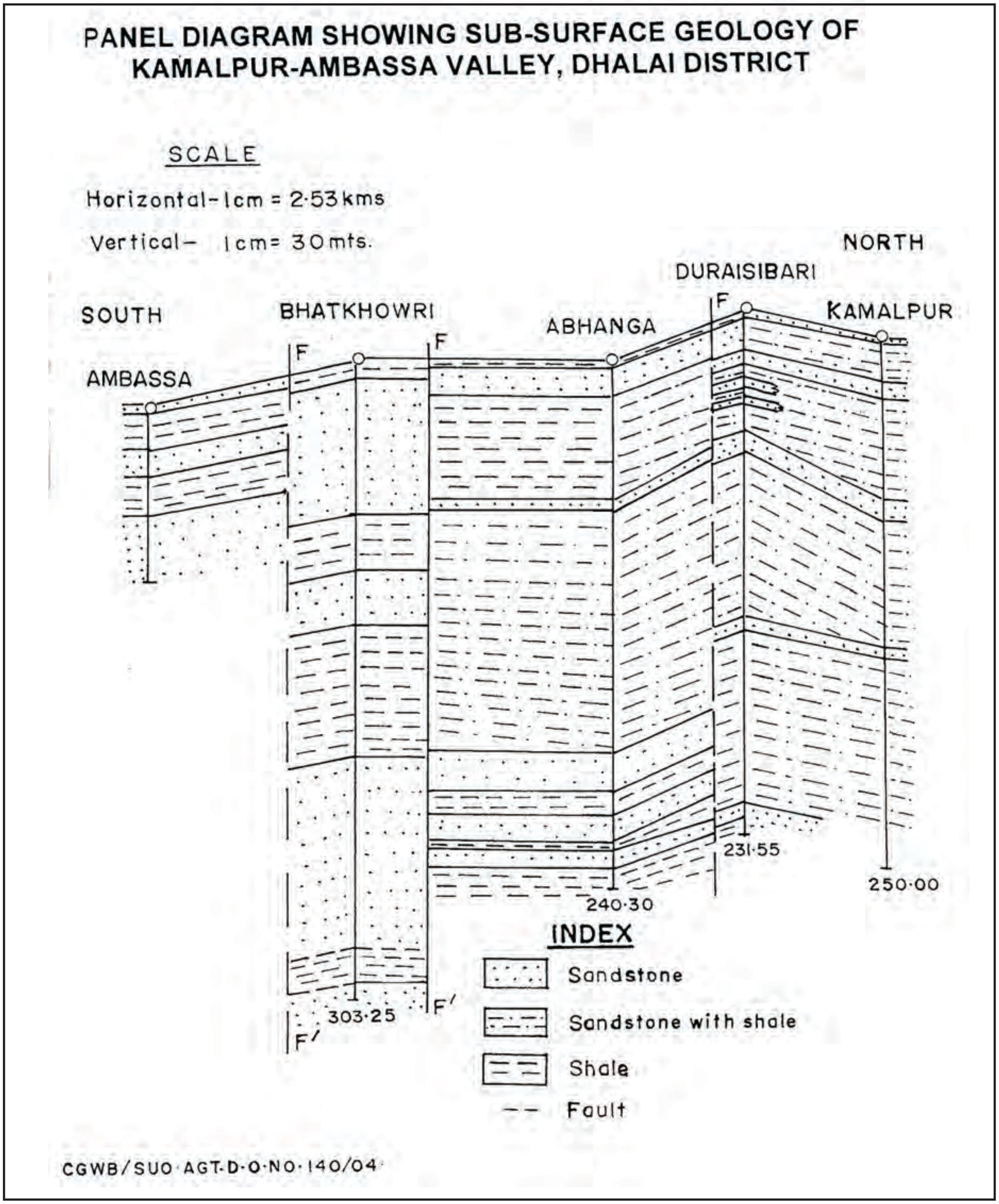


Fig. 6.15

Ground water level conditions

Ground water regime of Tripura is being monitored through a network of 44 permanent observation stations (GWMS) four times in a year. The depth to water level during pre-monsoon period generally lies between 1.45 to 7.99m bgl and during post-monsoon period depth to water level lies between 1.02 to 5.63 m bgl. The fluctuation of water level varies between 0.17 to 4.58 m. The analysis of long-term water level trend (both pre-monsoon and post-monsoon period) of ground water monitoring stations indicates that there is no significant falling trend of water level in the state so far.

7.0 HYDROCHEMISTRY

Monitoring of water quality is an important exercise for establishing its suitability for various purposes like domestic, agricultural and industrial use and also for deciphering the water quality trends in space and time. Analysis of hydrochemical data also helps in evaluating the nature and extent of pollution, if any, and to ascertain the effectiveness of pollution control measures.

The general characteristics of ground water in Himalayan region of India indicating the desirable and permissible limits as prescribed by BIS are given in Table 7.1.

Table 7.1 Chemical Quality of Ground Water in Himalayas

Sl. No	Chemical Constituents	Jammu and Kashmir Himalaya	Himachal Himalaya	Uttarakhand Himalaya	Sikkim-Darjeeling Himalaya	Arunachal Himalaya	BIS (BIS, IS: 10500, 2003	
							Highest desirable level	Max. Permissible limit
1	pH	6.9-8.8	7.1-8.2	6.74-8.3	6.2-8	6.5-8.2	6.5	8.5
2	Electrical Conductivity (µS/cm at 25ºC	97-3220	120-1650	80-1090	21-410	12-1585	-	-
3	Total Hardnessas $CaCO_3$ (mg/l)	42-871	50-600	26-478	10-300	10-350	300	600
4	Calcium (mg/l)	12-144	12-180	8-68	1.6-62	0.10-5.6	75	200
5	Magnesium (mg/l)	2.6-193	2.40-60	1.2-55	0.61-24	Tr-2.63	30	100
6	Sodium (mg/l)	2-160	2.8-205	0.7-660	0.23-10	Tr-14.79	-	-
7	Potassium (mg/l)	2-215	0.6-88	0.1-106	Tr-7.8	Tr-1.38	-	-
8	Iron (mg/l)	0.1-17	NA	NA	Tr-20.7	ND	0.3	1.0
9	Bicarbonate (mg/l)	49-708	58-636	38-417	6.1-332	0.10-7.1	-	-
10	Chloride (mg/l)	4-273	3.6-142	3.5-217	1.4-16	0.11-4.9	250	1000
11	Sulphate (mg/l)	2-475	Tr-135	1.0-132	<1.0-3.75	ND	200	400
12	Nitrate (mg/l)	0.48-394	Tr-165	0.5-130	TR-7.2	<1	45	No relaxation
13	Fluoride (mg/l)	0.01-3.0	1-4	0.0-0.67	Tr-0.27	ND	1.0	1.5

ND: Not Detected

Tr: Traces

NA: Not analysed

The ranges of different chemical constituents in ground water are given in Plate Nos. V A, B, C, D and E.

The State wise chemical quality of ground water is as below:

7.1 JAMMU & KASHMIR

The study of ground water quality in the state of Jammu & Kashmir has indicated that concentration of various dissolved solids, specific conductance, chloride, nitrate, fluoride, iron and other water quality parameters are marginally higher in some isolated pockets. Ground water samples from the entire state were collected with the prescribed norms and analysed by adopting standard methods of analysis. The quality of ground water in three different regions viz. Jammu region, Kashmir region and Ladakh region is discussed hereunder.

Jammu Province

For evaluation of ground water quality of Jammu province a total of 534 ground water samples were collected. Out of which 210 and 126 samples belong to shallow and deeper aquifers respectively and remaining 198 were spring water samples. Minimum and Maximum values of water quality parameters are summarized in Table 7.2.

Table 7.2: General range of water quality parameters of Jammu Region

Sl. No.	Water Quality Parameters	Spring		Shallow aquifer		Deeper aquifer	
		Min	Max	Min	Max	Min	Max
1.	pH	6.80 Gandhir (Kathua)	8.25 Naili (Rajouri)	7.01 Wadala (Kathua)	9.30 Kalal (Rajouri)	6.50 Baguna (Jammu)	8.60 Dharmund (Doda)
2.	Electrical Conductivity µmhos/cm at 25°C	100 Shatani (Doda)	3100 Tatapani (Doda)	102 Dunga (Kathua)	3220 Suchetgarh (Jammu)	65 Parnala (Kathua)	1980 Kanga (Doda)
3.	Carbonate (mg/l)	00	Traces (Rapouri)	00	84 Kalal (Rajouri)	00	48 Barthal (Doda)
4.	Bicarbonate (mg/l)	43 Shatani (Doda)	628 Satinator (Doda)	84 Battle Ballia (Udhampur)	1049 Suchetgarh (Jammu)	07 Chak Sheikhan (Jammu)	1037 Kanga (Doda)
5.	Chloride(mg/l)	2.80 Thara (Poonch)	64 Jianganu (Udhampur)	3.5 Dharamshal (Rajouri)	440 Suchetgarh (Jammu)	3.5 Ircon (Doda)	220 Premnagar (Doda)
6.	Nitrate(mg/l)	Traces Balaspur (Udhampur)	80 Ramban (Doda)	Traces Takoli (Udhampur)	274 Gho brahamna (Jammu)	Traces Rakh Barthan (Jammu)	139 Premnagar (Doda)
7.	Fluoride(mg/l)	Traces (Rajouri)	3.00 Karol (Doda)	Traces Katra (Udhampur)	2.45 Kalal (Rajouri)	Traces Ramnagar (Udhampur)	1.90 Dhari (Udhampur)
8.	Sulphate(mg/l)	Traces Nal (Doda)	1350 Tata pani (Doda)	Traces Salan (Kathua)	330 suchetgarh (Jammu)	Traces Gagore (Jammu)	475 Magarkot (Doda)
9.	Calcium(mg/l)	08 Satinatar (Doda)	513 Tata pani (Doda)	01 Lalal (Rajouri)	160 Samba (Jammu)	3.6 Nagrota (Jammu)	166 Seri (Doda)
10.	Magnesium(mg/l)	Traces Meer (Udhampur)	69 Tanori (Udhampur)	1.7 Chowki handa (Rajouri)	150 Satinatar (Doda)	0.1 Choudh-arywala (Jammu)	90 Magerkot (Doda)
11.	Sodium(mg/l)	0.7 Bida–II (Udhampur)	70 Kermur (Udhampur)	0.5 Dharmasal (Rajouri)	305 Suchetgarh (Jammu)	0.7 Amram (Jammu)	490 Kanga (Doda)
12.	Potassium(mg/l)	Pathanag (Rajouri)	35 Monthal (Udhampur)	Banpari (Rajouri)	320 Suchetgarh (Jammu)	Choudh-arywala (Jammu)	15 Balaspur (Udhampur)
13.	Total Hardness as $CaCO_3$(mg/l)	50 Shatani (Doda)	1296 Tatapani (Doda)	20 Kalal (rajouri)	800 Suchetgarh (Jammu)	20 Dharmund-II (Doada)	700 Seri (Doda)
14.	Iron (mg/l)	Traces Bida–II (Udhampur)	1.70 Safa Pani (Doda)	Traces Tikrai (Udhampur)	17 Ramnagar (Udhampur)	Traces Shamoo chaprial (Jammu)	11 Kanthan (Udhampur)

From the above table, it is observed that higher **electrical conductivity** of ground water to the tune of 3100-3200 micromhos /cm at 25^{o}C are found in Suchet garh of Jammu district and Tatapani of Doda district.

Fluoride concentrations beyond the permissible limits are observed in spring water (maximum of 3.0 mg/l) of Doda district and in shallow aquifer (2.45 mg/l) of Rajouri district as well as in deeper aquifer (1.90 mg/l) of Udhampur district.

Nitrate Concentration is generally low, but high values are also reported in some of the samples collected from Doda, Jammu and Rajouri districts. Maximum concentration of Nitrate 274mg/l is reported in the water samples collected from Gho-Bramana of Jammu district (Fig. 7.1).

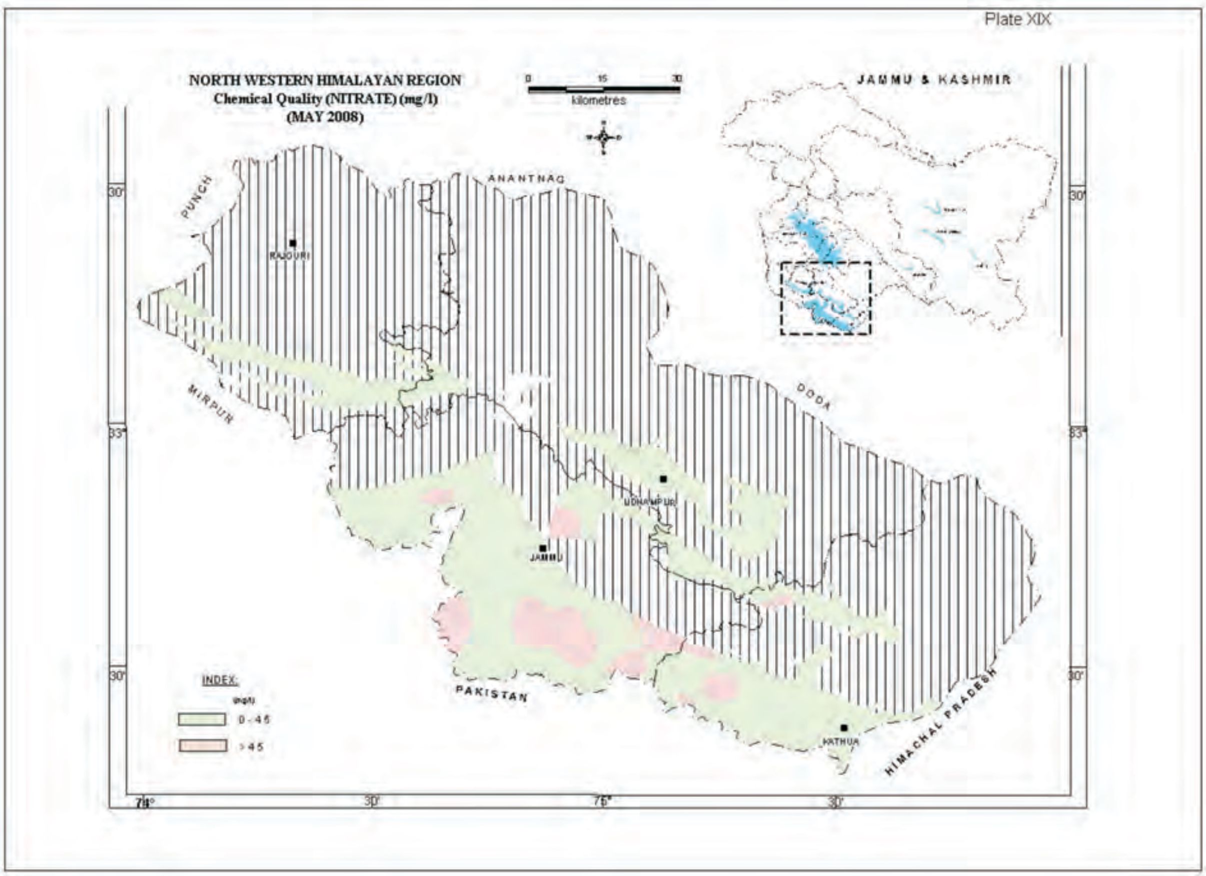


Fig. 7.1: Nitrate distribution in ground waters of Jammu region

Total Hardness values of Jammu region as per classification of Sawyer and M.C. Carty are depicted in Fig. 7.2. and presented in Table 7.3. It is observed that in case of spring water, majority of samples of Jammu region i.e. 51.0% falls under Very hard category. About 68.6% and 64.2% of samples collected from shallow and deeper aquifers respectively belong to Very hard category. Maximum concentrations of Total Hardness 1296 mg/l, 800 mg/l and 700 mg/l have been reported in water samples collected from Spring, shallow and deeper aquifers respectively.

Table 7.3: Hardness Classification of Ground Water from Jammu Province

Source Type	Soft 0-60 mg/l TH	Moderate Hard 61-120 mg/l TH	Hard 121-180 mg/l TH	Very Hard more than 180 mg/l TH
Spring	03(1.5%)	35(17.7%)	59(29.8%)	101(51.0%)
Shallow	02(0.9%)	19(9.1%)	45(21.4%)	144(68.6%)
Deeper	08(6.4%)	17(13.5%)	20(15.9%)	81(64.2%)

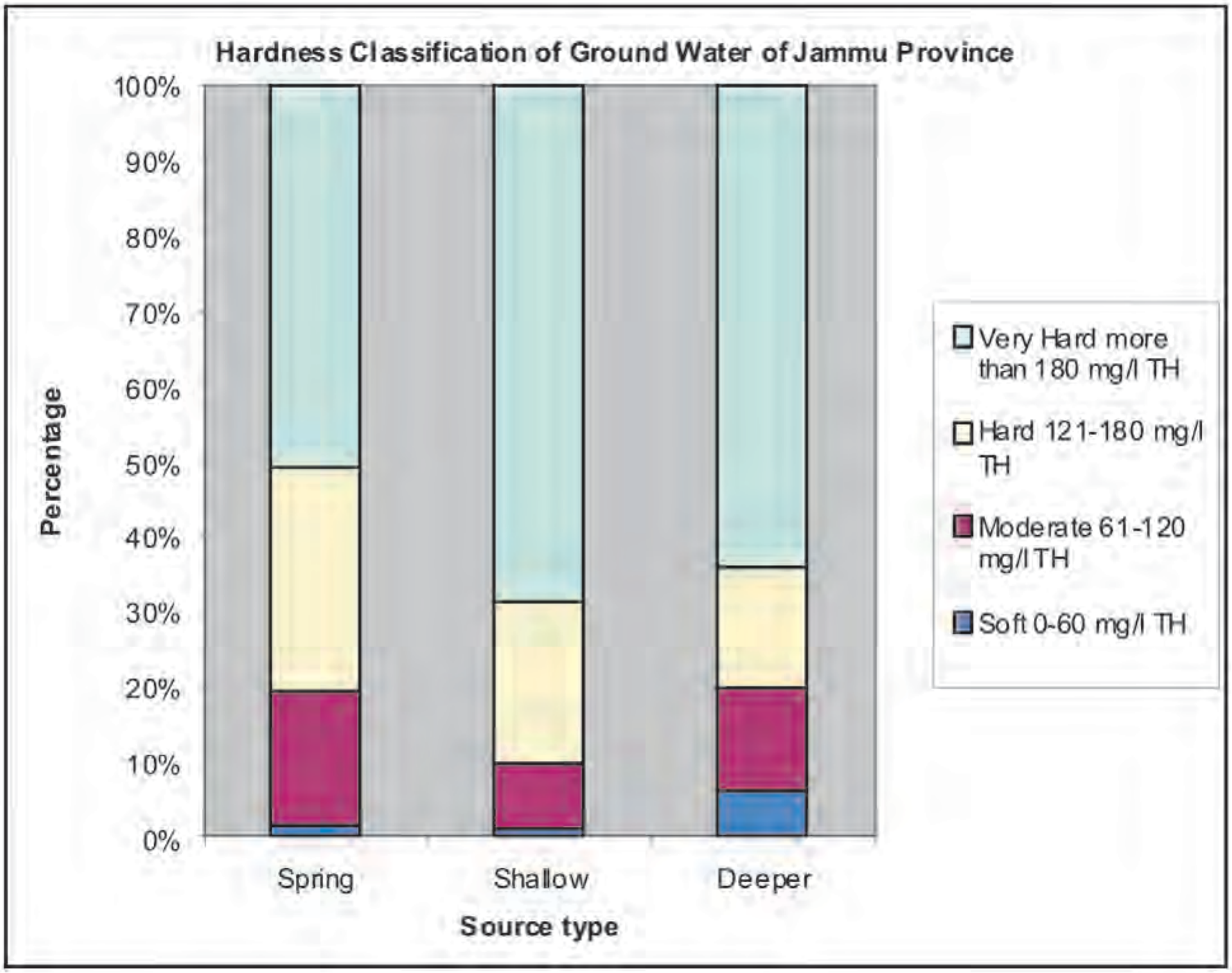


Fig. 7.2: Hardness Classification diagram of Jammu region

Higher concentration of **Iron** is found to occur in shallow as well as in deeper aquifers in the districts of Doda, Jammu, Udhampur and Kathua. The maximum concentration of 17 mg/l is determined in the water sample collected from the shallow ground aquifer in Ramnagar of Udhampur district.

Sulphate concentration is generally low in the area. It varies from Traces to 1350 mg/l in Tata pani (Hot spring) from Doda district. Sulphate concentration in shallow & deep aquifers is less, except in Jammu and Doda districts where maximum value of Sulphate is reported as 475 mg/l in deeper aquifer in Magarkot of Doda district and 330 mg/l in Suchet garh (Shallow Ground Water) from Jammu district.

Kashmir Region

For evaluation of ground water quality of Kashmir region, a total of 256 ground water samples were collected, out of which 114 and 60 samples were from shallow and deeper aquifers respectively and remaining 82 were spring water samples. Minimum and Maximum values of water quality parameters are summarized in Table 7.4.

Table 7.4: General range of water quality parameters of Kashmir Region

Sl. No.	Water Quality Parameters	Spring		Shallow aquifer		Deeper aquifer	
		Min	Max	Min	Max	Min	Max
1	pH	6.2 Asthal (Anantnag)	8.65 Ladu village (Pulwama)	6.9 Kangan (Pulwama)	8.80 Kadalbal (Pulwama)	7.00 Shippora (Budgam)	8.11 Sogam (Ananatnag)
2	Electrical Conductivity µmhos/cm at 25°C	89 Andarwan (Srinagar)	755 Safapora (Baramulla)	97 Udipora (Kupwara)	2800 Pampore (Pulwama)	202 Shera-Kashmir University (Srinagar)	1760 Sopore (Baramulla)
3	Carbonate (mg/l)	00 Dangerpore (Pulwama)	36 Ladu village (Pulwama)	00 Zewan (Pulwama)	30 Pampore (Pulwama)	00 Green colony Wuyan (Pulwama)	36 Mailngpore (Pulwama)
4	Bicarbonate (mg/l)	38 Chansornag (Ananatnag)	403 Safapora (Baramulla)	49 Udipora (Kupwara)	708 Gunderapher (Kupwara)	92 Jaubran (Pulwama)	1092 Sopore (Baramulla)
5	Chloride(mg/l)	2.8 Aripal (Ananatnag)	40.5 Asthal (Ananatnag)	04 Dholi pora (Baramulla)	291 Nowpore (Baramulla)	3.5 Jangalnar (Pulwama)	106 Hariniwas–II (Srinagar)
6	Nitrate (mg/l)	Traces Naudal (Pulwama)	31Safapora (Baramulla)	Traces Malingpur (Anantnag)	394 Pampore (Pulwama)	Traces Dus (Pulwama)	135 Islamia college (Srinagar)
7	Fluoride (mg/l)	Traces Trehgam (Baramulla)	0.65 Ladu village (Pulwama)	Traces Lodhawan (Kupwara)	1.00 Malingpur (Ananatnag)	Traces Pahloo Brain (Srinagar)	0.99 CSB Pampore (Pulwama)
8	Sulphate(mg/l)	Traces Awani gund (Pulwama)	80 Khunamuh (Pulwama)	Traces Zewan (Pulwama)	260 Pampore (Pulwama)	Traces Shippora (Budgam)	30 Bathyan (Kupwara)
9	Calcium(mg/l)	8.0 Chansernag (Ananatnag)	106 Safapora (Baramulla)	12 Udipora (Kupwara)	174 Gunderapher (Kupwara)	4.80 Camp HMT(Srinagar)	132 Sopore (Baramulla)
10	Magnesium(mg/l)	01 Bremsar (Anant nag)	80.5 Vetesta (Ananatnag)	2.6 Rambelpur (Anantnag)	193 Pampore (pulwama)	4.40 Tragpore (Baramulla)	96 Sopore (Baramulla)
11	Sodium(mg/l)	0.70 Kolgam (Ananatnag)	104 Kanis pora (Baramulla)	Udipora (Kupwara)	160 Pampore (Pulwama)	1.5 S K University (Srinagar)	112 Radio Kashmir college (Srinagar)
12	Potassium(mg/l)	Traces Cheshmashahi (Srinagar)	9.8 Kongbal (Ananatnag)	Traces Cherkot (Kupwara)	215 Kadal bal (Kupwara)	Traces S K University (Srinagar)	112 Islamia College (Srinagar)
13	Total Hardness as $CaCO_3$(mg/l)	36 Andarwan (Srinagar)	330 Safapora (Baramulla)	42 Udipora (Kupwara)	871 Pampore (pulwama)	93 Sadipora (Ananatnag)	725 Sopore (Baramulla)
14	Iron(mg/l)	Traces Zewan (Pulwama)	1.79 Lojpur (Pulwama)	Trace Letpur (Pulwama)	5.72 Sadipora (Ananatnag)	Traces (Budgam)	12.8 Mamet (Budgam)

From the above table, it is observed that **Electrical Conductivity** values are generally low with high value reported from Pulwama, Baramulla and Kupwara districts. The EC value 2800 micromohs/cm at 25ºC is recorded from shallow aquifer in Pampore from Pulwama district. In case of deeper aquifers, maximum value of 1760 micromhos /cm at 25ºC is recorded in Sopore of Baramulla district. Maximum value of 755 micromhos/cm at 25ºC is recorded from spring water in Safapora of Baramulla district.

Minimum concentration of **Nitrate** (0.02 mg/l) is reported from Verinag from Anantnag district. Maximum value of 394 mg/l is noticed in Pampore of Pulwama district. Majority of samples have nitrate concentration within the permissible (45 mg/l) limit. However, at a few places, high values are also reported (92mg/l in Cherkot from Kupwara, 135 mg/l in Islamia college from Srinagar district).

Fluoride concentration is low and within the maximum permissible limit of BIS (1.5 mg/l). It ranges from Traces to 0.65mg/l in Ladu village of Pulwama district, Traces to 1.0 mg/l in Malingpur of Ananatnag district and Traces to 0.99 mg/l in CSB Pampore of Pulwama district in the samples collected from spring, shallow and deeper aquifers respectively.

Sulphate concentration in the samples collected from the region is low. But high value is also reported i.e. 260 mg/l in Pampore (Shallow Ground Water) from Pulwama district.

High concentration of carbonates and bicarbonates of calcium and magnesium, in ground water causes hardness. **Total Hardness** values as per classification of Sawyer and M C Carty are depicted in Fig. 7.3 and are presented in Table 7.5. It can be seen that in case of spring water, 47.6% samples fall under Moderate hard category. About 79.8% and 53.3% of samples collected from shallow and deeper aquifers respectively belong to Very hard category.

Table 7.5: Hardness Classification of Ground Water from Kashmir Region

Source Type	**Soft 0-60 mg/l TH**	**Moderate Hard 61-120 mg/l TH**	**Hard 121-180 mg/l TH**	**Very Hard more than 180 mg/l TH**
Spring	04(4.8%)	39(47.6%)	28(34.7%)	11(13.4%)
Shallow	01(0.1%)	06(5.2%)	16(14.0%)	91(79.8%)
Deeper	00	03(5.0%)	25(41.7%)	32(53.3%)

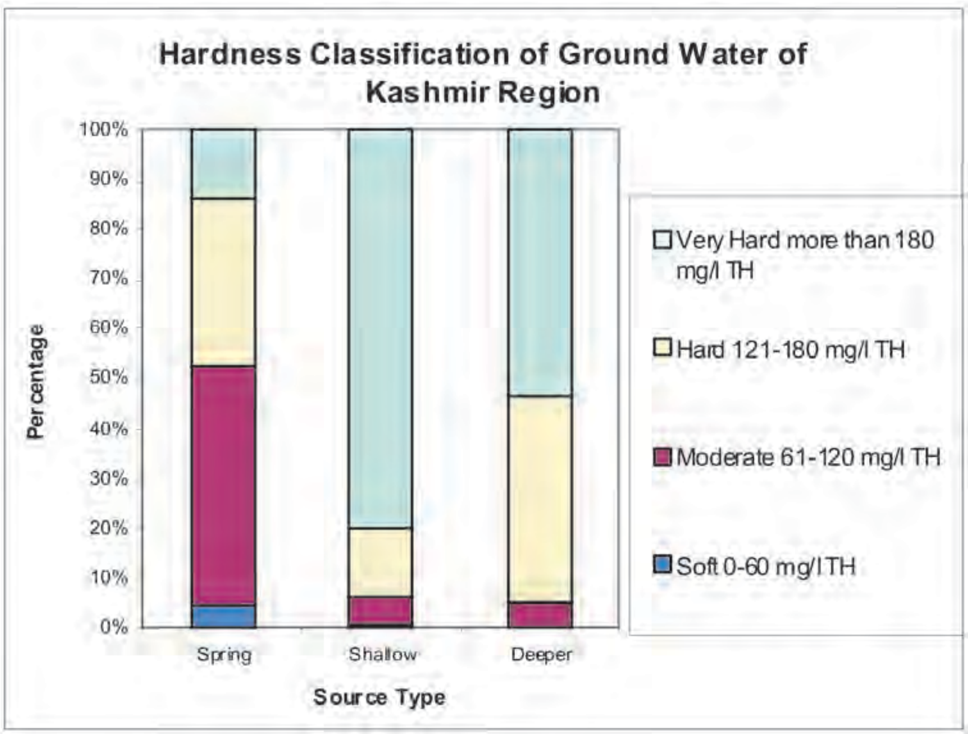


Fig. 7.3: Hardness Classification diagram

Iron concentration is moderately high in shallow and deeper ground water and reported as high as 12.8 mg/l in Mamet of Budgam district, 6.6 mg/l in Upper Ishber of Srinagar district, 6.3 mg/l in Kahanpora of Baramulla district. In case of Spring samples, maximum concentration 1.12 mg/l is reported in Dangarpur spring from Pulwama.

Ladakh Region

For evaluation of ground water quality of Ladakh Region a total of 157 ground water samples were collected including 118 samples from Springs and remaining 39 samples from deeper aquifers. Minimum and Maximum values of water quality parameter are summarized in Table 7.6.

Table 7.6: General range of water quality parameters of Ladakh Region

Sl. No.	Water Quality Parameters	Spring		Deeper aquifer	
		Min	Max	Min	Max
1	pH	6.60 Kuleum Leh	8.25 Darkat Kargil	6.90 Kahardung Leh	7.80 Lagiiung Leh
2	Electrical Conductivity µmhos/cm at 25°C	36 Changra Leh	1482 Chumathang-II	47 KahardungLeh	600 Genshchaska Kargil
3	Carbonate (mg/l)	00	Traces Chumathang-II Leh	00	00
4	Bi carbonate (mg/l)	12 ChangraLeh	458 Chumathang-II Leh	31 KahardungLeh	216 Sankoo Kargil
5	Chloride(mg/l)	3.50 Channigund Kargil	117 Chumathang-II Leh	3.50 Opp to Masque Kargil	21 Lagiiung Leh
6	Nitrate(mg/l)	Traces Bukhrilo Kargil	32 Upper Baroo Kargil	Traces Smar Kargil	9.61 Tumer Village Leh
7	Fluoride(mg/l)	Traces Karkichhu Kargil	12 Panamic Yogma	Traces Shankar Leh	1.63 Sankoo Kargil
8	Sulphate(mg/l)	Traces Beyama Kargil	303 Nmche Kargil	Traces Dalchike Kargil	269 Genshchaska Kargil
9	Calcium(mg/l)	3.2Changra Leh	113 Namche Kargil	2.40 Opp to Masque Kargil	71 Sankoo Kargil
10	Magnesium(mg/l)	Upper Baroo Leh	35 Namche Kargil	2.40 Skampuk	34 Genshchaska Kargil
11	Sodium(mg/l)	Bukhrib Kargil	350 Chumathang-II Leh	Traces Khardung Leh	18 Lagiung Leh
12	Potassium(mg/l)	0.10 Astakba Leh	21 Chumathang-II Leh	Traces Khardung Leh	5.60 Sankoo Kargil
13	Total Hardness as CaCO3(mg/l)	16 ChangraLeh	426 Namche Kargil	44Khardung Leh	340 Genshchaska Kargil

Maximum **Bicarbonate** concentration is reported as 458 mg/l from Leh district.

Nitrate concentration is low and within the maximum permissible limit of BIS for drinking water purpose (45 mg/l).

Fluoride concentration in Kargil district is in general low and within permissible limit (1.5 mg/l), except in deeper aquifer (1.63 mg/l) at Sankoo in Kargil district. High fluoride (12.0mg/l) is found to occur in spring water at Panamic Yogma in Leh district.

Sulphate concentration is generally low but high values are also observed 303 mg/l south east of Namche of Kargil district. In spring water and deep aquifers, it ranges from traces to 303 mg/l (Namche) and traces to 269 mg/l (Genshchaska) respectively.

Concentrations of **Sodium and Potassium** are low in Ladakh area. High value of Sodium (350 mg/l) has been reported from hot springs at Chumathang-II from Leh district.

Total Hardness values are classified (Sawyer and M C Carty) and show that in case of springs and deeper aquifers, majority of samples 48.7% and 43.6%fall under Moderate hard category. None of the category exceeds more than 50.0% (Fig. 7.4 and Table 7.7).

Table 7.7: Hardness Classification of Ground Water from Ladakh Region

Source Type	Soft 0-60 mg/l TH	Moderate Hard 61-120 mg/l TH	Hard 121-180 mg/l TH	Very Hard more than 180 mg/l TH
Spring	16(13.7%)	57(48.7%)	28(23.9%)	16(13.7%)
Deeper	01(2.5%)	17(43.6%)	14(36.0%)	07(17.9%)

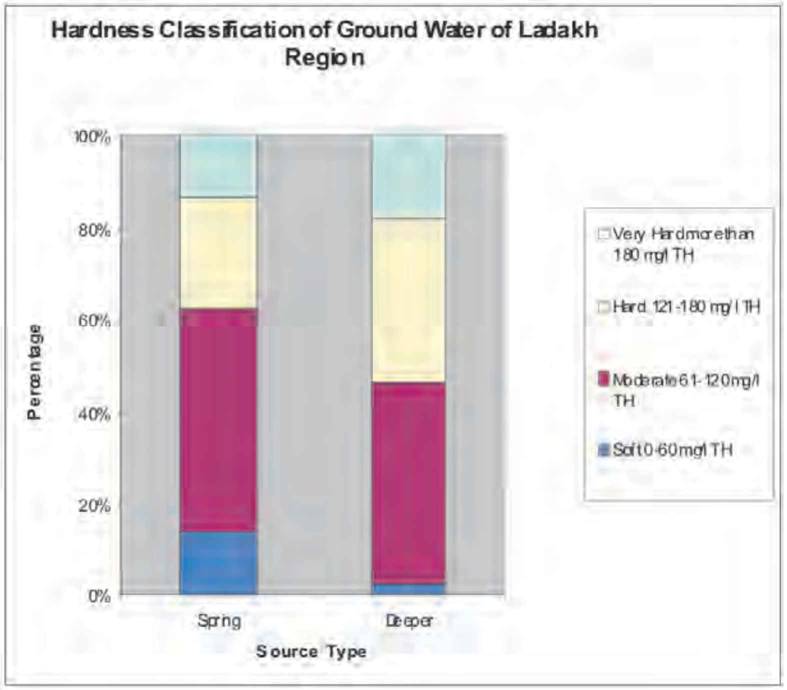


Fig. 7.4: Hardness classification of ground water from Ladakh region

In general, **Iron** concentration in Leh district is below 1.0 mg/l. But in Kargil district, 5.1 mg/l of Iron is reported from spring water in west of Simla.

7.2 HIMACHAL PRADESH

To evaluate the chemical quality of ground water in the State of Himachal Pradesh, 78 water samples were analysed which were collected from Ground Water Monitoring Stations during the pre-monsoon period (May 2009). The chemical analysis results of the samples (Table 7.8) show that in general the chemical constituents are within the permissible limit. Hence, ground water in the area is fresh and potable. However, at places in Kangra, Una and Solan districts, the nitrate values are above the permissible limit (>45 mg/l). **Total Hardness** of the water ranges from moderate to very hard category as per the classification of Sawyer and M C Carty.

From the tables, 7.9 to 7.15 it has been observed that the chemical constituents of spring waters in all the areas are within the permissible limit and are potable for drinking purpose. Nitrate values, in 3 samples collected from Simla area (50-105 mg/l) & one sample from Mandi (52 mg/l), are >45 mg/l. The concentration of Fluoride above permissible limit in spring water has been observed in parts of Kinnaur (Wangtu, Kilba), Chamba (Kandu, Dalhaousie, Chahla) and Kullu (Beas Kund), Marhi, Nehru kund, Brahgram, Shat, Bagianda, Jari, Jarad).

The concentrations of all the chemical constituents in hot springs are quite high and above permissible limit. The EC and chloride concentration are in the range of 1480-10270 micromhos/cm at 25^0C and 312-3440 mg/l respectively. The higher concentrations are mainly observed in Simla area. The Fluoride content is also above permissible limit mainly in Simla and Kinnaur.

It has been observed that the chemical constituents of the tube well water are in general within permissible limit. The water sample collected from Sumdo in Lahaul & Spiti shows higher concentration of all the constituents. Nitrate concentration of water sample collected from monitoring well in Una district and from tube well at Mogi Nand in Sirmour district is reported as 135 and 104 mg/l (above permissible limit of 45 mg/l) respectively (Fig. 7.5). The Fluoride content is found above permissible limit in some places like Nigulsari, Nichar and Tapri of Kinnaur district.

Table 7.8: Chemical Analysis result of water sample from GWMW (May 2010)

S.No.	District (No. of Samples)		pH	ECµS/cm at 25°C	HCO_3	Cl	So_4	NO_3	F	Ca	Mg	Na	K	*Total Hardness as $CaCO_3$*
									(in mg/l)					
1.	KANGRA (24)	Min	7.10	120	58	5.3	Tr	Tr	Tr	12	3.6	5.5	0.6	50
		Max	8.00	1200	634	85	165	**49 (Bod, Dehra Gopipur,)**	0.45	92	54	85	88	430
2.	UNA (20)	Min	7.10	330	98	11	05	2.22	Tr	14	11	9.80	0.7	95
		Max	7.90	920	519	85	120	**135 (Daulatpur, Kaluwal, Gagrate, Guglehr, Jalera, Ishpur)**	0.45	84	60	100	16	340
3.	MANDI (9)	Min	7.70	230	174	5.3	Tr	Tr	Tr	18	2.40	6.50	1.70	75
		Max	7.90	1480	491	135	115	28	1.80 (Gutkar)	180	45	77	16	600
4.	KULU (3)	Min	7.40	230	110	7.10	10	2.78	Tr	34	4.80	2.80	4.5	105
		Max	7.60	510	153	21	50	49	0.26	62	11	20	6.7	200
5.	HAMIRPUR (4)	Min	7.6	310	104	3.6	08	6.11	Tr	34	9.7	7.7	1.3	125
		Max	7.80	460	281	21	30	19	0.15	74	15	14	6.4	200
6.	SOLAN (10)	Min	7.50	300	159	7.10	12	5.78	0.05	22	06	28	1.70	105
		Max	8.20	1270	616	82	135	**121 (Bhageri, Palahi, Dabota,)**	0.60	164	29	108	12	530
7.	SIRMAUR (12)	Min	7.80	210	98	5.30	Tr	Tr	Tr	14	13	5	1.2	100
		Max	8.20	1220	409	142	100	96 (Kala Amb)	0.65	46	24	205	28	235

Table 7.9: Range of chemical constituents of spring and tube well water in Lahaul & Spiti district

Constituents	Springs(14)		Hot Springs(3)		Bore wells fitted with Hand pumps(9)	
	Min	Max	Min	Max	Min	Max
pH	7.05	7.80	7.00	7.05	7.25	8.00
EC (micro-mhos/ cm at 25^0C)	190	1135	**5170(Sumdo)**	**5420(Sumdo)**	246	**1100 (4250 only at Sumdo)**
HCO_3 (mg/l)	61	201	500	824	49	**232 (622 only at Sumdo)**
Cl (mg/l)	3.5	18	883	1152	3.50	**18 (592 only at Sumdo)**
NO_3 (mg/l)	4.2	38	2.70	7.60	3.0	**Within 45 (one sample from Hurling shows 60 i.e. beyond permissible)**
F (mg/l)	ND	0.98	**1.30(Sumdo)**	**1.80(Sumdo)**	ND	**1.30(Sumdo)**
Ca (mg/l)	15	164	501	581	28	**160 (480 only at Sumdo)**
Mg (mg/l)	8.5	52	49	55	16.0	**99.0**
Na (mg/l)	ND	25	375	375	ND	**22 (225 only at Sumdo)**
K (mg/l)	ND	3.8	125	138	0.20	**4.40 (70 only at Sumdo)**
Total Hardness as $CaCO_3$ (mg/l)	110	626	1476	1652	135	**641 (1952 only at Sumdo)**

Table 7.10: Range of chemical constituents of spring and tube well water in Mandi district

Constituents	Springs (24)		Hot Springs (2)		Tube well at Sihan
	Min	Max	Min	Max	
pH	7.45	8.40	8.05	8.15	8.20
EC (micro-mhos/cm at 25^0C)	58	655	1480	**9700(Tatapani)**	282
CO_3 (mg/l)	ND	24	-	-	-
HCO_3 (mg/l)	24	256	122	262	177
Cl (mg/l)	5.3	43	312	1723	14
NO_3 (mg/l)	0.53	7.7(**52** in only one sample from **Mandi**)	0.70	1.60	-
F (mg/l)	ND	0.85	**1.03(Tatapani)**	**1.66(Tatapani)**	0.24
Ca (mg/l)	9.8	69	43	64	43
Mg (mg/l)	2.4	38	23	35	7.1
Na (mg/l)	1.6	29	240	2050	18
K (mg/l)	0.8	12	52	68	2.8
Total Hardness as $CaCO_3$ (mg/l)	35	309	201	304	137

Table 7.11: Range of chemical constituents of spring and tube well water in Simla district

Constituents	Springs (43)		Hot Springs (2)		Bore wells fitted with Hand pumps (11)	
	Min	Max	Min	Max	Min	Max
pH	6.85	8.40	7.18	7.42	6.95	8.15
EC (micro-mhos/cm at 25^0C)	152	920	**3520(Jyori)**	**10270(Tatapani)**	88	606
HCO_3 (mg/l)	30	192	278	333	18	223
Cl (mg/l)	7.0	62	897	3440	10	49
NO_3 (mg/l)	ND	45**(3 samples from Simla, Vikas Nagar & Lalpani shows 50-105)**	2.50	4.50	ND	16
F (mg/l)	ND	**1.0 (Lakkar Bazar, Marhog)**	**2.1(Tatapani)**	**4.0(Jyori)**	0.20	**1.6 (Ashwani Khad)**
Ca (mg/l)	11.05	83	11.05	79	6	63
Mg (mg/l)	3.4	37	18	37	2.3	25
Na (mg/l)	32	60	580	1900	2.3	23
K (mg/l)	2.0	60	60	250	0.6	35
Total Hardness as $CaCO_3$ (mg/l)	51	228	273	440	36	228

Table 7.12: Range of chemical constituents of spring and tube well water in Sirmour district

Constituents	Springs (16)		Dug Well (18)		Bore wells fitted with Hand pumps (10)	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**
pH	7.4	8.35	7.35	8.10	7.55	8.15
EC (micro-mhos/cm at 25^{0}C)	65	1285	295	690	170	1270
HCO_3 (mg/l)	29	328	88	316	70	392
Cl (mg/l)	3.5	58	7.1	43	7.1	141
NO_3 (mg/l)	0.25	25	ND	18	ND	23 **(104 in one sample from Mogi Nand)**
F (mg/l)	ND	0.72	0.07	0.23	0.10	0.47
Ca (mg/l)	8.0	247	28	106	18	82
Mg (mg/l)	7.3	106	11	33	7.3	44
Na (mg/l)	2.0	25	4.3	51	6.0	110
K (mg/l)	ND	2.8	0.8	4.0	0.5	3.7
Total Hardness as $CaCO_3$ (mg/l)	31	836	58	355	90	378

Table 7.13: Range of chemical constituents of spring and tube well water in Kinnaur district

Constituents	Springs (16)		Dug Well (18)		Bore wells fitted with Hand pumps (10)	
	Min	Max	Min	Max	Min	Max
pH	6.85	7.53	7.15	7.52	7.00	7.68
EC (micro-mhos/cm at 25^0C)	107	738	328	1780	112	1032
HCO_3 (mg/l)	18	171	104	329	37	305
Cl (mg/l)	3.5	18	7.1	213	7.1	78
NO_3 (mg/l)	0.08	7.0	0.46	3.70	1.2	22
F (mg/l)	0.06	**3.0 (Wangtu, Kilba)**	2.80	**7.5(Chholing, Karcham, Thopan Dogri)**	0.10	**2.72(Nigulsari, Nichar, Tapri)**
Ca (mg/l)	16	100	22	106	16	139
Mg (mg/l)	2.4	33	1.2	17	2.4	37
Na (mg/l)	2.4	18	18	270	3.2	76
K (mg/l)	2.2	12	4.5	38	2.0	15
Total Hardness as $CaCO_3$ (mg/l)	49	343	59	118	54	500

Table 7.14: Range of chemical constituents of spring water in Chamba district

Constituents	Springs (37)	
	Min	**Max**
pH	7.15	8.25
EC (micro-mhos/cm at 25^0C)	66	815
HCO_3 (mg/l)	24	299
Cl (mg/l)	7.1	36
NO_3 (mg/l)	1.0	44
F (mg/l)	0.15	**2.5 (Kandu, Dalhaousie, Chahla)**
Ca (mg/l)	6	98
Mg (mg/l)	1.2	68
Na (mg/l)	1.7	9.8
K (mg/l)	0.10	6.9
Total Hardness as $CaCO_3$ (mg/l)	25	485

Table 7.15: Range of chemical constituents of spring water in Kullu district

Constituents	Springs(35)	
	Min	Max
pH	7.05	8.6
EC (micro-mhos/cm at 25^0C)	32	2010
HCO_3 (mg/l)	9.1	244
Cl (mg/l)	3.5	397
NO_3 (mg/l)	1.2	14
F (mg/l)	0.08	**21 (Beas Kund, Marhi, Nehru Kund, Brahgram, Shat, Bagianda,Jari, Jarad)**
Ca (mg/l)	2.4	140
Mg (mg/l)	1.2	68
Na (mg/l)	0.7	390
K (mg/l)	0.6	340
Total Hardness as $CaCO_3$ (mg/l)	10	220

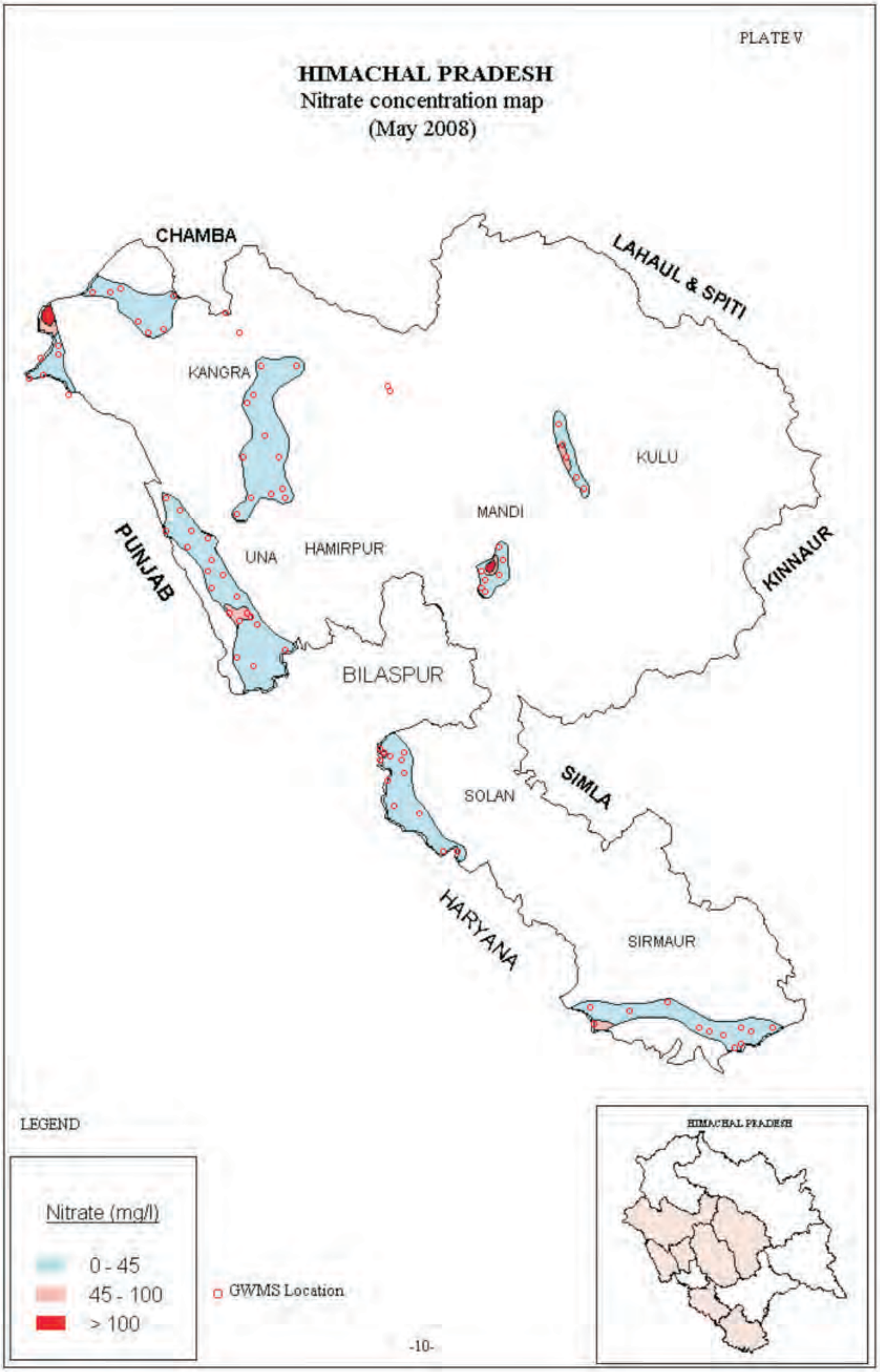


Fig. 7.5: Nitrate concentration in Himachal Pradesh

7.3 Uttarakhand

To evaluate the chemical quality of ground water in Uttarakhand State, 85 water samples were analysed, out of which 77 samples were collected from Ground Water Monitoring Wells and the remaining 8 samples were collected from springs during the pre-monsoon period (May 2009).

The chemical quality of ground water of shallow and deep aquifers in Uttarakhand State varies widely depending on physiography, soil texture and geology of the area. The aquifers are mostly dominated by Ca-Mg-HCO_3 and Ca-HCO_3 types of ground water. The general chemical quality reveals that most of the wells contain low dissolved mineral contents and hence, ground water in Uttarakhand state is fresh and potable. A description of various hydrochemical parameters as per the available analysis is given below:

pH*:* Ground water is weakly acidic to weakly basic in nature. pH of ground water varies from a minimum of 6.74 at Lalkuan, Nainital district to a maximum of 8.33 at Sipahidhara and Garampani springs, both located in Nainital district.

Electrical Conductivity (EC): The Electrical Conductivity (EC), which is a measure of the degree of mineralization in the ground water, is observed to vary from a minimum of 80 ìS/cm (at 25°C) at Redapur, Dehradun district to a maximum of 1090 ìS/cm at Dhanpura, Haridwar district. The majority of the samples (60 out of 85 or 70.59%) have shown EC in the range of >250-750 ìS/cm.

Bicarbonate*:* Concentration of bicarbonate in ground water varies from a minimum of 38 mg/L at Redapur, Dehradun district to a maximum of 417 mg/L at Jaspur, Udham Singh Nagar district.

Carbonate: Concentration of carbonate is found to be varying from 12 mg/L at Garampani spring to 25 mg/L at Sipahidhara spring in Nainital district.

Chloride: From the chemical analysis results it has been observed that 94.12% of the samples have shown chloride concentration in the range of 0-50 mg/L whereas 2.35% have shown concentration varying from >50-100 mg/L. Only 1.18% of samples have shown chloride concentration of >100-150 mg/L while another 2.35% have shown concentration >150 mg/L in Uttarakhand, indicating the predominantly fresh ground water.

Sulphate: Apart from the not detectable (nd) values of sulphate, the minimum concentration of sulphate in ground water was 1.0 mg/L only. The maximum sulphate concentration of 132 mg/L was observed at Bhaniawala hand pump in Dehradun district.

Nitrate:

Table 7.16: Frequency distribution of Nitrate concentration (May 2009)

Nitrate (mg/L)	**<45**	**>45**
No. of Samples	60	10
% of Total No.	85.71	14.29

A perusal of the frequency distribution of nitrate concentration given in Table 7.16 indicates that majority of samples (85.71%) are suitable for drinking purpose. Higher nitrate of above permissible limit of 45 mg/L was found in only 10 wells (14.29%), which are predominantly dug wells and are not in active/frequent use. Overall, the nitrate concentration in the monitoring wells in Uttarakhand indicates that ground water is suitable for drinking purpose.

Fluoride*:* Fluoride concentration in ground water was found to be varying from a minimum of 0.04 mg/L at Kanwali dug well in Dehradun district to a maximum of only 0.67 mg/L at Chudiala piezometer in Haridwar district.

Calcium*:* Concentration of calcium in ground water in Uttarakhand was found to be varying between 8 mg/L Redapur in Dehradun district and a maximum of 68 mg/l at Banna Khera dug well in Udham Singh Nagar district.

Magnesium: Minimum concentration of magnesium in ground water was 2 mg/L observed at Redapur and Chharba in Dehradun district whereas the maximum concentration was 55 mg/L at Kichha in Udham Singh Nagar district. Out of 85 samples, 23 samples (27.06%) have shown magnesium higher than the Acceptable Limit of 30 mg/L. The high magnesium concentration in ground water is attributed to geogenic source and in many cases, can be correlated with high calcium concentration in ground water. Overall, it may be concluded that ground water is suitable for drinking purpose.

Sodium: There is no guideline regarding suitability of ground water for drinking purpose based on sodium concentration. Sodium concentration in ground water varies from a minimum of 2 mg/L at Garampani spring in Nainital district to a maximum of 114 mg/L at Jaspur dug well in Udham Singh Nagar district.

Potassium: Concentration of potassium in ground water in Uttarakhand was found to be varying between a minimum of 0.4 mg/L at Bahadrabad dug well, Haridwar district, to a maximum of 81 mg/L at Dhanpura dug well, located also in Haridwar district. Like sodium, there is no guideline regarding suitability of ground water for drinking purpose based on concentration of potassium.

Total Hardness (as $CaCO_3$): The data indicates that Total Hardness in ground water of Uttarakhand during pre-monsoon 2009 was minimum (26 mg/L) at Redapur dug well in Dehradun district while the maximum value of 478 mg/L was found at Jhagarpuri hand pump in Udham Singh Nagar district. As per the revised guideline of BIS (BIS, IS:10500, 2003), the Acceptable Limit is 200 mg/L and the Permissible Limit (in absence of alternate source) is 600 mg/L. Hydrochemical analysis reveals that overall ground water is suitable for drinking and domestic purpose.

The general chemical quality reflects that most of the spring water contains low dissolved minerals content, which brands the spring water as quite fresh and suitable for both drinking and irrigation purposes. The Fluoride content is marginally beyond permissible limit at places in Pauri and Chamoli districts. District wise quality of spring water is given in Table 7.17.

Table 7.17: Quality of Spring water in Uttarakhand State(Analyzed chemical data presented in district wise with range value in mg/l)

District	Ec	pH	HCO_3	Cl	SO_4	NO3	F	Ca	Mg	Na	K	Total Hardness	Remarks
Almora	75-400	7.1- 8	8.1-70	25-100		0.6-46				2-50		40-300	
Bageshwar	50-640	7.8-8.1	18-232	7.00-64.00	Nd-6	0.2-28	ND-0.19	4-40	1.2-46	1.7-27	1.3-6.5	10-290	
Pithoragarh	40-1363	6.92-8.20	12-897	1.8-50		Nil-32	ND-0.29	4-222	2.4-40	0.4-30	0.3-38	30-720	Devisagar, Hot Spring
Champawat	50-440	7.17-8.25	18-244	3.5-34	Nil-18	Nd-6.3	0.05-0.64	4.8-82	1.2-23	4.8-28	0.10-9.6	15-167	
Nainithal	70-660	7-8.08	45-179	5.0-14.0				2.2-61	Nd-19	3.5-72	0.9-1.9	70-120	
U S Nagar													
Dehradun	30-475	7.38-8.22	15-238	1.5-23				4-64	Nil-24			15-120	
Haridwar													
Pauri	61-606	7.07-8.12	37-275	3.5-18	4.4-62	Nil-3.2	0.11-3.15	10-62	2.4-58.4	5-12	0.7-4.2	35-340	
Tehri	170-2720	8-8.20	4.9-232	7.1-14	6.4-1465	Nd-6.4	0.02-0.51	12-325	15-212	2.3-9.5	0.3-3.7	60-1681	Kadukhal, Hot Spring
Uttarkashi	18-1025	8-8.10	61-625	3.5-85	ND-9.6	0.39-20	ND-0.98	2.0-24	1.2-34	0.7-221	0.2-10	15-135	Ganganani Hot Spring
Rudraprayag	60-960	7.8-8.03	19-464	7.0-43		Nil-8	ND-1.6	8-136	2-19	Nd-45	Nd-20	30-350	
Chamoli	30-2100	7.5-8.10	31-1196	3.5-99		ND-23	Nd-2.26	2-76	3.6-70.2	4-524	0.4-33	10-350	Badrinath Hot Spring

Ground water requirement in Uttarakhand is increasing day by day with the growth in population and industries. The districts like Haridwar, Dehradun, Nainital and Udham Singh Nagar have been demarcated for industrial development due to their approachability, plain land, raw material and above all availability of water resources. For the disposal of industrial waste and effluents these locations are also congenial due to frequent availability of rivers and streams. But gradually it will pose threat to ground water resources once the pollution load of rivers & streams gets increased by industrial effluents. The effluents generated and discharged into the rivers/streams by 44 different industries Viz. Agro based paper industries, waste papers based industries, sugar industries, Distilleries and others are 183657 kiloliters per day (KLD). The rivers like Kicha, Dhell and Kali alone receive 47800, 41900 and 12972 KLD respectively from paper industries. The data pertaining to industrial effluents is presented in Table 7.18.

Table 7.18: INDUSTRIAL PROFILE OF GROSSLY POLLUTING INDUSTRIES

S.N.	Industrial Sector	Kumaon Region		Garhwal Region	
		No. of units	Effluent in KLD	No. of units	Effluent in KLD
1.	Agro-based Paper Industries	08	71000	00	00
2.	Waste Paper-based Industries	19	72000	02	4320
3.	Sugar Industries	06	7000	04	17137
4.	Distilleries	02	6000	00	00
5.	Others	03	6200	00	00
	Total	**38**	**162200**	**06**	**21457**

Source: State pollution Control Board, Dehradun

The water bodies in the form of river and tributaries are receiving huge volume of Industrial and Domestic effluents which are shown as at a glance in the following Table 7.19.

Table 7.19: WATER BODIES RECEIVING INDUSTRIAL AND DOMESTIC EFFLUENT

S.N	Water Bodies (River/tributaries)	Quantity of effluent (KLD)	S.N.	Water Bodies	Quantity of effluent (KLD)
1	River Gogi	4400	10	Terhipula Nala	5000
2	River Dandi	7000	11	River Pili	1500
3	River Kichha	47800	12	River Bhakhara	1000
4	River Lavera	4000	13	River Apsara	1000
5	River Dhell	41900	14	Hathichingar Nala	0
6	River Bahella	11000	15	River Baigul	3300
7	River Kosi	14000	16	River Song	2372
8	River Khankara	4000	17	River Kali West	12972
9	River Pilakhar	00	18	River Banganga	7013

Source: State pollution Control Board, Dehradun

7.4 West Bengal & Sikkim

Various deleterious and toxic elements like Arsenic, Fluoride are not yet reported from Sikkim and Darjeeling Himalayas. Water from springs and Kholas (streams) in Sikkim is used for drinking and other domestic purposes. Water samples collected from the boreholes constructed by CGWB during pumping tests have been analyzed. In the following table (Table 7.20) characteristics of ground water from spring and boreholes are given against the standard set by Indian Council of Medical Research.

The quality of ground water is excellent in nature except higher concentration of iron in bore well water. Ground water is of Ca-Mg-bicarbonate type. The spring water shows very low concentration of the constituent ions. However, there are some higher ranges of chemical constituents e.g. 410 micromhos /Cm of EC, 361 mg/l of TDS, total hardness of 300 mg/l, 332 mg/l of HCO_3 and marginally higher concentration of iron.

Table 7.20: Chemical Quality of Ground water in Sikkim

Sl. No	Chemical Constituents	Springs	Boreholes	I.S.I, 1983 standard (for drinking)	
				Highest desirable level	Max. permissible limit
1	pH	6.7 –8.1	6.2 -8.0	6.5-8.5	8.5-9.2
2.	Sp.cond.(micromhos/cm At 25°C)	21 - 410	37 -349		
3.	TDS (ppm)	8 - 361	20 -214	500	1500
4.	Total hardness as $CaCO_3$ (ppm)	10 - 300	20 -170	300	600
5.	Calcium (ppm)	1.6 - 62	4 - 40	75	200
6.	Magnesium (ppm)	0.61 - 24	2.4 -17	30	No relaxation
7.	Sodium (ppm)	0.23 - 10	0.46 - 3.5	-	-
8.	Potassium (ppm)	Trace - 7.8	0.39 –2.9	-	-
9.	Iron (ppm)	Trace - 0.38	0.247-20.7	0.3	1.0
10.	Silica (ppm)	Trace - 16	7.6 -14	-	-
11.	Bicarbonate (ppm)	6.1 - 332	12..1 –30.5	-	-
12.	Chloride (ppm)	1.4 - 16	5.3 –11.0	250	1000
13.	Sulphate (ppm)	-	< 1. 0 - 3.75	150	400
14.	Nitrate (ppm)	Trace - 7.2	<0.1- <1.0	45	No relaxation
15.	Fluoride (ppm)	Trace - 0.12	<0.01-0.27	0.6-1.2	1.5

7. 5 ARUNACHAL PRADESH

In order to adjudge the quality of spring water, samples were collected from various spring locations for their chemical analysis. For deciphering the suitability of the spring water for various purposes like drinking, irrigation and industrial uses, various diagrams/formula were utilized. Plots of the chemical data, their results and interpretation are enumerated below.

Plot of chemical data in Piper diagram: The cation triangle in Piper plot indicates that for most of the spring water samples, the relative proportion of alkaline earth (Ca+Mg) is high compared to the proportions of alkalis (Na+K). Similarly, for the anions plot the relative proportions of bicarbonate (HCO_3) are high, while chloride (Cl) and sulphate (SO_4) are absent or negligible. From Piper tri-linear diagram (Fig 7.6) and also from the Table 7.21, it can be interpreted that the spring water is generally of HCO_3-CO_3 type which indicates that the groundwater is of recent evolution and it is formed through the recharge from rainfall. The chemical data of springs presented in Table 7.22 also indicates that the water is fairly fresh with low electrical conductivity (EC) and total dissolved solids (TDS) and it has not travelled for a long distance within the aquifer.

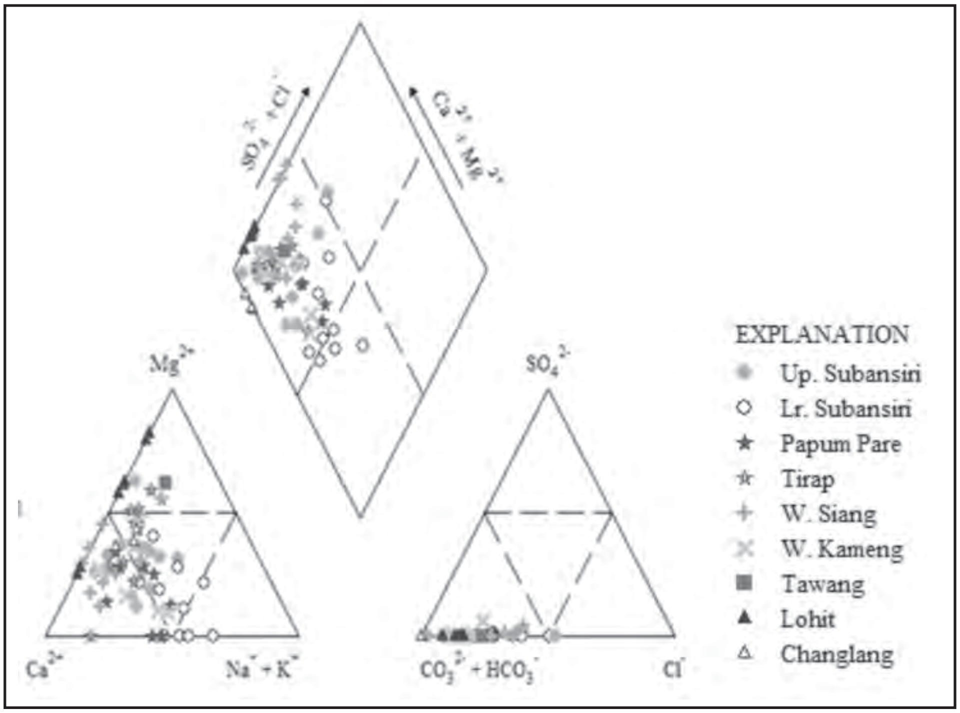


Fig. 7.6: Plot of Chemical parameters of spring water in Piper Diagram

Explanation of Piper sub-divisions

1. Alkaline earth (Ca+Mg) exceed alkalis (Na+K)
2. Alkalis exceeds alkaline earths
3. Weak acids (CO_3+HCO_3) exceed Strong acids (SO_4+Cl)
4. Strong acids exceeds weak acids
5. Chemical properties of the water are dominated by alkaline earths and weak acids
6. Calcium-chloride type
7. Sodium-chloride type
8. Sodium-Bicarbonate type
9. Mixed type (No cation-anion exceed 50%)

Table 7.21: Characterization of spring water of Arunachal Pradesh on the basis of Piper-trilinear diagram

Subdivision in Piper	Upper Subansiri	Lower Subansiri	Papum Pare	West Siang	West Kameng	Tawang	Lohit
1	100	60	100	100	100	100	100
2	0	40	0	0	0	0	0
3	100	90	100	90	100	100	100
4	0	10	0	10	0	0	0
5	100	60	100	100	100	100	100
6	0	10	0	0	10	0	0
7	0	10	0	0	10	0	0
8	0	10	0	0	10	0	0
9	0	40	0	0	0	0	0

Table 7.22: Chemical analysis data of spring water

District	pH	EC	TH (as $CaCO^{-}_{3}$)	Conc. meq/l									
				Ca	Mg	Na	K	Fe	CO_3	HCO_3	Cl	NO_3	SO_4
Upper Subansiri (9/11)*	7.08-8.15	41-305	20-170	0.299-0.749	0.082-0.411	0.087-0.348	0.026-0.102	0.0-0.04	0.0	0.295-1.803	0.113-0.313	0.006-0.008	**0.0**
Lower Subansiri (10/12)*	7.7-8.2	32-124	56-40	0.100-0.399	0-0.576	0.087-0.435	0.026-0.077	0-0.048	0.0	0.197-0.705	0.113-0.395	0-0.0113	**0.0**
Papum Pare (9/10)*	7.4-8.0	42-339	20-145	0.299-1.896	0.0-0.987	0.87-0.609	0.026-0.051	0-0.011	0.0	0.606-2.393	0.113-0.31	0.0-0.01	**0.0**
West Siang (13/13)*	7.15-8.0	12-203	10-200	0.10-1.397	0.82-2.632	0.0-0.218	0.0-0.051	0-0.021	0.0	0.098-1.196	0.113-0.31	0.0-0.023	**0.0**
West Kameng (6/13)*	6.5-8.02	18-1582	10-350	0.10-5.589	0.082-1.81	0.026-14.79	0.026-1.381	0.0-0.054	0.0	0.295-7.097	0.113-4.909	0.0-0.034	**0.0**
East Kameng (0/3)*	7.15-7.51	46-110	40-90	0.20-0.599	0.0-0.329	0.218-0.435	0.026	0.021-0.032	0.0	0.295-1.295	0.113-0.197	0.00	**0.0**
Tawang (1/3)*	7.48-7.8	68-249	10-40	0.20-1.397	0.411-0.576	0.087-0.131	0.026	0.0-0.008	0.0	0.508-1.098	0.197-0.31	0	**0.0**
Lohit (7/9)*	7.0-7.85	73-337	33-178	0.399-2.595	0.197-2.139	0.00	0.00	0.00	0.0	0.524-3.278	0.197-0.395	0.00	**0.0**
*Samples used after ion balance / Total number of samples; Error = ±10%													

Based on hardness, it may be inferred that majority of the spring water samples are soft barring few stray results.

Tables 7.23 & 7.24 show that in general, the spring water sample belongs to the excellent to good category while a few samples fall within permissible category.

Table 7.23: Classification based upon percent Sodium

District	Excellent	Good	Permissible
Up. Subansiri	45.455	54.545	
Lr. Subansiri	8.333	41.667	50.000
Papum Pare	50.000	40.000	10.000
W. Siang	92.308	7.692	0
W. Kameng	69.231	23.077	7.692
Tawang	100.000	0	0
E. Kameng	0.000	66.667	33.330

Table 7.24: Suitability of spring water for irrigation based on sodium-adsorption-ratio

District	SAR	Excellent	Range	Good	Permissible
Upper Subansiri	S1 (<20)	100.00	0.114 to 0.524	0.00	0.00
Lower Subansiri		100.00	0.204 to 0.974	0.00	0.00
Papum Pare		100.00	0.137 to 0.682	0.00	0.00
West Siang		100.00	0.066 to 0.338	0.00	0.00
West Kameng		100.00	0.087 to 7.913	0.00	0.00
Tawang		100.00	0.137 to 0.210	0.00	0.00
East Kameng		100.00	0.677 to 0.704	0.00	0.00

The cation triangle in Piper plot indicates that for most of the ground water samples from different aquifers, the relative proportion of alkaline earth (Ca+Mg) is high compared to the proportions of alkalis (Na+K) barring few samples. However, similarly, for the anions plot, the relative proportions of bicarbonate (HCO_3) are high, while chloride (Cl) and sulphate (SO_4) are absent or low. From Piper tri-linear diagram (Fig 7.7) and also from the Table 7.25, it can be interpreted that the ground water from shallow and deeper aquifers is, in general, of HCO_3-CO_3 types which indicates that the groundwater in both shallow and deeper and shallow aquifers may be of younger evolution and may be formed through the recharge from rainfall in recent time. The chemical data of ground water presented in Table 7.26 also indicates that water is fairly fresh with low electrical conductivity (EC) and total dissolved solids (TDS) and it has not travelled for a long distance within the aquifer. Although the ground water samples are fresh and worthy for usage for all purposes, still it may further be noted that the deeper aquifer samples in several occasions possess Fe (Iron) beyond permissible limit, while the shallow aquifer possesses Fe below permissible limit and hence, the shallow aquifer water may be designated as excellent for all types of uses.

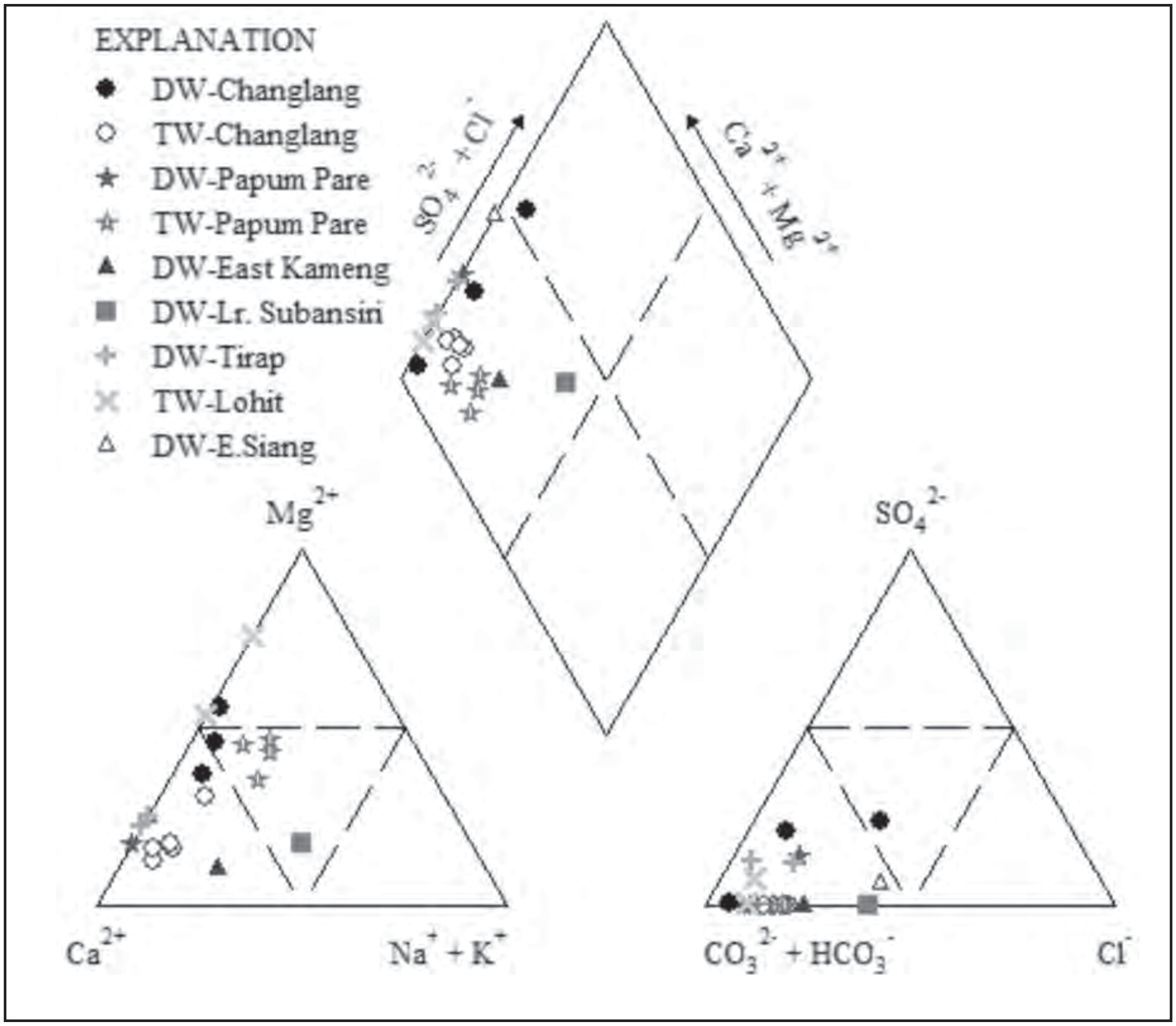


Fig. 7.7: Piper plot of shallow and deeper aquifer waters

Table 7.25: Characterization of ground water of dug and tube well of Himalaya on the basis of Piper-trilinear diagram

Subdivision of Piper	Papum Pare		East Kameng	Lower Subansiri	Lohit	East Siang
	Dug Well	Tube Well	Dug Well	Dug Well	Tube Well	Dug Well
1	100	100	100	100	100	100
2	0	0	0	0	100	90
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0

Table 7.26: Chemical analysis data of ground water collected from dug wells and tube wells

District	Type of well	pH	EC (µS/cm)			mq/l										
				TDS	TH	Ca	Mg	Na	K	Fe	F	CO_3	HCO_3	Cl	SO_4	NO_3
Lower Subansiri	DW	7.0 -7.9	113-316	72	15-85	0.1996	0.08226	0.174	0.026	0	0.00	0	0.295	0.197	0	0.000
East Kameng	DW	7.0	137	80	30	0.499	0.08226	0.087	0.102	0.009	0.00	0	0.606	0.197	0	0.008
East Siang	DW	7.7	156	102	65	0.998	0.329	0.000	0.000	0.009	0.009	0	0.688	0.508	0.083	0.000
Papum Pare	DW	8.1	257	167	70	1.1976	0.247	0.000	0.000	0.009	0.004	0	1.787	0.395	0.354	0.000
Changlang	TW	7.60-8.00	260-280	166-179	50-80	1.048-2.595	0.329-0.550	0.174-0.218	0.026	0.05-0.07		0	1.639-2.131	0.282-0.423	0	0.009-0.01
Papum Pare	TW	6.89-7.70	90-278	100-480	43-135	0.699-1.297	0.658-1.398	0.348-0.392	0.0-0.051	0.08-0.27		0	1.295-2.606	0.197-0.310	0	0.001-0.016
Lohit	TW			124		0.499-0.798	0.905-1.563	0.000	0.0	0.32		0	1.901-2.00	0.200	0.021-0.187	0.000

It may be inferred that majority of the water samples from both the aquifers are soft to moderately soft barring few stray results of hard water in shallow aquifers.

Table 7.27 shows that all ground water samples both from shallow and deeper aquifers belong to the excellent to good category and are suitable for irrigation.

Table 7.27: Classification based upon percent Sodium

District	Type of well	Water Class based of Na%	
		Excellent	Good
		<20	20-40
Lower Subansiri	DW	0	100
East Kameng	DW	0	100
Papum Pare	TW	50	50

Based upon SAR value the aquifer water samples are designated as excellent from the shallow and deeper horizons. The data are presented in the following Table 7.28.

Table 7.28: Suitability of Ground water for irrigation based on SAR

District	Type of well	Calculated SAR	SAR	Salinity hazard	Water class
Lower Subansiri	DW	0.3754	<20	S1	Excellent
East Kameng	DW	0.5391			
Papum Pare	TW	0.337-0.408			

7.6 Ground Water Pollution Hazards in Himalayan Area

Ground water pollution, both geogenic and anthropogenic, has been reported from some places in the Himalayan terrain. The contaminations like fluoride contamination, occurrence of high iron, marshy gases in ground water and to some extent nitrate contamination are found to occur in ground water, which have already been discussed. Marshy gases especially the flammable gas which is derived from underground biochemical processes is encountered in deep tube wells.

Dissolved nitrogen in the form of NO_3 is the most common contaminant of ground water. Nitrates consumed over a very long period of time by human being may cause harmful health hazards. The anthropogenic sources of nitrates are landfills, industrial wastes, sewage and animal wastes and agricultural sources. Nitrate pollution is observed from various localities in J & K, in parts of Himachal Pradesh and Uttarakhand.

Table 7.29: Nitrate distribution in J & K state.

Kashmir Region

Sr. No.	Nitrate Concentration	Type of Sample	Anantnag	Baramulla	Budgam	Kupwara	Pulwama	Srinagar
1	< 45 mg/l	Spring	40(100%)	4(100%)	0	4(100%)	23(100%)	10(100%)
		Shallow	13(100%)	31(93.9%)	0	30(93.7%)	22(95.6%)	11(84.6%)
		Deep	0	12(100%)	5(83.4%)	7(100%)	17(100%)	17(94.4%)
2	45-100 mg/l	Spring	0	0	0	0	0	0
		Shallow	0	2(6.1%)	0	2(6.3%)	0	2(15.4%)
		Deep	0	0	1(16.6%)	0	0	1(5.6%)
3	> 100	Spring	0	0	0	0	0	0
		Shallow	0	0	0	0	1(4.4%)	0
		Deep	0	0	0	0	0	0

Jammu Region

Sr. No.	Nitrate Concentration	Type of Sample	Doda	Jammu	Kathua	Poonch	Rajouri	Udhampur
1	< 45 mg/l	Spring	53(98.1%)	0	21(100%)	0	30(100%)	53(100%)
		Shallow	0	42(80.7%)	75(90.4%)	0	23(92%)	46(97.8%)
		Deep	39(88.6%)	37(100%)	20(100%)	0	0	25(100%)
2	45-100 mg/l	Spring	1(1.9%)	0	0	0	0	1(2.2%)
		Shallow	0	8(15.5%)	7(8.4%)	0	1(4.0%)	0
		Deep	3(6.8%)	0	0	0	0	0
3	> 100	Spring	0	0	0	0	0	0
		Shallow	0	2(3.8%)	1(1.2%)	0	1(4.0%)	0
		Deep	2(4.6%)	0	0	0	0	0

Ladakh Region

Sr.No.	Nitrate Concentration	Type of Sample	Kargil	Leh
1	< 45 mg/l	Spring	54(100%)	64(100%)
		Shallow	0	0
		Deep	14(100%)	25(100%)
2	45-100 mg/l	Spring	0	0
		Shallow	0	0
		Deep	0	0
3	> 100	Spring	0	0
		Shallow	0	0
		Deep	0	0

High nitrate concentration has been observed in shallow aquifers to the tune of 274-394 mg/l and in the deeper aquifers ranging between 135 & 139 mg/l. Highest concentration of 394 mg/l has been observed in Pampore area of Pulwama district of Jammu & Kashmir State. Spring water is relatively fresh Table 7.29.

Nitrate contamination in ground water

In Himachal Pradesh, nitrate concentration of water samples collected from GWMW in Una district and from tube well at Mogi Nand in Sirmaur district is reported as 135 and 104 mg/l (above permissible limit of 45 mg/l) respectively. Nitrate concentration in spring water is also found high to the tune of 50-105 mg/l, collected from Simla & Mandi districts.

In Uttarakhand, nitrate more than the acceptable limit of 45 mg/L is observed along a narrow, elongated zone in the west central part of Doon Valley in Dehradun district along Kanwali-Ramgarh-Sabhawala-Dharmawala-Judli belt, which is attributed to anthropogenic contamination in and around the dug wells, almost all of which are presently not in use. Similarly, high nitrate is also found around Missarpur-Dhanpura area and around Bugawala-Shahidwala Grant area in Haridwar district, which again is observed in open and unused/less frequently used dug wells from which ground water samples were collected. Another dug well at Kichha, Udham Singh Nagar district has shown nitrate >45 mg/L and is also due to the unhygienic practices of local populace in and around the well. It is observed that people were not using many of these dug wells in recent years (thereby rendering these dug wells as either abandoned or defunct) and are increasingly using piped either water supply or hand pumps for drinking and domestic purpose. It is recommended that the open dug wells where high nitrate is observed (in parts of Dehradun, Haridwar and Udham Singh Nagar district) should not be used and pipeline water (properly treated and chlorinated) should be used instead for drinking purpose in these areas.

Fluoride contamination in ground water

Fluoride is one of the minor constituents in ground water normally present in low concentrations, but plays a very important role in evaluating of water quality for potable purpose. The fluoride content in water, even though in low concentrations, is completely absorbed by living organisms. Fluoride after certain limits acts as toxic substance and hazardous for living organisms. The most important health related problems due to excess of fluoride are dental carries, mottling of teeth, cumulative fluorosis causing skeletal damage and deformation in adults and children.

Fluoride pollution is observed from various localities in J & K State and in hot spring water of Himachal Pradesh Table 7.30.

Table 7.30: Fluoride distribution in ground water based on no. of samples analysed In J & K State

Jammu Region

			Doda	Jammu	Kathua	Poonch	Rajouri	Udhampur
1	< 1.0 mg/l	Spring	52(96.3%)	0	21(100%)	0	0	53(100%)
		Shallow	0	52(100%)	82(98.8%)	0	24(96%)	47(100%)
		Deep	29(65.9%)	37(100%)	20(100%)	0	0	24(96%)
2	1.0 - 1.50 mg/l	Spring	0	0	0	0	0	0
		Shallow	0	0	1(1.2%)	0	0	0
		Deep	3(6.8%)	0	0	0	0	0
3	> 1.50 mg/l	Spring	2(3.7%)	0	0	0	1	0
		Shallow	0	0	0	0	1(4.0%)	0
		Deep	12(27.3%)	0	0	0	0	1(4.0%)

Ladakh Region

			Kargil	Leh
1	< 1.0 mg/l	Spring	52(98%)	62(95.4%)
		Shallow	13(100%)	25(96.1%)
		Deep	0	0
2	1.0 - 1.50 mg/l	Spring	1 (2%)	0
		Shallow	0	0
		Deep	0	0
3	> 1.50 mg/l	Spring	0	3 (4.6%)
		Shallow	0	0
		Deep	0	1(3.9%)

High Fluoride in ground water is observed in spring water (3 mg/l) in Jammu Region and as high as 12 mg/l in Ladakh Region. The aquifers are also having marginally high concentration of fluoride in Jammu and Ladakh Regions.

In Himachal Pradesh, high concentration of fluoride is found in hot spring water in Simla, Mandi and Lahaul & Spiti districts and the concentration ranges from 1.0 to 4.0 mg/l. In Simla, tube well water is also having marginally higher concentration to the tune of 1.0-1.60 mg/l. In other States in Himalayan area, higher concentration of fluoride has not been reported.

High Iron in ground water

Iron is the essential micro-nutrient for biotic population. Iron may be present in natural sources in igneous rocks, amphiboles, ferro-manganate soils and in combined form i.e. as iron sulphide, iron sulphite, magnetite, iron oxide etc. It may be constituent of sandstone rocks, oxides, carbonates, sulphides or iron clay minerals. The iron is one of the less toxic pollutant in water and its presence has been observed in natural water in appreciable quantities. The high iron concentration in untreated ground water may turn its taste different and may be rejected by consumer public. The ground water with high iron content cause staining of clothes, while washing and imparts a bitter stringent taste to it.

High iron levels in groundwater are widely reported from Jammu & Kashmir State, especially from Kashmir valley and Sikkim State (iron concentration in Sikkim is as high as 20 mg/l).

The areas where iron concentrations in ground water more than the permissible limit in J& K State are shown in Table 7.31.

Table 7.31: District wise high Iron concentration in ground water in J & K State

Sl. No.	District	Location	Iron (mg/l)
1	Doda	Safapani	1.70
2		Kotri	1.76
3		Ramban	1.34
4		Dharmund	1.86
5		Sanghaldhan	2.72
6		Sirlan	1.68

7		Lamber	1.26
8	Jammu	Lam	2.53
9		NavaKhu	9.75
10		Tandaseeda	1.26
11		Chowki chora	1.65
12		Nikowal	12.2
13		Didyal	1.1
14		Raiyan	1.65
15		Swankha	1.44
16	Kathua	Parnala	16.0
17		Billawar	2.88
18		Sallan	1.63
19		Mandli	7.25
20		Nagri	7.50
21		Lakhanpur	2.72
22		Mahichak	1.67
23		Chira	2.56
24		Kandhamun	2.1
25		Sandhar	1.21
26	Rajouri	Kalal	7.70
27		Sasalkot	4.35
28		Chhani parat	2.60
29		Bhamla	1.83
30	Udhampur	Salabara	2.70
31		Chani mansar	2.06
32		Dehrai	5.1
33		Ramnagar	17.0
34		Khera Lahir	2.01
35		Kanthan	11.0
36		Mangrauli	1.50
37	Baramulla	Ghoshbug	5.40
38		Renji hamray	4.37
39		Khanpora	6.32
40		Trikulbal	5.10
41	Budgam	Khag Malpura	11.60
42		Mamet	12.8
43		Humhama	1.45
44	Kupwara	Badar Payeen	1.65

45	Pulwama	Dangarpur	1.12
46		Wuyan	1.50
47		Shar shali	2.87
48		Lilihar	2.67
49		Kandarbal	2.28
50		Sadipur	5.72
51		Festapur	2.32
52		Green colony Wuyan	3..0
53		Jaubran	1.51
54	Srinagar	Iqbal park	4.17
55		Upper Athwajan	3.36
56		Upper Ishber	6.60
57	Kargil	West of Silma	5.10
58		Mangmur village	1.50

Demarcation of gaseous aquifers

Marshy gases especially the inflammable gas which is derived from underground biochemical processes is encountered in deep tubewells of J & K State. It is reported from the private drilling units engaged in drilling of tubewells in Kashmir valley that during the time of assembly fabrication and lowering fires had occurred resulting into loss to human life and material. Based on the data collected from CGWB exploration, the areal extent of occurrence of gaseous aquifers are demarcated which extends from the confluence of Mwar nala with that of Pohru river in the north to Achabal, Sopore, Haigam, Gund Jahangir in the east. The methane gas is a decomposition product of buried plants and animal matter in Karewa formations. The minimum concentration of methane in water is sufficient to produce an explosive methane-air mixture above the water from which, it bubbles out and depends on the temperature, pressure, quantity of water pumped and volume of air into which the gas evolves. During electrical logging of borehole drilled by CGWB, the presence of marshy gases is clearly shown by disturbances in electrical log, especially resistivity log. The safety measures include adequate ventilation and precaution during the assembly lowering.

Presence of Heavy Metals

Distribution of heavy metals in ground water is studied in Jammu, Kathua and Pulwama districts in J & K State (Table 7.32, 7.33 & 7.34), and it is observed that distribution of heavy metals in the ground water of these three districts is below permissible limits of BIS, except manganese in shallow ground water in few dug wells of Kathua district where it is found more than permissible limit (0.3 mg/l).

Table 7.32: MINIMUM AND MAXIMUM VALUE OF TRACE ELEMENTS IN GROUND WATER AND EFFLUENT SAMPLE INDUSTRIAL AREA OF JAMMU DISTRICT

(All the concentration expressed in mg/l)

Sr. No.	Heavy Metals	Bari Brahmana		Bari Brahmana Industrial area effluent samples and Nallah		PHE & MES Deep tubewell samples		SIDCO Deep tubewell samples		From Miscellaneous Sources		Gangyal Dep tubewell samples		Gangyal effluent & nallah samples industrial area		BIS Standard IS: 10,500, 1991	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1	Zinc	0.011	0.3	0.015	2.503	0.031	1.422	0.06	0.44	0.066	0.882	0.043	0.12	0	14.568	5	15
2	Mangnese	0	0.502	0.013	2.063	0.01	0.033	0.006	0.188	0.044	0.888	0.004	0.02	0	0.623	0.1	0.3
3	Chromium	0	0.013	0	0.049	0.009	0.016	0.005	0.01	0	0.006	0.003	0.009	0	0.011	0.05	-
4	Strontium	0	0.439	0.011	0.559	0.304	0.466	0.175	0.286	0.195	0.366	0.28	0.452	0.028	0.567	-	1
5	Iron	0.032	1.028	0.145	5.036	0.125	0.223	0.124	2.042	0.274	1.757	0.063	0.189	0	7.939	0.3	1
6	Copper	0.004	0.046	0.001	0.318	0.002	0.11	0.004	0.024	0.005	0.03	0.003	0.02	3	0.298	0.05	15
7	Cadmium	0	0.01	0.001	0.011	0.002	0.003	0.002	0.004	0.001	0.004	0.002	0.004	0	0.01	0.01	
8	Lead	0	0.142	0	0.167	0.013	0.039	0.027	0.062	0.016	0.102	0.033	0.056	0	0.146	0.05	-
9	Nickel	0.004	0.045	0	3.16	0.016	0.024	0.017	0.032	0.013	0.058	0.017	0.028	4	0.094	-	

Table 7.33: Minimum and Maximum Value of Trace Elements in Ground Water Samples of Kathua District

Concentration in mg/l

Sl. No.	Heavy Metals	Surface Water		Shallow aquifer (hand pump)		Shallow aquifer (Dug well)		Deep Aquifer (Tube well)		BIS Standard IS: 10,500, 1991	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1	Zinc	nd	0.029	0.025	0.33	nd	1.588	0.05	0.112	5	15
2	Manganese	0.017	0.085	nd	0.386	nd	2.294	nd	0.099	0.1	0.3
3	Chromium	nd	0.005	nd	0.061	nd	0.061	nd	0.002	0.05	-
4	Strontium	ND	ND	ND	ND	ND	ND	ND	ND	-	1
5	Iron	ND	ND	ND	ND	ND	ND	ND	ND	0.3	1
6	Copper	nd	nd	nd	0.01	nd	0.05	nd	0.1	0.05	15
7	Cadmium	nd	nd	nd	nd	nd	nd	nd	nd	0.01	-
8	Lead	0.003	0.017	nd	0.042	0.002	0.028	nd	0.013	0.05	-
9	Nickel	nd	nd	nd	0.11	0.01	0.13	nd	nd		-

Table 7.34: Minimum and Maximum Value Of Trace Elements in Ground Water Samples of Pulwama District

(All the concentration expressed in mg/l)

Sr. No.	Heavy Metals	Shallow aquifer (DugWell)		Deep Aquifer (Tube well)		IS: 10500, 1991 BIS Standard	
		Min.	Max.	Min.	Max.	Min.	Max.
1	Zinc	nd	0.05	nd	0.008	5	15
2	Magnese	nd	0.006	nd	0.092	0.1	0.3
3	Chromium	nd	0.033	nd	0.05	0.05	-
4	Strontium	ND	ND	ND	ND	-	1
5	Iron	ND	ND	ND	ND	0.3	1
6	Copper	0.001	0.009	0.003	0.025	0.05	15
7	Cadmium	nd	nd	nd	nd	0.01	-
8	Lead	nd	0.014	nd	0.012	0.05	-
9	Nickel	0.102	0.132	0.108	0.123	-	-

7.7 Hydrochemistry of North Eastern States contiguous to Himalayan Region

In general, chemical quality of ground water in the North Eastern States, contiguous to Himalayan Region, is found to be good and potable, except higher concentration of Iron (beyond permissible limit of I mg/l), Fluoride (beyond permissible limit of 1 mg/l) and Arsenic (above permissible limit of 0.01 mg/l) in parts of North Eastern States. State wise details are as under:

7.7.1 Assam

In the state of Assam, in general, the quality of ground water is suitable for both domestic and irrigation purposes. Concentrations of different chemical constituents are within permissible limit. However, concentration of some constituents exceeds permissible limit in few pockets.

- EC value ranges from 44 to 784 micro Siemens /cm at 25°C.
- pH is an important factor in determining the chemical and biological properties of water. In the area, pH ranges between 5.70 & 9.50, which indicates that ground water is almost neutral to feebly alkaline in nature and within permissible limit for drinking.

- Iron concentration exceeds permissible limit in most of the districts of Assam. It ranges from below detection limit (BDL) to 14.69 mg/l. It has been observed that iron concentration is more in low level terrace deposits which are semi-lateritised and contribute to such excess iron content due to geochemical changes involved in lateritisation and pedogenesis. The low iron concentration trend is observed along the major recent river flood plains. The removal of high Iron content may be done by using Iron removal filter (aeration method) for both community and individual use.

- Chloride concentration of the ground water ranges between 3.54 to 113 ppm. Natural water which is being replenished every year directly from rain water together with drainage facilities does not obviously permit enrichment of chloride in ground water.

- Concentration of Carbonate was found below detection limit to 39 ppm.

- Fluoride content in ground water in parts of Karbi Anglong, Nagaon and Kamrup districts exceeds the permissible limit of 1 ppm and ranges upto 4.16 ppm. In Fluoride affected areas, it is suggested to use alternate source of water. It was found that in most of the cases, deeper aquifer is free from high Fluoride content.

- Arsenic contamination above permissible limit of 0.01 mg/l has been found to occur in shallow aquifers in parts of Dhemaji district and Majuli area of Jorhat district. The maximum concentration of 0.09 mg/l has been recorded. Arsenic free ground water (possibly deeper aquifer) may be explored for drinking purpose. Aquifer augmentation by surface water can also be explored.

7.7.2 Manipur

Ground water quality analysis in the state of Manipur shows that in general, the Ground Water is suitable for both drinking and irrigation purposes. It reveals that pH value, Electrical conductance and Bi-Carbonate contents range from 6.73 to 7.42, 580 to 1021 µS/cm at 25^{o}C and 305 to 578 mg/l respectively. All parameters are within the permissible limits.

Arsenic concentration above permissible limit in shallow ground water has also been reported from Thoubal and Bishnupur districts of Manipur valley. Chemical analysis of water samples showed that arsenic concentration varies from 0.1776 to 0.4994 mg/l. Arsenic free ground water may be obtained in deeper aquifers and from surface water which needs to be explored.

Except a few local patchy occurrences of Arsenic and Iron, ground water is potable, and good for domestic, agricultural and industrial uses.

7.7.3 Meghalaya

In general, chemical quality of ground water in the state of Meghalaya is found to be good and potable. The range of concentration of different chemical constituents in ground water is as under:

- EC value ranges from 33 to 647 micro Siemens /cm at 25^{o}C, which indicates the freshness and potable nature of water.
- pH value in ground water varies from 6.48 to 7.95 which are within permissible limit.
- Carbonate concentration is found below detection limit.

- Bicarbonate varies from 6.15 to 196 mg/l.
- Chloride content ranges between 3.54 to 42 mg/l. This is well within the permissible limit.
- Fluoride concentration ranges from BDL to 0.54 mg/l in deeper aquifers, which is well within the permissible limit of 1.0 mg/l.
- Calcium (02-46 mg/l) and Magnesium (1.2-10.93 mg/l) presence in the water sample is within the permissible.
- The total hardness of the analyzed water samples varies from 15 to 180 mg/l.
- Concentration of Iron ranges from below detection (BDL) limit to 3.30 mg/l which is beyond permissible limit.

7.7.4 Mizoram

In general, chemical quality of ground water in the state of Mizoram is very good and potable and it can be utilized for agricultural and industrial uses. The range of different chemical parameters of ground water, mainly collected from shallow aquifers, is as below:

- pH varies from 7.11 to 7.88.
- Electrical Conductance ranges from 72 to 348 micromhos/cm at 25^{o}C.
- Fluoride varies from 0.1 to 1.22 mg/l and is within permissible limit.

Ground water of Mizoram state is deficient in iodine, which leads to goitre. Hence, it is recommended to use iodized salt.

7.7.5 Nagaland

In general chemical quality of ground water in the state of Nagaland is found to be good and potable for domestic, agricultural and industrial uses. The major chemical parameters like pH, Electrical Conductivity, Chloride, Fluoride, Iron etc are within permissible limit of BIS drinking water. The range of different chemical parameters is as under:

- pH varies from 6.66 to 7.7.
- Electrical Conductance ranges from 105 to 930 micromhos/cm at 25^{o}C.
- Fluoride varies from 0.03 to 1.04 mg/L and is within permissible limit.
- Iron content in ground water varies from 0.02 to 0.75, which is well within the permissible limit.

7.7.6 Tripura

A study of the analytical results of the water samples collected both from the water table aquifers and deeper aquifers indicate that there is no considerable difference between quality of ground water from water table aquifers and deeper aquifers. The range of major chemical constituents is as under:

- The pH values of the ground water ranges from 6.42 to 8.50. The waters are slightly alkaline in nature.
- Specific conductance of ground water in the state varies from 40-741 micro siemens /cm at 25°C.
- Carbonate content varies from 09-18 mg/l in ground water but at a few places, it occurs in negligible quantities.

- Bicarbonate content of the ground water in the state ranges from 24 to 264 mg/l. Bicarbonate is the chief source contributing to the alkalinity of the waters.
- Sulphate concentration is comparatively low and ranges from BDL to 33 mg/l. This low concentration of Sulphate indicates that water is of recharging type.
- Chloride content of the water in general ranges from 10 to 113 mg/l.
- Calcium and Magnesium in the form of carbonate and bicarbonate presence in the water sample is within the permissible range. Thus, the ground water of the state is generally soft.
- Fluoride concentration ranges from 0.01-0.98 mg/l and is within the permissible limit.
- Iron concentration ranges from 0.04 to 6.12 mg/l and as high as 10.0 mg/l.

8.0 GROUND WATER RESOURCE POTENTIAL

The states of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Darjeeling District of West Bengal and Arunachal Pradesh constituting the Indian counterpart of the Himalayas, mostly represent the hills and mountains having higher topographical gradient where surface run off component is always much greater than the groundwater infiltration. However, presence of numerous springs, weathered material in hill slopes and success of groundwater drilling in mountainous areas, corroborate the occurrence of groundwater even at higher altitudes with high slopes. As groundwater resources form an integral part of water resources development for an overall development of any state or country, it is obligatory to deduce the groundwater resources of these hilly mountainous states of the Himalayas in Indian subcontinent for planned development of the vital groundwater resources.

Groundwater resources and irrigation potential for the given state have been computed based upon the methodology suggested by Groundwater Estimation Committee constituted by the Ministry of Water Resources, Government of India. The methodology is known as Groundwater Estimation Methodology 1997 (GEC-97). Two approaches are recommended for computation of Groundwater Resources viz. Water level fluctuation method (WLF) and Rainfall infiltration method (RIF). As per the GEC-97 norms, the areas having more than 20% slopes are not considered suitable for ground water recharge. Consequently, a lion's share of the Himalayan states is considered unsuitable for ground water recharge and the groundwater resources arrived at through calculations are at the low key. State wise Groundwater resources for the entire country have been estimated as on 2009. As on March 2009, the net Ground Water Availability in the Himalayas is 1012288.4 hectare metres (ham), while the existing Gross Ground Water Draft for All Uses comes to 247466 ham. The stage of Ground Water Development in the Himalayas varies from 0.066 in Arunachal Pradesh to 66.33 % in Uttarakhand. The overall stage of groundwater development in Himalayas is 28.80%. In Himalayas, groundwater development has yet to gain popularity barring a few valleys and the foothills. Accessibility and paucity of terrain worthy rigs are the root causes of poor groundwater development. Success of groundwater exploration in Sikkim and Ladakh has proved the potentiality of aquifers even at higher altitude. The figure of groundwater development in the Himalayas, as shown above, is generated due to the development of the resources through construction of the dug wells and tube wells in the foothills and valleys. The respective groundwater resources of the states incorporated in Himalayas are described below.

8.1 Jammu and Kashmir

As indicated earlier, the ground water resource estimation in the state is confined to the valley area only. The estimated ground water resources of the state are given in Table 8.1.

Table 8.1: Ground water resources of Jammu & Kashmir (As on 2009)

S. No.	Assessment Unit/ District	Valley Area (hect)	Net Ground Water Availability (ham)	Existing Gross Ground Water Draft for All Uses (ham)	Stage of Ground Water Development (%)
1	Jammu Jammu District	200000	83819.29	19142.80	22.83
2	Kathua Kathua District	87500	35495.40	6721.60	18.93
3	Srinagar Srinagar District	55000	14895.40	9277.00	62.28

4	Anantnag Anantnag District	75000	45645.96	4860.60	10.64
5	Baramula Baramula District	120000	46117.79	4544.80	9.85
6	Badgam Badgam Distrcit	85000	25182.88	7532.20	29.91
7	Pulwama Pulwama District	105000	27999.48	7680.00	27.42
8	Kupwara Kupwara District	60000	18970.63	4472.40	23.57
9	Udhampur Udhampur District	10000	5487.20	2064.00	37.61
10	Rajauri Rajauri District	35000	10625.09	3632.70	34.18
11	PoonchPoonch District	20000	7025.92	2314.50	32.94
12	Doda Doda District	10000	5338.17	1009.20	18.90
13	Kargil Kargil District	10000	1552.75	132.00	8.50
14	Leh*Leh District	110000	4403.27	58.80	1.33
	Total	**982500**	**332559.23**	**73442.60**	**21.97**

* In Leh district 4271500 ha of total area is illegally occupied by China.

The stage of ground water development in the Jammu and Kashmir Himalaya varies from 1.33% in Leh Valley to 62.28% in Srinagar valley. The entire valley area in the Jammu and Kashmir state falls under the safe category and overall stage of ground water development of the State is 21.97%.

8.2 Himachal Pradesh

The ground water resource estimation in the state has been assessed for the valley areas. Details are given in Table 8.2.

Table 8.2: Ground water resources of Himachal Pradesh (As on 2009)

S. No.	Assessment Unit/ District	Valley Area (hect)	Net Ground Water Availability (ham)	Existing Gross Ground Water Draft for All Uses (ham)	Stage of Ground Water Development (%)
1	Indora valley Kangra District	26545	9833.24	4918.03	50.01
2	Nurpur valley Kangra District	23775	8627.32	3143.45	36.44
3	Balh valley Mandi District	9500	2903.36	810.02	27.90
4	Paonta valley Sirmaur District	15627	7482.32	2042.95	27.30
5	Kala Amb valley Sirmaur District	250	126.41	314.22	248.57
6	Nalagarh valley Solan District	23849	7753.24	3932.37	50.72
7	Una valley Una District	49300	15879.04	15502.46	97.63
8	Hum valley Una District	2200	526.86	350.72	66.57
	Total	**151046**	**53131.79**	**31014.22**	**58.39**

The stage of ground water development in Himachal Himalaya varies from 27.30% in Paonta valley to 249% in Kala Amb. Kala Amb valley falls under ‘Overexploited’ and Una Valley falls in ‘Critical’ category. The overall stage of Ground Water development in the state is 58.39%.

8.3 Uttarakhand

Blocks have been taken as the assessment unit for resource estimation in the state. The block wise break up of the resource estimation is given in Table 8.3.

Table 8.3: Ground water resources of Uttarakhand (As on 2009)

S. No.	Assessment Unit/ District	Valley Area (hect)	Net Ground Water Availability (ham)	Existing Gross Ground Water Draft for All Uses (ham)	Stage of Ground Water Development %
1	Doiwala Block Dehradoon District	51057	25572.57	1349.98	5.27
2	Sahaspur Block Dehradoon District	52061	25791.90	1686.03	6.53
3	Bahadrabad Block Hardwar District	33763	20185.42	14440.0	71.54
4	Bhagwanpur Block Hardwar District	31537	12717.39	16966.57	133.41
5	Gurukul Narsan Block Hardwar District	23107	19056.55	15715.60	82.47
6	Laksar Block Hardwar District	27778	13025.18	18565.26	142.53
7	Roorkee Block Hardwar District	22836	18109.15	15758.6	87.02
8	Khanpur Block Hardwar District	17814	4625.91	3117.86	67.39
9	Gadarpur Block Udham Singh Nagar District	23326	7226.31	5256.68	72.74
10	Sitarganj Block Udham Singh Nagar District	33254	10960.79	7629.64	69.60
11	Rudrapur Block Udham Singh Nagar District	31153	7880.80	6838.26	86.77
12	Jaspur Block Udham Singh Nagar District	23229	8868.06	6836.73	77.09
13	Bazpur Block Udham Singh Nagar District	28646	8151.94	6905.15	84.70
14	Kashipur Block Udham Singh Nagar District	18517	7331.68	6179.41	84.28
15	Khatima Block Udham Singh Nagar District	35157	11586.26	9561.40	82.52
16	Ramnagar Block Nainital District	12366	3481.20	1117.10	32.08
17	Haldwani Block Nainital District	11277	5338.71	1317.41	24.67
	Total	**476878**	**209909.8**	**139241.7**	**66.33**

The stage of ground water development in the Uttarakhand Himalaya varies from 5.27% (Doiwala Block) to 142.53 % (Laksar Block). All the blocks fall under 'Safe category' except Bhagwanpur and Laksar blocks which fall under 'Over exploited' and Bahadrabad, Gurukul Narsan and Roorkee blocks, which fall under 'Semi critical' category. The overall stage of ground water development of the state is 66.33%.

8.4 Sikkim State

The ground water resource estimation of Sikkim state has been done considering the districts as assessment unit. District wise details are given in Table 8.4.

Table 8.4: Ground water resources of Sikkim (As on 2009)

S. No.	Assessment Unit/ District	Valley Area (hect)	Net Ground Water Availability (ham)	Existing Gross Ground Water Draft for All Uses (ham)	Stage of Ground Water Development %
1	East Sikkim District	422600	805.00	437.00	54.30
2	North Sikkim District	75000	250.00	56.00	22.25
3	South Sikkim District	95400	1365.00	264.00	19.35
4	West Sikkim District	116600	2205.00	195.00	8.84
	Total	**709600**	**4625.00**	**953.00**	**20.60**

The stage of ground water development of Sikkim Himalaya ranges from 8.84% (West Sikkim district) to 54.30% (East Sikkim district). The overall stage of ground water development of the Sikkim Himalaya is 20.60%. All the districts fall under 'safe' category.

8.5 Foothill part of Darjeeling District

The groundwater resources of the hilly parts of Darjeeling are not computed. However,the ground water resources estimation of the Foothill portion of Darjeeling District has been done on the basis of district taking blocks as the assessment unit. The details are furnished in Table 8.5.

Table 8.5: Ground water resources of foothill part of Darjeeling district (As on 2009)

S. No.	Assessment Unit/ District	Valley Area (hect)	Net Ground Water Availability (ham)	Existing Gross Ground Water Draft for All Uses (ham)	Stage of Ground Water Development %
1	Kharibari-Phansidewa Block Darjeeling District	48006	26316.41	1894.63	7.2
2	Siliguri-Naksalbari Block Darjeeling District	36798	20744.03	677.55	3.27
	Total	**84804**	**47060.44**	**2572.18**	**5.47**

The stage of ground water development in the foothill areas of Darjeeling area varies from 7.2 to 3.27 %. Both the blocks fall under 'Safe category'.

8.6 Arunachal Pradesh

The ground water resource estimation of the area under Arunachal Himalaya has been done on the basis of district as an assessment unit due to paucity of block-wise data. The ground water resource potential of the remaining five districts namely Upper Siang, Anjaw, Dibang Valley, Kurung Kumey and Tawang could not be estimated due to paucity of data. District wise details of Arunachal Himalaya are given in Table 8.6.

Table 8.6: Ground water resources of Arunachal Pradesh (As on 2009)

S. No.	Assessment Unit/ District	Valley Area (hect)	Net Ground Water Availability (ham)	Existing Gross Ground Water Draft for All Uses (ham)	Stage of Ground Water Development %
1	Lohit District	200000	175032.00	5.30	0.003
2	Lower Dibang valley Dibang District	120000	85536.00	33.50	0.039
3	East Siang District	84025	66399.58	70.60	0.106
4	West Siang District	10459	5571.62	0.00	0.000
5	East Kameng District	31250	15213.83	15.00	0.099
6	West Kameng District	6175	2152.33	0.00	0.000
7	Lower Subansiri District	10135	2307.82	5.00	0.217
8	Upper Subansiri District	700	299.38	0.00	0.000
9	Papum Pare District	17819	12489.67	113.50	0.910
	Total	**480563**	**365002.23**	**242.90**	**0.066**

The stage of ground water development in the state is very low which ranges from 0% (West Siang, West Kameng and Upper Subansiri district) to 0.91% (Papum Pare district). There is no draft for all uses in the West Siang, West Kameng and Upper Subansiri district. The overall stage of ground water development in the state is 0.066%. All the districts fall under 'safe' category.

8.7 Ground Water Potential of North Eastern States contiguous to Himalayan Region

Assessment of Ground Water Potential as on March 2009 has been done for the States of Assam, Tripura, Mizoram and in parts of Nagaland, Manipur and Meghalaya. Most parts of Nagaland, Manipur and Meghalaya are not suitable for ground water recharge due to hilly terrain. As on March, 2009, the Net Ground Water Availability in the North eastern States is 32.8381 BCM, while the existing Gross Ground Water Draft for All Uses comes to 6.20668 BCM. The stage of Ground Water Development in the Himalayas is varying from 0.15 in Meghalaya to 22% in Assam. The overall stage of groundwater development in Himalayas is 19%. The groundwater resources of the respective North Eastern States are as follows:

8.7.1 Assam

The Net Ground Water Availability of Assam has been worked out to be 27.81 billion cubic metres (BCM) after deducting the natural discharge during non-monsoon season. The existing gross ground water draft for all uses is 6.03 BCM of which 5.333 BCM is the gross ground water draft for irrigation use and 0.69 BCM is the gross ground water draft for domestic and industrial use. The stage of ground water development varies from 4 to 54% with overall percentage of 22%. All the districts are under 'Safe' category. District wise ground water resources are given in Table 8.7.

8.7.2 Manipur

The total area considered for the resource estimation is 2441.40 sq km, which covers Imphal West, Imphal East, Thoubal and Bishnupur districts and parts of Churachandpur district of Manipur valley. Rest of the four districts were excluded for recharge assessment due to more than 20% slope. The Net Ground Water Availability of the state has been worked out to be 0.40 BCM after

Table 8.7: Ground water resources of Assam (As on 2009)

S. No.	Assessment Unit/ District	Valley Area (hect)	Net Ground Water Availability (ham)	Existing Gross Ground Water Draft for All Uses (ham)	Stage of Ground Water Development %
1	Barpeta	324500	92318	38167	41
2	Bongaigaon	215200	135870	57766	43
3	Cachar	378600	102002	3921	4
4	Darrang	348100	166661	51161	31
5	Dibrugarh	338100	179465	26677	15
6	Dhemaji	323700	169471	14065	8
7	Dhubri	279800	163561	18112	11
8	Golaghat	350200	131624	22143	17
9	Goalpara	182400	101055	26610	26
10	Hailakandi	132700	30851	2119	7
11	Jorhat	285100	127371	17109	13
12	Kamrup	358100	166256	71597	43
13	Karbi Anglong	142800	34379	2803	8
14	Kokrajhar	353800	160970	15054	9
15	Karimganj	180900	42558	2836	7
16	Lakhimpur	227700	119815	12876	11
17	Morigaon	155100	69106	28189	41
18	Nagaon	359300	184462	71932	39
19	N.C. Hills	22200	8596	714	8
20	Nalbari	225700	84915	45728	54
21	Sibsagar	266800	131653	18704	14
22	Sonitpur	532400	235209	37647	16
23	Tinsukia	379000	143132	16697	12
	TOTAL	**2781300.21**	**602625**	**22**	
	State Total (BCM)	**27.81**	**6.03**	**22**	

Table 8.8: Ground water resources of Manipur (As on 2009)

S. No.	Assessment Unit/ District	Valley Area (hect)	Net Ground Water Availability (ham)	Existing Gross Ground Water Draft for All Uses (ham)	Stage of Ground Water Development %
1	Imphal West	45970	7789	135	2
2	Imphal East	70900	11583	42	0.36
3	Thoubal	61670	10151	101	1
4	Bishnupur	45600	7199	40	0.56
5	Churachandpur	20000	3193	85	3
	TOTAL	**244140**	**39915**	**403**	**1**
	State Total (BCM)	**2.44**	**0.40**	**0.004**	**1**

deducting the natural discharge during non-monsoon season. The existing gross ground water draft for all uses is 0.004 BCM of which 0.0033 BCM is the gross ground water draft for irrigation use and 0.0007 BCM is the gross ground water draft for domestic use. The overall stage of ground water development of Manipur is 1%. As such, all the blocks and Bishnupur and Churachandpur districts fall under Safe category. District wise details are given in Table 8.8.

8.7.3 Meghalaya

The total area considered for the resources estimation is 215781 ha, after excluding the hilly area having > 20% slope. The Net annual Ground Water Availability of the state works out to be 1.11 BCM after deducting the natural discharge during non-monsoon season. At present there is only 150 ham Ground Water draft on account of irrigation and the annual domestic draft is 0.0002 BCM, the Gross Ground Water draft for all uses is 0.002 BCM. The over-all stage of ground water development of the state is a meager 0.12%. Details are given in Table 8.9.

Table 8.9: Ground water resources of Meghalaya (As on 2009)

S. No.	Assessment Unit/ District	Valley Area (hect)	Net Ground Water Availability (ham)	Existing Gross Ground Water Draft for All Uses (ham)	Stage of Ground Water Development %
1	East Khasi Hills	67656	36242	6.0	0.02
2	West Garo Hills	34844	25965	153.55	0.59
3	East Garo Hills	22656	7316	1.76	0.02
4	Jaintia Hills	62500	34020	1.98	0.006
5	West Khasi Hills	14375	4704	2.03	0.04
6	Ri-Bhoi	10000	1966	1.25	0.06
7	South Garo Hills	3750	879	0.67	0.08
	TOTAL	**215781**	**111092**	**167.24**	**0.15**
	State Total (BCM)		**1.11**	**0.002**	**0.15**

8.7.4 Mizoram

The state of Mizoram has more than 97% of hilly area. Recharge worthy area has been calculated as 13791 ha. The Net Annual Ground Water Availability of the state works out to be 0.0395 BCM after deducting the natural discharge during non-monsoon season. The Gross Ground Water draft for all uses is 0.0004 BCM. The overall stage of ground water development of the state is a meager 1.09%. Details of ground water resources of Mizoram are given in Table 8.10.

Table 8.10: Ground water resources of Mizoram (As on 2009)

S. No.	Assessment Unit/ District	Valley Area (hect)	Net Ground Water Availability (ham)	Existing Gross Ground Water Draft for All Uses (ham)	Stage of Ground Water Development %
1	Aizawl	1173	347.61	13.69	3.94
2	Champhai	3332	729.09	5.52	0.76
3	Kolasib	1882	605.25	4.72	0.78
4	Lawngtalai	2451	731.33	5.78	0.79
5	Lunglei	1157	497.46	6.79	1.37

6	Mamit	1511	442.56	0.69	0.16
7	Saiha	1120	291.20	3.01	1.03
8	Serchipp	1165	305.09	2.90	0.95
	TOTAL	**13791**	**3949.59**	**43.10**	**1.09**
	State Total (BCM)		**0.0395**	**0.0004**	**1.09**

8.7.5 Nagaland

The total area considered for the resources estimation is 252172 ha, after excluding the hilly area having > 20% slope. The Net Ground Water Availability of the state worked out 0.38 BCM after deducting the natural discharge during non-monsoon season. The existing gross ground water draft for all uses is 0.01 BCM. The overall stage of ground water development of the state is a meager 2%. District wise details are given in table 8.11.

Table 8.11: Ground water resources of Nagaland (As on 2009)

S. No.	Assessment Unit/ District	Valley Area (hect)	Net Ground Water Availability (ham)	Existing Gross Ground Water Draft for All Uses (ham)	Stage of Ground Water Development %
1	Kohima	21360	3369	71.64	2.13
2	Dimapur	91000	15320	286.60	1.87
3	Phek	15343	2259	46.82	2.07
4	Mokokchung	27618	3981	73.41	1.84
5	Zunheboto	10940	1746	50.98	2.92
6	Wokha	22831	3891	56.67	1.46
7	Tuensang	50730	4971	133.51	2.69
8	Mon	12350	2028	82.87	4.09
	TOTAL	**252172**	**37564.92**	**802.52**	**2**
	State Total (BCM)		0.38	0.01	2

8.7.6 Tripura

The total area considered for the resources estimation is 619784 ha, after excluding the hilly area having > 20% slope. Net ground water availability in the state is of the order of 2.74 BCM. Ground

Table 8.12: Ground water resources of Tripura (As on 2009)

S. No.	Assessment Unit/ District	Valley Area (hect)	Net Ground Water Availability (ham)	Existing Gross Ground Water Draft for All Uses (ham)	Stage of Ground Water Development %
1	West Tripura	211818	101785	10415	10
2	South Tripura	200749	79687	3568	4
3	North Tripura	99365	45546	1609	4
4	Dhalai	107852	46774	760	2
	TOTAL	**619784**	**273792**	**16352**	**6**
	State Total (BCM)		2.74	0.16	6

water development is done mainly through dug wells and shallow tube wells from unconfined aquifer. The stage of ground water development in Tripura is 6%. The details are given in Table 8.12.

8.7.7 Arunachal Pradesh (Parts)

In North Eastern parts, only two districts viz. Tirap and Chenglang of Arunachal Pradesh have been considered. An area of 65500 hectares is considered to be recharge worthy. Net Annual Ground Water Availability is assessed as 0.3586 ham and existing gross ground water draft is assessed as 0.00028 ham with stage of ground water development at 0.063 %. Details are given in Table 8.13.

Table 8.13: Details of ground water resources of Tirap and Chenglang districts (As on 2009)

S. No.	Assessment Unit/ District	Valley Area (hect)	Net Ground Water Availability (ham)	Existing Gross Ground Water Draft for All Uses (ham)	Stage of Ground Water Development %
1	Tirap	12500	9900.16	2.80	0.028
2	Changlang	53000	25960.29	25.50	0.098
	TOTAL	**65500**	**35860.45**	**28.30**	**0.063**
	State Total (BCM)		0.3586	0.00028	0.063

9.0 ISSUES AND PROBLEMS IDENTIFIED IN RESPECT OF GROUND WATER DEVELOPMENT IN HIMALAYAN REGION OF INDIA

Since age old times the entire population, residing in hilly areas of the Himalayan states of India remained totally dependent on streams and spring water for drinking as well as for other domestic uses because of their habitation on hill tops and hill slopes. Various ground water structures were not in practice due to their constructional difficulties in undulating terrains. But in the present situation of growing population as also due to climatic aberration, availability of ground water in springs and streams in mountainous terrains is becoming scarce day by day. This has warranted the necessity of deciphering ground water from further deeper sources as also to make the springs and initial order stream sources more perennial adopting various scientific measures so that sustainable water supply may be continued.

In this regard, some of the important issues related to ground water development in the Himalayan areas of India have been discussed briefly in the following paragraphs.

- **Problems in conducting geophysical surveys:** To locate ground water worthy zones in virgin areas, underlain by consolidated and semi-consolidated formations, geophysical prospecting is an authentic method. High slope and undulations hinder conducting geophysical surveys in major parts of Himalayas barring the intermontane valleys and the foothills, due to non-availability of suitable electrode spacing.

- **Constraint in deploying rigs for exploration:** Because of hilly and rugged terrain condition, good road infrastructure is yet to be developed in the Himalayan states. Since most of the localities are unmotorable, it is difficult to explore the areas through ground water exploration deploying rigs. Besides, there is necessity for selection of terrain worthy rigs. It has been found that Percussion- Rotary combination rig is suitable in the foothill areas having semi-consolidated to unconsolidated formation with overlying bouldery formation. Similarly ODEX-DTH combination rigs would be suitable in the intermontane valleys and hill slopes underlain by boulders and consolidated formations.

- **Spring sustainability:** In majority of the rural as also urban areas spring sources form the backbone of drinking water supply system. Irrigation practices in the higher altitude are also mostly banking on springs or initial order streams, fed by the springs. Drying of springs and variations in discharge of springs during different seasons are being caused due to human interventions (of various land use) as also climatic change. Proper springshed development is required to tackle the situation.

- **Dispersed population**: Scattered population in Himalayas creates problem in planning of water supply system. Many of the springs are found to oocur in the hillslopes or small valleys while many times it could be seen that the demography is on the hill top.

- **Unscientific age old cultivation practices and grazing:** In many of the Himalayan States, in the hill slope, Jhum/ shifting cultivation are common method of cultivation for which deforestation is being done. Similarly grazing practices in the hills is also destroying the grassland and the bushes in the hill slopes. It affects discharge of the springs and accentuates soil erosion.

- **Deforestation due to urbanization:** Due to the impact of deforestation to negotiate with the rise in population and development of urban establishment and roads, many streams or spring sources are being dried up.

- **Anthropogenic impact on water bodies:** Unplanned urbanization along lakes, rivers and water bodies has resulted into drying up of water bodies. Besides being the sources of water supply, these water bodies act as recharging bodies to ground water. Kandi/ Bhabhar areas are facing acute shortage of water because of drying of tanks/ponds. High Karewas plateau lands are also facing shortage of water. Deep water levels exist in Kandi area and in high plateau table lands.

- **Practicing rainwater harvesting and artificial recharge to groundwater in Himalayas:** Rainwater Harvesting and Artificial Recharge are to be practiced on a larger scale in the Bhabhar areas, which act as recharging zone for Terai areas. This will help maintaining discharge/pressure head of the artesian wells. Similar practices are to be adopted in the areas of Lesser and Higher Himalayas.

- **Conservation of free flows in Artesian wells:** The artesian aquifers are required to be protected by putting sluice valves on the wells, which arrest the free flow of water. Most of the shallow artesian aquifers got dried because of the over development of ground water in the area especially in Udham Singh Nagar and Nainital District of Uttarakhand

- **Contamination of shallow aquifers:** It is observed in Uttarakhand and Himachal Pradesh that the shallow aquifer gets contaminated and gives foul smell as many industries discharge their untreated effluents directly to nearby water bodies, which affects the quality of drinking water. Ground water pollution studies are to be taken up in project mode to bring out clearer picture in realistic manner with remedial measures.

- **Disruption of water supply system in various seasons:** Some time erratic and torrential rainfall causes high siltation in seasonal nalas and spring source areas, which results into disruption in water supply system. Similarly, the storm flow along the channel also breaks the long water supply pipe lines from springs or streams. In high altitude ice formation in the pipelines during winter is a perennial problem.

- **Poor agrarian economy due to non-existence of irrigation system:** Other than rain-fed irrigation, water sources have not been developed adequately in the Himalayan areas causing one crop system in hill agriculture. The terrain condition may be a hindrance. However, rainwater harvesting practices in slopes should be prioritized.

- **Climatic change and rainfall aberration:** It has been noticed by the Scientists that the climatic change, evident through gradual rise in temperature, is resulting into recession of glaciers which in turn will retard the snow melt input to river and springs and may pose a major problem in water availability in Himalayas. Similarly erratic rainfall is also influencing reduction in natural ground water recharge and large storm flow causing flash floods and mass movements/ landslides in succession.

- **Special issues:** The area also has special issues like emanation of marshy gases from the deeper aquifers of Kashmir valley. For this information is to be passed to the concerned Department/ Ministry for exploration.

- **High iron in ground water:** Presence of iron above the permissible limit of drinking water standard, have been reported from Sikkim and Arunachal Pradesh.

- **Occurrence of high Fluoride in groundwater:** Fluoride more than the permissible limit for drinking water standard, is reported from hand pump fitted tube wells in a few pockets of Doda, Kishtwar and Ramban districts of the J&K state, constructed by the State Government.

- **Need for Mass awareness and training for the Hilly people:** Public awareness programmes regarding artificial recharging of ground water and rain water conservation for future sustainability including other issues existent in the Himalayan states are not being done adequately. These are required to be taken up expeditiously.

- **Detailed Micro-level survey/ investigations for water resources development:** Detailed micro level hydrogeological surveys are required in Lesser and Higher Himalayas with emphasis on water conservation. The emphasis is also required to be given on the identification of vulnerable sites prone to lose formation and susceptible to landslides and soil erosion.

- **Augmentation of recharge through renovation of surface water bodies:** To augment the discharge and sustainability of the springs, small surface water reservoirs have to be developed at suitable locations on higher level. The reservoir can be developed by constructing gully plugs, check dams, gabion structures etc. at suitable places. These reservoirs will not only provide surface water availability but will also help in recharging the aquifers.

- **Need for special drilling technique in Doon Valley**: In Doon Valley, boulder formation is very common where a bore hole/tube well construction is very slow and expensive and need special techniques for installation of tube wells.

- **Conservation of seepage zones:** At many places, seepage zones trickle down water to the mountain slopes where soil gets unnecessarily oversaturated all the times. These can be tapped into the storage tanks with proper construction through spring development.

- **Enacting environmental surveillance to protect water sources**: Sometimes, the upcoming infrastructure developments are also the responsible factors which affect/vanish the existing spring flow as also the water bodies. Therefore, upcoming projects have to be vetted and assessed environmentally through statutory agencies of the Government.

- **Proper drilling site selection:** The site selection for drilling operation (whether vertical/ horizontal or inclined drilling) must be ascertained in the light of Environmental Impact assessment.

10.0 STRATEGIES AND PLAN FOR GROUND WATER DEVELOPMENT IN HIMALAYAN REGION OF INDIA

In the Himalayan states of India more than 60 percent people live in the rural areas, amongst which only half of the rural population have access to clean and safe drinking water. Women folk often wake up early and walk down for several hours to fetch the water for entire day's need from distant springs. Due to degradation in the catchment areas, springs are either drying up or lose their sustainability. As a result, the villagers have to look for another perennial spring through tedious search in forest clad mountains and hills. In this situation of present crisis of water supply in Himalayan states of India, community participatory approach is necessitated in identification of water sources, to design their own water supply system and then operation and maintenance of sources. In view of the climatic aberration, besides spring development, the deeper sustainable sources of groundwater are required to be tapped through borewells and tube wells. In this regard, holistic approach should be adopted. In the following paragraphs, strategies to be adopted for development of groundwater resources in Himalayas are discussed.

Before building up the strategy to plan for augmentation of groundwater in the Himalayas, it is obligatory to know the mode of occurrence of groundwater in Himalayas.

10.1 Availability of groundwater in Himalayas

In the Himalayas groundwater occurs in various modes right from the higher Himalayas to the foothills. Groundwater occurs in perched condition in the sloping horizons which gets recharged intermittently from the rainfall in hilly areas. The aquifers in the sloping terrain are formed by colluvial boulders, pebbles, sand and clay underlain by weathered mantle of the country rocks. Thickness of the colluvium and weathered horizon varies from place to place depending mainly on the climate, rainfall and, mineralogy of the underlying rock formations. Water in this horizon remains under unconfined condition and has a higher velocity due to the topographic gradient. Bulk of the water recharged from rainfall flows in the subsurface of the perched aquifer horizon and forms subsurface storm runoff as also the base flow in the streams and rivers (Fig 10.1). The subsurface storm run-off is controlled by the extent of porosity developed in the perched formation and piping developed due to the solution activity of underground water, pre-existing voids of decayed roots, effect of burrowing organisms etc. Many of the springs in the Himalayas are generated in this zone along the slopes or in the foothills or valleys where the groundwater table cuts the ground surface. When two springs coalesce at higher altitude, they give rise to 1st order streams and two first order streams generate a second order stream and so on. Besides recharge from rainfall, the streams in Himalayas are also fed by snowmelt water.

Although it is not known to the common people, who believe that at higher altitude groundwater cannot exist, that ground water also travels along the fracture and fissure conduits in hard rocks occurring below the weathered horizon. This groundwater at deeper locales also has a downward movement along the slope. At places if such water bearing fractures cut the land surface, fracture springs generate. The groundwater in deeper fractures can be tapped through deep bore wells as drilled in the suitable locales in Sikkim and other Himalayan States.

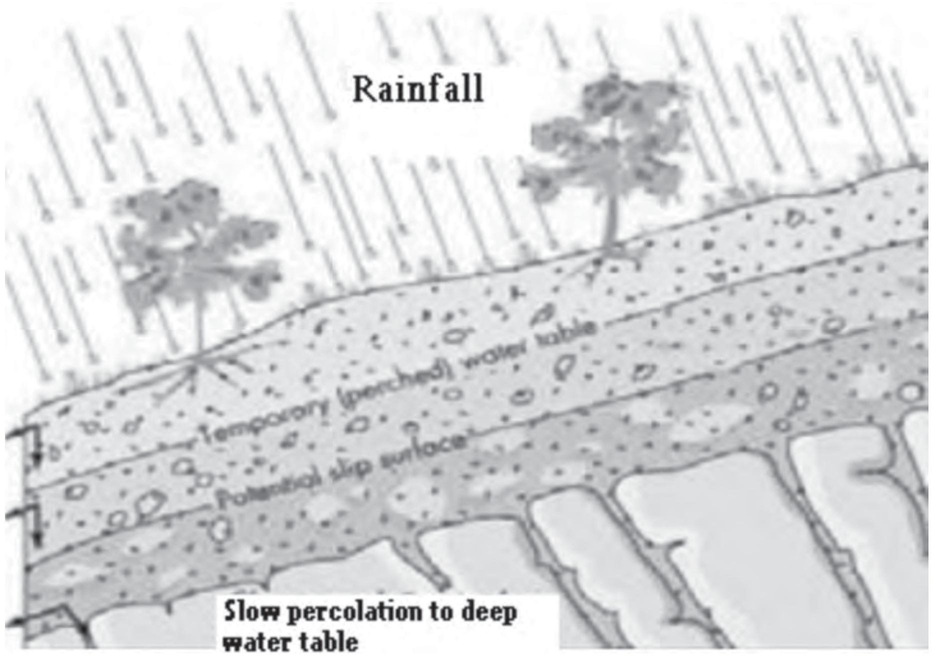


Fig. 10.1 Perched aquifer along Hill slope and instantaneous rise in water table due to recharge from rainfall

In recent years due to various factors like climatic change causing rainfall aberration and glacial retreat, anthropogenic menaces like deforestation, urbanization, road infrastructure development, encroachment to water bodies or drainage system, both ground and surface water resources have diminished. As groundwater occurs below land surface it is less vulnerable thus more sustainable than the surface water. At this juncture, it is necessitated to arrest optimum surface run-off and to harvest maximum rainwater through:

Suitable conservation techniques.

1. Hill and catchment area treatment.
2. Grass plantation, forestry development and stopping the grazing activities to reduce soil erosion as also to enhance the groundwater recharge.
3. To delineate cavernous limestone areas in Himalayas with possibilities for prolific storage of groundwater.

In view of the optimum utilization of groundwater in the Himalayas and rainwater harvesting, the following activities in Central Ground Water Board should be geared up forthwith.

i. Coverage of the entire Himalayan tract in India through Groundwater management studies coupled with Remote Sensing and geophysical studies in the valleys and foothills.

ii. Where ever road is not motorable, the areas may be covered through nonconventional methods (based on studies on remote sensing and aerial photographs) with limited field checks and hydrogeological traverses.

iii. Since the valley areas in the Himalayas are most important for human settlement, industrial set up and agriculture, sustainable water supply in the valleys is to be ensured. For this purpose, assessment of groundwater in the catchment area is required to be worked out.

10.2 Tube wells/ Bore wells

- From ground water resources data, it is clear that in all the states located in Himalayas, the stage of ground water development is in the low key barring some of the areas like Haridwar district in Uttarakhand and Kala-Amb-Sirmaur district in Himachal Pradesh which are over-exploited owing to densely located belt of industries. Nevertheless, in overall situation the ground water through tube well development in Himalayan belt is needed to be geared up in an adequate and sustainable manner after considering economic and hydrogeological factors.

- A lion's share of the Himalayas is underlain by crystallines, consisting of Granites and Granite Gneisses, Quartzites, Schists, Phyllites etc. which had undergone polyphase deformations and eventually possess thrust, fault, joints and fissures developed in them. These features have contributed secondary porosity in the host rocks and behave as a good repository of ground water. But in the Himalayan area, groundwater resources have not been developed much through tube wells and bore wells. Only in the recent years, CGWB has undertaken exploratory drilling programme in certain areas like Kargil, Srinagar and Leh-Ladakh of Jammu & Kashmir; Simla of Himachal Pradesh; Nainital and Pauri district of Uttarakhand; Namchi, Singtam and Rumtek areas of Sikkim, Lohit and Papumpare districts of Arunachal Pradesh. But this programme needs accelerated efforts in Himalayan areas especially in intermontane valleys and associated river terraces. For construction of bore wells, efforts should be made to select the well sites through geophysical surveys. Areas, where regionally extended potential joints and fractures are identified by resistivity surveys, may be developed by bore well/ dug-cum-bore well. Preferably, portable DTH / ODEX combination rigs have to be deployed in these areas for their easy approachability. The weathered zone may be tapped by large diameter dug wells. While executing these works, precautions have to be taken in such a way that ground water development should not affect the spring discharge.

- In the semi-consolidated formations, Central Ground Water Board has constructed a few deep tube wells down to the depth of 80 to 120 m. Yield of the wells varies from 10 to 30 m^3/hr for a drawdown of 9 to 15 m. Large diameter dug wells of 5 to 8 m depth in the bouldery formation or in the weathered sandstone beds are expected to yield good discharge of around 15 m^3/day.

- In the valley or foothill areas, where construction of ground water structures like large diameter dug wells or tube wells is feasible, farmers should be encouraged to adopt the practice of cultivation through ground water structures at least for supplemental irrigation in the time of peak water scarcity.

- In the river valleys, large diameter RCC Collector wells with infiltration galleries may be constructed for rural and urban water supply system.

- The loosely cemented sandstones like Siwalik and Buxa formations with boulders, pebbles and clay form low-lying hills. Ground water development in this formation is possible through shallow ground water structures in select areas. Large diameter dug wells (2 to 3 m diameter and 10 to 12 m depth) in the bouldery formation or in the weathered sandstone are expected to yield 25 to 30 m^3/ day.

- The Himalayan front i.e. foothill zone has a high southward sloping alluvial plain. It comprises of clay, silt, sand and gravels of Older and Younger alluvial formations. The underlying rocks belong to Siwalik/Buxa formation. Dug wells and shallow tube wells of around 10 m depth are feasible in the piedmont deposits with expected yield of about 15-45 m^3/hr for a drawdown of 5-20 m.

- In intermontane valleys, potential aquifers occur in shallow as well as in deeper zones in which following ground water abstraction structures are feasible:

✓ 6-7 m deep dug wells with yield prospect of 42-63 m^3/day for 3-5 hours of pumping in a day.

✓ Shallow tube wells of 60-70 m depth are expected to yield 15-35 m^3/hr for a drawdown of 6-18 m.

✓ The development of ground water from deeper aquifers down to the depth of 150 m bgl is feasible at some places, which may yield 0.36 (free flow) – 29.98 m^3/ hr for a drawdown of 6-21 m. These may be utilised both for drinking and irrigation purpose.

✓ At places, an average thickness of 3-4m of alluvial veneer could be seen in the valleys, while average thickness of weathering in the underlain consolidated formations may vary from 5-10m. These valley areas could be fully developed through construction of tubewells by deploying portable DTH-Percussion combination rig for augmentation of water supply and irrigation.

✓ In the river valleys, RCC Collector wells with infiltration galleries may be constructed.

10.3 Development and Revival of springs

A spring or seepage occurs when groundwater emerges naturally on the earth's surface by either gravity or artesian pressure. Springs commonly occur along hillsides and in low areas where porous soils or fractured rock formations allow water to flow onto the ground surface. Springs can occur at a single point or over a large area, called seepage. A slow hillside seepage or trickle where no visible water flow is observed should not be considered a true spring. A spring should have flow of water year-round and have at least a five liter per minute flow rate to be considered worthwhile for development. The springs located on hillsides at higher altitude can be tapped for water supply under gravity to the lower topographic locales. This configuration can result in significant savings in energy, as the supply costs no electricity or pump costs. Springs developed in low areas generally require a source of power and a pump to lift the water to its point of use.

Springs are less costly to develop than dug wells and tube wells. However, before a spring is developed, it is essential to check both the quantity and quality of the spring water because springs are highly susceptible to contamination and seasonal changes in flow rate.

Proper spring development involves protecting both the spring and its water quality from environmental damage and contamination, as well as improving access to the water for all its intended uses.

Planning

Before starting the project, a long-term water management plan should be developed for the proposed spring. For this stage, some important considerations are as follows:

- What water sources are currently being tapped?
- How much water they provide?
- How much additional water will be required from the proposed spring on a daily and annual basis?
- What types of material and equipment are required and what are their costs?
- How the spring harvesting box should be designed, so that water flow is effectively collected and does not result in any surface contamination or freezing in the winter?

Monitoring

The key to successful spring development is to ensure that there is adequate water flow and water quality for the intended purpose. It is therefore, essential to:

- Test the flow rate of the spring to ensure that the flow rate is at least five litre per minute or more and that the water flows year-round. The flow rate can be checked carefully by bucket or any alternate arrangement.

- Test the water quality by taking a water sample, in a clean container, and sending it to a laboratory for chemical analysis.

Once the spring flow and chemical water quality are determined to be acceptable, then action can be taken to proceed with the spring development. If not, other water supply options should be considered.

Protecting the existing perennial springs:

There are three fundamental objectives in protecting spring:

- To prevent pollution of the spring water by humans, animals, insects, and surface-water run off.
- To increase the infiltration rate at the spring outlet.
- To store overnight flow from the spring for use during the day.

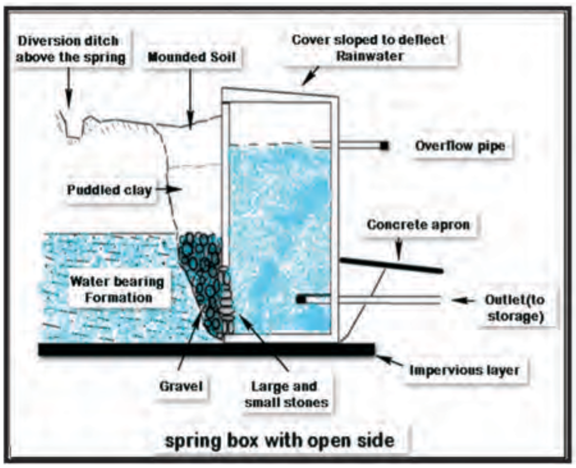
A properly designed protective structure of spring ensures an increased flow from the spring. To protect the spring and increase the flow of water, the material deposited at the spring outlet and the vegetation must be cleared away. By channelling the spring flow into a collection area, a good quantity of water can be stored for the community and distributed to community standpoints or to individual houses.

In order to store spring water, there are several possible designs for spring harvesting boxes but, generally their basic features are similar. Spring boxes serve as collectors for spring water. They can be used as storage tanks when a small number of people are being served and the source is located nearby the users. When large number of people is served, the water collected in the spring box flows to larger storage tanks.

Two basic types of spring boxes are: 1. A box with a pervious side for collection of water from a hillside, and 2. A box with a pervious bottom for collection of spring water flowing from a single opening on level ground. To determine which design is to be adopted, one has to dig out the area until an impervious layer is reached. The source of the spring flow is to be located and accordingly the site specific design is to be conceived as suitable.

10.3.1 Spring development involving small Catchment area

Spring box with open side: A spring box with a pervious side is needed to protect springs flowing from hillsides. The area around the spring must be dug out so that all available flow is captured and channelled into the spring box.



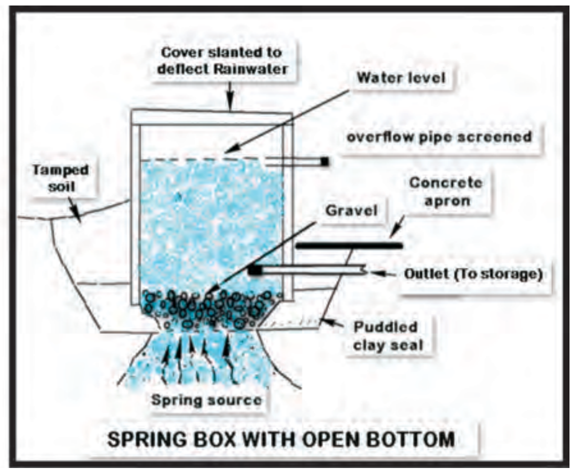


Fig. 10.2: Spring box design (a) Open sided (b) Open bottom

After this has been done, a collection box can be built around the spring outlet as shown in Fig.10.2 (a). The dugout area should be lined with gravel. The gravel placed against the spring opening serves as a foundation for the box and prevents the spring water from washing soil away from the area. The gravel pack also filters suspended solids. The gravel-filled area should be between 0.5-1.0m wide depending on the size of the spring collection area. To ensure that no contamination reaches the water, the gravel pack should be at least 1m below the ground surface. This is done either by locating the spring catchment in the hillside or by raising the ground level with backfill.

Caution must be taken not to disturb ground formations when digging out around the spring, otherwise, the flow of the spring may be deflected in another direction or into another fissure. The area must, however, be dug out enough so that the spring box fits into impermeable material. In cases where the box does not reach impermeable material, puddle clay should be used to seal the area around the sides of the spring box.

10.3.2 Spring box with open bottom: If a spring flows through a fissure and emerges at one point on level ground, a spring box with an open bottom can be developed as shown in Fig.10.2 (b). The area around the spring is dug out until an impermeable layer is reached. The spring box is placed over the spring and gravel to collect the flow, and clay or concrete is packed around the box to prevent seepage between the ground and the box. Sometimes a small sump can be built at the bottom so that sediment settles in one place.

The design of both types of spring boxes is basically the same and includes the following features:

- A water tight collection box constructed of concrete, brick, clay pipe or other material,
- A heavy removable cover that prevents contamination
- An overflow pipe, and
- A connection to a storage tank or directly to a distribution system

The spring box with an open bottom is simpler and cheaper to construct. Generally, on level ground, flow from only one source must be captured and collection of all available flow is much easier. Costs are lower because less digging and fewer materials are required.

10.3.3 Spring source development (Spring shed Development) involving larger catchment area

Spring source area development (Spring shed Development) involving an appreciable catchment area along the hillslope may be taken up through rain water harvesting and artificial recharge techniques impeding the speed of running water and injecting the same through pits and recharge shafts (Fig 10.3). Through these practices not only the soil moisture will be conserved, there will be an augmented discharge in the springs down slope. This will help in reducing the surface run-off of rainwater in the spring source area and more water will infiltrate underground to recharge the spring. It involves:

- ➢ Selection of springs for development work (selection criteria: need for such project, number of beneficiaries, etc.)
- ➢ All the information pertaining to the spring, such as type of spring, its location with latitude and longitude for working with the data and information in GIS, measurement of discharge in various seasons (daily/weekly discharge may be collected) and to collect the information from the old villagers like village captains/ Pradhans/ and aged people regarding its discharge in previous decades before development and plausible causes of reduction in discharge, if any, as per their view, recharge area demarcation, subsurface information, land use pattern, slope, demarcation of spring shed area, conducting hydrogeological surveys, type of aquifer material in the perched aquifer occurring in the hill slope through cutting trenches and pits, structures like joints, fissures and fractures in the bed rocks, their orientations etc.
- ➢ Adopting various engineering measures, such as, barbed wire/stone wall fencing of the recharge zone (to keep away livestock foraging, biomass extraction and other human activities), digging trenches, Staggered trenches and pits (infiltration wells) along contours (Fig 10.4&6) and permeable spots (places of deep weathering, bedding plane, joints, etc.), Percolation through renovated or newly constructed tanks and revival of natural/ manmade lakes(Fig 10.5) for recharging to the spring shed, gully plugging, construction of subsurface dykes/dams(Fig 10.7&8), bunding in terraces and making them inward sloping, stone and mud built water retention structures, etc.
- ➢ Vegetative measures, such as, plantation of low water demanding and shallow rooted grass/ shrubs/trees, mulching barren spots with weeds/leaf litter, etc.,
- ➢ Social measures such as ban on grazing, fuel wood and fodder cutting, social fencing and preventing the recharge zone from wild fires.

➢ The last and quite decisive sociological aspect calls for cooperation/participation of the people dependent on the spring source area, which needs to be kept into consideration for success of the above mentioned measures. Spring discharge needs to be stored in suitable leak proof ferro cement tanks, connected with pipeline and loss of water has to be minimized, and distribution among the community be rationalized.

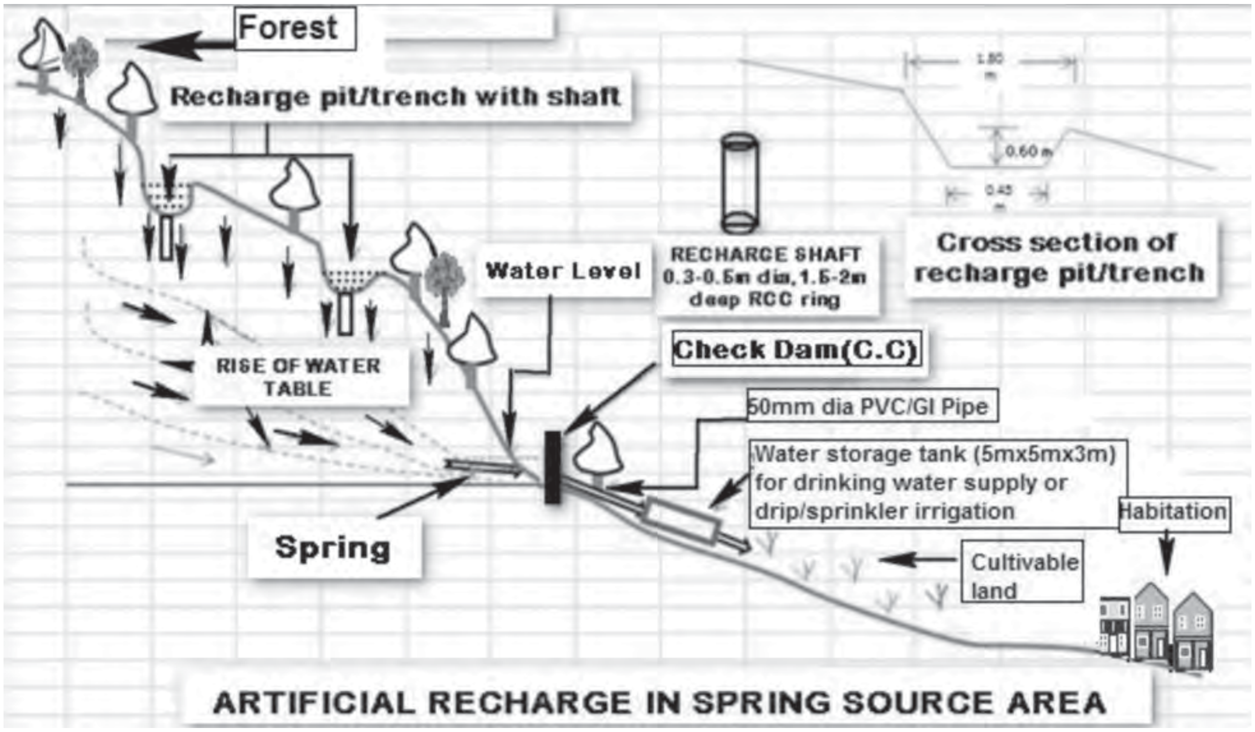


Fig. 10.3 Slope treatment for artificial recharge in the spring catchment area for Sustainability

Spring shed development in Sikkim: Fig.10.4 Series of staggered pits in slopes for artificial recharge in spring shed; Fig.10.5 Renovation of a desilted pond in S.Sikkim for Rainwater harvesting and recharge to the spring shed; Fig.10.6 Staggered pit under construction (Source of photographs- RMDD,Govt. of Sikkim)

Fig.10.4

Fig.10.5

Fig. 10.6

Construction of Cut-off Walls/Subsurface dykes/dams along hill slope tapping the perched aquifer (Fig 10.7) and subsequent enhancement of Spring discharge (Fig 10.8) at Gouchar, Chamoli District, Uttarakhand (Source: Shivanna K et al, Curr. Sci, Vol. 94, No.8, 2008)

Fig. 10.7 Fig. 10.8

10.4 Conservation of rainwater by adopting suitable methods:

The present water supply in Himalayas is mainly through spring water. However, due to injudicious deforestation and destruction of hills nearby the catchment areas, many springs, lakes and dug/ tube wells in the valley/ foothills have dried up, whereas the rain water flows as runoff causing landslides and flash floods downstream. If the runoff of rain water is arrested and harvested, the problem of water supply during the non rainy seasons could be solved to some extent.

Successful implementation of rainwater harvesting structures, mainly for conservation, primarily depends on topographic set up, hydrogeological factors, soil and land use factors, etc. The different rainwater harvesting and artificial recharge structures feasible in three different agro-climatic regions of Himalayas are as follows (Table 10.1):

Table 10.1: Feasible Rainwater harvesting and Artificial Recharge structures in Himalayas

Himalayan Foot Hills region	Humid Higher Himalayan region	Cold-desert climatic region
1.Rooftop rain water harvesting 2.Revival and recharge of village ponds 3.Collection from hill slopes 4.Contour trenching 5. Sub-surface dams/ dykes bandharas for increasing the sustainability of springs and dugwells present in down streams. 6.Gabion structures/nala bunds	1.Rooftop rain water harvesting 2.Revival and recharge of village ponds and Lakes 3.Diversion of perennial springs and streams water in storage structures 4.Subsurface dams/dykes and cut-off walls in slopes 5.Collection of rainwater from hill slopes through small pits with impermeable membrane like silpauline/polythene sheet 6.Gabion structures/ nala bunds	1.Revival and recharge of village ponds and Lakes 2.Construction of small ponds adjacent to kuhls 3.Check dams 4.Subsurface dams/dykes and cut-off walls in slopes 5.Diversion of perennial springs and streams water in storage structures 5. Collection of rainwater from hill slopes through small pits with impermeable membrane like silpauline/polythene sheet 6.Gabion structures/nala bunds for snow water harvesting

10.4.1 Roof Top Rain Water Harvesting

For intercepting the rain, the entire rooftop area is to be connected through the gutters with the collecting PVC tanks or subsurface concrete cisterns (Fig 10.9). The gutters should pass through a sand-gravel filter chamber generally fitted above the collecting tank. A provision for flushing arrangement may be kept for the first showers to drain out the accumulated unwanted materials from rooftop. The collecting tanks are to be cleaned and chlorinated at regular interval. Provision is to be made to divert the overflowing excess collected water to dug wells or into a recharge pit from the storage tank.

The advantages of the roof top rainwater harvesting structures are:

- ✓ The rainwater is, in general, free from impurities and requires simple treatment. It can be utilized for any domestic work.

- ✓ Soil erosion will be restricted due to the arrest of runoff water.

- ✓ The schemes are relatively low cost and involve one time investment only and beneficiaries can maintain it easily.

The roof top rainwater harvesting should be popularized in the area, especially, in town and it should be made mandatory by the State Governments. To create mass awareness among the public for conservation and augmentation of sustainable water resources, the roof top rainwater harvesting are selected in such places like schools, hospitals, community halls where large roof catchments are available.

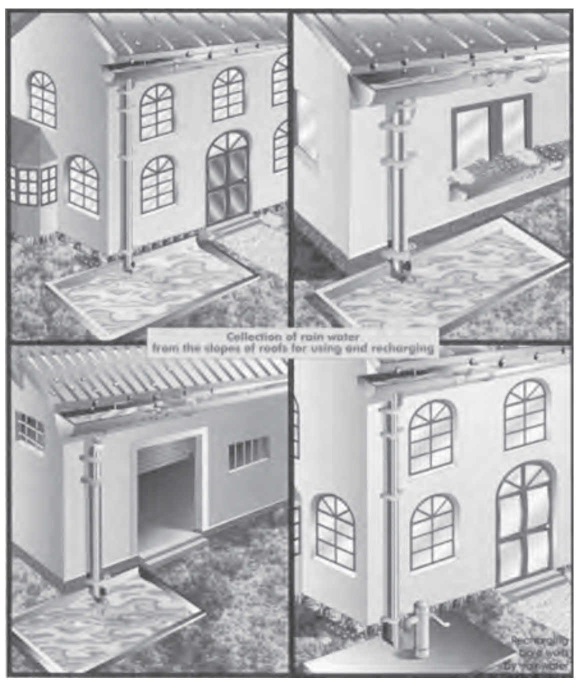


Fig. 10.9 Rooftop Rainwater Harvesting

10.4.2 Water conservation practices in slopes

In the foregoing chapters it has been discussed that the high gradient in bulk of the landscapes available in Himalayas poses main hindrance of optimum rainwater harvesting in the hill slope. However, in the intermontane valleys or along the river valleys gentle slope exists where various rainwater harvesting measures like construction of ponds, percolation tanks, contour bunds could be constructed. To overcome the hurdles appropriate techniques are to be adopted.

Fig. 10.10

Fig.10.11

Fig.10.12

Fig. 10.13

Fig.10.14

Fig.10.15

Types of landscape in Himalayas: Example from Arunachal Fig 10.10 & 10.13 Near Dirang River valley in Lesser Himalaya, W.Kameng District, Fig 10.11 & 10.12 Jhum land in steep slope, Papumpare District, Fig 10.14 Plain land in the foothill Fig 10.15 Intermontane valley surrounded by hills, Papumpare District

In sloping topography, great deal of soil and water conservation could be done if the slopes are bunded, terraced and trenches are cut along the contours along the hill slopes (Fig 10.16, Fig 10.17 & Fig 10.18). However, bunding process is highly applicable in the Himalayan areas where slope is less, whereas in terrain with high slope, slope terracing is suitable. These processes would also accentuate high soil moisture through recharge along the slopes which may further facilitate agriculture even after rainy season. It is being practiced in restricted areas of Nainital, Almora, Sikkim and Darjeeling District of West Bengal , East, West and Upper Siang Districts(Fig 10.19, Fig 10.20, Fig 10.21,Fig 10.22) of Arunachal Pradesh, but it is yet to be popularized throughout the Himalaya, where feasible, especially where Jhum cultivation is going on.

Rainwater harvesting in steep landscape through bench terracing and cultivation: Example from East Siang District, Arunachal Pradesh

For augmentation of irrigation water at higher altitude, it is required to conserve rainwater on the intermontane valleys or hill tops or table lands along hill slopes. However, in this regard a few necessary observations are to be made before conservation of rainwater otherwise there is every possibility of its leakage or infiltration along high hill slopes or its loss on evaporation.

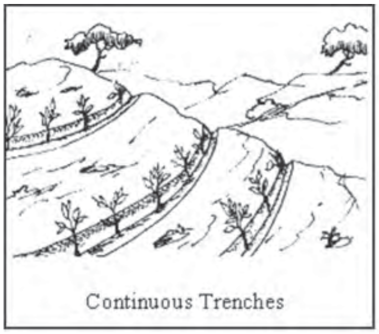


Fig.10.16 Contour trenches

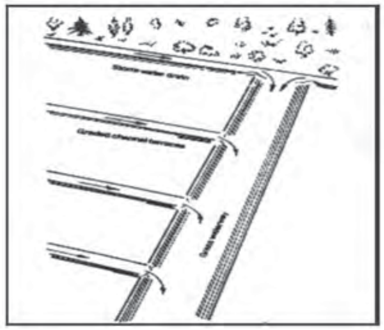


Fig.10.17 Terrace drainage

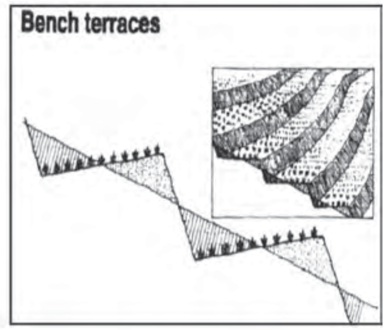


Fig.10.18 Bench terraces

Fig. 10.19

Fig. 10.20

Fig. 10.21

Fig. 10.22

The infiltration characteristics of soil as also the permeability of the weathered and rocky basement should be known for successful harvesting of rainwater. Good quality polythene sheets are highly in use as impervious membrane for harvesting of rainwater for conservation and recharge (Kar, 2004a, 2006; Saha et al., 2007; Samuel and Satapathy, 2008). Especially on high hill tops such type of impervious membrane with some indigenous arrangement to minimize evaporation loss is worthwhile for effective rainwater harvesting. In a research paper (Saha et.al, 2007) of ICAR from Umiam, Meghalaya, Saha and his co-workers have narrated their studies conducted on rainwater harvesting on high altitudes of Meghalaya. The harvesting tank coated by polythene named as Jalkund (Fig 10.23) is able to harvest rainwater to the tune of varying capacity of 6000–30,000 liters of water. However, farmers may have option for the capacity according to their water requirement for the crop intended to be cultivated and also for diversified use of stored water in various farm activities like crop, livestock and fish production during post-rainy season (stress period). The *Jalkund* can be prepared from clay and cow-dung plastering followed by 3–5 cm cushioning with dry pine leaf, laying down of 250 mm LDPE black agri-film and covering with 5–8 cm bamboo thatch to minimize evaporation loss. It is also further advised to use neem oil to minimize evaporation. The study revealed that the cost per litre of stored water was Rs 0.14 during the first year considering Rs 4205 of total cost which came down to Rs 0.046 per litre of stored water during the third year owing to negligible maintenance cost. Feedback from beneficiaries envisages that 30,000 litres of stored water in *Jalkund* could support 200 tomato plants, rear five piglets or two ducks or 50 poultry birds along with reasonable amount of fish seedlings from November to April. Using stored water economically in various farm activities is the most acceptable and profitable one particularly to those on the hilltops, who are the worst sufferers due to water scarcity. From this success story, similar type of rainwater harvesting and rural development activities could be applied elsewhere in the Himalayas.

Fig. 10.23 **Fig. 10.24**

Steps of construction of Jalkund and rainwater harvesting (Fig 10.23). Pisciculture (Fig 10.24) in the harvested water (Photo source: Saha et al. Curr. Sci., Vol. 92, No. 9, 10: May 2007)

10.4.3 Rainwater harvesting in the foothills and valleys

Foothills and valleys of Himalayan area are very much congenial for rainwater harvesting owing to availability of adequate run-off of water in them. The only exercise is to locate feasible site for construction of pond or small reservoir so that the collected water can be used in lean season. In some of the areas in Himachal Pradesh, Uttarakhand and in Arunachal Pradesh, ponds are being practiced as a suitable rain Water harvesting structure. These ponds are being constructed by the Government agencies for different purposes like Fisheries, Irrigation and livestock development. In Arunachal Pradesh, such types of ponds (Fig 10.25) are being constructed through the Fisheries Department in the foothill areas. Apatani valley at Ziro and Hapoli of Lower Subansiri District, Arunachal Pradesh is famous for its double cropping system where fish and paddy are jointly cultivated with the rainwater harvested in the bunds (Fig 10.26).

Fig. 10.25 Pisciculture in a Pond in Foothill of Arunachal Pradesh

Fig. 10.26 Fish-cum Paddy cultivation in Ziro valley, Arunachal

In Nagaland, numbers of harvesting ponds are constructed in the valleys surrounded by the terraced hill slopes and this is traditionally practiced by the Naga tribes since age-old time and this process is called *Zabo* system (Fig 10.27 & 10.28).

Fig.10.27

Fig.10.28

Conservation of rainwater (Zabo system) in the valleys and slopes located in High altitude of Nagaland

Such intermontane valleys as also river valleys in the foothills may be fully utilized for adequate monsoon run-off harvesting for supplemental irrigation, fishery, piggery, poultry and development of agro forestry through oil palm cultivation in the *Jhum* lands which is available in the foothills having conducive climate for its luxuriant growth (Kar et al., 2008). In Uttarakhand, harvesting run-off water has been initiated in Bageshwar district with the help of Low Density Polythene as a lining of ponds.

10.4.4 Rainwater harvesting through check dams

The areas in the foothills and valleys in Himalayas, where slope is less, are suitable for large-scale rainwater harvesting for conservation as well as artificial recharge to ground water by constructing check dams and gabion structures and sub-surface dams/dykes along the streams (Fig 10.29). Check dams in series with recharge shafts may be constructed in the stream bed to achieve maximum rainwater harvesting and recharge to the subsurface.

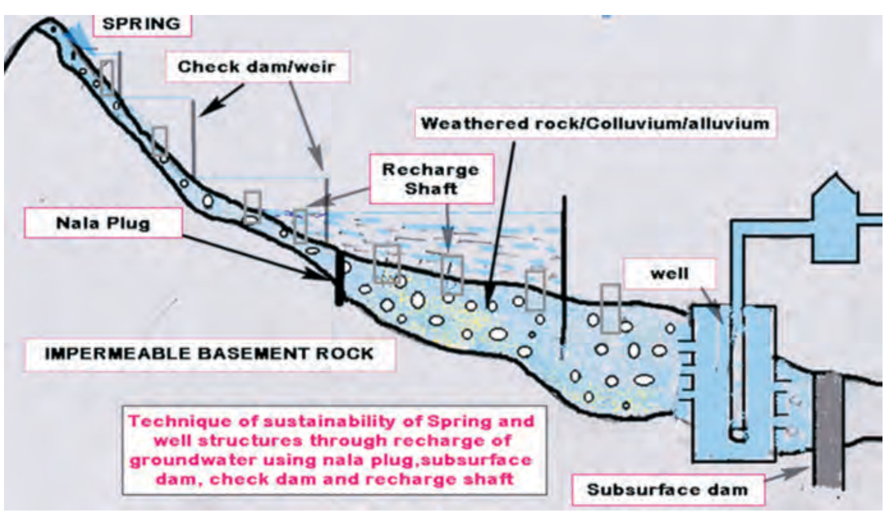


Fig. 10.29 Optimum rainwater harvesting through series of check Dams and artificial recharge along stream valleys in foothills

In low rainfall, regions as also in the rain shadow areas, a cost effective loose-boulder check dams and bamboo-boulder check dams are also utilizing the local materials. However, such type of structures have been found unsuitable with a very low life in the high rainfall regions with comparatively moderate to high slope because of heavy inrush along the streams. Hence, gabion structure (Fig 10.30) of thickness 1.5-2m with spill way facility and other required engineering design and C.C. check dams with proper civil design would be highly suitable in such terrains (Fig 10.31).

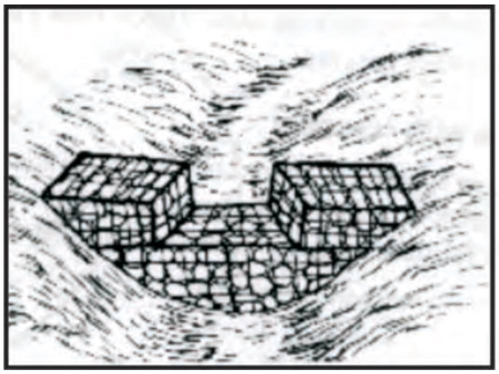


Fig 10.30 A Gabion

Fig 10.31 A Check Dam

Gabion and check dam are highly suitable structures in foothills and Valleys to harvest lot of rainwater as also help in groundwater recharge

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G. B. Pant Institute of Himalayan Environment and Development

(Autonomous Institute of Ministry of Environment and Forests, Government of India)

Sikkim Unit, Pangthang-Gangtok, Post Box 24-Gangtok, East Sikkim 737 101 INDIA

Tel: 03592-237328/237189; Fax: 03592-237415; Email: kksingh@gbpihed.nic.in; singhkk20@yahoo.com

June 30, 2013

Dr. K.K. Singh
Scientist 'F' & In-charge

To
The Chairman
Central Ground Water Board
Bhujal Bhawan, NH-IV
Faridabad, Haryana

Dear Shri Sushil Gupta,

On behalf of G.B. Pant Institute of Himalayan Environment and Development, I appreciate your ingenious efforts as this report provides comprehensive information on the groundwater scenario in the Himalayan Regions. It will indubitably serve as a fundamental reference tool for understanding and managing water resources in the Himalayan Regions.

Regards,

KK Singh

(K.K. Singh)

DR. TRILOCHAN SINGH,
Scientist 'G' (Retd.)
Wadia Institute of Himalayan Geology
Deptt Sci & Technology, Govt. of India

EARTH SCIENTIST
Mobile : +91 9818287900
E-mail : tskaith@rediffmail.com
170 / DG - III, Vikas Puri,
New Delhi - 110 018.

CHAIRMAN
State-level Expert Appraisal Committee
Deptt. of Environment & Forest,
Govt of Arunachal Pradesh.

04/07/2013

The Chairman
Central Ground Water Board
Bhujal Bhawan, NH-IV,
Faridabad - 121001 (Haryana).

Dear Shri Sushil Gupta,

At an outset, I would like to put on record my sincere thanks for having confidence on my professional capabilities and assigning me the task to review the document entitled "Hydrogeology of the Himalayan Region, India".

I have gone through the three chapters, Chapters 8-10, and have enclosed my comments for your kind perusal and further necessary action. Since there are a number of minor editing also, I have taken the liberty to do the changes (editing as well changes suggested) in the document directly. The document is in word file and the changes are on the track-change mode. It will help you to see the suggested changes. In case you agree with the change, the file may be converted accepting the changes. The document, after accepting the changes, must be thoroughly checked for its proper format.

I am not sure if I have done justice with the manuscript because of the time constraints. I have, however, suggested some points, which came in mind spontaneously.

I appreciate your ingenious efforts as this document provides a comprehensive information on the groundwater scenario in the Himalayan Regions. It will indubitably serve as a fundamental reference tool for understanding and managing water resources in the Himalayan Regions.

With Regards,

Sincerely Yours,

Trilochan Singh.

NOTE : I am sending this letter through email, hence it may be treated as signed.

Residence : 170 / DG-III, Vikas Puri, New Delhi – 110018.

Department of Earth Sciences
Indian Institute of Technology
ROORKEE - 247667, INDIA

Tel: (01332) 285549
Fax: (01332) 285638, 273560
Email: saraffes@iitr.ernet.in
arun.k.saraf@gmail.com
Web: http://drarunsaraf.tripod.com

Dr. Arun K. Saraf
Professor

July 1, 2013

To
The Chairman,
Central Ground Water Board,
Bhujal Bhawan, NH-IV,
Faridabad- 121001, Haryana

Dear Sir,

At the outset, I would like to congratulate you and your team and sincerely appreciate your ingenious efforts at CGWB for bringing first time such a comprehensive, nicely organised and timely report on groundwater status and future scenario of the Himalayan mountain region. Himalaya is not only highest mountain chain of the world but also unique indicator of global climate changes and therefore such a comprehensive information provided by you on groundwater scenario in the Himalayan Region definitely will go a long way towards national interest. It will absolutely serve as an essential reference tool for understanding and overall managing water resources of the Himalayan Region.

With regards,

Yours faithfully,

(Arun K. Saraf)

ADMINISTRATIVE MAP OF THE HIMALAYAN AND NORTH EAST REGION PLATE - I

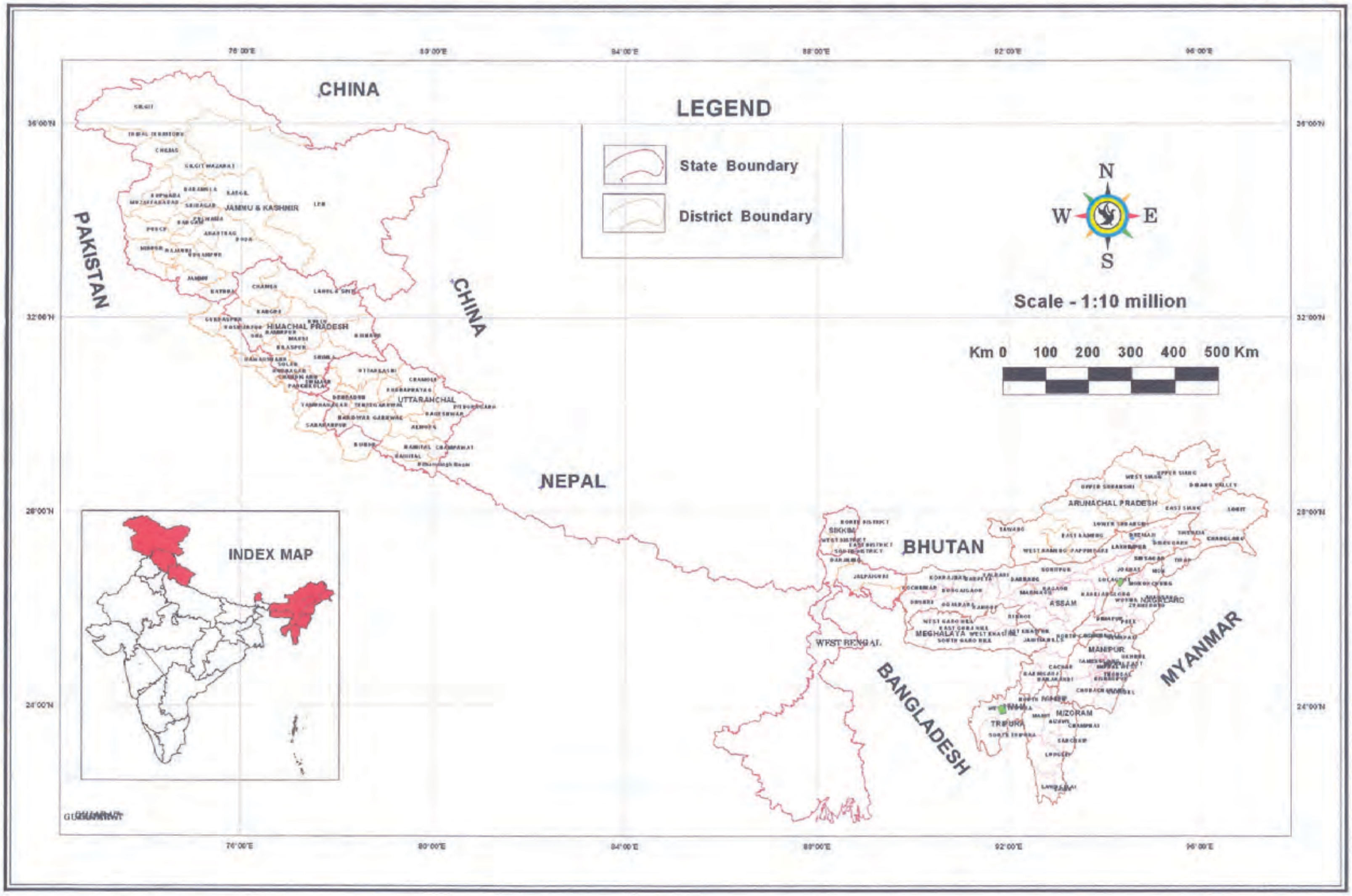
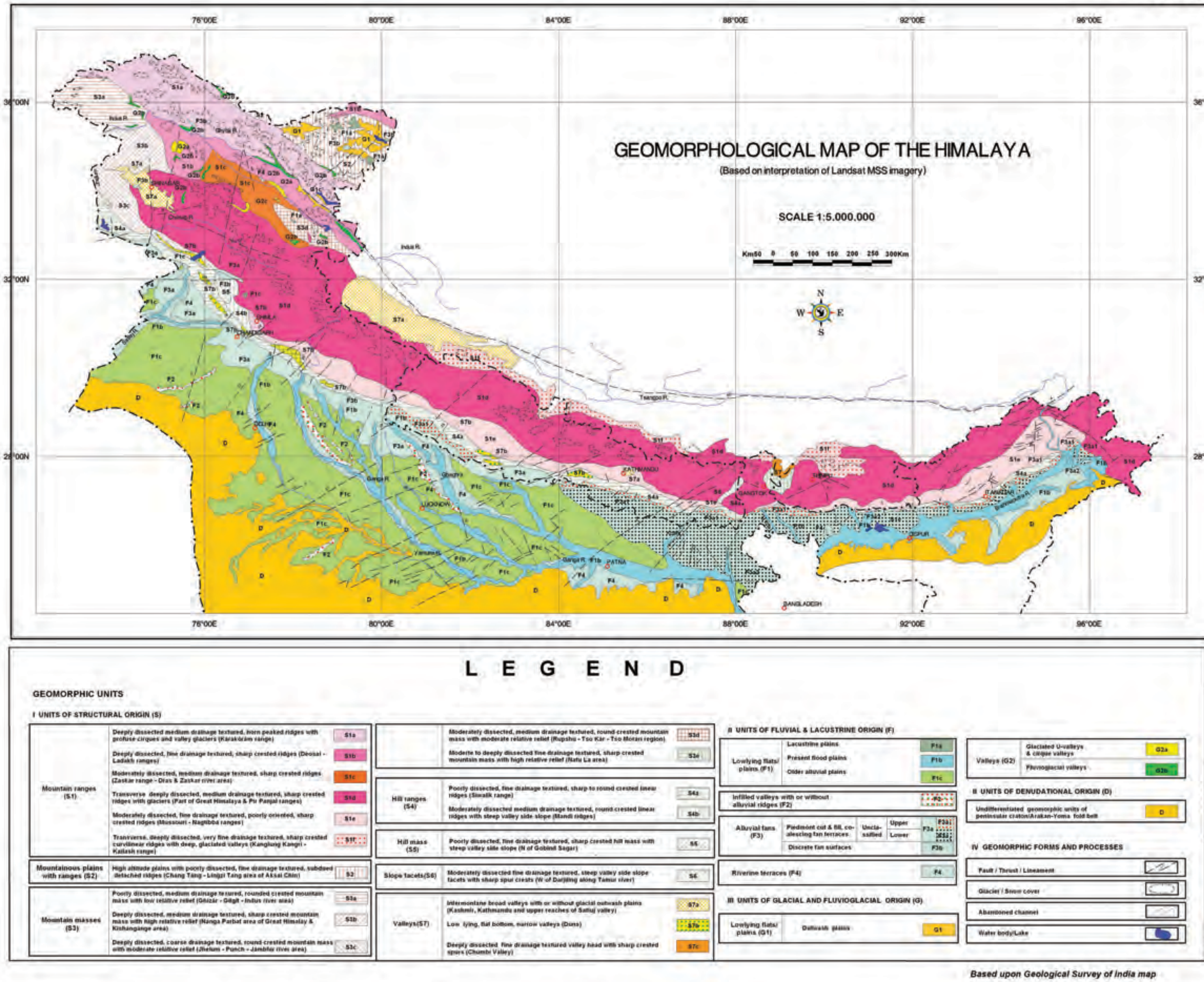


PLATE - II


GEOMORPHOLOGICAL MAP OF THE HIMALAYA
(Based on interpretation of Landsat MSS imagery)
SCALE 1:5,000,000
Km50 0 50 100 150 200 250 300Km
N
W
E
S
76°00E
80°00E
84°00E
88°00E
92°00E
96°00E
36°00N
32°00N
28°00N
L E G E N D
GEOMORPHIC UNITS
I UNITS OF STRUCTURAL ORIGIN (S)
Mountain ranges (S1)
Deeply dissected medium drainage textured, horn peaked ridges with profuse cirques and valley glaciers (Karakoram range) S1a
Deeply dissected, fine drainage textured, sharp crested ridges (Deosai - Ladakh ranges) S1b
Moderately dissected, medium drainage textured, sharp crested ridges (Zaskar range - Dras & Zaskar river area) S1c
Transverse deeply dissected, medium drainage textured, sharp crested ridges with glaciers (Part of Great Himalaya & Pir Panjal ranges) S1d
Moderately dissected, fine drainage textured, poorly oriented, sharp crested ridges (Mussouri - Nagtibba ranges) S1e
Transverse, deeply dissected, very fine drainage textured, sharp crested curvilinear ridges with deep, glaciated valleys (Kanglung Kangri - Kailash range) S1f
Mountainous plains with ranges (S2)
High altitude plains with poorly dissected, fine drainage textured, subdued detached ridges (Chang Tang - Lingzi Tang area of Aksai Chin) S2
Mountain masses (S3)
Poorly dissected, medium drainage textured, rounded crested mountain mass with low relative relief (Ghizar - Gilgit - Indus river area) S3a
Deeply dissected, medium drainage textured, sharp crested mountain mass with high relative relief (Nanga Parbat area of Great Himalay & Kishanganga area) S3b
Deeply dissected, coarse drainage textured, round crested mountain mass with moderate relative relief (Jhelum - Punch - Jambfar river area) S3c
Moderately dissected, medium drainage textured, round crested mountain mass with moderate relative relief (Rupshu - Tso Kar - Tso Moran region) S3d
Moderte to deeply dissected fine drainage textured, sharp crested mountain mass with high relative relief (Natu La area) S3e
Hill ranges (S4)
Poorly dissected, fine drainage textured, sharp to round crested linear ridges (Siwalik range) S4a
Moderately dissected medium drainage textured, round crested linear ridges with steep valley side slope (Mandi ridges) S4b
Hill mass (S5)
Poorly dissected, fine drainage textured, sharp crested hill mass with steep valley side slope (N of Gobind Sagar) S5
Slope facets(S6)
Moderately dissected fine drainage textured, steep valley side slope facets with sharp spur crests (W of Darjiling along Tamur river) S6
Valleys(S7)
Intermontane broad valleys with or without glacial outwash plains (Kashmir, Kathmandu and upper reaches of Satluj valley) S7a
Low lying, flat bottom, narrow valleys (Duns) S7b
Deeply dissected fine drainage textured valley head with sharp crested spurs (Chumbi Valley) S7c
II UNITS OF FLUVIAL & LACUSTRINE ORIGIN (F)
Lowlying flats/ plains (F1)
Lacustrine plains F1a
Present flood plains F1b
Older alluvial plains F1c
Infilled valleys with or without alluvial ridges (F2) F2
Alluvial fans (F3)
Piedmont cut & fill, co-alescing fan terraces
Uncla-ssified
Upper
Lower
F3a
F3a1
F3a2
Discrete fan surfaces F3b
Riverine terraces (F4) F4
III UNITS OF GLACIAL AND FLUVIOGLACIAL ORIGIN (G)
Lowlying flats/ plains (G1)
Outwash plains G1
Valleys (G2)
Glaciated U-valleys & cirque valleys G2a
Fluvioglacial valleys G2b
II UNITS OF DENUDATIONAL ORIGIN (D)
Undifferentiated geomorphic units of peninsular craton/Arakan-Yoma fold belt D
IV GEOMORPHIC FORMS AND PROCESSES
Fault / Thrust / Lineament
Glacier / Snow cover
Abandoned channel
Water body/Lake
Based upon Geological Survey of India map

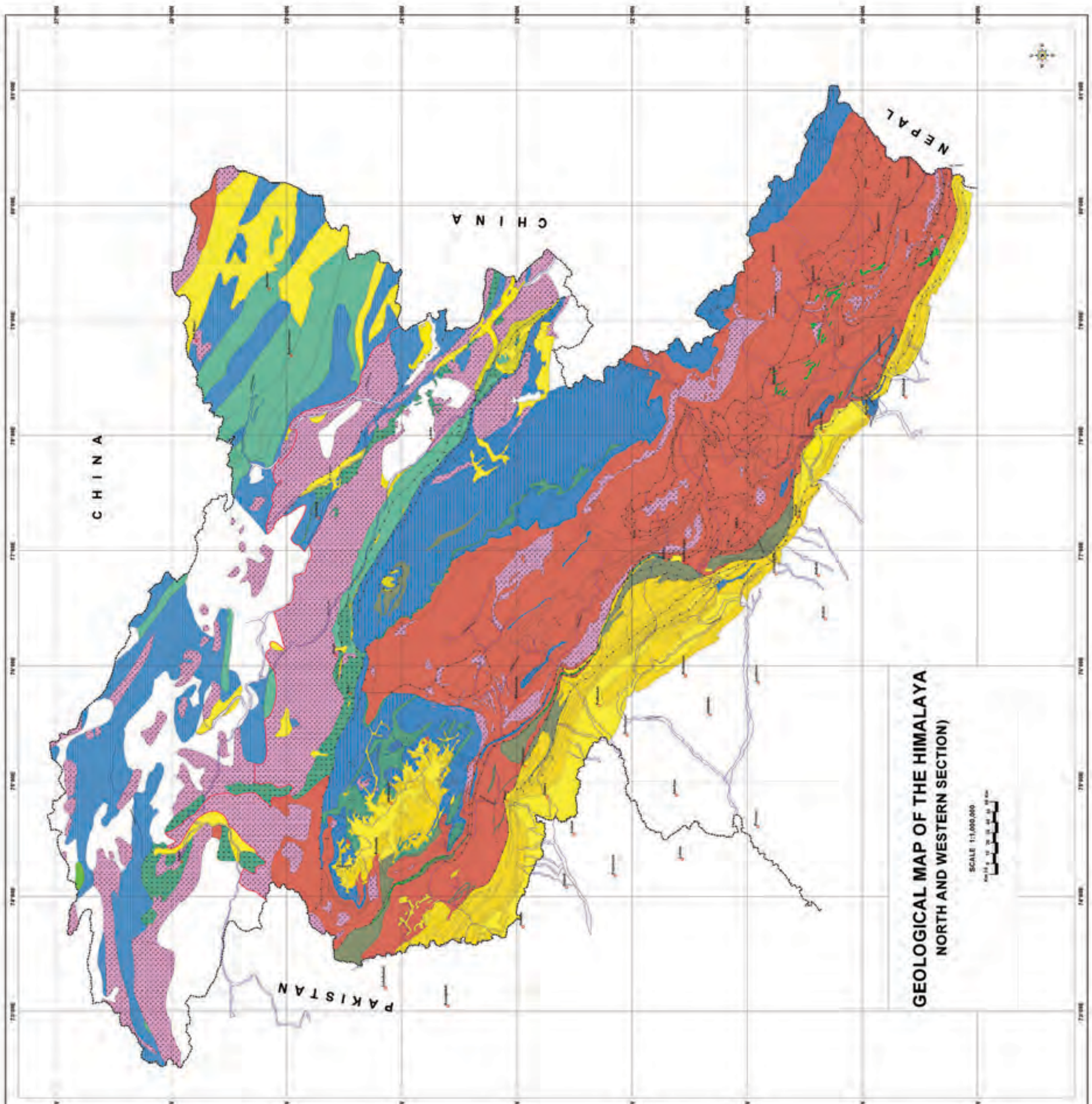


PLATE - III A
GEOLOGICAL MAP OF THE HIMALAYA
NORTH AND WESTERN SECTION)
SCALE 1:1,000,000
C H I N A
C H I N A
P A K I S T A N
N E P A L

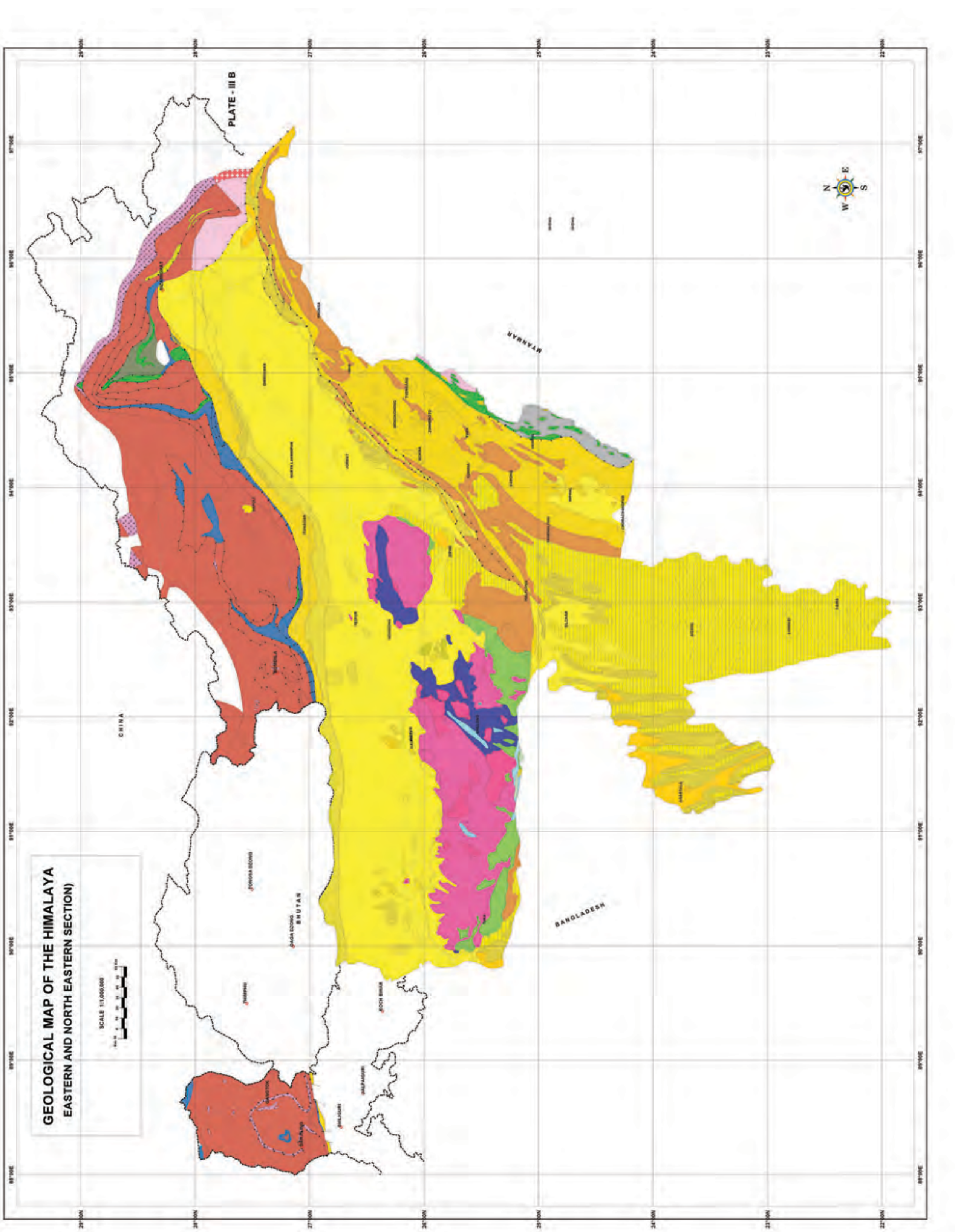
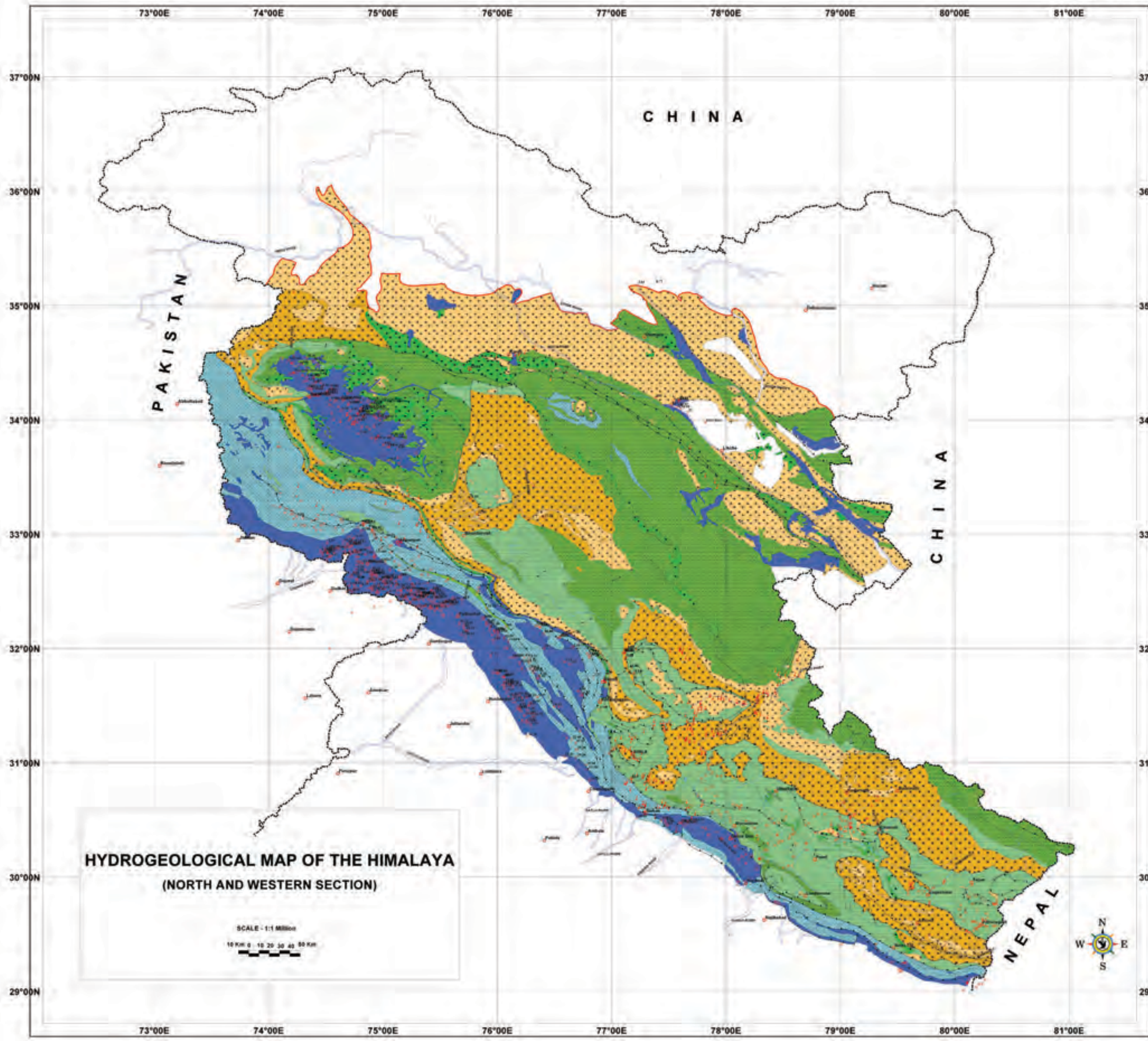
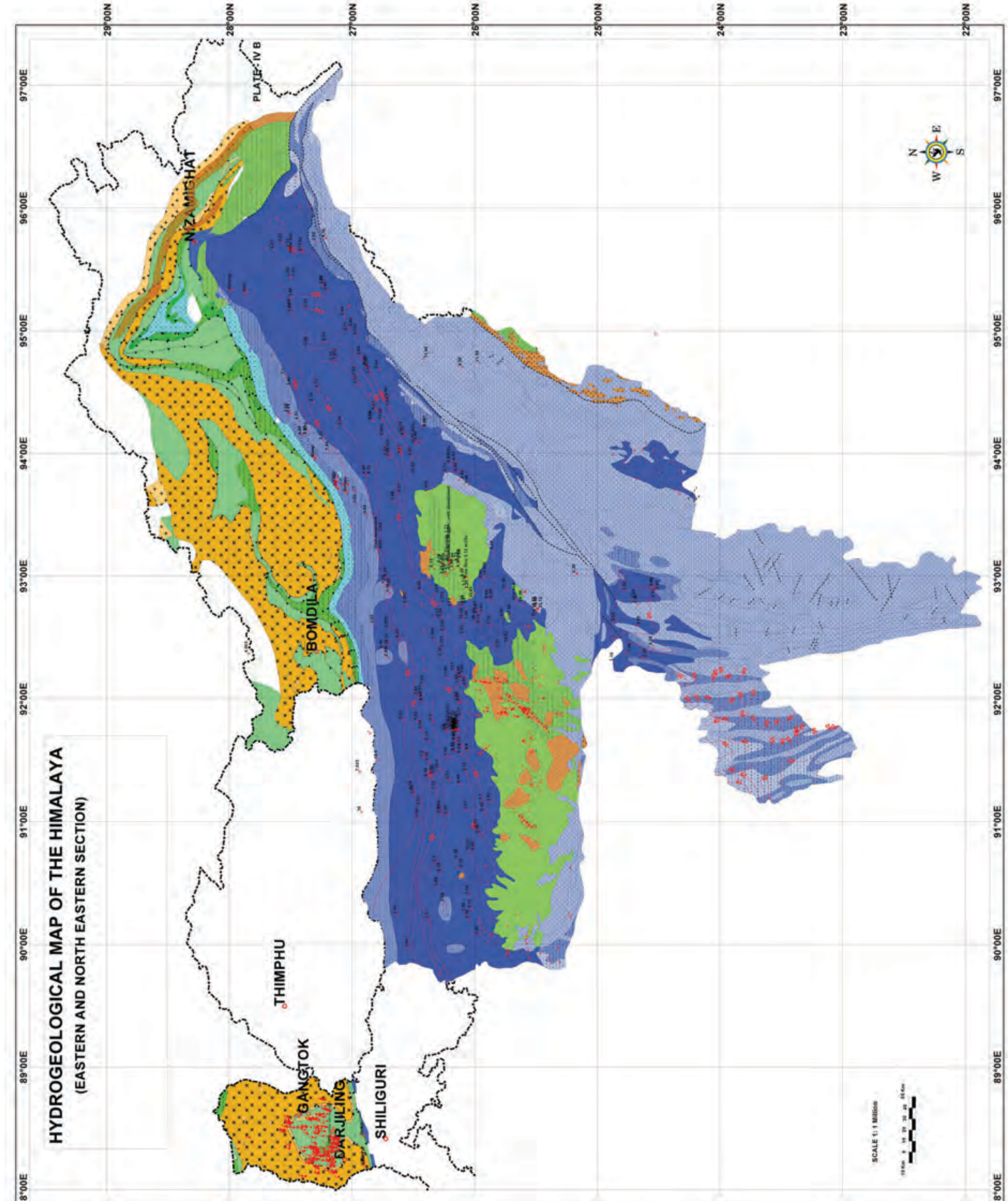

GEOLOGICAL MAP OF THE HIMALAYA
EASTERN AND NORTH EASTERN SECTION)
SCALE 1:1,000,000
PLATE - III B
CHINA
BHUTAN
BANGLADESH
MYANMAR
N
E
S
W

PLATE - IV A



HYDROGEOLOGICAL MAP OF THE HIMALAYA
(NORTH AND WESTERN SECTION)
SCALE - 1:1 Million
CHINA
PAKISTAN
NEPAL
73°00E
74°00E
75°00E
76°00E
77°00E
78°00E
79°00E
80°00E
81°00E
37°00N
36°00N
35°00N
34°00N
33°00N
32°00N
31°00N
30°00N
29°00N
N
S
E
W


HYDROGEOLOGICAL MAP OF THE HIMALAYA
(EASTERN AND NORTH EASTERN SECTION)
PLATE - IV B
THIMPHU
GANGTOK
DARJILING
SHILIGURI
BOMDILA
SCALE 1: 1 Million
88°00E
89°00E
90°00E
91°00E
92°00E
93°00E
94°00E
95°00E
96°00E
97°00E
29°00N
28°00N
27°00N
26°00N
25°00N
24°00N
23°00N
22°00N

L E G E N D

LESSER AND OUTER HIMALAYA

AGE	SEDIMENTARY AND METAMORPHIC ROCKS
QUATERNARY	Alluvium, river terraces, glacial deposits.
MIOCENE TO NEOGENE	Lower,Middle and Upper Siwalik Groups in Western Himalaya, Middle Siawalika in Arunachal Pradesh and undifferentiated Siawalik Group in Eastern Himalaya.
PALAEOCENE TO MIOCENE	Undifferentiated Muree Group/Dharamshala Group/Dagsai and Kasauli Fm.,Upper and Lr. Muree Groups of J&K and H.P.Yinkiong Fm of Arunachal Pradesh,Subathu Fm. Of Western Himalaya,Undiffeentiated Manikot Shell Limestone and Subathu Fm, Manikot Shell Limestone and Subathu Fm of U.P.,Undifferentiatiated Punch-Mandi and Rajpura Fm, Punch-Mandi Formation and Rajpura Formataion of J&K.
LOWER PALAEOZOIC (CAMBRIAN) TO CRETACEOUS	Damuda Fm, Rangit pebble slate of Sikkim-Darjeeling, Bharell Fm, Bichom Fm and Garu Fm of Arunachal Pradesh, Undifferentiated Bichom Fm and Miri Fm, Aggolomeratic slate of J&K, Boulder slate of U.P., Miri Fm of Arunachal Pradesh, Tal Fm with Undifferentiated Manicot Shell Limesotne of U.P. Tal Fm of H.P. and U.P.
PROTEROZOIC (Sedimentaries/Low and High grade crystalline metamorphites)	Undifferntiated Bhimdasa and Sincha Formations, Undifferentiated Gamir and Balla Fms and Ramban Fm, Sirban Group of J&K, Undifferentiated Blaini & Infra-Krol Fms and Krol Fm, Simla Group, Jaunsar Group, Dharagarh Fm and Deoban Group of H.P and U.P.; Betalghat Fm, Morar Chakrata Fm,Amri Fm, Bijni Fm, Banali Setangal Fm, Bhimtal Fm, Garhwal Group, Almorah-Dadatnoli Crystallines, Ramgarh Fm, Undifferentiated Askot and Baijnath Crystallines of U.P.; Sundar Nagar Group and Shali Group, Jutogh Group of H.P.; Gorubathan Fm, Bauxa Fm of Sikkim-Darjeeling; Pola Fm, Tenga Fm, Lumla Fm, Dirang Schist, Khetabari Fm, Tidding Fm, Noimi Fm, Dedja Fm, Undefferentiated Potin and Khetabari Fm of Arunachal Pradesh; Rayeng Fm of Sikkim-Darjeeling of Sikkim and Arunachal Pradesh

IGNEOUS ROCKS

AGE	IGNEOUS ROCKS
PROTEROZOIC - EOCENE	Abor and Tuting Volcanics of Arunachal Pradesh; Panjal volcanics and Sauni Volcanics of J&K; Mandi-Darla volcanics of H.P., Bhawali volcanic and volcanics of Garhwal Group of U.P.
PROTEROZOIC - TERTIARY	Lohit Granitoid complex (with Diorite intrusives) and gneissic granites of Arunachal Pradesh, Lingtse Granite gneiss of Sikkim-Darjeeling, Granitic rocks within Almora and equivalent crystallines of W Himalaya (unknown age).

HIGHER HIMALAYA

AGE	SEDIMENTARY AND METAMORPHIC ROCKS
QUATERNARY	Alluvium, river terraces, glacial deposits.
PLIOCENE - LOWER PLEISTOCENE	Karewa Group of Kashmir Basin.
EOCENE	Nummulitic Fm of Kashmir Basin,Kanji Group of Spiti-Zanskar Basin.
PERMIAN - CRETACEOUS	Undifferentiated Gimual and Chikkim Fms, Spiti Fm of Spiti Zanskar and Kumaun Basin, Lailang Group, Undifferentiated Kuling Fm and Lailang Group, Tandi Group of Spiti Zanskar basin; Undifferentiated Chocolate, Kalapani, Kuti, Kioto and Lapthal Fms of Kumaun basin, Wumuh Fm, Vihi Group, Undifferentiated Zewan Fm and Vihi group of Kashmir Basin. Undifferentiated Bishot & Kalhel Fms of Chamba-Bhaderwah basin; Tso Lhama Fm of Sikkim-Darjeeling.
CAMBRIAN - PERMIAN	Undifferatiated Mamal & Zewan Fms, Undifferentiated Agglomerate Slate with Nishatbagh Beds, Undifferentiated Syringothyris & Fenestella Fms, Undifferentiated Morgan, Muth & Aishmuqam Fms (ODm), Undifferentiated Lolab & Karihul Fm of Kashmir basin; Gamgul Fm/ Salooni Fm, Agglomerate Slate of Chamba-Bhaderwah basin; Kuling Fm of Spiti-Zanskar and Kumaun Basins; Kanawar Group, Pangmur La Fm, Undifferentiated Thango-Takche Fms and Muth Formations, Taglang La Fm, Rockchung Fm, Kunzam La Fm of Spiti-Zanskar basin, Muth Fm of Kashmir and Spiti Zanskar basin; Undifferentiated Ralam, Garbyang, Shiala, variegated and Muth Fm of Kumaun basin, Lachi Fm and Everest Limestone of Sikkim-Darjeeling.
PROTEROZOIC	Ramsu Fm, Machhal Fm, Tanwal Fm, Undifferentiated Dogra Group, Undifferentiated Kiber, Lopara and Dul Fms of Kashmir basin, Manjir Fm, Katarigali Fm, Chamba/Bhaderwah Fm, Kulu Group of Chamba-Bhaderwah Basin, Batal Fm, Suru crystallines, Tso Morari gneissic complex of Spiti-Zanskar basin, Martoli Fm of Kumaun basin, Larji Fm and Rampur Group and Vaikrita Group of H.P., Salkhala Fm, Undifferentiated Nanga Parbat Crystallines of J&K, Central crystallines, Agastmuni Fm, Bhilangana Fm of Uttaranchal, Everest pelite, Kanchanjangha gneiss, Darjeeling gneiss and its probable equivalents,Chungthang Fm of Sikkim-Darjeeling, Se-La Fm and Undifferentiated Granitic gneisses of Arunachal Pradesh.

IGNEOUS ROCKS

AGE	IGNEOUS ROCKS
PROTEROZOIC - TERTIARY	Tertiary granite, Kaplas, Mandi, Dalhousie, Dhauladhar and equivalent granites, Chor, Bandal and equivalent granites of Western Himalaya, Tourmaline Granite of Arunachal Pradesh and Sikkim and Darjeeling, Gneissic granites of Arunachal Pradesh.
PROTEROZOIC - CRETACEOUS	Balchandhura volcanics of Kumaon basin, Panjal Volcanics of Kashmir basin & Chamba-Bhaderwah basin, volcanics within Bafliaz Fm of Kashmir Basin. Phe Volcanics of Spiti-Zanskar basin; Manikaran Volcanics of H.P.
CRETACEOUS - TERTIARY	Tidding Serpentinite of Arunachal Pradesh

LADAKH AND KARAKORAM HIMALAYA

AGE	SEDIMENTARY AND METAMORPHIC ROCKS
QUATERNARY	Alluvium and glacial deposits.
TERTIARY	Unclassified Tertiary Formation
PERMIAN - TERTIARY	Indus Group, Sangeluma Group of Indus Ophiolite belt, Unclassified Permian to Paleogene Fms, Burtse Fm, Margo Fm.
LOWER PALAEOZOIC - TRIASSIC	Unclassified Fms, Yapchan Fm, Saser Brangsa Fm, Shyok Group of Shyok Ophiolite belt, Pangong metamorphic complex.
PROTEROZOIC (Undifferentiated)	Unclassified Proterozoic Fms

IGNEOUS ROCKS

AGE	IGNEOUS ROCKS
PROTEROZOIC - TERTIARY	Tirit/Kakset granitoid complex, Karakoram granitoid complex, Ladakh granitoid complex, Unclassified granites, undifferentiated Mesozoic to Tertiary granitoid complex, Mesozoic granites, Undifferentiated Proterozoic granites, granites of unknown age.
MESOZOIC - TERTIARY	Dras volcanics, Khardung Volcanics, Undifferentiated volcanics, Mesozoic volcanics
CRETACEOUS - TERTIARY	Ultrabasics of Indus Ophiolite belt

Unmapped Area

Boundary : International

Thrust

Synclinal Axis

Anticlinal Axis

Fault

Drainage

Important Location

Area north of this line is occupied by PAKISTAN

NORTH EASTERN REGION CONTIGUOUS TO HIMALAYA

AGE	SEDIMENTARY AND METAMORPHIC ROCKS
QUATERNARY (Q)	Undifferentiated fluvial sediments, Hapoli Fm, Older Alluvium
PLIO-PEISTOCENE	Dihing Fm, Dupitila Fm and Namsang Fm
MIO-PLIOCENE	Tipam Gp and Cheenapara Fm
MIOCENE	Surma Gp, Bokabil Fm, Bhuban Fm and Baghmara Fm
EOCENE-OLIGOCENE	Barail Gp and Simsang Fm
EOCENE	Disang Gp
PALAEOCENE-EOCENE	Jaintia Gp
CRETACEOUS-PALAEOCENE	Oceanic Pelagic Sediments
CRETACEOUS	Khasi Gp
CARBONIFEROS-PERMIAN	Lower Gondwana
PALAEOPROTEROZOIC-MESOPROTEROZOIC	Shillong Gp
PROTEROZOIC (Undiff.)	Naga Metamorphics
ARCHAEAN(?)-PROTEROZOIC (Undiff)	Gneissic Complex of Meghalaya

IGNEOUS ROCKS

	AGE	IGNEOUS ROCKS
PLUTONIC ACID	NEOPROTEROZOIC - LOWER PALAEOZOIC	Kyndem Nongpoh, Mylliem Granites, South Khasi Batholith and equivalent granites
INTERMEDIATE/BASIC	CRETACEOUS-TERTIARY (K/T)	Alkali Complex of Sung Samchampi
VOLCANIC	CRETACEOUS	Sylhet Trap of Meghalaya
	PROTEROZOIC	Khasi Greenstone
OPHIOLITES	CRETACEOUS-PALAEOGENE	Ophiolites of Nagaland

CHLORIDE IN GROUND WATER (in mg/litre)

PLATE - V A

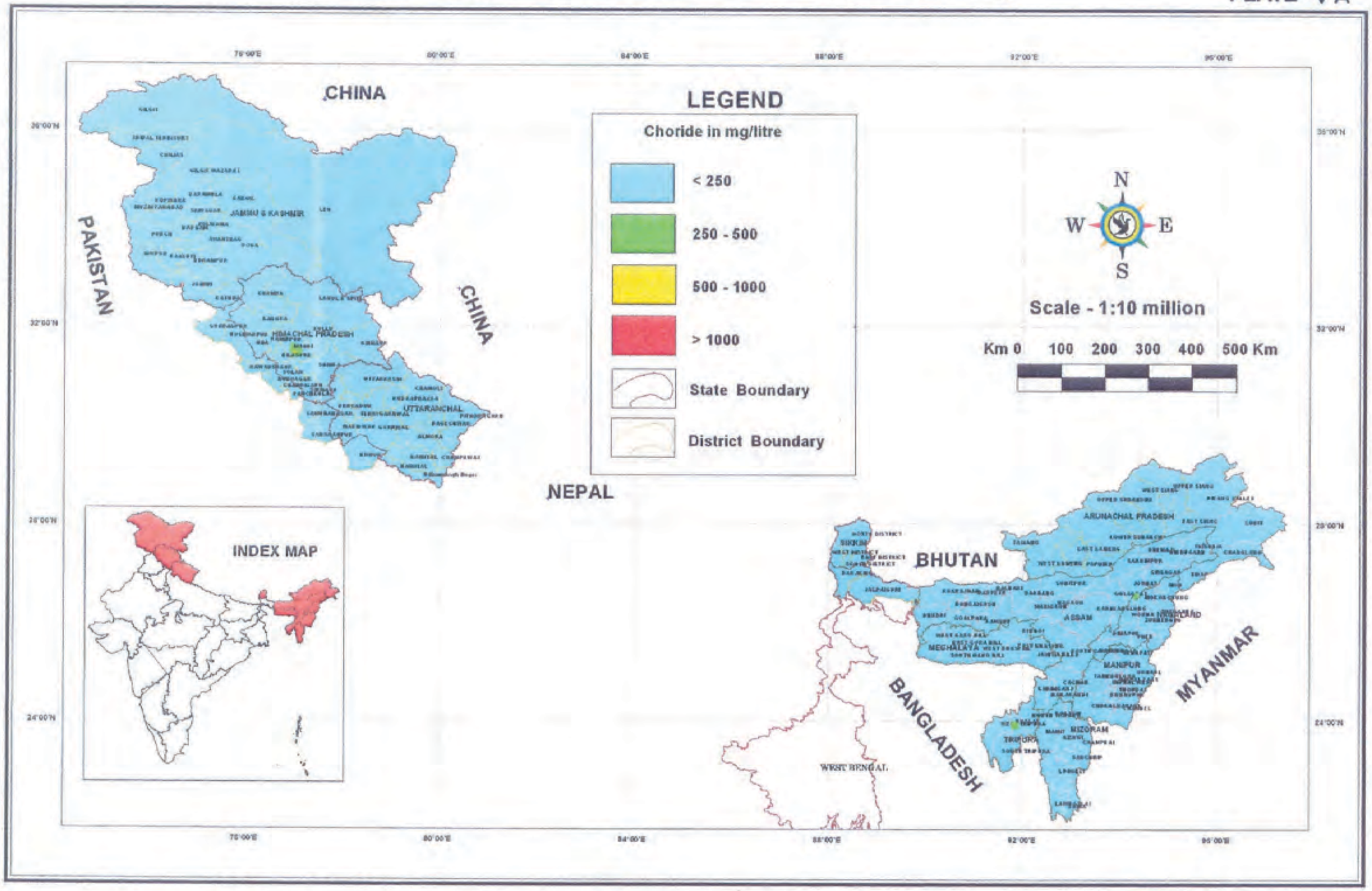


PLATE - VB

ELECTRICAL CONDUCTIVITY IN GROUND WATER (in micro siemens/Cm) IN HIMALAYA REGION

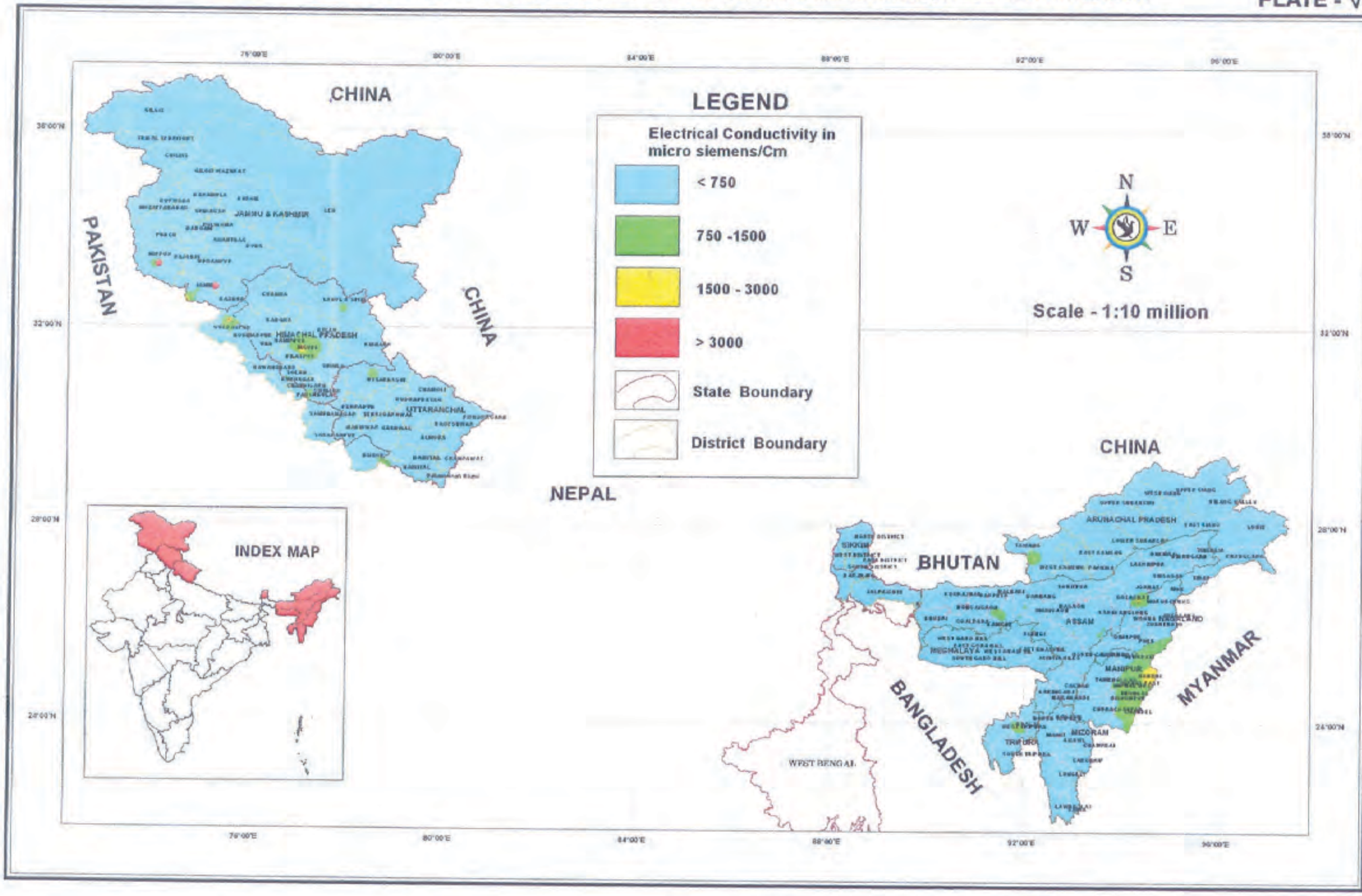
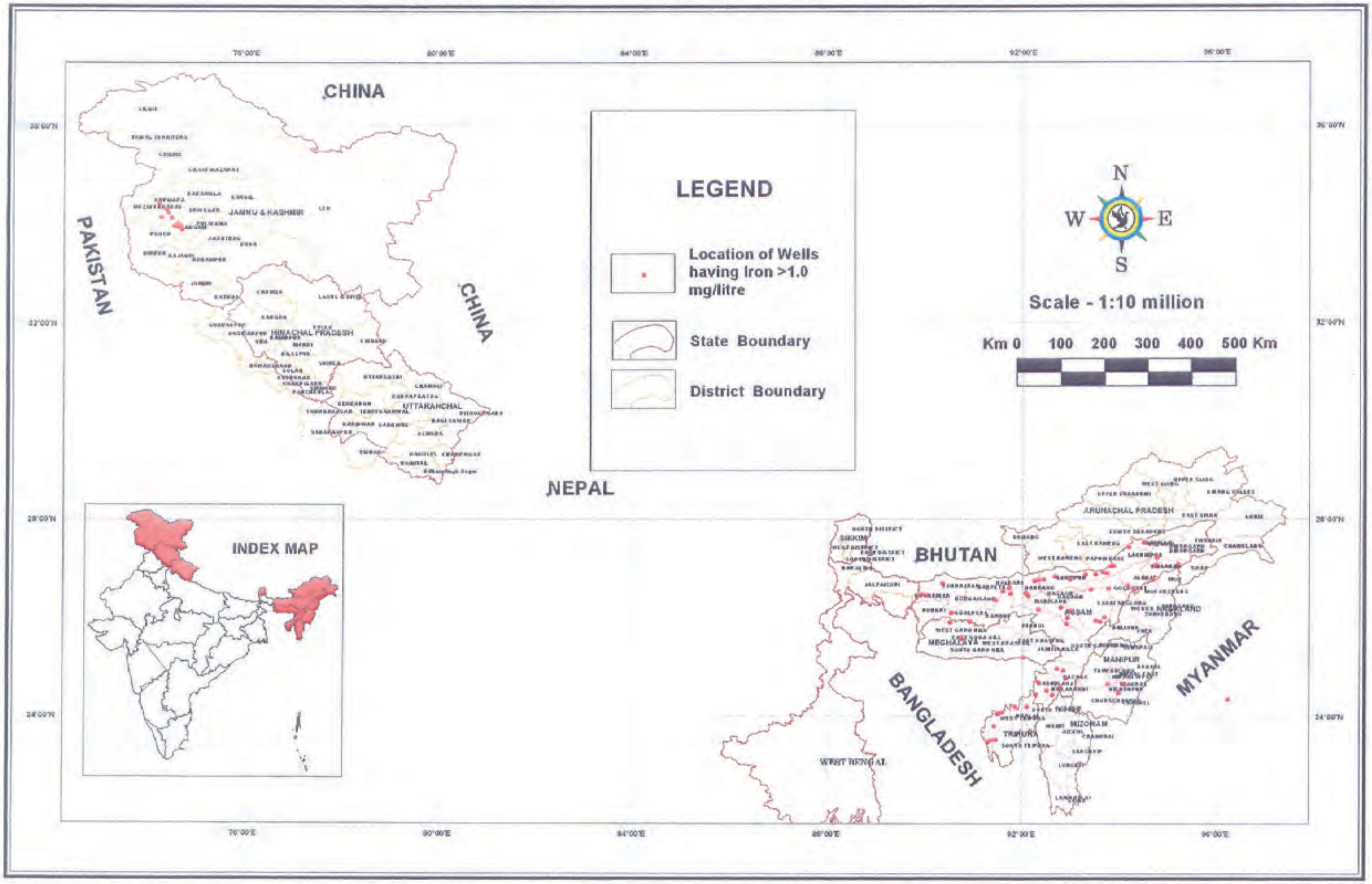


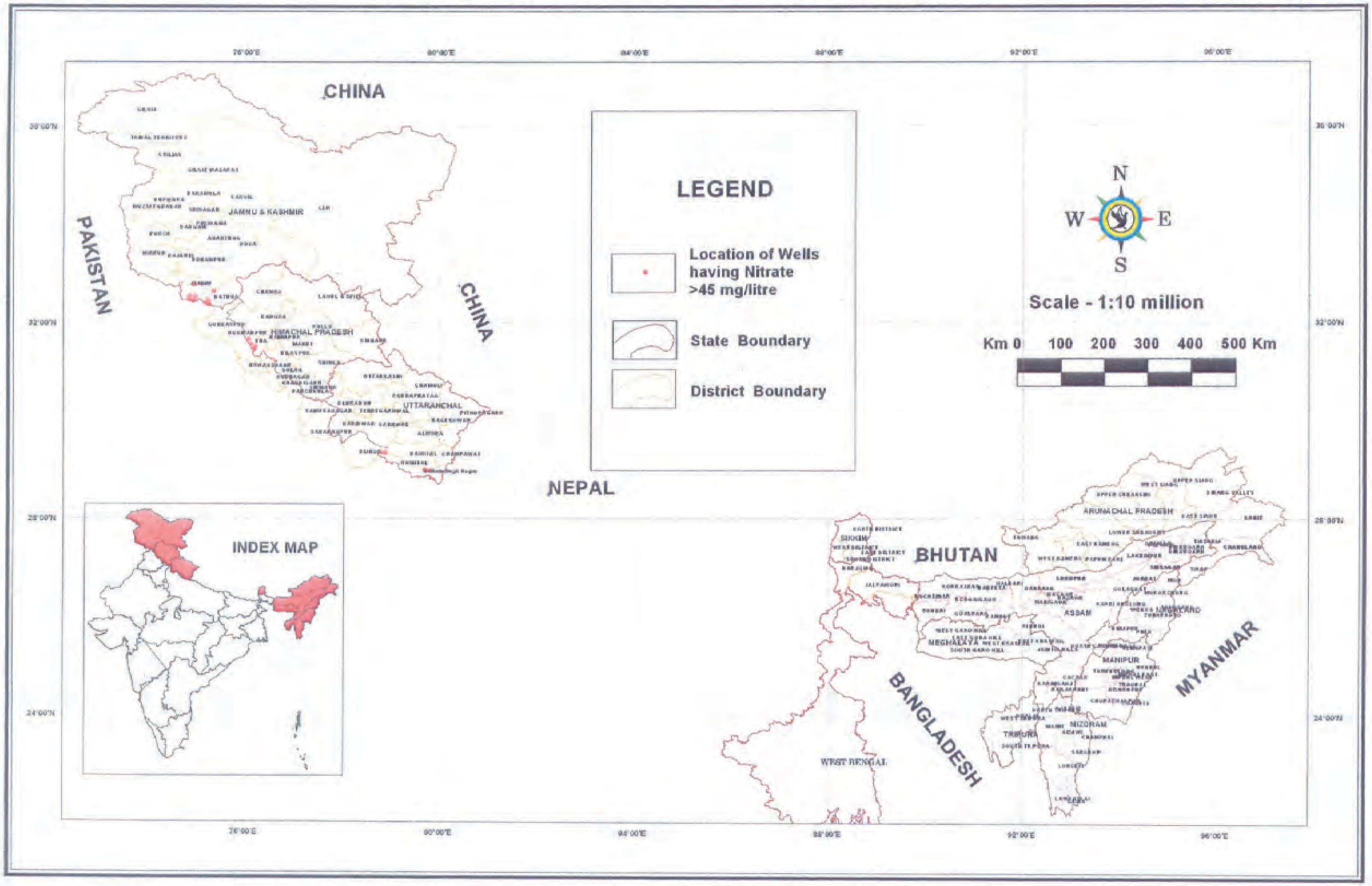
PLATE - VC

IRON IN GROUND WATER (in mg/litre)



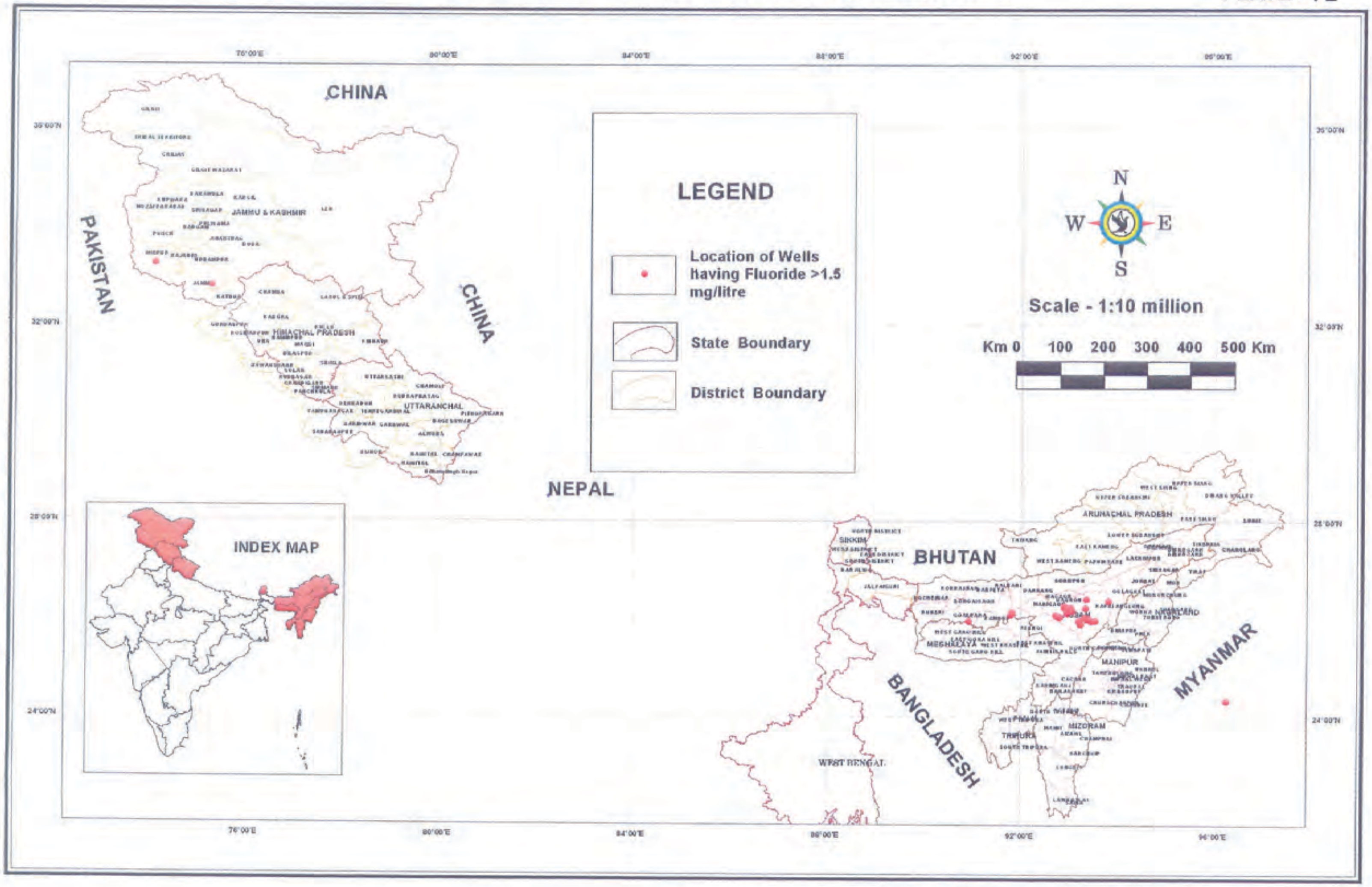
NITRATE IN GROUND WATER (in mg/litre)

PLATE -VD



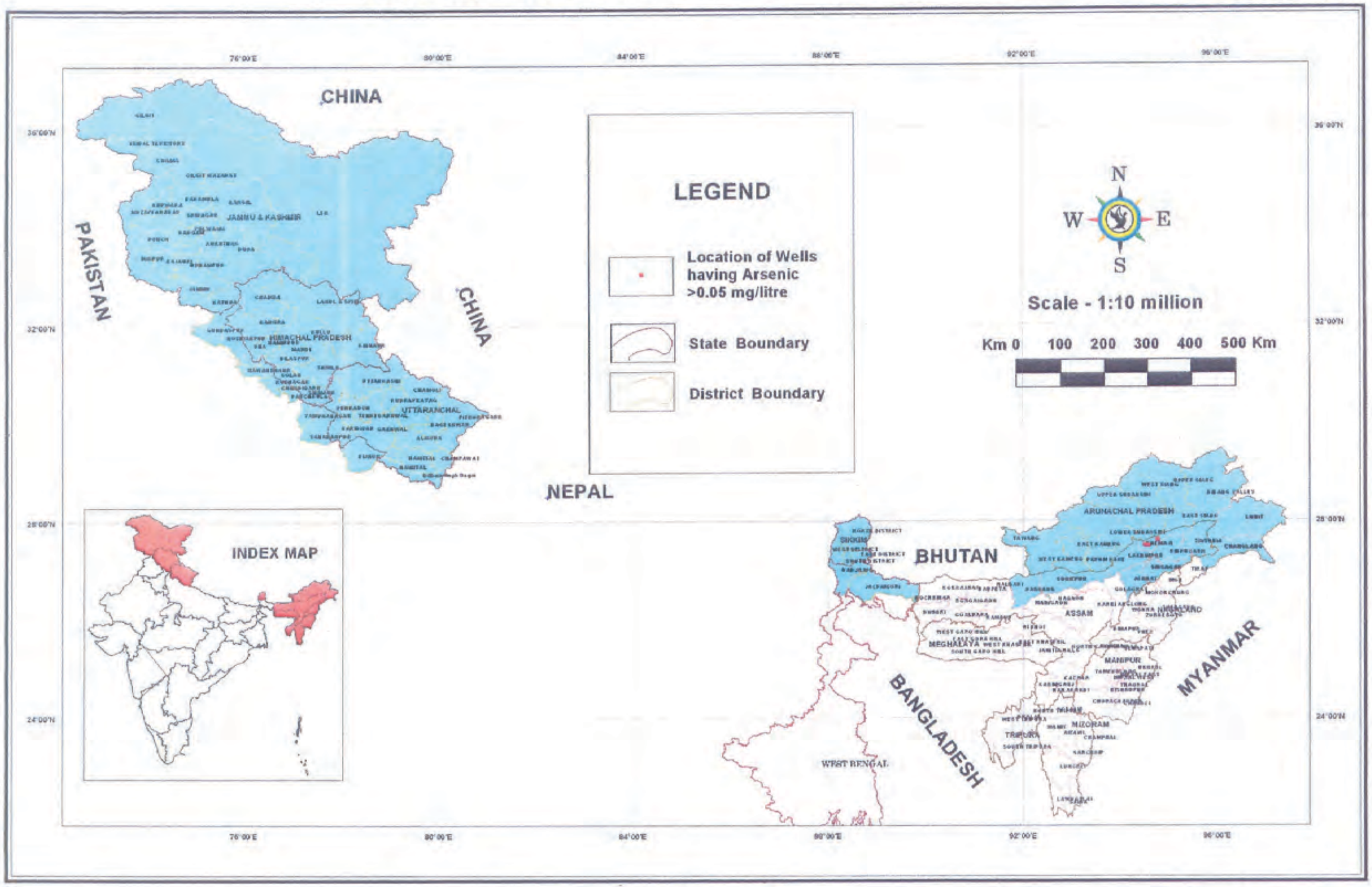
FLUORIDE IN GROUND WATER (in mg/litre)

PLATE - VE



ARSENIC IN GROUND WATER (in mg/litre)

PLATE -VF



भारत के हिमालयी क्षेत्र का भूजल परिदृश्य
Ground Water Scenario of Himalayan Region, India

योगदान / Compiled by

श्री जी.सी. साहा, क्षेत्रीय निदेशक (सेवानिवृत्त), पूर्वोत्तर क्षेत्र, गुवाहाटी
Shri G.C.Saha, Regional Director (Retd.), NER, Guwahati

श्री ए.के. भाटिया, क्षेत्रीय निदेशक (सेवानिवृत्त), उत्तरांचल क्षेत्र, देहरादून
Shri A.K.Bhatia, Regional Director (Retd.), UR, Dehra Dun

श्री ए.रे., क्षेत्रीय निदेशक (सेवानिवृत्त), उत्तर पश्चिम हिमालयी क्षेत्र, जम्मू
Shri A.Ray, Regional Director (Retd.), NWHR, Jammu

श्री सी.पी. श्रीवास्तव, क्षेत्रीय निदेशक (सेवानिवृत्त), पूर्वी क्षेत्र, कोलकाता
Shri C.P. Srivastava, Regional Director (Retd.), ER, Kolkata

श्री सुनील कुमार, क्षेत्रीय निदेशक, मुख्यालय, फरीदाबाद
Shri Sunil Kumar, Regional Director, CHQ, Faridabad

श्री सुजीत सिन्हा, वैज्ञानिक डी, मुख्यालय, फरीदाबाद
Shri Sujit Sinha, Scientist-D, CHQ, Faridabad

संकलन / Compiled by

श्री ए. कार, अधीक्षण भू जल विज्ञानी, मुख्यालय, फरीदाबाद
Shri A. Kar, Suptdg. Hydrogeologist, CHQ, Faridabad

श्री एस.के. जुनेजा, वैज्ञानिक डी, राज्य एकक कार्यालय, दिल्ली
Shri S.K. Juneja, Scientist-D, State Unit Office, Delhi

श्री एन.आर. भगत, वैज्ञानिक डी, उत्तर पश्चिम हिमालयी क्षेत्र
Shri N.R. Bhagat, Scientist-D, NWHR

डॉ. पी.एन. सिंह, वैज्ञानिक सी, उत्तरांचल क्षेत्र
Dr. P.N. Singh, Scientist-C, UR

श्री वी.एन., नेगी, वैज्ञानिक सी, पूर्वोत्तर क्षेत्र
Shri V.N. Negi, Scientist-C, NHR

सुश्री एस. बंद्योपाध्याय, वैज्ञानिक सी, पूर्वोत्तर क्षेत्र
Ms. S. Bandyopadhyay, Scientist-C, NER

सुश्री परवीन कौर,वैज्ञानिक बी, मुख्यालय, फरीदाबाद
Ms. Parveen Kaur, Scientist-B, CHQ, Faridabad

श्रीमती पी. कंवर, सहायक भू जल विज्ञानी, उत्तर पश्चिम हिमालयी क्षेत्र
Mrs P. Kanwar, AHG, NWHR

श्रीमती आर भट्टी, सहायक भू जल विज्ञानी, उत्तर पश्चिम हिमालयी क्षेत्र
Mrs R. Bhatti, AHG, NWHR

अन्य सहयोगी / Other Associates

श्री आर.के. कलिता, सहायक भूजलविज्ञानी
Shri R.K. Kalita, Asstt. Hydrogeologist

श्री ए.सी. हजारिका, मुख्य प्रारूपकार
Shri A. C. Hazarika, Chief Draftsman

श्रीमती बी.बी. देवी, मुख्य प्रारूपकार
Mrs B.B.Devi, Chief Draftsman
श्रीमती एम. बोरपुजारी, ड्राफ्ट्समैन ग्रेड–I
Mrs M.Borpujari, Draftsman Grade-I

श्रीमती एस. दास, ड्राफ्ट्समैन ग्रेड–I
Mrs S. Das, Draftsman Grade-I

जल संरक्षण वर्ष 2013 Water Conservation Year

जल बचायें - जीवन बचायें Save Water - Save Life

Central Ground Water Board
Bhujal Bhawan , NH-IV, Faridabad-121001
Tel. 0129-2425870/2427961 Fax: 0129-2425870
Website: cgwb.gov.in

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