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JOGAMAYA DEVI COLLEGE

आत्मदीपो भव

Changing Trend in Human Thoughts and Perspective: Science, humanities and Culture
Changing Trend in Human Thoughts and Perspective: Science, humanities and Culture

Changing Trends in Human Thoughts and Perspectives: Science, Humanities and Culture Part II

Changing Trends in Human Thoughts and Perspectives:
Science, Humanities and Culture

Part II

Jogamaya Devi College Interdisciplinary Volume 1, Issue 2

Jogamaya Devi College
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FOREWORD

It is encouraging to note that the Research Committee of Jogamaya Devi College, Kolkata, has gone past the teething problems in publishing their institutional research-cum-review journal. One of the objectives of publishing the journal, as was mentioned in the foreword of the first volume, was de-compartmentalizing knowledge, so that one specializing in a subject or a branch thereof, can have a glimpse into the happenings in other subjects or branches. It seems that some authors have taken this objective quite seriously and have tried to present bits of their own subjects to create interest among the general reader, including those from other disciplines. However, sometimes the articles have been too technical in nature and suitable for readers from the same discipline or same specialization.

A review article on the paleopiezometry, dealing with the development of various piezometers, devices to measure remnant stress in quartz-bearing rocks and study the relationship of stress and recrystallized quartz grainsize, probably belongs to the last category.

However, a welcome trend is the concern for nature and environment revealed in several articles. One such article has dealt with environmental consciousness in Indian literature, especially in the writings of best known Bengali authors. Another has dealt with 'Balneotherapy'(therapy based on bathing in water or mud laden with minerals), which the common man would understand as a part of 'naturopathy'. It is the same concern for environment that has given rise to the term 'eco-feminism', which tries to put nature and women, of course not all, in the same oppressed category. An article also reviews the history of environmental education in India. It would remind students and younger academicians of the order of the Hon'ble Supreme Court in response to a November 1991 appeal by M.C.Mehta, which made it mandatory to include environmental education in school and college level education.

A valuable and truly research article deals with the impact of the COVID-19 and on-line teaching-learning that the pandemic has forced upon the educational system. It would be a useful document in the post-Covid days, especially for those associated with distance education, and may encourage continuation of the on-line methods to some extent, in specific areas. It may be mentioned that the term 'blended teaching-learning' has already become popular among educationists.

Success of the articles would be measured not only by the knowledge they transmit to the readers, but also by interest they arouse and the thoughts they provoke. Honest feedback from the readers about how readable and useful they find the articles, would help the would-be contributors as well as the editorial board in improving the acceptability of the journal.

Pratip Kumar Chaudhuri

⌘ Changing Trends in Human Thoughts and Perspectives: Science, Humanities and Culture, Part II,
Jogamaya Devi College Interdisciplinary Volume 1, Issue 2 (2020)

FROM PRINCIPAL'S DESK

Jogamaya Devi College gladly presents interdisciplinary publication of college whose theme is Changing Trends in Human Thoughts & Perspectives.

All credit goes to great enthusiasm of college Research Committee due to which publication of the 2nd volume got possible within six months of publication of 1st volume of the E-Book. Respecting the theme of the book, articles of the present volume too are written on different change of trends.

I express my sincere thanks to the contributors, reviewers and committee members for their efforts towards publishing the volume even in this tough time.

Regards

Principal

⌘ Changing Trends in Human Thoughts and Perspectives: Science, Humanities and Culture, Part II,
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FROM THE EDITORS' DESK

The Research Committee of Jogamaya Devi College resolved in 2017 to publish in each academic session an interdisciplinary e-book on a particular theme, to provide a platform for the teachers and researchers from various disciplines to bring out their discourses on that theme. The first two volumes, highlighting the contemporaneous environmental issues and sustainable development that were published in 2018 and 2019 respectively, received fairly good response and appreciation from the academicians. But the third one in this series, comprising eclectic treatises on the gradual evolution of human ideas and concepts on various aspects of science and humanities, surpassed all its predecessors. So many articles were submitted for it that it was not possible to publish them in a single e-book, which compelled us to come out with another volume with the same theme in the same calendar year. This is, in short, the raison d'etre of our present volume, titled '*Changing Trends in Human Thoughts and Perspectives: Science, Humanities and Culture, Part – II*'.

The first article of this e-book, "নিসর্গনীতি ও সাহিত্যে পরিবেশ চেতনা" by Aditya Haldar, comprises two parts; the first part described the development of the social ecology in India, and the second part narrated the influence of nature and environmental consciousness in the literature, with special reference to the creations of three prominent Bengali authors: Rabindranath Tagore, Bibhuti Bhushan Bandyopadhyay and Tara Shankar Bandyopadhyay.

Microstructural analyses are gradually becoming more and more important in the comprehensive investigations of rock deformation in a region; and the microstructural parameters are being widely used in the determination of the prevalent rheological factors of deformation, like differential stress, strain, strain rate etc. In the article titled "Four decades of recrystallized quartz grainsize paleopiezometry: Progressive development of the principles", Bhaskar Ghosh has described the development of the different methods for measurement of differential stress from recrystallized quartz microstructures, and compared the merits and demerits of those methods as revealed from their applications in the study of various naturally deformed rocks.

The limitations of conventional medical treatments and modern medicines have long been known, which are even more exposed during the present pandemic situation. This has prompted people throughout the ages to look for traditional, natural cures for various ailments. Kaushik Kiran Ghosh, in his article titled "A discourse on Balneotherapy – an ancient rejuvenating geomedical practice", describes one such natural treatment, balneotherapy, a kind of stimulus-adaptation therapy that uses the natural ingredients such as hot spring water. In this treatise of largely multidisciplinary nature, the author has explained the different medical, geochemical and hydrogeological aspects of this therapy.

The ongoing COVID-19 crisis has suddenly brought about prolonged closure of the educational institutions, and forced the teachers and students to adopt themselves to new methods of teaching. In order to study the implications of the newly introduced learning methodologies, Rituparna Mukherjee conducted a survey on a group of 20 teachers and 160 students of English and Communicative English in two undergraduate colleges, and presented her observations in the article titled "Constraints and possibilities in the changing teaching-learning paradigms of tertiary level formal ESL classroom teaching in Kolkata due to COVID-19: A case study".

Ranu Naskar, in her article "Changing trends in environmental education of India in 20th and 21st century: an overview", described the progress of environmental education and the gradual development of environmental awareness in our country after the UNESCO-UNEP intergovernmental conference of 1977.

Two seemingly diverse disciplines of natural and social sciences, ecology and feminism, were unified during the 1960s and 1970s to develop a new study area, ecofeminism, which addresses the problems of both the degradation of nature and the oppression of women in the society. The last article in this issue, "Feminism to ecofeminism", Soma Mandal described the progressive emergence of this subject, along with a note on its relevance in the post-COVID 19 scenario.

From a large number of articles submitted for publication in this volume, we could select only the above six after the initial scanning by the editorial board and thorough reviews by eminent academicians from different disciplines. We regret that we cannot publish a number of articles which, in spite of presenting excellent works of review and research, were not relevant to this theme. We hope that these authors will understand our constraints and consider our subsequent interdisciplinary volumes for publishing their articles in future.

It would not have been possible to complete all the works for this volume within four months of publication of the previous one without unstinting support and active cooperation of a number of teachers and researchers. We gratefully acknowledge the selfless contribution of our revered colleague Dr. Broti Gayen of the Department of Bengali, who painstakingly edited the language of the Bengali article and helped the author to make necessary corrections. Sincere thanks to our Principal and the teachers of our college for the support and encouragement we have received in different stages of the work. We conclude this with a hope that this humble effort will satisfy its intended readers, the teachers, researchers and students, and encourage them to use this platform to disseminate their works.

Sushree Chakraborty
Bhaskar Ghosh
Soma Mandal
Piali Mondal
Kaushik Kiran Ghosh
(Members of the Editorial Team)

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নিসর্গনীতি ও সাহিত্যে পরিবেশ চেতনা

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প্রবন্ধসার **(Abstract):** কোনও জৈব পরিবেশ সংগঠনে, অজৈব পরিবেশের সঙ্গে আমাদের এই মানবজীবনের আদান-প্রদানের একটি ঘনিষ্ঠ সম্পর্ক রয়েছে। জৈব এবং অজৈব পরিবেশ মূলত একে অপরের পরিপূরক। যে-কোনও অঞ্চলের প্রানী বা গাছপালার উপর আলো, উষ্ণতা, জল বা মাটির গভীর প্রভাব থাকে। জীবের সাথে অন্যান্য জীব ও তার চারপাশের পরিবেশের সম্পর্কের বৈজ্ঞানিক চর্চাকে বলা হয় নিসর্গনীতি। কিন্তু গত দেড়শ বছরে নিসর্গনীতির ধারণাগুলি জ্ঞান তত্ত্বের নানা শাখায় জনপ্রিয়তা পেয়েছে। সমাজতত্ত্ব থেকে সাহিত্যে এমনকি নারীবাদী সন্দর্ভেও নিসর্গনীতিকে বিভিন্ন আঙ্গিকে ভাবা হয়েছে। এই প্রবন্ধটির প্রথম পর্বে ভারতবর্ষের সামাজিক নিসর্গনীতির সংক্ষিপ্ত বর্ণনা করা হয়েছে। প্রবন্ধটির দ্বিতীয়পর্বে সাহিত্যে প্রকৃতি ও পরিবেশ চেতনার প্রভাব এবং বাংলা সাহিত্যের অন্যতম গুরুত্বপূর্ণ তিনজন লেখক রবীন্দ্রনাথ ঠাকুর, বিভূতিভূষণ বন্দ্যোপাধ্যায় ও তারাশঙ্কর বন্দ্যোপাধ্যায়ের লেখায় যে পরিবেশ ও প্রকৃতি চেতনার বিস্তার পাওয়া যায় তার চিত্র তুলে ধরা হয়েছে।

বীজ শব্দঃ নিসর্গনীতি, মিথোজীবি, প্রকৃতি ও পরিবেশ।

পরিবর্তনই প্রকৃতির অভিমুখ। পৃথিবী তার জন্মের সূচনাকাল থেকে প্রায় ৪০০ কোটি বছর ধরে পরিবর্তনের বিভিন্ন স্তর পেরিয়ে গড়ে তুলেছে বর্তমান পরিবেশ। এই পৃথিবীতে আদিম মানুষের সন্ধান পাওয়া যায় প্রায় ৩০ লক্ষ বছর আগে। বিবর্তনের ধারায় পুরাতনের বিলুপ্তি ঘটে, সম্পুর্ণ নতুন প্রানী ও উদ্ভিদের আবির্ভাব হয়। পৃথিবীর ক্রমবিকাশ পর্যায়ের বর্তমান পর্যন্ত মানুষ হল সর্বশেষ এবং সর্বশ্রেষ্ঠ সংস্করণ। আজকের মানুষের পূর্বপুরুষ এসেছে প্রায় ২৫ হাজার বছর আগে। ক্রমে শুরু হলো মানুষের অবাধ বিচরণ ও প্রকৃতির উপর আধিপত্য। অরণ্যচারী মানুষ পৃথিবীর ক্ষতি করেনি। কিন্তু সভ্যতা যত এগিয়েছে, সৃষ্টির শ্রেষ্ঠ জীব পরিবেশের ভারসম্য ততই নষ্ট করে চলছে।

বায়ুমন্ডল, বারিমন্ডল, মৃত্তিকামন্ডল এবং জীবমন্ডল নিয়ে হলো এই পৃথিবী। সমগ্র পৃথিবীর চারটি মন্ডলই আজ নানা দূষণের শিকার। পরিবেশের উপর মানুষের হস্তক্ষেপের মূলে রয়েছে জনসংখ্যার ক্রমবর্ধমান চাপ। বিজ্ঞান ও প্রযুক্তির নানা কৃৎকৌশল নিয়ে বিরাট সংখ্যক মানুষ নিজেদের প্রয়োজনে প্রাকৃতিক পরিবেশের ওপর প্রভাব বিস্তার করে তাকে পরিবর্তিত করছে। কোটি কোটি বছর ধরে বিভিন্ন প্রাকৃতিক শক্তি পৃথিবীর পরিবেশের যা পরিবর্তন করতে পেরেছে, বিগত একশ বছরেই মানুষ হয়তো তার বেশি পরিবর্তনের অংশীদার হয়েছে। ভূপৃষ্ঠে এবং জীবমন্ডলে মনুষ্যসৃষ্ট অনেক পরিবর্তন সাধিত হয়েছে। ফলে আমরা পেয়েছি পৃথিবীর তাপমাত্রা বৃদ্ধি, সমুদ্রের জলমাত্রা বৃদ্ধি, জলের অম্লতা বৃদ্ধি, জলের লবনাক্ততা বৃদ্ধি, পরিবেশ দূষণ, ওজোন স্তর পাতলা হওয়া, মরুময়তা বৃদ্ধি, বৈচিত্র্যের বিনাশ আর পরিবেশের বিপজ্জনক ভারসাম্যহীনতার সমস্যা এবং তার ফলে মানবজাতির অস্তিত্বেরই সংকট দেখা দিয়েছে অবশ্যম্ভাবী রূপে (দাস ২০১৫)।

উনিশ শতকের শেষার্ধে চার্লস ডিকেন্স ও কার্ল ফ্রিডরিখ এঙ্গেলস শিল্প-বিপ্লবের কুপ্রভাবের প্রতি দৃষ্টি আকর্ষণ করেন। তবু শিল্প ও প্রযুক্তি সম্পর্কে সচেতন হতে আমাদের সময় লেগেছে। দ্বিতীয় মহাযুদ্ধের পর পরিবেশে প্রযুক্তির অপপ্রভাব প্রায় সমস্ত ধনী ও উন্নত দেশেই স্পষ্ঠ হয়ে উঠেছে। পঞ্চাশের শতকের শেষ ভাগে র‍্যাচেল কারসন যখন তাঁর ‘Silent Spring’ বইয়ের মাধ্যমে রাসায়নিক দূষণের কথা বলেন তখন সেই কাহিনী অনেকে বিশ্বাস করেননি। দ্বিতীয় বিশ্বযুদ্ধের পর থেকেই উন্নত দেশগুলিতে পরিবেশ-সংক্রান্ত সমস্যা অনুভূত হচ্ছিল। এটি সার্বজনীন সমস্যা সে ধারণা আমাদের মধ্যে এসেছে অনেক পরে। ১৯৭২ সালে স্টকহোমে সম্মিলিত জাতিসংঘের প্রয়াসে পরিবেশ সম্পর্কে যে আলোচনাসভা অনুষ্ঠিত হয়েছিল তাতে অধিকাংশ দরিদ্র দেশেরই ধারণা ছিল যে পরিবেশ সমস্যা কেবল শিল্পোন্নত দেশগুলিরই মূল সমস্যা এবং দরিদ্র দেশগুলোর সমস্যা হল শিল্পোন্নতির মাধ্যমে দারিদ্র মোচন করা। এমনকি, অনেকেই মনে করেছেন যে

পরিবেশ-সমস্যা বা দূষণ-সমস্যার নাম করে আন্তর্জাতিক ক্ষেত্রে কেবল ধনী ও দরিদ্র দেশগুলির পার্থক্য জিইয়ে রাখার চেষ্টা করা হচ্ছে। স্টকহোমে ভারতের প্রধানমন্ত্রী শ্রীমতী গান্ধীও বলেছিলেন 'Poverty is the worst pollutant'। দরিদ্র দেশে যদি দারিদ্রই পরিবেশ-দূষণের মূল কারণ হয় তবে উন্নয়নের সাহায্যে দারিদ্র্যের সঙ্গে সঙ্গে পরিবেশ-সমস্যাও মিটবে বলে আশা করা যেতে পারে। ১৯৯২ সালে রিও ডি জেনিরোতে বসুন্ধরা সম্মেলনে বিশ্ব উষ্ণায়ন নিয়ে আলোচনা এবং উষ্ণায়ন গ্যাসগুলির নির্গমন নিয়ন্ত্রণ করার কথা ঘোষণা করা হয় (রায় ২০১৫)।

পরিবেশ বলতে বোঝানো হয় মানুষের চারপাশে অবস্থিত সজীব ও নির্জীব উপাদান, জীবজন্তু, গাছপালা এবং মানুষের হাতেগড়া সব কিছু নিয়ে যে বিরাট জগত তার সবটাই। পরিবেশ সম্পর্কিত ধারণা মূলত এক ভৌগোলিক ধারণা। ভৌগোলিক কাঠামো, যেমন বন-জঙ্গল, নদ-নদী, পাহাড়-পর্বত ইত্যাদি অনস্বীকার্যভাবেই পরিবেশের অন্তর্ভুক্ত। পরিবেশমন্ত্রক ও পরিবেশবাদ দুটি আলাদা বিষয়। পরিবেশমন্ত্রক হল সরকারের পরিবেশ বিষয়ক কার্যক্রম পরিচালনার সংগঠন আর পরিবেশবাদ হল একটা রাজনৈতিক মতবাদ, যা আমাদের পরিবেশ সমস্যাকে কেন্দ্রীয় স্তরে রেখে বা একমাত্র উপজীব্য করে, তা সমাধানের একটা সামগ্রিক দৃষ্টিভঙ্গি উপস্থিত করে। এই কার্যক্রম আবার সম্প্রসারিত হয়ে যায় ভৌগোলিক কাঠামোর সঙ্গে মিলে থাকে জীবজগতে। তাই জঙ্গলের সংরক্ষণের সঙ্গে সঙ্গে বন্যপ্রানীর সংরক্ষণের প্রসঙ্গও এসে যায় (চক্রবর্তী ২০১২)। পরিবেশের অপর একটি ধারণা পরিমন্ডল, আবহ, আবহাওয়া বা বাতাবরণ। এই ধারণায় যা কিছু আমাদের পরিবেষ্টন করে, ইংরেজীতে যাকে বলা হয় এনভিরন (Environ)করে, তাই হল পরিবেশ। এখানে পরিবেশ অনেক ব্যাপক অর্থে আমাদের কাছে হাজির হয়। যেমন সাংস্কৃতিক পরিবেশ, ধর্মীয় পরিবেশ, স্কুল- কলেজের পরিবেশ ইত্যাদি।

পরিবেশ এখানে ভৌগোলিক কাঠামোর সাথে মানসিক নির্মাণের সংশ্লেষে তৈরি। বর্তমান পৃথিবীতে সবচেয়ে আধিপত্যকারী জ্ঞান অবশ্যই বিজ্ঞান। জ্ঞানের ক্ষেত্রে আধুনিকতায় ধর্মীয় জ্ঞানের পরিবর্তে বিজ্ঞান একভাবে সামাজিক আধিপত্য স্থাপন করতে পেরেছে। এমনকি সবচেয়ে আধিপত্য সামাজিক ব্যবস্থা পুঁজিবাদও তার অর্থনীতির জ্ঞানতাত্ত্বিক বৈধতার সন্ধান করে বিজ্ঞানের সন্দর্ভে। পুঁজিবাদী অর্থনীতির নির্ভুলতা তাই সবসময় যাচাই করা হয় বৈজ্ঞানিক হিসেব নিকেশ দিয়ে। ব্রাহ্মণতুল্য বিজ্ঞানের আশীর্বাদ বৈশ্য-ক্ষত্রিয় পুঁজিবাদের সাম্রাজ্যটিকে বৈধতা দিয়ে চলছে। এই অর্থে বিজ্ঞান ও পুঁজিবাদ আমাদের পরিবেশের অবিচ্ছিন্ন অংশ (চক্রবর্তী ২০১২)।

সমাজতাত্ত্বিকরা নিসর্গনীতিকে ভেবেছেন মানবসমাজের অবস্থান থেকে। সামাজিক নিসর্গনীতির মূল কথা হল কীভাবে প্রকৃতি-পরিবেশ সামাজিক কাঠামোকে নির্ধারণ করে এবং অপরদিকে সামাজিক সংগঠন কীভাবে প্রকৃতি-পরিবেশকে পরিবর্তিত করে। ভারতবর্ষের সামাজিক নিসর্গনীতি ভাবনার পথপ্রদর্শক রাধাকমল মুখার্জি একজন অর্থনীতিবিদ হিসেবে ভারতবর্ষীয় সমাজকে ভাবতে শুরু করে উপলব্ধি করেন যে সমাজ-অর্থনীতির সন্দর্ভ ভারতের নদ-নদী, জলা-জঙ্গল, পশু-পাখিদের বাদ দিয়ে তৈরী করা সম্ভব নয়। তিনি নিসর্গনীতিকে শুধুমাত্র জীববিদ্যা, উদ্ভিদবিদ্যা বা ভূগোলের মধ্যে সীমায়িত করতে চাননি। তিনি নিসর্গনীতিকে সংজ্ঞায়িত করেন এক বিশেষ 'Viewpoint and attitude' হিসেবে যা প্রাণ ও পরিবেশের সকল সম্পর্ককে ধারণ করতে পারে। তিনি বৈজ্ঞানিক নিসর্গনীতির মিথোজীবিতার (Symbiosis) ধারণা দিয়ে বুঝতে চাইছিলেন মানুষের সমাজকে। মিথোজীবিত্ব হল দুটি বা ততোধিক প্রাণী বা উদ্ভিদের মধ্যে এমন একটি সম্পর্ক যেখানে প্রতিটি প্রাণী বা উদ্ভিদ পরস্পরের সাথে সহযোগিতার মধ্যে দিয়ে এক যৌথ জীবনশৈলী গড়ে তোলে (চক্রবর্তী ২০১২)।

প্রকৃতি সম্পর্কে মানুষের শুরু থেকেই ভীতি-মিশ্রিত একটি শ্রদ্ধার ভাব রয়েছে, যা বিবৃত হয়েছে বিভিন্ন প্রাচীন দর্শনে, লোকগাথায়। প্রকৃতি-উপাসনা যে-কোন প্রাচীন ধর্মেরই অঙ্গ। প্রকৃতি সম্পর্কে এই শ্রদ্ধা, প্রকৃতির সঙ্গে ঐক্যের নতুন একটি মতাদর্শের আধুনিক পুনরুজ্জীবন ঘটে উনবিংশ শতাব্দীতে, ইউরোপ এবং আমেরিকায়। এই নতুন ভাবনা আজকের শিল্পজাত দূষণের সমস্যা নিয়ে ভাবিত ছিল না, এর মূল আশঙ্কা নাগরিক যন্ত্রসভ্যতার বিকাশের ভবিষ্যৎ নিয়ে। আধুনিক বিজ্ঞানের যান্ত্রিক দৃষ্টিভঙ্গি এবং যন্ত্রসভ্যতার ক্রমবিকাশ মানুষকে তার 'স্বাভাবিক' কাজকর্ম থেকে, প্রকৃতি থেকে বিচ্ছিন্ন করে শিল্পদানবের দাস করে তুলছে। এই যন্ত্রসভ্যতার বিকাশের ফলে ভবিষ্যতের সমাজ ব্যবস্থায় যে পরিবর্তন আসতে পারে তা নিয়ে উনবিংশ শতাব্দীর বিভিন্ন চিন্তাবিদ, ওয়েন থেকে মার্কসকে ভাবিত করেছিল। আধুনিক যন্ত্রসভ্যতা-বিরোধী ও প্রকৃতি প্রেমের মতামত নিয়ে প্রথম আমেরিকায় সংরক্ষণ আন্দোলন (Conservation

Movement) প্রকাশিত হয়। এই আন্দোলনকে বলা যেতে পারে আধুনিক পরিবেশবাদী আন্দোলনের প্রথম ধাপ, যা একশ বছর আগেই, ১৮৭০ সালে, আমেরিকার জাতীয় বনভূমি (National Park) ঘোষণা বনাঞ্চল সংরক্ষণের কাজে সরকারকে বাধ্য করে। খন্ডিতভাবে এই আন্দোলন হয়ে উঠল প্রযুক্তি-কন্টকিত নাগরিক সভ্যতার থেকে দূরে কিছু বিচ্ছিন্ন দ্বীপ গড়ে তোলা। যার মর্মকথা, এই আন্দোলনের পুরোধা থেরোর ভাষ্যে, নির্জন প্রকৃতিতেই (Wilderness) মানুষের প্রকৃত সত্ত্বা বিকশিত হয়। এই নির্জন প্রকৃতির সংরক্ষণই মানব সভ্যতার টিকে থাকার কষ্টিপাথর। পশ্চিমি নাগরিক সভ্যতায় যান্ত্রিকতায় ক্লান্ত অনেক মানুষ এই চিন্তায় আকৃষ্ট হল।

প্রকৃতি-প্রিয়তার এই ধারাটি আজকের পরিবেশ আন্দোলনে আরও সুসংহত। তারা মনে করেন প্রকৃতির সম্পর্কে সম্যক উপলব্ধি ছিল আদিম মানব সমাজ গুলির, সেই চিন্তা ধারাই আজও অনুকরনীয়। যেমন একজন প্রখ্যাত সমাজবিদ একদা বলেছিলেন '… এই যান্ত্রিক (বৈজ্ঞানিক) দৃষ্টিভঙ্গির, যে দৃষ্টিভঙ্গি সবকিছুকে পরিমাপ করতে চায়, তার সঙ্গে আমাদের জানা প্রাচীনতম একটি উপজাতি, অস্ট্রেলিয়ার আদিবাসীদের দৃষ্টিভঙ্গির তুলনা করা যাক। …এই দৃষ্টিভঙ্গিতে মানুষ ও প্রকৃতির মধ্যে কোনো নির্দিষ্ট বিভাজন নেই, বিভাজন নেই সচল ও অচলের মধ্যে, অতীত, বর্তমান ও ভবিষ্যতের মধ্যে। অস্ট্রেলিয়ান এই 'আদিম' চিন্তা জীববিদ্যা এবং সাংস্কৃতিক দৃষ্টিকোণ থেকে আজকের যান্ত্রিক বিশ্ববীক্ষা থেকে অনেক অগ্রসর' (মামফোর্ড ১৯৭০)। এই ধারাতেই আরেকটু এগিয়ে এটাও মনে করা হয় যে সেই প্রাচীন সমাজই ছিল প্রকৃত পরিবেশ সচেতন। প্রাচীন ধর্ম ও সংস্কৃতির মধ্যে পরিবেশের সম্পর্ক ছিল অত্যন্ত নিবিড়। যেমন 'প্রাচীন যুগে প্রত্যেকটি গাছ, প্রত্যেকটি ঝরনা, প্রত্যেকটি পাহাড়ের একটি নিজস্ব সত্তা ছিল। …কোনো গাছ কাটা, পাহাড় খোঁড়া বা ঝরনাকে বাঁধ দেওয়ার আগে এগুলির আত্মাকে সন্তুষ্ট করে নিতে হত' (হোয়াইট ১৯৭০)। প্রকৃতির যে নিজস্ব সত্তা রয়েছে তা স্বীকার করা হত। ফলে প্রকৃতির অস্তিত্ব বা মূল্যায়ন মানব নির্ভর নয়, তার নিজস্ব 'মূল্য' আছে, আর এই উপলব্ধির মধ্যে পরিবেশ সচেতন মানবসভ্যতার বিকাশের পথ নিহিত (রোলস্টোন ১৯৮৩) এই বিশ্বাসকে দৃঢ় ভিত্তি দিতে আমেরিকার পরিবেশবাদী আইনজীবি ক্রিস্টোফার স্টোন দাবী করেছেন যে কর্পোরেশনগুলির মতই বিভিন্ন প্রাকৃতিক বস্তুকে যেমন গাছ, নদী, হ্রদ বা পাহড়কে, আইনি অধিকার দিতে প্রকৃতিকে কোনোভাবে বিপর্যস্ত করার অভিযোগে বিভিন্ন প্রকল্প বাতিল বা স্থগিত করা হয়েছে। যেমন হাডসন নদীর তীরে বিদ্যুত-কেন্দ্র স্থাপনের বিরোধিতার একটি প্রবল যুক্তি ছিল যে 'হাডসন নদী জাতির যে আধ্যাত্মিক প্রয়োজন মেটায় তা বানিজ্যিক সামগ্রী ও অর্থ দিয়ে পরিমাপ করা অসম্ভব'।

প্রকৃতি-কেন্দ্রিকতা চরমে এসে পৌঁছেছে পরিবেশ-নারীবাদীদের (Eco-feminist) ভাবনায়। নারীবাদী নেত্রী স্টেফানি লেল্যান্ড মনে করেন প্রকৃতিতে যৌন বিভাজনই যত নষ্টের মূল। তার মতে এই যৌন বিভাজন আসে বিবর্তনের একটি স্তরে কোনো প্রাকৃতিক দুর্যোগের ফলে। এর আগের অযৌন অবস্থাটা ছিল নারীভিত্তিক। পুরুষ-যৌনতা উদ্ভবের ফলে মানুষ নিজেদের প্রকৃতি থেকে বিচ্ছিন্ন বলে মনে করা শুরু করে, এই পুরুষত্বই সচেতনার অভিব্যক্তি ঘটায়, মানুষ তার নিজস্ব ভাবনাকে মূর্তরূপ দিতে শুরু করে। প্রকৃতি থেকে এই বিচ্ছিন্নতাই পরিবেশ ধ্বংসের মূল কারন (লেল্যান্ড ১৯৮৩)। মার্কস বলেছিলেন যে নিকৃষ্টতম স্থপতি ও সর্বোত্তম মৌমাছির মধ্যে পার্থক্য এই যে স্থপতি তার স্থাপত্য কর্মকে বস্তুতে গঠন করার আগে চিন্তায় রূপ দেয়। মানুষের এই চেতনার বিকাশেই প্রকৃতি-কেদ্রিকতার আপত্তি, এমনকি খ্যাতনামা বিজ্ঞানী ও কৃত্রিম কীটনাশক তৈরীর বিরোধিতায় বলেন যে মূল সমস্যা 'অন্যান্য প্রানীদের ভাবনা প্রকৃতি-নির্ধারিত, কিন্তু দুর্ভাগ্য যে মানুষ তা নয়, সে ভাবে, পরিকল্পনা করে এবং তা কার্যকরী করে' (টাকার ১৯৮২)।

প্রকৃতি-কেন্দ্রিক ভাবনা থেকে পরিবেশ-কেন্দ্রিক ভাবনার তফাতটা হল এই যে পরিবেশ- কেন্দ্রিক চিন্তা প্রকৃতির গুরুত্বকে আধ্যাত্মিক স্তরে না বিচার করে বিজ্ঞান সম্মতভাবে তার কার্যকারিতাকে প্রমাণ করবার চেস্টা করে। অর্থাৎ একটি গাছ বা প্রানীর সংরক্ষণে প্রকৃতির নৈতিক অধিকারের দাবী না তুলে বাস্তুসংস্থানে প্রাকৃতির ঐ বিষয়গুলির ভূমিকা কতটা জরুরি তাকেই গুরুত্ব দেয়। পরিবেশ-কেন্দ্রিক ভাবনার কেন্দ্রবিন্দু হল স্বাভাবিকভাবে বাস্তুসংস্থানকে অক্ষুন্ন রাখা। গত দেড়শো বছর ধরে জীববিদ্যার একটি শাখা হিসেবে ইকোবিদ্যা (Ecology) ক্রমশ পরিণত হয়ে উঠেছে। পরিবেশ ও প্রানীজগতের আন্তঃসম্পর্ক ও তাতে মানুষের ভূমিকা নিয়ে কিছু আলোচনা চলছে। পরিবেশ ও প্রানীজগতের আন্তঃসম্পর্ক ও তাতে মানুষের ভূমিকা নিয়ে কিছু আলোচনা, চিন্তা অনেকদিন ধরেই চলছে (রায় ২০১৫)।

প্রকৃতির কোলে ভারতীয় সভ্যতার জন্ম। বিরাট স্নিগ্ধ অরণ্যানী প্রাচীন যুগের মানুষের মধ্যে প্রকৃতির সাথে এক সহমর্মিতার চিন্তা গড়ে তুলতে সাহায্য করেছিল; প্রকৃতির উপর প্রভুত্বর ধারণা তখনও তাদের আসেনি। বৈদিক সাহিত্যে প্রাকৃতিক শক্তিগুলির প্রতি এক ভয়

মিশ্রিত শ্রদ্ধার,এক কৃতজ্ঞতার সুন্দর প্রকাশ ঘটেছে। প্রাকৃতিক শক্তি গুলিকে অদ্ভুত সুন্দর, মনোমুগ্ধকর, রহস্যময়, অতলস্পর্শী, বলশালী এবং সর্বোপরি মানুষের কল্যাণকামী হিসেবে বর্ণনা করা হয়েছে। বৈদিক যুগের মানুষের একটি মৌল প্রশ্ন ছিল-যা কিছু দেখছি, যা কিছু ঘটেছে, তার পিছনে কি কোন শক্তি আছে? ঋষি দীর্ঘতমা প্রশ্ন করেছেন- জগতের ছয়টি বিভাগকে যিনি সৃষ্টি করেছেন এবং পালন করেছেন, সেই এক সত্তা কে? এই প্রশ্নের উত্তর দিতে গিয়ে বৈদিক মানুষ নানা কল্পনা, নানা কাহিনীর অবতারণা করেছেন, পরবর্তীকালে নানা ভাবে আলোচিত হয়েছে। প্রকৃতির এই সকল বৈচিত্র্য ও নানা কার্যকলাপের পিছনে যে এক সত্তা আছে, তাকে অনেক সময় বলা হয়েছে অজ, কখনও বা এক, কখনও বা ইন্দ্র যিনি আকাশ ও মর্ত্যকে বলপূর্বক পৃথক করে রেখেছেন।

বৈদিক মন্ত্রে মানবকেন্দ্রিক পরিবেশ ভাবনার উপস্থিতি লক্ষ্য করা যায়। বিরাট সংখ্যক মন্ত্র ইন্দ্র নামক দেবতার উদ্দেশ্যে রচিত হয়েছে। তিনি বজ্রের মত শক্তিশালী, মেঘকে খন্ড খন্ড করে ভেঙ্গে দেন, যার ফলে বৃষ্টি হয়। আবার অগ্নিকে যজ্ঞের পুরোহিত বলে বর্ণনা করা হয়েছে। অগ্নি যজ্ঞস্থলে সকল দেবতাকে নিয়ে আসেন। তিনি দেবতা ও মানুষের মধ্যে দৌত্যের কাজ করে। আপঃ (জল)-কে জগতের মৌল উপাদান হিসাবে দেখানো হয়েছে। বিশ্বকর্মা প্রথমে জলকে সৃষ্টি করেন এবং স্বর্গ ও মর্ত্য সেই জলে ভাসমান। দেবতা ও দানবের সৃষ্টির পূর্বেই জলের সৃষ্টি হয়। ঋগ বেদের নাসদীয় সূক্তে বলা হয়েছে যে জগতের মৌল উপাদান হল জল (চক্রবর্তী ২০১৯)।

বাংলার পাল ও সেন যুগে রচিত 'চর্যা গীতি'তেও প্রকৃতির সঙ্গে মানুষের যে মেলবন্ধন রয়েছে তার বহু তথ্য পাওয়া যায়। চর্যাকারেরা বৌদ্ধতান্ত্রিক যোগী সিদ্ধ পুরুষ। তারা যোগীসন্ত-সামাজিক-গৃহস্থ-বিত্তবান ও শিক্ষা-সংস্কৃতিপুষ্ট বৌদ্ধ সমাজ থেকে বিচ্যুত ছিলেন। পূর্ব ভারত ও প্রান্তিক আরণ্য পার্বত্য অঞ্চলই ছিল ঐ গুহ্য সাধনত্ত্বের ও চর্যার বিকাশ ও প্রসার ক্ষেত্র। চর্যাকারেরা তাদের রচনায় অন্ত্যজ শ্রেনীর জীবনের খন্ড চিত্র নির্মান করেছেন।'আরণ্য ও পার্বত্য অঞ্চলের মানুষের জীবন-জীবিকার চিত্র শবরের দুটি পদে পাওয়া যায়। দরিদ্রের সংসার। তারা ছিলেন নাগরিক জীবন থেকে বিচ্যুত মানুষ। শবর বধূর পরিধানে ছিল ময়ূরের পুছ,গলায় গুঞ্জা ফুলের মালা, কর্ণে কুন্ডল, পরিবেশ আরণ্য প্রকৃতির, তাম্বুল-কর্পূরই ব্যসন, তীর-ধনুই জীবিকা উপকরণ। কার্পাস ও কঙ্গু-চিনার (কাগনি ধানের)চাষ হয়। শকুন ও শিয়ালের উৎপাত থেকে ক্ষেত রক্ষা করার জন্যে বাঁশের কঞ্চির বেড়া দেওয়া হত। এখানেই কৃষির (কার্পাস ও কাগনি ধানের) কথা একটু মিলেছে। তাঁতী, ব্যাধ, সূতার, জেলে, শুঁড়ী প্রভৃতি বৃত্তিজীবীর নামও পাই' (শরীফ ১৯৭১)।

খ্রিস্টীয় ত্রয়োদশ শতক থেকে পর্যন্ত বঙ্গদেশের মনসা, চন্ডী, ধর্মঠাকুর প্রভৃতি লৌকিক দেবদেবীর মাহাত্ম্যকে কেন্দ্র করে যে কাব্য গড়ে উঠে তাই মঙ্গলকাব্য নামে পরিচিত। পৌরাণিক দেবদেবীর পরিবর্তে লৌকিক দেবদেবীর প্রাধান্য পেয়েছে এই কাব্য গুলিতে। সমকালীন সমাজ চিত্র ও মানব চরিত্রের উপাদান এবং প্রকৃতির অপরূপ চিত্র নির্মান করা হয়েছে। মনসা মঙ্গল কাব্যে চাঁদ সদাগারের বানিজ্য যাত্রার বর্ণনা এবং পশ্চিমবঙ্গের পথঘাট ও নদনদীর নিঁখুত চিত্র পাই। চন্ডী মঙ্গল কাব্যে ধনপতি সদাগারের সিংহলে সমুদ্রপথে বানিজ্য যাত্রার বর্ণনায় যেন প্রকৃতির রূপ উন্মোচিত হয়েছে (শরীফ ১৯৭১)।

আধুনিক বাংলা সাহিত্যেও পরিবেশ ও প্রকৃতি নিয়ে অজস্র লেখা আমরা পাই। রবীন্দ্রনাথ যখন তাঁর সুদীর্ঘ জীবনে সাহিত্য চর্চায় নিবিষ্ট-তখনও ইকোলজি, ইকোসিস্টেম শব্দগুলি তেমন তাৎপর্য খুঁজে পায়নি। তবে তাঁর দীর্ঘ জীবনে তিনি দেখেছেন নানা রুপান্তর। একটি বিশ্বযুদ্ধের শুরু থেকে শেষের প্রত্যক্ষদর্শী। তিনি প্রত্যক্ষ করলেন, গোটা বিশ্বটাই যেন বদলে যাচ্ছে। তাঁর ছোট্রবেলার ছায়াঘেরা শহর কিংবা স্নিগ্ধ গ্রামজীবনই বদলে গেল, কী নিদারুণ গতিতে! কলকাতার মাঠ-গাছ-পুকুর হারিয়ে গেল ইট-কংক্রিটের জঙ্গলে। বহুদর্শী রবীন্দ্রনাথ, সত্তায় অনুভব করেছিলেন এক আসন্ন যুগান্তর। আর সেই পরিবর্তনশীল সময়ের হাত ধরে চলতে চলতেই রচনা করলেন এমন কিছু গদ্য বা পদ্য যা পরবর্তীকালে পরিবেশবিদ্যাচর্চার অন্যতম উপাদান হিসেবে গৃহীত হতে থাকে। ১৯২০ সালে কর্ণেল বিশ্ববিদ্যালয়ের কৃষিবিজ্ঞানের ছাত্র লিওনার্ড এর সঙ্গে আলোচনায় তাকে জানিয়েছিলেন, শান্তিনিকেতনে তিনি যে শিক্ষাপ্রতিষ্ঠান গড়ে তুলেছেন, তার চারপাশে ছড়িয়ে আছে গ্রাম-আর গ্রামগুলোও ধ্বংসের মুখে। পরবর্তীকালে তাঁদের যৌথ উদ্যেগে ১৯২২ সালে শুরু হয়েছিল গ্রাম পুনর্গঠনের এক অভিনব প্রয়াস-'শ্রীনিকেতন' (মুখোপাধ্যায় ২০১৮)।

রবীন্দ্রনাথের প্রকৃতিতন্ময়তা বা নিসর্গচেতনা বহু আলোচিত এবং অত্যন্ত পরিচিত বিষয়। প্রকৃতির সঙ্গে তাঁর গভীরতম দেওয়া-নেওয়া সম্পর্ক সখ্য আর প্রীতির সুরে বাঁধা। প্রকৃতির সঙ্গে যেমন তাঁর ছিল সংলগ্নতা-তেমনই অন্তরতম আকর্ষণ ছিল অতীত ভারতের প্রতি। সময়ের সঙ্গে পা-মিলিয়ে চলায় কখনও বিপন্ন হননি লেখক। তবু সে-কাল এ-কালের প্রতি তুলনায় তিনি বিষণ্ন। কোলাহলমুখর নাগরিক জীবনের প্রাচুর্যে আর উন্মত্তায় তিনি চিরব্যথিত এবং নিয়ত অতৃপ্ত-

‘ওই যে নগরী-জনতারণ্য,
শত রাজপথ, গৃহ অগন্য
কতই বিপণি, কতই পণ্য
কত কোলাহলকাকলি।
কত না অর্থ, কত অনর্থ
আবিল করেছে স্বর্গমর্ত
তপনতপ্ত ধূলি-আবর্ত
উঠিছে শূন্যে আকুলি’।

কোথায় সেখানে প্রকৃতি এবং পরিবেশের সুস্থ সুসম্পূর্ণ বিন্যাস সেখানে নেই

‘আকাশ আলোকপুঞ্জ,
ছায়াসুশীতল নিভৃতকুঞ্জ...’

আসলে পরিবেশের সমগ্রতার মতই নগর বা নাগরিক জীবন মানবসত্তার সামগ্রিকতাকেও উপেক্ষা করে। ‘জীবনস্মৃতি’র ছোট্র ছেলেটি একলা শৈশবের নিঃসঙ্গ দুপুরে যখন দেখত পুব দিগন্তের পান্ডুবর্ণের নীলিমার মধ্যে উধাও চলে যাওয়া কলকাতা শহরের নানা আকার, নানা আয়তনের উঁচু নিচু ছাদের সারি তখন ‘ভিক্ষুক যেমন প্রাসাদের বাহিরে দাড়াইয়া রাজভান্ডারের রুদ্ধ সিন্দুকগুলির মধ্যে অসম্ভব রত্নমানিক কল্পনা করে, আমিও তেমনি ঐ অজানা বাড়ি গুলিকে কত খেলা ও কত স্বাধীনতায় আগাগোড়া বোঝাই মনে করিতাম। সেই ‘ইটের পরে ইটের’ নাগরিক সজ্জা কল্পনাপ্রবণ বালককে যতই মুগ্ধ করুক না কেন, গ্রাম থেকে সদ্য আসা ‘মানসী’র বধুটির কিন্তু মোটেই ভালো লাগেনি।

‘শিক্ষা’ গ্রন্থের অন্তর্গত সুবিখ্যাত ‘তপোবন’ প্রবন্ধে রবীন্দ্রনাথ সতর্ক করে দেন আমাদের, কোন পশু-পাখিকে- মোটকথা প্রাণীকে, যদি আমরা নিছক খাদ্য হিসাবে দেখি, তবে তাকে সত্যরূপে, সমগ্ররূপে দেখতে পাইনা। প্রাণ জিনিসটাকে তুচ্ছ করে দেখাই আমাদের অভ্যাস হয়ে যায়। ‘শুদ্ধমাত্র প্রাণী হত্যা করাই আমাদের স্বভাবের অঙ্গ হয়ে উঠে এবং নিদারুন অহৈতুকী হিংসাকে জলে-স্থলে আকাশে, গুহায়, গহ্বরে, দেশে-বিদেশে মানুষ ব্যাপ্ত করে দিতে থাকে। ১৯৩৮ সালে রবীন্দ্রনাথ বন ধ্বংসের পরিমাণে উত্তরাঞ্চলে তাপ বৃদ্ধি দেখে আতঙ্কিত হয়েছিলেন। আজ বিজ্ঞানীরা ভোগবাদী শিল্পোন্নত দেশগুলিতে মনুষ্যসৃষ্ট তাপদূষণ সমস্যা ‘গ্রিন হাউস এফেক্ট’ নিয়ে বিভ্রান্ত, বিচলিত। বন ধ্বংস হচ্ছে সভ্যতার উদরপূর্তির স্বার্থে-পৃথিবীর-আর পৃথিবীরও জ্বর বাড়ছে উত্তরোত্তর। রবীন্দ্রনাথ জানতেন না ‘ওজোন হোল’ কিংবা ‘গ্রিনহাউস এফেক্ট’-এর মতো বৈজ্ঞানিক পরিভাষা। কিন্তু ভয়ঙ্কর কোনও এক দুঃসময়ের ইঙ্গিত পেয়েছিলেন তিনি। ‘অরণ্য দেবতা’য় বলেছিলেন, ‘অরণ্য নষ্ট হওয়ায় এখন বিপদ আসন্ন। সেই বিপদ থেকে রক্ষা পেতে হলে আবার আমাদের আহ্বান করতে হবে সেই বরদাত্রী বনলক্ষ্মীকে’। শুধু এই কি? গাছ কাটার অনিবার্য কারণ যে ভূমিক্ষয়-তা-ও পরিবেশমনস্ক রবীন্দ্রনাথ উল্লেখ করতে ভোলেননা। তিনি মনে করিয়ে দেন যে, ‘বোলপুরে ডাঙ্গার কঙ্কাল আজ’-সেও একদিন সবুজ ছিল (মুখোপাধ্যায় ২০১৮)।

ঈশোপনিষদের সেই কবিপ্রিয় মন্ত্রানুসরণে, তিনি অগ্নিতে আছেন, জলে আছেন, ওষধিতে আছেন, আমাদের মধ্যেও তাঁর অস্তিত্ব। তবে হাজার বছরের বনস্পতিতে তিনি স্পন্দমান! এই ব্রহ্মবোধ, কালের মাত্রা পেরিয়ে এ পৃথিবীর ধূলি-তৃণ-মাটি-জল-ফুল-ফল-সব কিছুর সঙ্গে নিজেকে অভিন্ন করে দেখার শিক্ষা দিয়েছিল। ‘উৎসর্গ’ কাব্য গ্রন্থের চতুর্দশ কবিতায় তিনি এক সুগভীর কৃতার্থবোধে আচ্ছন্ন,-পৃথিবী বিশ্বব্রহ্মাণ্ডের সঙ্গে একাত্মঃ

‘তৃণে পুলকিত যে মাটির ধরা লুটায় আমার
সামনে

সে আমায় ডাকে এমন করিয়া কেন যে কব তা
কেমনে।
মনে হয় যেন সে ধূলির তলে
যুগে যুগে আমি ছিনু তৃণজালে
সে দুয়ার খুলি কবে কোন ছলে বাহির হয়েছি
ভ্রমনে।
হই যদি মাটি হই যদি জল
হই যদি তৃণ, হই ফুলফল
জীবসাথে যদি ফিরি ধরাতল, কিছুতেই নাই
ভাবনা।

পরিবেশ চেতনা দেয়, প্রকৃতিকে ভালোবাসার শিক্ষা। কালীগ্রাম থেকে লেখা এক চিঠিতে উচ্চারিত হয় সেই ভালোবাসারই কথা-'ঐ যে মস্ত পৃথিবীটা চুপ করে পড়ে আছে ওটাকে এমন ভালোবাসি- ওর এই গাছপালা, নদীমাঠ' কোলাহল, নিস্তব্ধতা, প্রভাত, সন্ধ্যা সমস্তটাসুদ্ধ দুহাতে আঁকড়ে ধরতে ইচ্ছে করে'। ভালোবাসার নিজস্ব নিয়মেই, মনে হয় তাঁর উন্মুক্ত-প্রসারিত প্রকৃতির কোলে বসে-

'তোমারেই যেন ভালোবাসিয়াছি
শতরূপে শতবার
জনমে জনমে যুগে যুগে অনিবার'।

বিভূতিভূষণ তাঁর পথের পাঁচালীতে পল্লী বাংলার সমতল ভূমির নিসর্গচিত্র এবং আরণ্যক এ সেই নিসর্গচিত্রের পরিবর্তিত রূপ অঙ্কন করেছেন। বিহারের মালভূমি ও পাহাড়-অধ্যুষিত ভূ-প্রকৃতির নিসর্গ-চিত্র আরণ্যক উপন্যাসের উপজীব্য। ভু-প্রকৃতির বৈপরীত্যে প্রাকৃতিক-সৌন্দর্যের রূপ ভিন্ন। দ্রষ্টার চোখে দুটি ভিন্নরুপের উপলব্ধি ও প্রকাশ। আবার শুধু পরিবেশ ও পরিবেস্টনীর পার্থক্যে নয়, উপন্যাস দুটির কেন্দ্রীয় চরিত্রের বয়সভেদে এই উপলব্ধির বৈচিত্র্য। 'পথের পাঁচালী'তে যে ছিল বালক, 'আরণ্যক'-এ সে পূর্ণ যুবক। 'পথের পাঁচালী'তে যে মুগ্ধ গ্রাম্য বালকের প্রকৃতি-চেতনার অংকুরোদগম, 'আরণ্যক'-এ চেতনা সহস্রদল পদ্মের মত বিকশিত। তাই 'পথের পাঁচালী' নিসর্গ সৌন্দর্য-চেতনার উন্মেষপর্ব, আর 'আরণ্যক' বিকাশপর্ব। 'আরণ্যক' শুধুমাত্র ধারাবাহিক প্রকৃতি-বর্ণনার আলেখ্য নয়, প্রকৃতির সঙ্গে মিশে থাকা মানব-জীবনকে ফুটিয়ে তুলেছেন তিনি অপূর্বভাবে। অর্থাৎ 'আরণ্যক' এর একদিকে মানুষ আর অন্যদিকে প্রকৃতি। মানুষের কথা অন্তহীন নয়, কিন্তু প্রকৃতির কথা অনন্ত। 'গিরিশৃঙ্গমালার মহৎ মৌনে ধ্যাননিমগ্না' এই আরণ্যভূমির সৌন্দর্য-বর্ণনা চিরনূতন। প্রকৃতি এখানে অনন্ত-যৌবনা-ইন্দ্রসভায় উর্বশীর মতো। শুধু দেখার মতো চোখ আর অনুভব করার মন ব্যতীত সেই সৌন্দর্য উপলব্ধি করা কঠিন। এমনি এক ঘন বর্ষার বর্ণনার ও অনুভূতিঃ-'….এই সবুজের সমুদ্র-বর্ষা সজল হওয়ায় মেঘকোজ্জ্বল আকাশের নীচে এই দীর্ঘ মরকত শ্যাম তৃণভূমির মাথায় ঢেউ খেলিয়া যাইতেছে আমি যেন একা এ আকুল সমুদ্র নাবিক-কোন রহস্যময় স্বপ্ন বন্দরের উদ্দেশ্যে পাড়ি দিয়াছি'। 'সরস্বতী কুন্ডীর পাঁড়ের তিন দিকের নিবিড়' বনভূমির অপরূপ সৌন্দর্য যেমন 'বুকের রক্তের স্পন্দনের মধ্যে' অনুভূত তেমনই যুগলপ্রসাদের মত বৃক্ষলতা প্রেমিক সৌন্দর্য-পূজারী মানুষও এক বিস্ময়, নিজ অর্থব্যয়ে সরস্বতী কুন্ডী জঙ্গলের শোভা বর্ধন করার জন্য নানা প্রকার ফুল গাছ ও লতাগুল্ম রোপন যুগল প্রসাদের চরিত্রের বৈশিষ্ট্য। বিভূতিভূষনের নিজের ভাষায় 'লোকটার উদ্দেশ্য বুঝিয়া তাহার উপর আমার শ্রদ্ধা হইল। লোকটা সম্পূর্ণ বিনা স্বার্থে বিস্তৃত বন্য ভূমির সৌন্দর্য্য বৃদ্ধি করিবার জন্য নিজের পয়সা ও সময় ব্যয় করিতেছে, যে বনে তাহার নিজস্ব কিছু নেই-কি অদ্ভুত লোকটা'। এছাড়া সৌন্দর্য-সাধক সত্যচরনের দৃষ্টিতে জঙ্গলের বিশেষ করে 'শাল ও বিড়ির পাতার জঙ্গল' এর বর্ণনা প্রাকৃতিক নৈসর্গিক চিত্রকে আমাদের সামনে জীবন্ত করে তুলছে। 'বনের মধ্যে কাটা-লতা ঝোপ হইতে মাথা উঁচু স্তম্ভের মাথায় একটা বিরাট মুখ খোদাই করা' এবং শুধু একটি নয়, অনেকগুলি। জঙ্গল মহালের কর্মচারীর কথায়-'এ দেশে আগে অসভ্য বুনো জাতির রাজ্য ছিল, তাদেরই হাতে তৈরী ওগুলো সীমানার নিশান-দিহি খাম্বা' (দত্ত ১৯৯৩)।

তারাশঙ্করও তাঁর অনেক উপন্যাসে পল্লীপরিবেশের নিসর্গতা তুলে ধরতে সমর্থ হয়েছেন। 'হাঁসুলী বাঁকের উপকথা'য় পল্লীসমাজ ও পল্লীজীবনের বাস্তবতার সঙ্গে পল্লীপরিবেশের মেলবন্ধন ঘটিয়েছেন। এ উপন্যাসে রাঢ় ভূখন্ডের কোনই তীরবর্তী কাহার সম্প্রদায়ের জীবনবাস্তবতার উপস্থাপনা করেছেন। নদীর তীরবর্তী নীলকুঠি সংলগ্ন ভূখন্ডে ভদ্রপল্লী থেকে দূরত্বে কাহার সম্প্রদায়ের বসবাস।

বাংলাদেশের একটি বিশেষ ভৌগোলিক অঞ্চল, রাঢ় অঞ্চলের কোপাই নদীর তীরবর্তী বাঁশবাদী নামক ছোটগ্রামের প্রেক্ষাপটে আলোচ্য উপন্যাসের কাহিনীটি রচিত। হাঁসুলী বাঁক কোপাই নদীর মাঝামাঝি অবস্থিত। উক্ত স্থানে অত্যন্ত স্বল্প পরিসরের মধ্যে নদী বাঁক নিয়েছে বলে, নদীর রূপ সেখানে হয়েছে হাঁসুলি গয়নার মত। এই কারণে বাঁকটকে বলা হয় হাঁসুলী বাঁক। নদীর বেড়ের মধ্যে হাঁসুলী বাঁকে ঘণ বাঁশ বনে ঘেরা মোট আড়াইশ বিঘা জমি নিয়ে বাঁশবাদী মৌজা গঠিত। বাঁশবাদী বেশ ছোট গ্রাম, দুটি পুকুরের চার পাড়ে ত্রিশ ঘর কাহারের বসতি। সন্ধ্যার প্রাককালে বাঁশবন থেকে অন্ধকার ঘিরে ধরে কাহারের পাড়াকে। 'হাঁসুলী বাঁকের পশ্চিম দিকের প্রথম বাঁকটি বেলগাছ আর শ্যাওড়া ঝোপে ভর্তি-একটি কাহার সম্প্রদায়ের দেবপীঠ-ব্রহ্মদৈত্য তলা। হাঁসুলী বাঁকের দেশ বেশ কড়া ধাতের মাটির দেশ। প্রখর গ্রীষ্মে নদী শুকিয়ে মরুভূমি হয়ে যায়, চারদিকে ধূ ধূ বালির রাজ্য, একপাশে একহাঁটু গভীর জলের প্রবাহ মাত্র। খালবিল পুকুর সব শুকিয়ে যায়,একটা শূন্যতা চারদিকে হাহাকার করে। মাটি পাথরের মত শক্ত হয়ে যায় আর আগুনে পোড়া লোহার মত তপ্ত। আষাঢ় থেকে আশ্বিন মাস পর্যন্ত কোপাই নদীর তীরের অধিবাসীরা; দুর্ভাবনাগ্রস্ত হয়ে থাকে বর্ষায় ভরা নদী ভয়ংকর হয়ে ওঠে। দু-তিন বছর যে প্রবল বান আসে তাকে কাহাররা বলে 'হড়পাবান' (মুখোপাধ্যায় ২০০৬)।

পরিশেষে বলা যায় নিসর্গনীতি একটি বৃহত্তর ধারণা। সামাজিক নিসর্গনীতি এর একটি অংশমাত্র। পৃথিবীর নিসর্গ আজ ভীষণভাবে ক্ষতিগ্রস্ত। তাই সমগ্র পৃথিবীতে বর্তমানে নিসর্গকে উপলব্ধি ও বাঁচানোর প্রক্রিয়া শুরু হয়েছে এটা খুবই আশার কথা। অপরদিকে ভারতীয় প্রকৃতি ও পরিবেশ চেতনার উপলব্ধি শুধুমাত্র আমরা প্রাচীন সাহিত্যেই নয় এর ধারাবাহিকতা যেন মধ্যকালীন সাহিত্য পেরিয়ে আধুনিক সাহিত্যে এসে পৌঁছেছে। আধুনিক বাংলা সাহিত্যের বিভিন্ন লেখার মধ্যে এর প্রকাশ ঘটেছে। আধুনিক রবীন্দ্রনাথ থেকে শুরু করে মহাশ্বেতাদেবীর 'অরণ্যে অধিকার', সুধাংশু শেখর চক্রবর্তীর 'অরণ্য কন্যা', কিন্নর রায়ের 'প্রকৃতি পাঠ', সাধন চট্টোপাধ্যায়ের 'জলতিমির', অমর মিত্রের 'কৃষ্ণগহ্বর' ও 'হাঁসপাহাড়ী', শরদিন্দু সাহার 'উজানী মঙ্গল', সুকান্তি দত্তের 'যুধান কথা'য় তার ধারাবাহিকতার প্রমান পাওয়া যায়।

কৃতজ্ঞতা স্বীকারঃ

আমি কৃতজ্ঞতা জানাই অজ্ঞাত নির্দেশককে, যিনি আমার ক্ষুদ্র প্রচেষ্টাকে প্রতিনিয়ত সমর্থন করেছেন। বিনম্রচিত্তে কৃতজ্ঞতা জানাই কলিকাতা বিশ্ববিদ্যালয়ের বঙ্গ ভাষা ও সাহিত্য বিভাগের শ্রদ্ধেয় অধ্যাপক সনৎকুমার নস্কর মহাশয়কে যিনি লেখাটি পর্যালোচনা করে প্রকাশের অনুমতি দিয়েছেন। ধন্যবাদ জানাই যোগমায়াদেবী কলেজের গবেষণা-আয়োগের প্রতিটি সদস্যবর্গকে যাদের প্রচেষ্টা ছাড়া লেখাটি প্রকাশ অসম্ভব হত। কৃতজ্ঞতা ও প্রনাম জানাই এই প্রতিষ্ঠানের ড. ভাস্কর ঘোষ, ড. কৌশিক কিরণ ঘোষ ও ড. সুশ্রী চক্রবর্তীকে যাদের অনুপ্রেরণায় এই প্রবন্ধটি লেখা। ধন্যবাদ জানাই এই প্রতিষ্ঠানের বাংলা বিভাগের অধ্যাপিকা ড. ব্রতী গায়েনকে যিনি ভাষা সংশোধন করাই শুধু নয়, তাঁর ব্যক্তিগত সংগ্রহ থেকে মূল্যবান পুস্তক সরবরাহ করে লেখাটি পরিমার্জিত করে নির্ভুলভাবে প্রকাশে সহায়তা করেছেন। বিশেষ ধন্যবাদ জানাই বাংলাবিভাগের অধ্যাপিকা ড. পারমিতা বন্দ্যোপাধ্যায়কে যিনি শত ব্যস্ততার মধ্যেও সবসময় সহায়তা করেন। এছাড়া ধন্যবাদ জানাই অধ্যাপক তুহিন কুমার দাস, ড. প্রসেঞ্জিত ঘোষ, রজত কুমার নস্কর ও ড. বিজন মন্ডলকে তাদের মূল্যবান পরামর্শ ও সবসময় পাশে থাকার জন্য।

গ্রন্থপঞ্জীঃ

১. চক্রবর্তী, পার্থ, ২০১২। প্রকৃতি পরিবেশ নিসর্গনীতি, সেতু প্রকাশনী, কোলকাতা।

২. রায়, মোহিত (সম্পাদিত), ২০১৫। পরিবেশ চর্চাঃইতিহাস ও বিবর্তন, অনুষ্টুপ, কলকাতা।

৩. চক্রবর্তী, নির্মাল্য নারায়ণ, ২০১৯। পরিবেশ ও নীতিবিদ্যা, পশ্চিমবঙ্গ রাজ্য পুস্তক পর্ষৎ, কলকাতা।

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২১. শরীফ, আহম্মদ, ১৯৭১। বাঙালী ও বাঙলা সাহিত্য, বর্ণ মিছিল, ঢাকা।

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Four decades of recrystallized quartz grainsize paleopiezometry: Progressive development of the principles

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Abstract: Measurement of differential stress can be important in the comprehensive structural and tectonic analyses of a region. In the long run, it helps in the study of various tectonic phenomena of the lithosphere. The mean size of the dynamically recrystallized quartz grains in a deformed rock is a function of the differential stress it was subjected to, and the grainsize–stress relationship serves as the most commonly used piezometer or stress indicator in the quartz-rich rocks. This relationship has been worked out by different workers, based on a wide range of theoretical models and empirical investigations, and the piezometers thus developed by them differ considerably.

The piezometers introduced in the 1970s were based on the principle of equality of the dislocation strain energy at the grain boundary and that within the volume of a closed recrystallized grain under steady state. The influence of temperature on the grainsize–stress relationship was not considered. But some of the later workers recognised the effect of temperature, and developed a new category of piezometers based on the nucleation-and-growth model of recrystallization. The validity of these two sets of models is yet to be resolved conclusively. Present workers are divided on the selection of an appropriate model for paleopiezometry of the natural tectonites.

This article reviews the gradual development of the various piezometers based on the relationship of stress and recrystallized quartz grainsize, and explains the applicability and limitations of these piezometers as revealed from the later investigations. The contrasting views of different workers on the two major categories of piezometers have also been discussed.

Keywords: paleopiezometry, differential stress, dynamic recrystallization, quartz, grainsize, dislocation creep regimes.

1. Introduction

Precise measurement of the differential stress (σ_{diff}; Table 1A) in a deformed rock is essential for a comprehensive interpretation of the nature and extent of its deformation, for the determination of other rheological factors like strain rate and effective viscosity, and also for the study and numerical modelling of continental rheology and a wide variety of geological and geophysical phenomena in the crust and the upper mantle (Mercier et al. 1977, Hacker et al. 1990, 1992, Lu & Jiang 2019). In addition, it is useful in the study of origin of seismicity, the economic utilization of some forms of geothermal energy, and the exploration of some mineral and fossil fuel reserves (Mercier et al. 1977). This has elicited extensive researches in the last few decades to develop better and more accurate procedures for paleopiezometry (i.e. measurement of ancient stress; *paleo*: ancient, *piezo* (Greek $\pi\iota\acute{\varepsilon}\zeta\omega$)*:* stress or pressure, and *metry*: measurement).

Table 1A: The symbols used in the article, with brief explanations.

Symbol	Description	Equations and Unit(s)
σ_{diff}	Differential stress, the difference between maximum and minimum principal stresses, i.e. $\sigma_{diff} = \sigma_1 - \sigma_3$. Maximum shear stress acting on a plane, $\sigma_{s\text{-}Max} = (\sigma_1 - \sigma_3)/2$, therefore $\sigma_{diff} = 2\sigma_{s\text{-}Max}$. {1}, {2}. This relation is used to compare the empirical results of axial compression with those of general shear (e.g. section 5.4.1. in Heilbronner & Kilian 2017).	It occurs in all the equations except Eq. (xx). Unit(s) in Eq. (vii) kilo bars; other equations: mega pascal (MPa).
d_{RQ}	The mean diameter of dynamically recrystallized quartz grains. Ranalli (1984) observed that the recrystallized grainsize in rocks and metals has a lognormal distribution, and advocated the use of the median grainsize (geometric mean) instead of the mean (i.e. arithmetic mean) to measure stress.	It occurs in all the equations except Eq. (i) and Eq. (ii). Unit(s) in Eq. (iii), Eq. (iv): millimetre (mm); other equations: micron (μm)
ρ	The dislocation density (i.e. dislocations per volume of crystalline material) within the volume of the grain in steady state.{3}	Eq. (i) and Eq. (ii). Unit: cubic millimetre
b	Burgers vector, which indicates the direction and minimum amount of lattice displacement caused by the dislocation{3}. It measures the magnitude and orientation of lattice distortion.	Eq. (i), Eq. (ii), Eq. (iii). Unit: millimetre
τ	The shear modulus, also called the rigidity modulus, it is the ratio of shear stress and shear strain {1}, {2}.	Eq. (i). Unit: MPa
ν	The Poisson ratio, i.e. the ratio between strain imposed on a sample in one direction and the resulting strain perpendicular to that direction. In case of volume constant deformation, Poisson's ratio is 0.5 {1}, {2}.	Eq. (i). It is dimensionless quantity.
Γ	The elastic parameter used by Twiss (1977). $\Gamma = \frac{\tau}{1-\nu}$	Eq. (ii), Eq. (iii). Unit: MPa
T	Temperature of deformation	Eq. (xxi), Eq. (xxii), Eq. (xxiii), Eq. (xxiv), Eq. (xxv). Unit: Kelvin.

The equations in this article are given in the straight parenthesis, and numbered with Greek numerals in order of their occurrence in the text, e.g. [Eq. (iii)]. The equations from other sources are referred in English numerals, as they appear in the original documents, e.g. from Twiss (1977), equation 2. {1}Twiss & Moores (2007). {2}Fossen (2016). {3}Passchier & Trouw (2005).

A major part of the Earth's crust is composed of quartz-rich rocks, which includes igneous rocks viz., quartzolites, quartz-rich granitoids, granites, granodiorites; sedimentary rocks e.g., orthoquartzites, arkosic and wacke sandstones, siltstones; and metamorphic rocks e.g., quartzites, quartz-schists, quartz mica-schists, gneisses. The piezometers or stress indicators frequently applied to these rocks are: dislocation density, subgrain size and recrystallized grain-size of minerals (Table 1B), microboudins, vein and fracture types, and deformation lamellae of quartz (Mercier et al. 1977, Twiss 1977, 1980, 1986, Tullis 1980, Etheridge et al. 1983, Koch 1983, Drury & Humphreys 1987, Blenkinsop & Drury 1988, Masuda et al. 1989, 2004, Laurent et al. 2000, Rowe & Rutter 1990, Ji & Zhao 1993, Orzol et al. 2003, Stipp & Tullis 2003, Shimizu 2008, 2012, Holyoke & Kronenberg 2010, Cross et al. 2017, Heilbronner & Kilian 2017, Tokle et al. 2019). Among these, however, the dynamically recrystallized quartz grainsize (DRQG) is the most widely used one; owing to the relative

simplicity of this stress gauge, the ease of measurement, and the greater abundance of quartz in the crustal rocks than any other minerals. Besides, as indicated in Fig. 9.10 of Passchier & Trouw (2005), dynamic recrystallization (DRX) in quartz starts at a lower temperature (~280 ^{O}C) than most other common minerals, except calcite (< 100 ^{O}C) and biotite (~200 ^{O}C), and continues over a wide range of temperature (~1000 ^{O}C). All these factors contributed to extensive application of DRQG piezometry in the estimation of stress from naturally deformed rocks, and consequently, as many as seventeen piezometric equations have been developed over the last 43 years (Table 2).

Table 1B: The abbreviations used in the article, in order of their first appearance in the text, with brief explanations. For symbols, please refer to Table 1A.

Abbreviation	Full Form and Description
DRX	Dynamic Recrystallization. It is the recrystallization that takes place during intracrystalline deformation (Passchier & Trouw 2005). This abbreviation has also been used by Shimizu (2008, 2011, 2012).
DRQG	Dynamically Recrystallized Quartz Grainsize. It is the size of recrystallized quartz grains. It is a functions of the differential stress operated on the rock during recrystallization, and widely used as a stress indicator of quartz-rich rocks.
BLG	Bulging Recrystallization. At low T, there may be local mobility of the grain boundary, which may cause it to bulge into the crystal with high ρ and form new, independent small crystals (after Passchier & Trouw 2005). It corresponds to DCR-1 of Hirth and Tullis (1992). Other Names: low-T or slow grain boundary migration, to indicate its differences with the fast, high-T grain boundary migration (GBM).
SGR	Subgrain Rotation Recrystallization. DRX through rotation of subgrains by addition of dislocations. Subgrains rotate with respect to each other and develop into new grains. It corresponds to DCR-2 of Hirth and Tullis (1992).
GBM	Grain Boundary Migration Recrystallization. Recrystallization by migrating grain boundaries throughout old grains in response to differences in dislocation density between two grains. (after Passchier & Trouw 2005) It corresponds to DCR-3 of Hirth and Tullis (1992). Other Names: High-T or fast grain boundary migration, to indicate its differences with the slow, low-T grain boundary migration that takes place during BLG.
DCR	Dislocation Creep Regime, identified by Hirth & Tullis (1992). The regimes 1, 2 and 3 are given as DCR-1, DCR-2 and DCR-3 respectively. Each DCR exists within a definite range of temperature and strain rate, and characterized by distinctive microstructural developments.

This work outlines the underlying principle of DRQG piezometry and its different models (Section 2), explains the logical bases of the two broad categories of DRQG piezometers along with a review of their gradual progress and refinement in the last four decades (Sections 3 and 4), and finally discusses the applicability, the limitations, and the comparative assessment of these piezometers in the light of the subsequent investigations (Section 5).

Table 2: The different types of dynamically recrystallized quartz grainsize piezometers developed in the last four decades, and the principles on which they are based. For symbols and abbreviation, see table-1A and Table-1B respectively.

Author(s)	Year	Piezometric Equation	Underlying Principle
Twiss.	1977	$\sigma_{diff} = 603.06\, d^{-0.68}$	The 'Twiss model'[1]
Mercier et al	1977	$\sigma_{diff} = 380.76\, {d_{RQ}}^{-0.7143}$	The 'Twiss model'[1]
Twiss	1980	$\sigma_{diff} = 669.097986\, {d_{RQ}}^{-0.68}$	The 'Twiss model'[1]
Koch	1983	$\sigma_{diff} = 4090\, {d_{RQ}}^{-1.11}$	The 'Twiss model'[1]
Drury et al.	1985	$\sigma_{diff} = 550\, {d_{RQ}}^{-1}$	The 'Twiss model'[1]
Bishop	1996	$\sigma_{diff} = 1264.11\, {d_{RQ}}^{-1.639}$	The 'Twiss model'[1]
De Bresser et al.	1998	$\sigma_{diff} = 8.138\, {d_{RQ}}^{-0.81} \exp\left(\frac{23.82}{RT}\right)$	The field boundary model[2] of nucleation-and-growth
Stipp & Tullis	2003	For DCR-1: $\sigma_{diff} = 1254.182\, {d_{RQ}}^{-1.639}$	The 'Twiss model' [1]. Considers the effect of recrystallization mechanism.
		For DCR-2 and DCR-3: $\sigma_{diff} = 668.95\, {d_{RQ}}^{-0.7936}$	
Shimizu	2008	$\sigma_{diff} = 352 {d_{RQ}}^{-0.8} \exp\left(\frac{698}{T}\right)$	The 'Twiss model'[1]
Holyoke & Kronenberg,	2010	For DCR-1: $\sigma_{diff} = 883.92\, {d_{RQ}}^{-1.852}$	The 'Twiss model' [1]. Considers the effect of recrystallization mechanism.
		For DCR-2 and DCR-3: $\sigma_{diff} = 489.725\, {d_{RQ}}^{-0.794}$	
Shimizu	2012	For α-quartz: $\sigma_{diff} = 250.78\, {d_{RQ}}^{-0.8} \exp\left(\frac{1193}{T}\right)$	The 'Shimizu model'[3] of nucleation-and-growth
		For β-quartz: $\sigma_{diff} = 405.56\, {d_{RQ}}^{-0.8} \exp\left(\frac{697.58}{T}\right)$	The 'Shimizu model'[3] of nucleation-and-growth
Cross et al.	2017	For 1 μm resolution $\sigma_{diff} = 592.92\, {d_{RQ}}^{-0.709}$	The 'Twiss model'[1]
		For sliding resolution $\sigma_{diff} = 450.82\, {d_{RQ}}^{-0.63}$	The 'Twiss model'[1]
Heilbronner & Kilian	2017	$\sigma_{diff} = 2138.13\, {d_{RQ}}^{-1.1614}$	The 'Twiss model'[1][4]

[1]Twiss (1977), explained in section 3.1. [2]De Bresser et al. (1998, 2001), explained in section 4.2. [3]Shimizu (1998), explained in section 4.1. [4]The equation has been obtained from Tokle et al. (2019).

2. The principle of measurement of stress from dynamically recrystallized quartz grainsize

Bulging recrystallization (BLG) starts in quartz at ~280°C, with successive occurrence of subgrain rotation recrystallization (SGR) at ~400°C, and grain boundary migration recrystallization (GBM) at ~ 500°C (Kruhl 1996, 1998, Stipp et al. 2002, Passchier & Trouw 2005). Each mechanism brings about the development of a distinctive assemblage of quartz microstructures (Vernon 2004, Trouw et al. 2010, Mukherjee 2013, 2015), and is characterized by a definite size-range of the dynamically recrystallized quartz grains (Stipp et al. 2010), which is a function of differential stress (σ_{diff}). The relationship between differential stress and the mean diameter of dynamically recrystallized quartz grains (d_{RQ}, Table 1A) forms the basis for all the DRQG piezometers. This σ_{diff} - d_{RQ} relationship has been determined by various workers, based on the results of the empirical investigations they performed on a wide range of natural rocks, synthetic aggregates of crystals (e.g. pure quartz crystals synthesized from silicic acid), or synthetic materials as mineral analogues (e.g. magnesium alloy as a quartz analogue). The metamorphic and rheological conditions of those experiments also varied widely –they were conducted over all possible ranges of temperature, confining pressure, strain rate, water content, and kinematic frameworks (coaxial and non-coaxial deformation, general or simple shear etc.) in which recrystallization of quartz can take place. As a result, the σ_{diff} - d_{RQ} relationships obtained from these works differ considerably.

Earlier the metallurgists and material scientists studied the relationship between σ_{diff} and recrystallized grainsize in the metals like nickel and nickel-iron alloys (Luton and Sellars 1969), α-iron (Glover and Sellars 1973), and copper and copper-aluminium alloys (Bromley and Sellars 1973). Around the seventh decade of the last century, the structural geologists started to conduct the experimental deformation of natural minerals such as calcite, dolomite, quartz, olivine, pyroxenes. A comprehensive review of these works is given in Carter (1976). The experiments on natural flints and orthoquartzite, carried out by a host of workers including Griggs et al. (1960), Carter et al, (1964), Raleigh (1965), Hobbs (1968), Green et al. (1970), Tullis et al. (1973), Parrish et al. (1976) etc. elucidated different aspects of quartz recrystallization. The outcomes of these empirical works, combined with some contemporaneous and later theoretical investigations and the studies of natural quartz-rich mylonites, paved the way for subsequent formulations of several models of DRX, which included the Twiss model (Twiss 1977), the Edward model (Edward et al. 1982), the Derby & Ashby model (Derby & Ashby 1987, Derby 1990), the Shimizu model (Shimizu 1998, 1999, 2003), the field boundary model (De Bresser et al. 1998), and the paleowattmeter model (Austin & Evans 2007). De Bresser et al. (2001) named the first four models after their respective inventors and presented an informative review. A comparative study on some of these models is also given in Xia & Platt (2018). Each model lays the foundation for one or more different piezometers, among which the commonly used ones are of two broad categories:

(a) The piezometers based on the Twiss model that equates the dislocation strain energy in the grain boundary to that in the enclosed volume of a recrystallized grain under steady state. These piezometers do not recognise the independent effect of temperature on the σ_{diff} - d_{RQ} relationship. The influences of different recrystallization mechanisms have been considered in the more recent ones of this category, and separate piezometric equations are given for the different regimes of dislocation creep (Hirth & Tullis 1992).

(b) The piezometers based on the different variants of the nucleation-and-growth model of recrystallization, which recognise the temperature-dependence of DRQG.

The piezometers of the above two categories are described in Sections 3 and 4, respectively.

3. The piezometers based on the Twiss Model of recrystallization: their formulation and progressive development

3.1. The early piezometers (1977 – 1985) and their underlying principle

In 1977, R. J. Twiss provided a theoretical model for the σ_{diff}– d_{RQ} relationship during steady state creep. It is based on the principle that, for a closed recrystallized grain under steady state, the total strain energy of dislocations along its boundary surface is less than or equal to the total strain energy of dislocation density within its volume. Assuming these two energies to be equal, the following relation was proposed between σ_{diff} (in Mega pascal or MPa), the steady state dislocation density within the grain volume (ρ, in mm^3, Table 1A), the length of the Burgers vector (b, in mm, Table 1A), the shear modulus (τ, in MPa, Table 1A), and the Poisson ratio (ν, Table 1A),

$$\sigma_{diff} = \alpha\left(\frac{\tau}{1-\nu}\right) b\rho^{\frac{1}{2}}$$ [Eq. (i), from Twiss (1977), equation 2]

Where α is an empirical parameter of order 1.

Introducing the elastic parameter Γ (in MPa, Table 1A) replacing $\frac{\tau}{1-\nu}$ in the above equation:

$$\sigma_{diff} = \alpha\Gamma b\rho^{\frac{1}{2}}$$ [Eq. (ii)]

Based on the simplifying propositions that (a) all the dislocations are edge dislocations, (b) all the boundaries are simple tilt boundaries, and (c) all the crystals are elastically isotropic (Twiss 1977, p. 230 – 231), the relationship between σ_{diff} (in MPa) and d_{RQ} (in millimetre, mm) may be expressed as:

$$log_{10}\frac{\sigma_{diff}}{\Gamma} = 0.38 - 0.68\, log_{10}\frac{d_{RQ}}{b}$$ [Eq. (iii)]

It is to be noted that the base of logarithm in the above equation is 10, though not explicitly stated in the original work (Twiss 1977, equations 3 – 9).

Eq. (iii) may be rearranged as follows.

$$\sigma_{diff} = Bd^{-0.68}$$ [Eq. (iv), from Twiss (1977), equation 11, p. 236]

Where $B = 10^{0.38}\Gamma b^{0.68}$, and d_{RQ} is in mm.

The empirically obtained magnitude of B for quartz being 5.5 (Twiss 1977, p. 236), we can derive from Eq. (iv) the following DRQG piezometer by converting the grainsize to micrometre (μm):

$$\sigma_{diff} = 603.06\ d_{RQ}^{\ -0.68} \qquad \text{[Eq. (v)]}$$

This is one of the earliest DRQG piezometer of this category, which is a constitutive equation of the following form.

$$\sigma_{diff} = B\ d_{RQ}^{\ -p} \qquad \text{[Eq. (vi)]}$$

As shown in Eq. (v), the constant quantities B and p suggested by Twiss (1977) are 603.06 and 0.68 respectively. But the contemporaneous and later workers, who developed their piezometers based on this model, have independently determined B and p by empirical investigations, and obtained widely varying values for them. As a result, σ_{diff} of a particular rock specimen measured from these piezometers may also vary considerably.

Another piezometer of this category, published simultaneously in the same issue of the same journal, was devised by Mercier et al. (1977) through a series of laboratory experiments with natural quartzites. The following relationship between d_{RQ} (in μm) and σ_{diff} (in kilo bars) was given:

$$d_{RQ} = 6.5\ \sigma_{diff}^{\ -1.4} \text{ [Eq. (vii)]}$$

Rearranging it in the form of Eq. (vi) and converting the differential stress to MPa, the following equation can be obtained.

$$\sigma_{diff} = 380.76\ d_{RQ}^{\ -0.7143} \qquad \text{[Eq. (viii)]}$$

In 1980, R. J. Twiss came up with a modified version of his piezometer, where the magnitudes for the elastic parameter Γ and the Burger Vector length b for quartz were revised to be 4.9 x10^4 MPa, and 5.0 x 10^{-4}μm respectively (Twiss 1980, p. 674, Table 2). Recalculating the value of B accordingly, we can derive the following piezometric relation from Eq. (vi):

$$\sigma_{diff} = 669.097986\ d_{RQ}^{\ -0.68} \qquad \text{[Eq. (ix)]}$$

In 1983, P. S. Koch communicated in his Ph. D. thesis (submitted to the University of California, Los Angeles) an empirically modelled piezometer which, in spite of some limitations pointed out by later workers, was the first of its kind to assess the effect of water on the rheology of quartz grains. His methodologies, as retrieved from the other publications (Koch et al. 1989, Hacker et al. 1990, 1992, Nadin 2007), involved experiments performed with flint, novaculite, and Simpson quartzite (an orthoquartzite with 99.75% quartz). The experiments were conducted over a wide range of temperatures, pressures, and strain rates; simulating both 'dry' and 'wet' conditions of deformation using copper and talc, respectively, as the confining media for the samples. Koch (1983) inferred that DRQG is independent of strain rate, water content, finite strain, temperature, and initial grainsize. The piezometer thus obtained is given below (taken from Nadin 2007):

$$\sigma_{diff} = 4090\ d_{RQ}^{\ -1.11} \qquad \text{[Eq. (x)]}$$

However, Hirth & Tullis (1992) commented that the empirically calibrated piezometers of Mercier et al. (1977) and Koch (1983) used microstructures from samples deformed with talc as a confining medium, which might produce erroneous results.

3.2. Recognition of the influences of different DRX mechanisms on the $\sigma_{diff} - d_{RQ}$ relationship, and the identification of dislocation creep regimes (1985 – 2017)

To study the mechanisms of DRX at high temperatures, Drury et al. (1985) carried out lab experiments using the polycrystalline magnesium aggregates as an analogue for minerals. They inferred that there is a strong link between the $\sigma_{diff} - d_{RQ}$ relationship_and the recrystallization mechanism, and the latter must be identified by detailed microstructural studies in all piezometric investigations. The same group of workers (White et al. 1985) performed similar empirical works on impure magnesium considering it to be a quartz-analogue, and derived the following simple piezometric equation for DRQG.

$$\sigma_{diff} = 550\ {d_{RQ}}^{-1} \quad \text{[Eq. (xi)]}$$

Hirth & Tullis (1992) identified three dislocation creep regimes (DCR) in experimentally deformed quartz aggregates: DCR-1 occurring at the lowest temperature and highest strain rate, to be succeeded in turn by DCR-2 and DCR-3 with increasing temperature and/or decreasing strain rate. Each DCR was characterized by a distinctive microstructural development and the prevalence of a particular recrystallization mechanism. They suggested that the recrystallized grainsize in DCR-1 and DCR-3 have greater dependence on stress than that for DCR-2, and pointed out that the recrystallization mechanisms must be taken into consideration on piezometer calibrations.

Another thesis with a recognized DRQG piezometer was submitted by R. R. Bishop in 1996 to the Brown University. He conducted axial compression experiments on very fine grained novaculite specimens in the Griggs apparatus (described in the later works of Post & Tullis 1999, Stipp & Tullis 2003, Holyoke & Kronenberg 2010). The specimens were deformed at 700-850 ºC in DCR-1 (Hirth & Tullis 1992), and the dominant recrystallization mechanism was BLG ('low-temperature migration recrystallization', as indicated in the Figure 7 of Post & Tullis 1999). The piezometer thus formulated is represented below in the form of Eq. (vi), derived from the generic equation 3, section 6.2 of Holyoke & Kronenberg (2010)

$$\sigma_{diff} = 1264.11\ {d_{RQ}}^{-1.639} \quad \text{[Eq. (xii)]}$$

Stipp & Tullis (2003) published the next piezometer of this category, by the experimental deformation of 17 natural quartzite (from Black Hills, U.S.A.) and one novaculite specimens in molten salt assembly of Griggs apparatus at a high-grade metamorphic condition (1500 MPa confining pressure, 800 – 1100°C temperature), and $2x10^{-7}$ to $2x10^{-4}$ s^{-1} strain rates. The stress – recrystallized grainsize plots thus obtained (Stipp & Tullis 2003, Fig. 4) revealed a distinct change in slope between DCR-1 and DCR-2, but no significant change in slope in between DCR-2 and DCR-3 (Hirth & Tullis 1992). They therefore inferred that while a single piezometer applies for DCR-2 and DCR-3, a separate one is necessary for DCR-1; and thus formulated two equations to represent the $\sigma_{diff} - d_{RQ}$ relationship. The one for DCR-2 and DCR-3 is rearranged as follows:

$$\sigma_{diff} = 668.95\ {d_{RQ}}^{-0.7936} \quad \text{[Eq. (xiii)]}$$

The following equation can be derived from the $\sigma_{diff} - d_{RQ}$ relationship given for DCR-1

$$\sigma_{diff} = 1254.182\ {d_{RQ}}^{-1.639} \qquad \text{[Eq. (xiv)]}$$

In both equations, σ_{diff} is in MPa and d_{RQ} is in μm.

They further noted that, although the theoretical basis for the piezometer of Twiss (1977) had been questioned by a number of subsequent workers for its inaccuracy, the $\sigma_{diff} - d_{RQ}$ relation represented in it was close to the DCR-2 – DCR-3 piezometer given in Eq. (xiii).

Stipp et al. (2010) statistically analysed the grainsize distribution of recrystallized quartz from 555 samples of quartz mylonites, deformed over a wide range of metamorphic conditions. They prepared a large database for DRQG measurement from 31 studies, obtained from the GSA Data Repository (www.geosociety.org/pubs/ft2010). Eliminating the studies with lesser data quality, and finally selecting from it 342 grains smaller than 100 μm, they plotted the frequencies against the recrystallized grainsizes using a linear distribution. In these plots they found two maxima at 10–20 μm and 70–80 μm, which correlate with distinct microstructures, and two minima at 35–40 μm and ~120 μm that represented the microstructural transitions from BLG to SGR and from SGR to GBM respectively. They attributed this discontinuous grainsize distribution to the three different DRX mechanisms, inferring that:

(a) Quartz mylonites require different piezometer calibrations for the different DRX mechanisms, or a comprehensive theoretical construct was needed that takes into consideration the different rates of DRX during BLG, SGR, and GBM.

(b) The experimentally calibrated DRQG piezometer of Stipp & Tullis (2003) provided reliable stress measurements for the recrystallized grainsize range corresponding to BLG, might apply reasonably well to SGR, but underestimated the stress for GBM (d_{RQ}> 120 μm).

The Griggs type piston-cylinder deformation apparatus, popularly known as the Griggs apparatus, has been widely used in DRQG piezometry (e.g. Bishop 1996, Stipp & Tullis 2003, Stipp et al. 2006). This instrument was re-calibrated by Holyoke and Kronenberg (2010) for both the molten salt cell and solid salt assemblies, over a wide range of differential stresses (4 – 480 MPa). Through this rectification, they revised the $\sigma_{diff} - d_{RQ}$ relations given by Bishop (1996) and Stipp & Tullis (2003) to propose two new piezometers, one for DCR-1 and the other for DCR-2 and DCR-3, as given in Eq. (xv) and Eq. (xvi) respectively (derived from the generic equation 3, Section 6.2 of Holyoke & Kronenberg 2010).

For DCR-1 (updated piezometer of Bishop 1996):

$$\sigma_{diff} = 883.92\ {d_{RQ}}^{-1.852} \text{ [Eq. (xv)]}$$

For DCR-2 and DCR-3 (updated piezometer of Stipp & Tullis 2003):

$$\sigma_{diff} = 489.725\ {d_{RQ}}^{-0.794} \qquad \text{[Eq. (xvi)]}$$

3.3. Introduction of the electron backscatter diffraction techniques in d_{RQ} measurement (2017 – present)

Cross et al. (2017) formulated one of the latest piezometer of the Twiss model category, by re-analysing the samples previously used in the piezometric investigations of Stipp & Tullis (2003) and Stipp et al. (2006). To obtain a more precise and reliable $\sigma_{diff} - d_{RQ}$ relationship,

they measured the grainsize by electron backscatter diffraction (EBSD), and could distinguish the recrystallized grain populations from the relict porphyroclasts more appropriately through the intergranular lattice distortion. They calibrated two σ_{diff} - d_{RQ} relationships: one for the EBSD maps made with a 1 μm step size, and the other for "sliding resolution" that combined 1 μm step size data at coarser grainsizes with 200 nm step size data at finer grainsizes, from which the following two equations are derived.

For 1 μm resolution:

$$\sigma_{diff} = 592.92\ d_{RQ}{}^{-0.709} \quad \text{[Eq. (xvii)]}$$

The following equation can be derived from the piezometer given for DCR-1, for sliding resolution:

$$\sigma_{diff} = 450.82\ d_{RQ}{}^{-0.63} \quad \text{[Eq. (xviii)]}$$

These two calibrations produced results within 10% of each other for recrystallized grainsizes between 10 μm and 100 μm. In the finer-grained (<10 μm) specimens, however, the latter one was stated to estimate stress more accurately. Both piezometers conform to the original light optical microscopy quartz piezometer of Stipp & Tullis (2003, 2006) within the experimental error limits.

A few months later, Heilbronner & Kilian (2017) applied the same method of investigation to formulate the next piezometer. They carried out high resolution EBSD analysis on seven samples of Black Hills Quartzite, deformed by general shear experiments, which were previously analysed by Heilbronner & Tullis (2002, 2006) using optical microscope (computer-integrated polarization microscopy). The piezometer thus devised by Heilbronner & Kilian (2017) predicted higher stress for a given grainsize than the piezometer of Stipp and Tullis (2003). They suggested that for grainsizes < 10 μm, the optical resolution is insufficient, and EBSD should be used. Their piezometric equation for DCR-2 and DCR-3, as retrieved and recalculated from the Figure 6 of Tokle et al. (2019), is given below.

$$\sigma_{diff} = 2138.13\ d_{RQ}{}^{-1.1614} \quad \text{[Eq. (xix)]}$$

4. The piezometers based on the nucleation-and-growth models: their formulation and progressive development

The piezometers of this category recognise the effect of temperature on the σ_{diff} – d_{RQ} relationship, and are based on the nucleation-and-growth model of DRX, the different variants of which were given by Derby & Ashby (1987), Shimizu (1998, 2003, 2008, 2012), and De Bresser et al. (1998, 2001). Among the early proponents of this model, Derby & Ashby (1987) suggested that the grainsize of recrystallized minerals was controlled by two microscopic processes: (a) 'nucleation' or formation of the new grains by BLG or SGR, causing grainsize reduction; and (b) grain-boundary migration driven by strain energy, leading to grain growth. Based on this model, Derby (1991) has given a generic relation between stress and dynamically recrystallized grainsize of metals and some minerals like pyrite, halite, olivine and ice (Derby 1991, equations 1, 5, 6, figures 1, 2). This model, however, has not been applied in DRQG piezometry. The most widely used piezometers of

this category are based on the Shimizu model of nucleation-and-growth, which is described below.

4.1. The Shimizu model of recrystallization (1998) and the piezometers based on it (2008 – present)

Ichiko Shimizu, in a series of investigations on DRX during high-temperature dislocation creep (Shimizu 1998, 1999, 2003), derived a universal law between stress and recrystallized grainsize of minerals. His nucleation-and-growth model assumed that the nucleation mechanism was driven by SGR and the grain growth was brought about by the distortional strain energy associated with subgrain walls and free dislocations. He expressed the mean d_{RQ} in terms of a constant rate of homogeneous grain nucleation (I) and the rate of radial grain growth (R') as follows.

$$d_{RQ} = \left(\frac{R'}{I}\right)^{\frac{1}{4}} \text{ [Eq. (xx)]}$$

Earlier he multiplied the RHS term with a geometric factor a, which is close to 1 (Shimizu 1998, equation 3), but eliminated it in the later publication (Shimizu 2003, equation 11).

Expressing I and R' as the function of σ_{diff} and temperature (T, in Kelvin), the following equation was derived:

$$\frac{d_{RQ}}{b} = A \exp\left(-\frac{Q_{gb} - Q_v}{mkT}\right)\left(\frac{\sigma_{diff}}{\mu}\right)^{-p} \qquad \text{[Eq. (xxi)]}$$

Where b = length of Burgers vector, τ = shear modulus, Q_{gb} = activation energy for transfer of an atom across the grain boundary, Q_v = activation energy for volume diffusion, k = Boltzmann constant, and A, m and p are the empirically derived constants. For BLG, p = 1.5 – 2.5 and m = 2 (from Derby & Ashby 1987); and for SGR recrystallization, p = 1.25 – 1.33 and m = 3 – 4 (from Shimizu 1998).

Based on the above principle, and reviewing all the contemporaneous theories for the development of recrystallized grainsize and examining their applicability, Shimizu (2008) came up with a scaling relation between d_{RQ} in steady-state (in μm) and σ_{diff} (in MPa). The DRQG piezometer thus derived (from equation 28 of Shimizu 2008) can be expressed as follows.

$$\sigma_{diff} = 352 d_{RQ}^{-0.8} \exp\left(\frac{698}{T}\right) \qquad \text{[Eq. (xxiii)]}$$

Here T is in Kelvin.

He later revised the above equation to rectify some numerical errors (Shimizu 2011), and further pointed out that only the strain energy was considered in it, neglecting the effects of surface energy (Shimizu 2012). Thus re-evaluating the $d_{RQ} - \sigma_{diff}$ relationship, he gave two separate equations for α-quartz and β-quartz (equations 68 and 67 of Shimizu 2012 respectively), from which the following two equations have been derived.

For α-quartz:

$$\sigma_{diff} = 250.78\, {d_{RQ}}^{-0.8} \exp\left(\frac{1193}{T}\right) \quad \text{[Eq. (xxiv)]}$$

For β –quartz:

$$\sigma_{diff} = 405.56\, {d_{RQ}}^{-0.8} \exp\left(\frac{697.58}{T}\right) \qquad \text{[Eq. (xxv)]}$$

4.2. The field boundary model of DRX and the piezometer formulated by De Bresser et al. (1998)

Contemporaneous to the Shimizu model of nucleation-and-growth, De Bresser et al. (1998) introduced their *'field boundary model'* to explain the grainsize reduction and grain growth during dynamic recrystallization. The reduction of grainsize in the zones of strain localization in a deforming rock, reported by a large number of workers (e.g. White et al. 1980, Tullis & Yund 1985, Jin et al. 1998, Shigematsu 1999) presumably represent a shift from the grainsize insensitive (GSI) diffusion creep to the grainsize sensitive (GSS) diffusion creep (Schmid 1982, Rutter & Brodie 1988, Furlong 1993, Busch & Van der Pluijm 1995, Vissiers et al. 1995). De Bresser et al. (1998, 2001) proposed that, instead of a transformation from the field of GSI creep to that of GSS creep, DRX takes place at or near the boundary between these two fields and balances the processes of grainsize reduction and grain growth.

They conducted a series of deformation experiments on the magnesium alloy Magnox A 180, an analogue for quartz; and observing that d_{RQ} decreases with increasing σ_{diff} and increasing T, they derived an equation relating these three variables (De Bresser et al. 1998, equation 6) which has been rearranged here as follows.

$$\sigma_{diff} = 8.138\, {d_{RQ}}^{-0.81} \exp\left(\frac{23.82}{RT}\right) \qquad \text{[Eq. (xxii)]}$$

4.3. The paleowattmeter model (2007)

In 2007, Austin and Evans have put forward an alternative model for DRX, which proposed that the steady-state recrystallized grainsize was the result of the balance between the increasing surface energy of nucleation, and the decreasing surface energy of grain growth. They expressed the grainsize of dynamically recrystallized minerals as a function of stress, temperature, and strain rate (Austin & Evans 2007: in equations 8, 9); and suggested that the stable grainsize during DRX is controlled by the 'rate of mechanical work' done by dislocation creep. They therefore preferred to designate the recrystallized grain size as 'paleowattmeter' rather than paleopiezometer (the rate of work is power, whose SI unit is watt). Though the strain-rate dependence of recrystallized grainsize has been advocated in some later works, it has been pointed out that the stresses estimated from quartz aggregates by the paleowattmeter model are consistently lower than all other piezometers; and it is not applicable in the domain of BLG (Lu & Jiang 2018). For such reasons, this model is not commonly applied in DRQG piezometry.

5. Discussions

As soon as the piezometers were formulated, they were put to the test through their applications in the studies of many natural shear zones across the world. A large number of empirical investigations, aimed at elucidation of different aspects of recrystallization and microstructure formation, also weighed up the validity and applicability of DRQG piezometry at different rheological and metamorphic conditions. In the early stage of recrystallized grainsize piezometry, White (1979) pointed out the possible sources of errors and inconsistencies, which included (a) the post-deformation annealing, (b) the inhibition of growth of the recrystallized grains by the presence of other mineral phases adjacent to them, (c) the temperature-dependence of grainsize, and (d) the effect of water content. Moreover, the applicability of the same piezometer for the different recrystallization mechanisms has also been questioned; suggesting that the σ_{diff}-d_{RQ} relationship may be different in the domains of BLG, SGR and GBM (Poirier & Guillop 1979, Mercier 1980, White 1982). Among these issues, the last one has been taken into consideration in some of the recent piezometers of Twiss model (e.g. Stipp & Tullis 2003, Holyoke & Kronenberg 2010), and different piezometric equations were given for the different DCRs (explained in section 3.2). The bearings of the other factors, as reassessed in the subsequent investigations, are briefly described in this section along with a comparative study of the two contrasting models of piezometry.

5.1. The influence of water in the system

Earlier, Griggs & Blacic (1965) and Griggs (1967) postulated that the presence of water causes mechanical weakening of quartzites, and suggested that the natural water-bearing quartzites are weaker than a synthetic aggregation of pure dry quartz. The investigations of Koch (1983), however, refuted the impact of water content on DRQG. But Paterson & Luan (1990), through an extensive review of previous researches, upheld the postulate of water-induced mechanical weakening, by showing that the stresses measured in the laboratory on natural quartzites (Heard & Carter 1968, Parrish et al. 1976, Tullis et al. 1979, Koch et al. 1980, Jaoul et al. 1984, Kronenberg & Tullis 1984, Mainprice & Paterson 1984) were significantly less than those measured on dry single crystals of quartz (Griggs & Blacic 1965, Griggs 1967, Heard & Carter 1968, Kekulawala et al. 1978, Blacic & Christie 1984, Doukhan & Trepied 1984, Ord & Hobbs 1986).

The empirical investigation of Luan & Paterson (1992) was carried out on low-porosity synthetic quartz aggregates which had water contents comparable to those of natural quartzites. They reported that the stress in equilibrated quartz aggregates decreased when the water pressure increased and vice versa, though they did not give a quantitative relationship between the two.

Stipp et al. (2006) experimentally deformed the Black Hills quartzite samples with three different initial water contents – 'as-is', water-added, and vacuum-dried – having equal, greater and less water contents respectively than the natural condition. The experiments, performed within DCR-2 and DCR-3 (Hirth & Tullis 1992), revealed that all the three types

of samples had the same $\sigma_{diff} - d_{RQ}$ relationship, implying that the water content of the natural quartz-rich mylonites is not a factor to be considered in the DRQG piezometry.

The latest deformation experiments on quartz recrystallization with varying initial water content was conducted by Palazzin et al. (2018), in which quartz powders, 'wet' porphyroclasts (with fluid inclusions) and 'dry' porphyroclasts (without inclusions) were subjected to axial compression in Griggs-type apparatus at high temperature and confining pressure. They reported that all porphyroclasts, irrespective of their fluid contents, showed pronounced strain weakening, and the strengths of most samples converged to similar values at large strain. They further observed that the rate and the extent of recrystallization were relatively greater in the wet quartz, and the water content of initially wet and dry quartz decreased and increased respectively during recrystallization.

5.2. The applicability of DRQG piezometry to polymineralic rocks

The grain growth of a mineral during the DRX may be significantly hindered by the presence of another mineral phase along its boundary, as it may obstruct the grain boundary migration of the main mineral phase (Olgaard 1990, Krabbendam et al. 2003, Herwegh & Berger 2004). With a reduced grainsize, the dominant deformation mechanism of the main phase can switch from the grainsize insensitive dislocation creep to the grainsize sensitive diffusion creep (Etheridge and Wilkie 1979, De Bresser et al. 1998, 2001).

Song & Ree (2007) studied the effects of the neighbouring mica bands on the DRX of quartz in a quartz-muscovite mylonite, and reported noticeable decrease of DRQG with increase in the mica fraction.

Hunter et al. (2019) observed similar inconsistencies in the grainsize and microstructures of recrystallized quartz in the interlayered units of monomineralic quartz-mylonites and polymineralic gneisses and schists, which were deformed under similar conditions. These works refuted the applicability of the quartz microstructures in polymineralic rocks to interpret the deformation, asserting that the DRQG piezometers may give erroneous values for differential stress in such rocks.

But the quartz-rich polymineralic rocks occupy a sizeable volume in the Earth's crust, and their exclusion from the piezometric studies may seriously hinder the tectonic interpretation of a region. Passchier & Trouw (2005) therefore recommended selective measurement of DRQG from such rocks so that the quartz grains are only measured from the middle of some quartz grain clusters, excluding those with other mineral phases at their boundaries.

5.3. The impacts of post-deformational grain growth

Recovery and annealing involve the growth of recrystallized grains after the deformation stops, which put severe limitation to the piezometers based on the recrystallized grainsize of minerals.

Twiss (1977) has pointed out the following four conditions in which the dynamically recrystallized grainsize may be preserved in a rock, and asserted that paleostress cannot be measured unless there is evidence for prevalence of at least one of this condition in a rock.

(a) If the deformation temperature is not very high, then the slow rate of grain growth, occurring over a short time-span, may not cause any substantial increase of grainsize.
(b) Even in case of a high deformation temperature, if the rock cools down rapidly then quenching may prevent any significant post-deformation grain growth.
(c) If a constant tectonic stress is maintained on the rock during its cooling, then its dynamically recrystallized grainsize may not change.
(d) The grain growth of a particular mineral in a polymineralic aggregate may be inhibited by the adjacent grains of other minerals, as described in section 5.2.

The above propositions were corroborated by the later workers, e.g. Christie & Ord (1980), Wilson (1982), Ord & Christie (1984), Michibayashi (1993), Hacker et al. (1990), Stipp et al. (2010); and many of them suggested that paleopiezometry can only serve as a 'minimum stress estimate' for the rocks deformed in high temperature, like the quartz mylonites undergoing GBM recrystallization. For the other rocks, however, the precise amount of differential stress can be measured if there are ample evidences against the occurrence of annealing. For example, Michibayashi (1993) applied DRQG piezometry to the mylonites of the Kashio Shear Zone, Japan where the temperatures of deformation was not very high, and the quartz microstructures (e.g. strong undulose extinctions, presence of elongated grains instead of polygonal ones, serrated grain boundaries) indicated that the effect of post-deformational annealing was negligible.

Heilbronner & Tullis (2002) carried out axial-compression and general shear experiments on Black Hills quartzite, in each of the three DCRs of Hirth & Tullis (1992), using a modified Griggs-type deformation apparatus. Of the several findings of this empirical work, the ones relevant to the present context are explained below.

(a) Annealing increased the average grain size of quartz grains. Four to five-fold increase in DCR-1 and DCR-2, and two to three times increase in DCR-3 was observed.
(b) Annealing brought about significant modifications in the quartz microstructures, producing equant, straight-sided, polygonal grains with a reduced grain boundary 'lobateness'. These changes of grain boundary were greatest for the samples deformed at highest temperature (DCR-3), where the grain boundary mobility was maximum.
(c) **Bearings on the DRQG paleopiezometry**: the post-deformation grain growth would lead to considerable underestimation of stress. The study of quartz microstructures was therefore essential to find out whether the recrystallized grains were subjected to static annealing after deformation.

Through their high pressure – temperature experiments on the grain growth of quartz samples (powder and quartzite), Fukuda et al. (2019) reported that the effect of grain growth was more significant above 600 °C (lower-crustal condition) than at 400 °C (representative temperature of middle-crust) – in the former situation the grains with initial sizes of < 100 μm grew to ~200 μm over an extrapolated time-span of 10^4 years. They therefore suggested that

the effect of grain growth should be considered carefully in the DRQG piezometry of lower-crustal rocks.

Soleymani et al. (2020) conducted similar experiments on quartzite with cooling rates of 2–10 °C/hour from 900-800 °C on a 'cooling ramp', and inferred that the conventional grain-size piezometry was likely to underestimate peak stresses, and should be considered as the indicator of average stress during the entire deformation instead of peak stress.

5.4. The contrasting views on temperature-dependence of grainsize: the two models of DRQG piezometry

The most debated issue regarding DRQG piezometry remains the selection of the appropriate model: the temperature-independent Twiss model or the temperature-dependent nucleation-and-growth model. Some of the contrasting views on the influence of temperature on quartz recrystallization, along with their logical or experimental bases, are discussed here.

Etheridge & Wilkie (1981), one of the earliest advocate of temperature-dependence of DRQG, measured about 200 samples from 22 mylonite zones of three different tectonic settings: a shallow dipping thrust zone in a sedimentary succession, a deeper level thrust zone of high grade metamorphic rocks; and steeply dipping fault zones in a low-grade metamorphosed granite. Metamorphic grade of these three settings varied from lower greenschist to amphibolite facies. They suggested that the contemporaneous piezometers did not take into consideration the influence of temperature and chemical environment on grainsize, and emphasized the need for a comprehensive and more precise equation to represent the $\sigma_{diff} - d_{RQ}$ relationship.

De Bresser et al. (1998, 2001) corroborated this, and the 'field boundary model' proposed by them (described in Section 4) necessitated the influence of temperature to be taken into consideration in the $\sigma_{diff} - d_{RQ}$ relationship. They therefore recommended the revision of their contemporaneous piezometers with quantification of the effects of temperature.

Stipp & Tullis (2003), on the other hand, made the following observations on the recrystallization of quartz and the associated microstructural processes.

(a) Temperature did not affect the recrystallized grainsize of quartz – the specimens with a similar stress but different temperatures had very similar recrystallized grainsizes. This was also established later in the empirical work of Stipp et al. (2006).
(b) There was no effect of α-quartz/β-quartz transition on the $\sigma_{diff} - d_{RQ}$ relationship.
(c) During the transition from DCR-1 to DCR-2 (Hirth & Tullis 1992), there are distinct microstructural and mechanical changes along with a possible change in the dominant recrystallization mechanism. However, the microstructural changes during DCR-2 to DCR-3 transition are mechanically insignificant and/or do not correspond to a major change in recrystallization mechanism.

Platt & Behr (2011), among the later exponents of the Twiss model, maintained that the newly recrystallized grains were stabilized at a critical size determined by BLG or SGR; and

the influence of temperature on the critical size could be neglected. They suggested that the growth of recrystallized grains stopped after reaching that critical size, because the two processes responsible for grain growth – strain-energy driven GBM (ρGBM) and surface-energy driven GBM (γGBM) – locally cancelled each other.

Shimizu & Ueda (2015) evaluated the relative importance of interfacial energy (or grain boundary energy) in the DRX of quartz, and suggested that contrary to the proposition of Platt & Behr (2011), grain growth would not stop at an unstable equilibrium state of the critical nuclei. They suggested that ρGBM dominated over γGBM, and was not neutralized by the latter during the high temperature – low strain rate creep of quartz. As a result, the steady-state grainsize in DRX is primarily controlled by a dynamic balance between the two opposing processes: the grainsize reduction by SGR nucleation, and the grain growth by ρGBM.

Fukuda & Shimizu (2017), in their theoretical investigation on quartz flow laws for strain rate measurement, commented that the temperature-dependence of the piezometric relation for quartz is negligible at temperatures above 800 °C. They, however, emphasized the influence of temperature in low to medium grade conditions occurring in the middle crust, and questioned the reliability of the flow law proposed by Hirth et al. (2001) in strain rate measurement as it applied the piezometer calibrated by Twiss (1977) to determine the paleo-stress in low-grade metamorphic conditions.

Nevertheless, the two piezometers published in the same year (Cross et al. 2017, Heilbronner & Kilian 2017) adopted the Twiss model (section 3.3). Xia & Platt (2018), studying the bulge size and grainsizes of quartz at the stages of initiation and completion of BLG across a mylonite zone, inferred that the recrystallized grainsize of quartz was controlled by the nucleation process and did not change after nucleation; and the $\sigma_{diff} - d_{RQ}$ relationship for quartz was likely to be temperature-independent.

Considering all the above contradictory views, no definite conclusion can be drawn regarding the 'temperature-effect' of DRQG piezometry. But we may observe an underlying conformity between the latest piezometers of these two categories. Although the piezometers based on the Shimizu model predicts steadily lower stress with increasing temperature, some of the proponents of this model have lately recognised the temperature-independence of the $\sigma_{diff} - d_{RQ}$ relationship above a certain temperature (Fukuda & Shimizu 2017), and thus acceding that DRQG might not have a linear, continuous relationship with temperature, at least within a certain range. Similarly, in some recent piezometers based on the Twiss model (e.g. Stipp & Tullis 2003, Holyoke & Kronenberg 2010), the influence of recrystallization mechanism on $\sigma_{diff} - d_{RQ}$ relationship has been recognised, and different piezometric equations have been formulated for different DCRs. One particular recrystallization mechanism is prevalent over a specific range of temperature, and each DCR is characterized by a distinctive range of temperature and strain rate (Fig. 2 of Hirth & Tullis 1992). It has therefore been recognised in the above piezometers that different $\sigma_{diff} - d_{RQ}$ relationships exist in different temperature

ranges. However, instead of a linear or continuous relationship of d_{RQ} with temperature or strain rate, a regular but discontinuous, 'stair-stepping' relationship has been considered in them. For example, a comparison between the two equations of Holyoke & Kronenberg (2010), i.e. Eq. (xv) and Eq. (xvi), indicates that a lower value of stress will be predicted at a higher temperature range (i.e. in DCR-2 or DCR-3) and vice versa.

6. Conclusions

Considering the limitations of DRQG piezometry, and in view of the absence of a universally accepted piezometric model, the following can be suggested on the measurement of stress from natural tectonites.

(a) **Importance of a detailed microstructural study:** Paleopiezometry is not to be regarded as an independent study, to be performed in isolation on a deformed rock. It should rather be a part of a comprehensive microstructural investigation of that rock. The importance of the study of microstructures in this context is explained below.

  (i) **Detection of post-deformational grain growth:** Study of the microstructures helps to ascertain whether the rock was subjected to any considerable post-deformational grain growth. If there are ample evidences for annealing in a tectonite, like high deformation temperature, polygonal and smooth grain boundaries instead of elongated and serrated ones etc., then DRQG piezometry should not be applied to it.

  (ii) **Identification of recrystallization mechanism:** To select the proper piezometric equation for a rock, it is essential to determine from the microstructures the mechanism of recrystallization prevalent in it and the dislocation creep regime (Hirth & Tullis 1992) in which the rock was deformed.

  (iii) **Estimation of temperature:** The precise measurement of the temperature of deformation is essential for stress measurement using the nucleation-and-growth model piezometers. It also helps to identify the recrystallization mechanism. Along with the classical petrological geothermometers based on metamorphic mineral assemblages, Passchier & Trouw (2005) recommended an independent determination of temperature from the microstructures. Detailed petrographic and microstructural studies are therefore advisable for independent verification and confirmation of temperature.

  (iv) **Application in polymineralic rocks:** The recrystallized quartz grains having other mineral phases at their boundaries must be excluded from grainsize measurement, to avoid overestimation of paleostress. In a polymineralic rock, d_{RQ} must be measured from the grains occurring within quartz grain clusters, which are surrounded by other quartz grains only.

(b) **Selection of the appropriate piezometric equation:** Since there is no universally accepted model for DRQG piezometry, it is advisable to select the appropriate piezometers from both categories to measure the paleostress. For example, if a rock has been deformed at high temperature in DCR-2 or DCR-3, then the piezometer of Holyoke & Kronenberg (2010) [Eq. (xvi)], and the β-quartz piezometer of Shimizu (2012) [Eq. (xxv)] may be recommended for stress measurement.

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A discourse on Balneotherapy – An ancient rejuvenating geomedical practice

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Abstract: Balneotherapy is a natural therapy which attempts the best use of natural elements such as hot spring water. In the historic past, people used geothermal water or miracle water for bathing and medicinal purposes. The word "spa" normally denotes a place where different medical treatments with thermal water are practiced. Different types of balneotherapic practices are bath cure, drinking cures, mud therapy, inhalation etc. Balneotherapy can be regarded as a kind of stimulus-adaptation therapy, because patients are repeatedly given therapeutic stimulation, including hot steam water bathing, exercises and other stimuli. The autonomic nervous system, endocrine system and immune system respond to these stimuli within a month in a non-specific manner. In the balneotherapic treatment, – heat, water, gas and mineral constituents – all are very important. Though balneotherapy is a very old traditional medical practice, it is still treated as an 'alternative medicine' in a country like India. However, rudimentary health tourism in the form of pilgrimage has already been developed surrounding the hot springs of India. Due to the multidisciplinary character of balneotherapy, there are ample opportunities to conduct research on the subject, especially in a country like India, and lots of innovative ideas may be developed and introduced in the field of geotourism and balneology.

Keywords: Balneotherapy, Balneology, medicinal water, thermal springs, geotourism, spa, health resort.

1. Introduction

Balneotherapy is a natural therapy which attempts the best use of natural elements such as hot spring water. The word "*balneo*" is derived from "*balneum*" in Latin, meaning "bath" in English. This therapy is carried out by hot-spring water bathing, various thermo and hydro therapies, physical exercise, drinking, inhalation etc. It is a very old traditional method to cure a disease. The rudiments of balneology appeared as early as the 5th century BC when Herodotus drew attention to the methods of prescription and application of mineral waters (Albu et al. 1997). In Japan, it is called "bath cure". Usually, the patients go to the *spa station* (health resort) in a cleaner environment and stay there for a period of time to enjoy the benefit of balneotherapic treatment.

2. Historical background of Balneotherapy

In the historic past, people used geothermal water or miracle water for bathing and medicinal purposes. Some of the ancient community considered the pungent hot spring water as panacea. Based on archaeological findings in Asia, mineral water has been used for bathing since the Bronze Age, about 5000 years ago (Lund 2005). Hot springs are regarded as sacred places in ancient Egypt. The Greeks and Romans were famous for developing spas and the

same traditional practice is found in the other parts of the world, such as in an island country like Japan. Health resorts were very common in the former Soviet Union and Czechoslovakia.

Therapeutic use of spa (thermal) waters has been a part of the cultural and medical traditions of the Europeans and especially the Central European (CE) nations. It is the culture of the middle and upper class people of that area to visit the health resorts regularly. The exclusive culture and balneological treatments were patronised by the former German Empire, Italy and Austro-Hungarian Monarchy (Varga 2010).

3. Spa and Health Resort: The Balneological Practicing Centre

The word "spa" normally denotes a place where different medical treatments with thermal waters are practiced. It is a place where there are hot-springs or related geological environment which are utilised for therapeutic purposes. An over-night accommodation facilities along with all modern amenities should be there in the spa.

The word "spa" is used as a Latin abbreviation for: S = salud, P = per, A = aqua, or "Health through Water". In Germany, they refer to the "Kur", which not only mean just a cure, but also refer to a series of treatments over time including baths, taking (drinking) water, massage, exercise, mud baths, etc. (Lund 2005). The term "cure treatment" is derived from the German word "Kurbehandlung" which means taking medical balneotherapy during a long term stay in a spa (Agishi & Ohtsuka 1998). In the modern world, the spas provide: (a) hydrothermal treatment, (b) Body shaping such as exercise, massage and fitness training, (c) herbal medical benefits and (d) life-style amenities. It is therefore spread over a multi-faceted field, and it deviates far from its original service.

4. Architecture and Design of a Spa

History of balneology and the importance of medical resorts have a long history starting from the Roman civilization, even from the pre-Roman time. The ruins of the Roman spa are found in Macedonia and several other places. Arabic medicine shared the medical knowledge with Greeks and Romans and '*hammam*' or public-health bath house took a vital role in the daily life of elites of ancient Arab (Sherwani et al. 2006). There developed some special professions in association with hammam such as '*bathman*'. Bathmen are the doctors or skilful health personnel who had been trained for the arrangement of the degree of heat required to maintain the temperature of bath house. All types of bath were available in Hammams namely cold, very hot or sub-tepid bath, mineral bath and/or spring bath (*hammam hammat*). The record indicates that hammam provided the promised cure to innumerable diseases, especially of chronic origin like hypertension, obesity etc. Paralysis

was alleviated completely when such bath was practiced with different herbal oil massages, and cupping therapy[1] as stated by different Unani physicians.

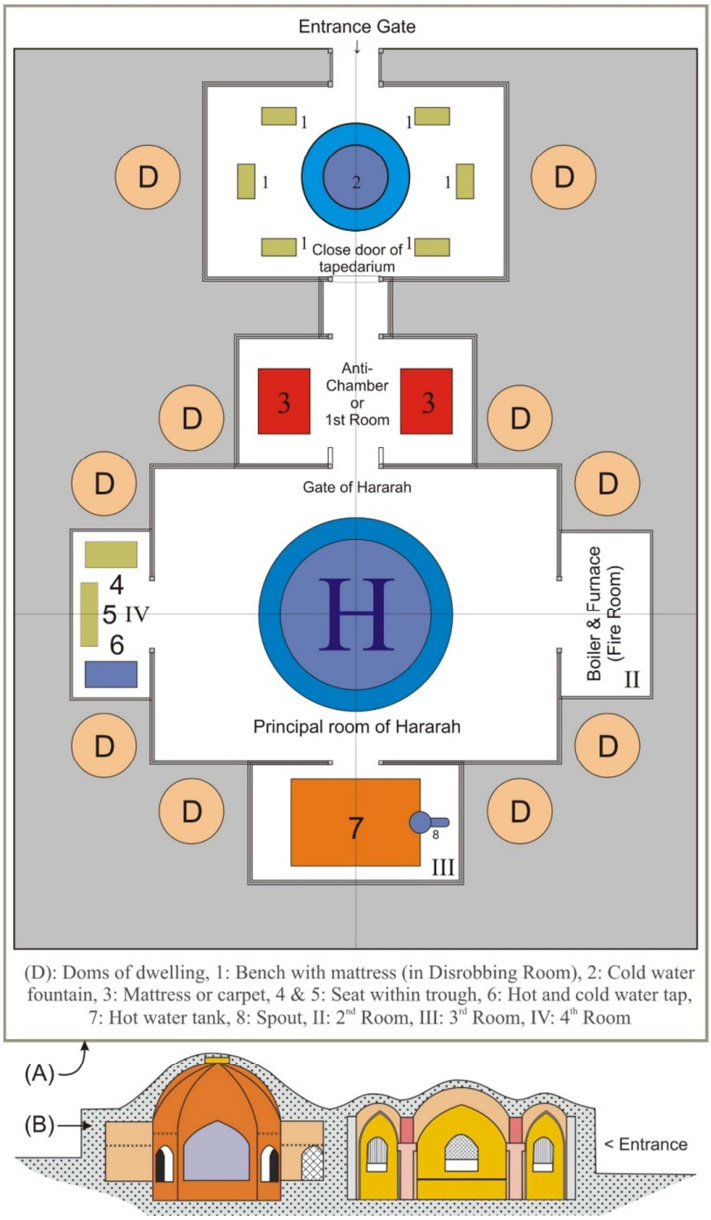


Figure 1: Sketch diagram showing ancient hammam (Public health bath house of Arab): (A) Plan view, (B) Section

The structure of the hammam is scientific and well organised. The important components are (Sherwani et al. 2006):

1. First apartment (disrobing room).
2. Principal bath house or square-shaped inner division of the building.
3. Chamber of the fire and boiler house for supplying hot water.
4. Third chamber: It contains a warm water tank fed by a spout into the dome (calidarium).

[1] **Cupping therapy** is an ancient form of alternative medicine in which a therapist puts special cups on your skin for a few minutes to create suction.

5. Fourth chamber: It was having two taps side by side, one hot, one cold and seats before the taps (frigidarium)
6. Harárah or chief portion or central part of principal bath house: It holds the shape of a cross containing all above-described chambers on its respective four angles (Figure 1).

The spas and medical resorts, therefore, have a legacy supported by historical, archaeological and architectural evidence. A comparative study between the ancient spas (hammams) and modern resorts can provide a complete idea about bath houses. Plan and structure of a modern spa depend on local culture - the balneological practices that have been adopted and practiced in that spa and available geothermal setting. Each and every spa is different from the other. However, on the basis of the use of geothermal water, there are two common plans for the hot water spas (Woodruff & Takahashi 1990). The unique design presented here was originally designed for a volcanic island of Hawaii, where geothermal water, local materials are used to develop the spa and native plants are used for landscaping and gardening (Figure 2). The second design (Figure 3) was adopted from the typical design for the Polynesian Pools in Rotorua, New Zealand. In this resort semi-private and private pools can be used by a single family or a small group on the basis of hourly rent. Though food-court and restaurant are available in the design, no lodging facilities are there within the arena. In both the cases, the pools may be covered, uncovered or there may be a provision of occasional covering for unpleasant weather. Figure 4 gives an idea of lifestyle, luxury and facilities of modern spas.

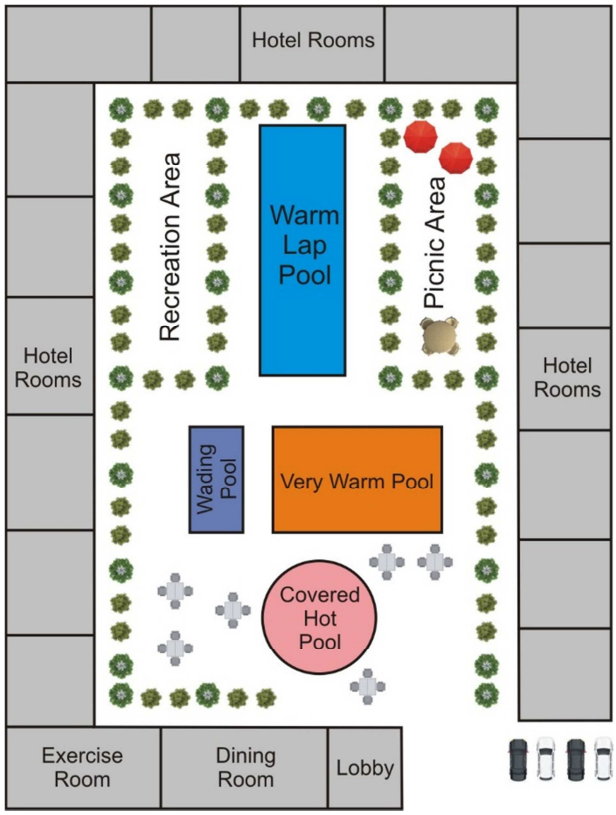


Figure 2: General scheme of a modern geothermal spa located in California

(Modified after Woodruff and Takahashi, 1990).

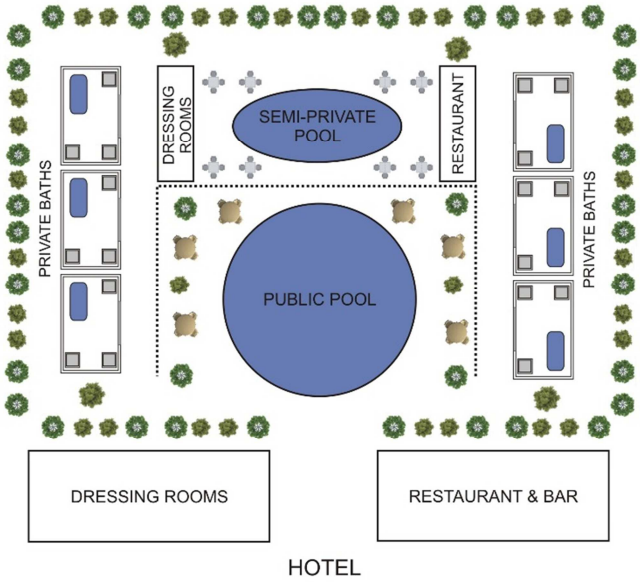


Figure 3: Design for a geothermal spa offering private, semi-private, and public bathing facilities (Modified after Woodruff and Takahashi, 1990).

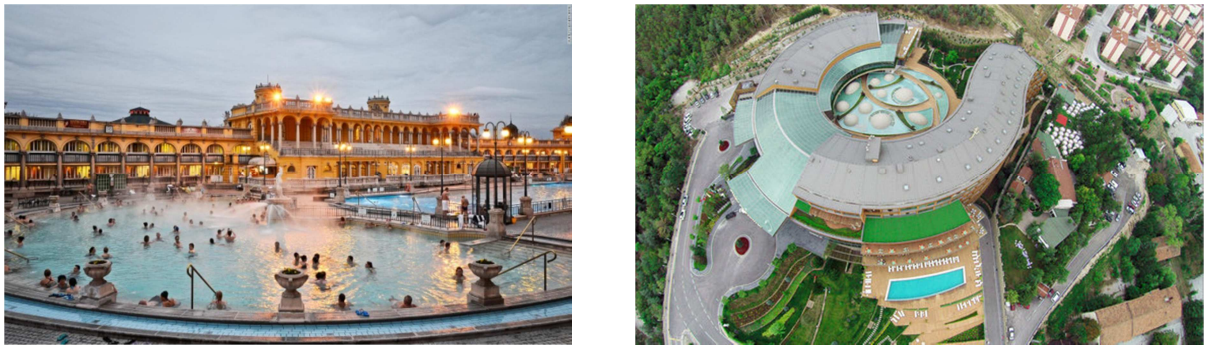
5. Importance of Balneotherapy in Modern Lifestyle

The modern lifestyle is full of stress and anxiety. The modern lifestyle related health problems like high or low blood pressure, blood-sugar etc. are very common now-a-days. In a health resort, a combination of balneotherapy along with other conventional medicines is practiced to reduce the health problem and the treatment is becoming popular day by day for its magical response without any adverse side effects. In the recent time, various other good practices like mental and physical health education, psychological counselling, sports therapy, dietary counselling, relaxation therapy etc. are adopted in the course of treatment, especially in the practice of health resort medicine. Though they are not associated with the traditional balneological practices, they have a specific positive impact in the treatment process. However, they are not elaborated here and are beyond the scope of our discussion.

Different types of balneotherapic practices are bath cure, drinking cures, mud therapy, inhalation etc. Fangotherapy is a treatment of the human body in which mineral-rich thermal mud, clay or peat is spread over the body for purification, revitalisation, and to reduce toxins. Thalassotherapy is the therapeutic use of seawater in cosmetic and health treatment. Though it is practiced in some health resorts, thalassotherapy, in the strictest sense, is not related to the balneological practices.

The most fundamental aspect of balneotherapy is the bath cure, that is hot spring water bathing. It is a habit of taking very hot water baths up to neck level at a temperature of 42°-44°C for a relatively short time duration such as 5-10 minutes. In case of high temperature geothermal water, it is left in open tanks to cool down to the desired temperature or is mixed

with inexpensive cold tap water. In the second case, mineral composition of original water changes reducing its efficiency as a natural medicine. The usual posture of bathing is a long-sitting or squatting position (Agishi & Ohtsuka 1998).



(A) (B)

Figure 4: Modern spas and health resorts. (A) The Széchenyi Baths (built in 1913) consist of three huge outdoor pools that are open all-year round, providing a great spot to cool off on hot days. (Photo source: CNN) (B) Eskisehir Spa and Thermal Hotel in Turkey (Photo source: architonic.com)

Bathing in water itself is a good exercise. Generally, exercises are of two types – active (yoga, athletics, gymnastics etc.) and passive (body massage). In bathing and swimming, physical exertion is an active participation, whereas the wave action in return provides an effect of passive massage. Therefore, the direct benefit of taking a hot-water bath is the physical effects such as buoyancy, hydrostatic pressure, viscosity of geothermal water etc. The other advantages are thermal, pharmacological and hydro-chemical effects. The temperature of the water-bath should be within the range of human tolerance, usually at a maximum level of 42°C. Some of the endocrine glands are reactivated and secrete more hormones at increased temperatures. Glutathione, an antioxidant naturally found in human cells, is capable of preventing damage to important cellular components caused by reactive oxygen species such as free radicals, peroxides, lipid peroxides, and heavy metals. It neutralises free radicals, boosts the immune system and detoxifies the body. It is observed that hyperthermia treatment with heat stress may cause oxidative stress, and cold stress is thought to augment the activity of the antioxidant defence system (Agishi & Ohtsuka 1998). Subsequent bathing in more than one time in a day for consecutive days stimulates the immune system of the body by glutathione metabolism in human erythrocytes and platelets by water bathing.

Balneotherapy can be regarded as a kind of stimulus-adaptation therapy, because patients are repeatedly given therapeutic stimulation, including hot steam water bathing, exercises, and other stimuli. The autonomic nervous system, endocrine system and immune system respond to these stimuli within a month in a non-specific manner. The potential level of physiological functions, in turn, are normalised which enhances the resistance potentials to endogenous and exogenous abnormal stimuli (Agishi & Ohtsuka 1998).

Recently people are habituated to live either in an artificial environment like air-conditioned office or apartment with artificial illumination or in an environment highly polluted with air, water, odour and/or sound pollution. Duties in night-shift and socio-economic strain due to ups and downs in money market are very common in the modern world. All these create lifestyle diseases along with some diseases related to stress-full life. On the other hand, medical support system enhances the normal span of life, which increases the ratio of old and aged persons in a society. Under this condition, the chronic disorder of health, the deterioration of hygiene and the frequency of functional diseases increase progressively. Thus it should be emphasised that balneotherapy is especially appropriate not only for the prevention and therapy of these disorders, but also for health promotion (Agishi & Ohtsuka 1998). The common physical disorders and diseases which confirm a good response to balneotherapic treatment are (Agishi 1995):

1. Prevention of adult diseases and occupational diseases
2. Building up physical strength, promoting health etc.
3. Chronic diseases
   A. Chronic rheumatic diseases
   B. Functional recovery of central and peripheral nervous neuro-paralysis
   C. Metabolic diseases such as diabetes, obesity and gout
   D. Chronic gastrointestinal diseases
   E. Chronic mild respiratory diseases: Young patients of bronchial asthma
   F. Circulatory diseases (moderate or less severe hypertension)
   G. Peripheral circulatory disorders
   H. Chronic dermal diseases such as eczema, dermatitis, psoriasis etc.
   I. Psychosomatic diseases and stress-induced diseases.
   J. Autonomic nervous dysfunction
   K. Vibration disorder
   L. Sequel of trauma
   M. Chronic gynaecologic diseases
4. Rehabilitation treatment after orthopaedic surgery.

In today's stressful and aging society, balneotherapy should be used effectively not only for the treatment of chronic diseases and rehabilitation, but also for preventing life-habit-related diseases which cannot be cured by drug therapy, and for maintaining and promoting health as well as establishing wellness in which the body and the mind are in good balance (Agishi & Ohtsuka 1998).

6. Hydrogeochemistry of geothermal waters

Japan has a long tradition and culture of balneotherapy. According to the definition of Japanese hot spring law the temperature of the water at source must be 25°C or more and that natural water must contain some radicals more than that the normal average (Agishi & Ohtsuka 1998). The important ingredients are free carbonic acid (H_2CO_3), and radicals of Lihium (Li), Strontium (Sr), Barium (Ba), ferrous (Fe^{2+}) and ferric (Fe^{3+}) ions, manganous

(Mn^{2+}) ions and ions of Hydrogen (H^+), Bromine (Br^-), Iodine (I^-), Fluorine (F^-), hydro-arsenic acid ($HAsO_4^{2-}$) and different compounds like meta-arsenic acid ($HAsO_2$), sulphur (HS^-, S_2O_3, H_2S etc.), meta-boracic acid (HBO_2), meta-silicic acid (H_2SiO_3), sodium bicarbonate ($NaHCO_3$) and some exceptional elements like Radon (Rn) or Radium salts (Ra).

There is a direct relation between total dissolved solids (TDS) and temperature of the water. The low temperature geothermal water usually contains dissolved solids in the range of 200-400 mg/L, whereas the high temperature fluids contain more than 1000 g/L (Kristmannsdóttir & Björnsson 2003). In Japan 2-3 g/L solids are very common in high-temperature volcanic water. The geothermal waters are usually meteoric in origin. Percolated water from the near-surface aquifer usually goes down to the deep interior of the crust, where it comes in contact with intruded magma and released out as geothermal spring. So, the recharge area of thermal aquifer should be in close vicinity to the subsurface heat source, such as magmatic intrusion within the crust. Hot-water springs of Leh and Ladakh are hydrothermal in origin. These are directly related to some subsurface igneous activity related to the Himalayan mountain building process. However, magmatic source of heat has no significance in the hot spring of peninsular India as there is no known recent igneous activity in the Indian shield. Regional high heat flows in the shield may be one of the reasons for the development of hot-spring. The presence of radioactive and inert gases such as Radon and Helium indicates a radiogenic heat source. Sometimes the reaction of seepage water with limestone or sulphide ore produces pungent low-temperature water. The gas content of the hot-spring may guide us to know the type of reaction and its use as a medicinal agent. Sometimes heat generated from the exothermic reactions during metamorphism might be accumulated in the geological past and come to the surface as a hot-spring. In a few cases, the heat source may be the frictional heat generated along the fault plane due to tectonic movement. In that case, the hot groundwater includes less mineral matter and is medically less appropriate for balneological use.

In the balneotherapic treatment, – heat, water, gas and mineral constituents – all are very important. The pH of the water is one of the indicators that can be used to get the immediate information of the medicinal water. Most of the waters considered for treatment of hydrotherapy or balneotherapy is not neutral in nature ($pH \neq 7$). They may be acidic in the presence of carbonic acid and sulphur and the pH may be as high as 1.4, which is used in "Jikan-Yu" therapy for dermal diseases in Japan (Agishi & Ohtsuka 1998). pH values are lower in high temperature water and it may increase as high as 11 (usual range pH = 9-10) in comparatively low temperature geothermal water. Similarly, the silica concentration of the waters is in direct relation with increasing temperature, carbonate concentration is in inverse relation to increasing temperature and the waters are highly depleted in magnesium, even at moderate temperatures (Kristmannsdóttir & Björnsson 2003).

The gases, which are very common in geothermal or balneological fluid, are carbon dioxide (CO_2), hydrogen sulphide (H_2S), methane (CH_4), hydrogen (H_2) and nitrogen (N_2). A comparable level of N_2 in some geothermal gases suggests that N_2 has been derived from the atmosphere along with meteoric water (Saxena1987). Dissolved oxygen level is always less

than the atmospheric concentration and helium (He) and argon (Ar) are common constituents in some springs, indicating their radioactive heat source. High CO_2 content is generally associated with the geothermal system in volcanic and magmatic areas (Arnorson & Barnes 1983). However, CO_2 of meteoric origin is also very common and derived through metamorphic and/or organic process. Presence of methane may be endorsed by the decomposition of organic matter inside the earth's crust. Hydrogen sulphide may be produced by heating of rocks containing sulphide minerals and organic matter, which imparts sulphur smell to the surrounding (Mahala 2019).

7. Geothermometry of Aquifer and Types of Thermal Manifestations

A very common classification scheme of geothermal water is based on the temperature as well as their impact on their potential use. Using this scheme, geothermal springs are ranked as low enthalpy (<100°C), moderate enthalpy (100°C to 175°C), and high enthalpy (>175°C) (Boden 2017, Ghosh 2020). Most of the geothermal waters of the Indian subcontinent are low-enthalpy type.

Any water-bearing geological formations are called aquifer (aqua-bearing formation). Geothermal systems or high-temperature aquifers are found in different parts of the world in the geological settings. These are basically the source of hot spring water. Nicholson (1993) offered a geothermal classification system based on the reservoir equilibrium, fluid type and temperature as follows:

1. Convective geothermal systems (dynamic systems): The system where meteoric water enters into the deep interior of the crust through cracks, comes in contact with heat source (usually near-surface magma) and returns to the surface as hot-spring.
   a. High temperature: liquid- and vapour-dominated
   b. Low temperature
2. Conductive geothermal systems (static systems): The system where heat comes to the surface through conduction.
   a. Low temperature
   b. Geo-pressurised (a special setting like an oil-bearing reservoir)

It was thought that the classification of the geothermal as well as hydrothermal systems had no significance in the practice of balneotherapy. In recent time, an emphasis has been given on understanding the origin of the thermal spring before going into randomised trial in medical sector.

8. Balneological Classification of Waters

It is hard to classify hot spring waters in terms of their therapeutic properties. The main problems are:

(a) Each and every thermal spring is unique and the chemical composition of expelled water differs from one spring to another. Therefore, it is hard to classify these waters on some fixed chemical and medical parameters.
(b) Though the quality of drinking water has a specific norm based on the directive of the World Health Organisation (WHO), only a few countries have specific regulations or acts on thermal water.
(c) Central European countries like Hungary, Slovakia, and Romania developed some regulations on 'mineral water' based on simple analogical studies (Varga 2010). However, whether these waters meet the criteria of a 'medical water' or not, that is yet to be identified.
(d) Biological activities and organic components of geothermal waters are not well-studied and the absorption of different chemical components of that water in human body through skin is yet to be studied scientifically. Lack of knowledge is also responsible for not developing a true classification scheme.
(e) The healing effects of balneotherapy in wide range of diseases are well described (Nasermoaddeli & Kagamimori 2005), however, exact mechanism of the healing spa cure and its relationship to the presence of certain chemical ingredients are completely undefined. So, the classification of medical water, based on their chemical ingredients, is not possible.

Table 1: Classification of medicinal waters as per Papp's system (Papp 1957).

Category	**Main features**
Simple thermal waters	$\geq 25°C$
Simple acidic (carbonised) waters	≥ 1 g/L free CO_2
Alkaline (Na-K-bicarbonated) waters	≥ 1 g/L total dissolved solid, Dominant anion: $HCO3^-$
Ca-Mg-bicarbonated waters	≥ 1 g/L total dissolved solid, Dominant cations: Ca^{2+}, Mg^{2+} Dominant anion: HCO3-
Chloridated (saline) waters	≥ 1 g/L total dissolved solid, Dominant cation: Na^+ Dominant anion: Cl^-
Ironic (ferrous) waters	≥ 10 mg/L Fe^{2+} or Fe^{3+}
Sulphuric waters	Total sulphur $\geq$ 1mg/L (HS or $S_2O_3^{2-}$ or S^{2-} or H_2S)
Sulphated waters	≥ 1 g/L total dissolved solid, Dominant anion: SO_4^{2-}
Iodated-brominates waters	≥ 1 mg/L I or ≥ 5 mg/L Br^-
Radioactive waters	Radon or toron (^{212}Pb) content

Following traditional methods and existing knowledge-base, Papp (1957) classified medicinal geothermal water into few groups based on their chemistry (Table 1). The classification scheme was very simple and it did not satisfy the purpose of a medical practitioner. Though spa waters used in prevention and therapy, balneotherapy and balneoprevention have some

indigenous problem: if the spring water 'A' contains chemical 'B' and the water 'A' successfully cures the disease 'C'; that does not mean that the chemical 'B' is responsible for curing the disease 'C'. Therefore, the exact inorganic analytical study cannot predict the therapeutic efficiency and more *medical trial* is necessary for qualifying a spa water to be a '*Medicinal Water*' (Varga 2010). Presence of some chemical constituents in terms of ppm or ppb level might influence the healing and curing property of so called medicinal water. There is enough scope of research in this field of medicinal chemistry.

However, attempts were made to classify thermal water based on their single property and the obvious choice was the temperature as the major criterion for classification. On the basis of temperature, water can be classified as (a) Cold (< 25°C), (b) tepid (25-34°C), (c) warm (34-42°C) and (d) hot (> 42°C) (Karagülle & Karagülle 2014). A similar classification scheme was proposed by Vouk (1923): (a) Hypothermal (cold) (<18°C, (b) Chliarothermal (tepid, 18-30°C), (c) Euthermal (warm, 30-50°C), (d) Acrothermal (hot) (50-70°C), and (d) Hyperthermal (steaming, 70°C or higher). The Vouk fixed the temperature in an arbitrary manner; however, the recent scheme considers the thermal tolerance of human body. The normal human body temperature is 37°C or 98.6°F. The temperature 37±1°C shows an isothermal effect and it is clear from the general principle of heat transfer that at a higher temperature heat is transferred from water to the body and at temperatures below 35°C it has a cooling effect. So, this average body temperature may be considered as an index in the hydrotherapy treatment. On the basis of diurnal and seasonal variation, the thermal spring may be homothermal or heterothermal. On the basis of morphological criteria (Schwabe 1936, Tuxen 1944) hot springs are divided into: (a) Limnotherm – a hot spring having a basin at the head, where surfacing waters collect prior to spilling over; and (b) Rheotherm – a hot spring where there is no storage basin at the head. Yoneda (1952) classified the various hot springs of Japan on the basis of algal flora in 5 types; viz. (a) *Synechococcus* type, (b) *Cyanidium* type, (c) *Mastigocladus* type, (d) *Oscillatoria* type and (e) *Phormidium* type. These classifications do not satisfy all the qualities of medicinal water for therapeutic use. Several successive classification schemes have been proposed (Vintras 1883, Kisch 1906, Peale 1906, Acciaiuoli 1952, Gomes et al. 2019 etc.) for the need of classifying different types of geothermal waters from different geological settings, but no one of them is all-inclusive type.

The scientific approach towards the classification of medicinal water was traced back to last half of 18th century when it was classified under the groups: (1) cold acidulous; (2) thermal acidulous; (3) sulphuric saline; (4) muriatic saline; (5) simple sulphurous; (6) sulphuretted gaseous; (7) simple ferruginous; (8) ferruginous and acidulous and (9) sulphuric ferruginous (Gairdner, 1832). Different independent classification schemes were developed in accordance with the need of the local community in different countries like America, France and Germany. Following the major ionic constituents medicinal waters are classified in a simple scheme (Albertini & Dachà 2007) as:

- Oligo-mineral and low mineralised water
- Sulphurous water
- Salt-bromine-iodine water

- Radioactive water
- Salt water
- Sulphate water
- Bicarbonate and carbonic waters
- Ferrous, arsenic water.

Komatina, (2004) indicates the division of medicinal waters as four (4) basic groups on the basis of concentration of mineralisation and eight (8) balneological applicable groups with respect to the presence of important components. The important parameters are:

A. Mineralisation and suitability for treatment by drinking or bathing

Type	Mineralisation (g/L)	Use
Waters with elevated mineralisation	1 to 5 g/L	Consumed for drinking
Waters with medium mineralisation	5 to 15 g/L; osmotic concentration approaches that of blood plasma	Suitable for balneology; taken as medicine
Waters with high mineralisation	15 to 35 g/L	Used exclusively for bathing purpose
	Brines 35 to 150 g/L	Used exclusively for bathing purpose

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B. Classification based on the presence of specific components

	Type	Mineralisation	Other features	Use
1.	Medicinal mineral water without specific components and properties	150 g/L	Nitrogen and methane gas	
2.	Carbonated mineral water	Fraction of g/L to 90 g/L	High concentration of carbon dioxide Variable chemical composition HCO_3 dominant anion	Treat disease of stomach, intestine, bile and urinary duct
3.	Hydrogen sulphide waters	More than 500 g/L	Diverse chemical composition, mineralisation and H_2S concentration. Include sulphates and chlorides	Bathing in water treat disease of skin, rheumatism and nervous disorders
4.	Radioactive mineral water	Ra $>1.0^{-11}$ g/L U $> 3.0^{-5}$ g/L Rn $> 1.85^{2}$ Bq/L	Balneology use radon	Nervous, cardiovascular diseases; skin ailments and gynaecological diseases
5.	Iron water, arsenic water and water with elevated content Mn, Al, Cu and Zn	Fe lower limit 20 mg/L As lower limit 0.7 mg/L		
6.	Bromine and iodine waters	Br > 25mg/L or I > 5mg/L		Drink and bath
7.	Waters with high content of organic substance	Variable: Several mg/L to more than 400 mg/L	Peat bog, mud flats, petroleum deposits	

8.	Silicic water	Si > 50 mg/L as H_2SiO_3	Present in thermal and high thermal water, Temperature > 35 °C Waters often contain medicinal Rn and CO_2 and other trace elements

The indicated classification makes it possible to ascertain from mineralisation values their suitability for treatment by drinking or bathing (Komatina 2004).

Considering data from German, Japanese and Icelandic geothermal water resources a generalised balneological classification of waters can be proposed (Kristmannsdóttir & Björnsson 2003). The balneological waters can be grouped as:

1. Carbonate water containing total carbonate (calculated as CO_2) in excess of 300 mg/L
2. Sulphide water containing H_2S in excess of 1 mg/L and of temperature > 40°C.
3. Highly mineralised warm (>40°C) waters with TDS (total dissolved solids) exceeding 1000 mg/L.
4. Iron rich water containing iron in excess of 20 mg/L and of temperature >40°C.
5. Fluoride water containing fluoride in excess of 2 mg/L and of temperature >40°C.
6. Iodide water containing iodide in excess of 1 mg/L.
7. Radioactive water containing radon in excess of 666 Bq/L.

This scheme was proposed for Icelandic health resort water and unfit for the classification of Indian hot-spring water. The hot springs of the Himalayan region have a magmatic association, whereas the peninsular hot-springs are completely non-volcanogenic. For example, the chemical analyses indicate that the spring waters of Odisha are Oligo-mineralic, but not identical to one another in their chemical characters. They are categorised mainly under three types, i.e. (i) sodium chloride (NaCl) type, (ii) sodium bicarbonate ($NaHCO_3$) type and (iii) calcium bicarbonate ($CaHCO_3$) type (Mahala 2019).

In recent times, the balneological classification of geothermal water is based on the mineralisation of waters. Three groups are: simple (TDS < 600 mg/L), oligo-metallique (700 – 1000 mg/L) and highly mineralised (>1000 mg/L).

As per the directive of the European Union, the important ingredients (in terms of TDS) of medicinal thermal waters are given in Table 2. The specifications prescribed by WHO and Indian Standards indicate that most of the thermal spring waters of peninsular India are suitable for drinking and domestic uses as most of the parameters are within the permissible limits with few exceptions (Mahala 2019).

In the recent past, it is becoming popular to classify medicinal water in the Piper diagram, which was initially developed by the Piper for illustrating the geochemistry of geothermal water. In Piper triangular diagram (Piper 1944), the relative concentration of cations (Na, K, Ca, Mg) and anions (Cl, CO_3, HCO_3, SO_4) are plotted to understand the chemical nature of water (Figure 5). This diagram is a combination of four triangular diagrams, out of which the

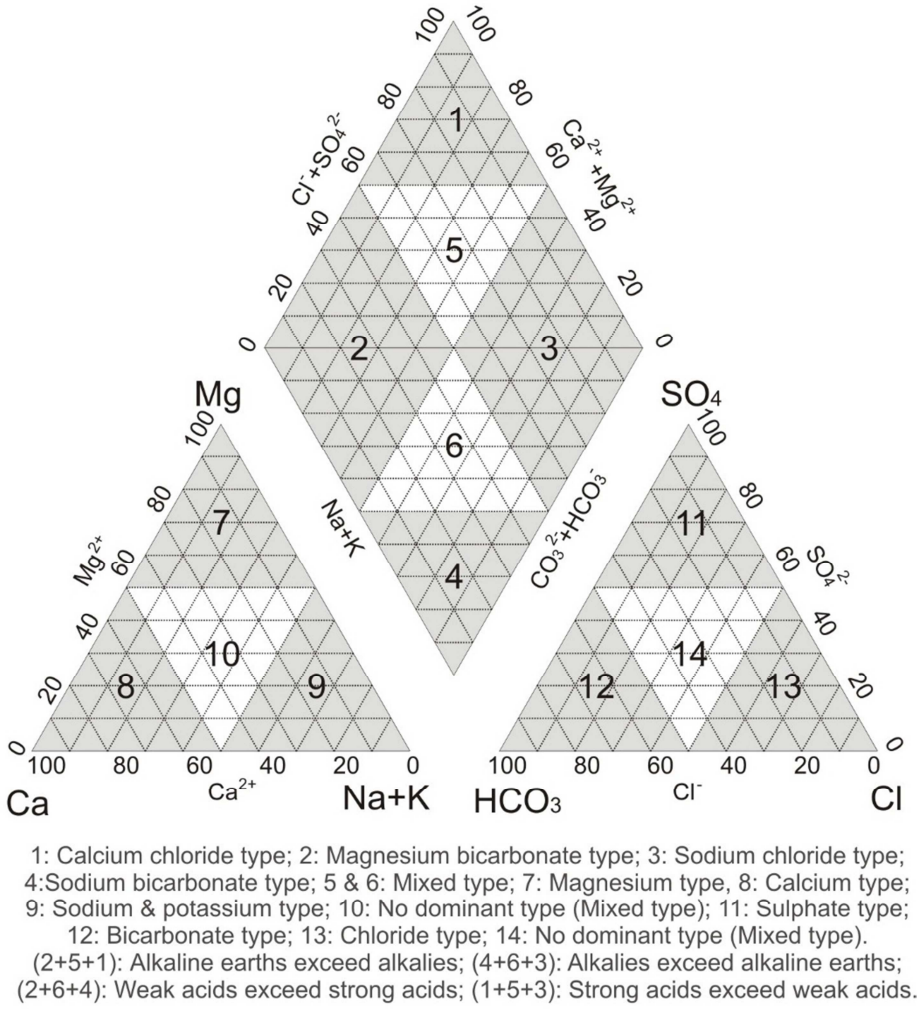
middle one is inverted. Actually, there are two triangular diagrams in the two sides of the base of the triangle, and one normal and one inverted triangular diagrams joining at the base form a diamond or rhomb, which forms the apex of the piper diagram. Piper diagram is now used to differentiate two similar medicinal waters collected from different sources and to identify their potential to be used for treating illness. However, the problem of using the Piper diagram to present the major ions in balneological classification is that the concentrations are renormalised. Also, Piper cannot accommodate all types of ions of water, which may be significant.

Table 2: Criteria for mineral waters in accordance with the EU mineral water directive (After Van der Aa 2003)

Mineral water type	**Criterion**
Very low mineral concentration	Mineral content (TDS)<50 mg/L
Low mineral concentration	TDS 50–500 mg/L
Intermediate mineral concentration	TDS 500–1500 mg/L
High mineral concentration	TDS >1500 mg/L
Containing bicarbonate	Bicarbonate >600 mg/L
Containing sulphate	Sulphate >200 mg/L
Containing chloride	Chloride >200 mg/L
Containing calcium	Calcium >150 mg/L
Containing magnesium	Magnesium >50 mg/L
Containing fluoride	Fluoride >1 mg/L
Containing iron	Bivalent iron >1 mg/L
Acid	Carbon dioxide >250 mg/L
Containing sodium	Sodium >200 mg/L
Suitable for low sodium diets	Sodium <20 mg/L

Table 3: Terms related to the use of thermal and mineral water associated with medical treatment.

Term	**Definition**
Taking the waters	Bathing in water for therapeutic purposes
Balneotherapy	Treatment employing bathing in thermal or minerals waters, gases or peloids, drinking water or inhaling gases or water
Balneology	The scientific field dealing with balneotherapy
Thalassotherapy	Treatment employing bathing in sea water or sea products
Hydrotherapy	Treatment immersing a part of or the whole body in plain water, often employing exercises, or the application of water jets
Pelotherapy	Application of peloids (mud or clay) for therapeutic purposes
Fangotherapy	Application of mud, peat, and clay for healing. purposes (*fango* is the Italian word for mud).
Cryotherapy	Application of low temperatures to decrease inflammation, decrease pain and spasm, promote vasoconstriction. (In some countries people use the term cryotherapy instead of balneotherapy).
Climatotherapy	Application of climatic factors for the prevention or treatment of disease or for rehabilitation



1: Calcium chloride type; 2: Magnesium bicarbonate type; 3: Sodium chloride type;
4:Sodium bicarbonate type; 5 & 6: Mixed type; 7: Magnesium type, 8: Calcium type;
9: Sodium & potassium type; 10: No dominant type (Mixed type); 11: Sulphate type;
12: Bicarbonate type; 13: Chloride type; 14: No dominant type (Mixed type).
(2+5+1): Alkaline earths exceed alkalies; (4+6+3): Alkalies exceed alkaline earths;
(2+6+4): Weak acids exceed strong acids; (1+5+3): Strong acids exceed weak acids.

Figure 5: Piper trilinear diagram

9. Therapeutic use of Geothermal Water: The balneological approach

Though balneotherapy is a very old traditional medical practice, it is still treated as an *alternative medicine* in a country like India. The use of different terms of balneotherapy is quite uncommon to general people. Different connotations are available for a single term and at the same time, same group of jargons are used to denote the similar but slightly different situations. For example, Latin speaking countries often use the term '*Crenotherapy*' instead of balneotherapy (Varga 2010). Therefore, a comprehensive terminology is required to explain the usefulness of thermal groundwater. It is described in Table 3.

The simple thermal water includes oligo-mineralic water or hot water with a negligible amount of mineral, and the water is characterised by heat and temperature. However, the curative action of the chemical components in waters may be related to the presence of individual ions (Nghargbu et al., 2013).

The medicinal properties and impact of different ions present in the geothermal water are given below:

9.1 Bicarbonate

The ions are especially important to treat rheumatism, skin disease and digestive disorders.

9.2 Sulphate

Sulphate water, represented by a higher concentration of SO_4, is antitoxic and antiseptic, has respiratory and anti-dermatitis effects, and is essential in the fluids of joints. Sulphate water is also used as a purgative and laxative, when internally taken as drinking water, which is beneficial for liver and gastrointestinal conditions (Dulaymie et al. 2013). Important applications are in the treatments of eczema, skin diseases, gastritis, respiratory problem, gout and rheumatism.

9.3 Chloride

Chloride water is essential for metabolic stimulation, and mineral springs naturally rich in chloride are beneficial for rheumatic conditions, arthritis, central nervous system, posttraumatic and postoperative disorders, as well as orthopedic processes and gynecological diseases (Mitija 1999).

9.4 Fluorine/Fluoride

Fluorine is essential for fibres of the skin, vertebrates, bones, and teeth. It provides hardness and stability, especially on the surface area. The efficiency in F concentrations leads to dental caries (Edmunds and Smedley1996). F^- concentrations more than 2.4ppm may cause skeletal fluorosis; in that case, the fluoride is classified as a toxic agent.

9.5 Bromine/Bromide

Br^- accompanied with other tracers like zinc and rubidium has a good ability to penetrate into psoriatic skin and effective for healing skin infection (Dulaymie et al., 2013).

9.6 Iodine

Iodine water acts on cardiac and circulation system, thyroid function, lipid metabolism, and respiratory diseases. It has an antioxidant defence mechanisms and a positive impact on the treatment of arteriosclerosis, diabetes mellitus and cataract (Winkler and Klieber 1998).

9.7 Iron

A higher concentration of iron in water for bathing and drinking is beneficial for anaemia and diseases like alopecia. Iron-rich water is sometimes referred to as chalybeate, ferruginous or ferrous water. Iron concentrations in bathing and drinking water benefit anaemia healing and alopecia diseases; iron is considered as a stringent agent as well as responsible for oxygen transport from the lungs to the other parts of the body. It cures the problems of infertility, anaemia, hangover, obesity and genital disability.

9.8 Magnesium

It is very important component to treat eczema, skin diseases, respiratory, gastritis, heart-burn and tubercular diseases and diseases of bladder and kidney.

9.9 Silica

Silica and Silicic acid (H_2SiO_3) provide healing effects to various body organs and immune systems. Silica water has been successfully used for treating atopic dermatitis, allergic rhinitis and conjunctivitis (Ghersetich et al. 2001).

9.10 Zinc

Tracers of zinc concentrations are needed in tissues to restore protein syntheses (Mitija 1999).

Table 4: Chemical classification of geothermal mineral waters base on their balneological effect

Chemical type of mineral water	Principal physiological properties	Principal medical use
Bi-carbonated water	Stimulating action on the hepatic and intestinal function, on certain general metabolism (excretion of uric acid, hypo-glycemiating effect)	Gastro-intestinal illness; hepatic insufficiency; gout
Sulphated water	Stimulating action on the billary and intestinal function; diuretic action gastro-intestinal illness	Hepatic insufficiency; problems with accumulation of organic waste
Sodium chlorinated water	Stimulating action on growth and cicatrisation (osseous tissue in particular)	Podiatry; after effects of osteoarticular traumatisms; chronic infection of the mucous membranes
Sulphurated water	Trophic effect on the skin and mucous membranes; antalgic, antispasmodic action	Chronic infections of the mucous membranes; rheumatology; spasms (digestive in particular); metabolic illness Treatment of skin diseases
Radioactive mineral waters	Uranium, Radium and Radon bearing water Effects on rheumatism and arthritis, heart and cancer.	Treatment of on rheumatism. arthritis and cancer.

9.11 Other trace elements

- Arsenic is fatal to the human body, but helpful in balneology. It has therapeutic use in chronic rheumatism, tuberculosis and respiratory diseases.
- Cu concentrations are essential for collagen-elastic syntheses, while Mo is essential for amino acid metabolism synthesis.
- Apart from these, the presence of aluminium, boron, chromium, cobalt, lithium, manganese, molybdenum, selenium etc. make the geothermal water more precious. It is impossible to explain their importance in this small effort.

Chemical classification of geothermal mineral water based on their balneological effect is given in Table 4.

10. Commercial Establishment for Balneotherapic Practice

The geothermal waters are used for the commercial benefits in three different ways:

1. Development of geothermal spas with all the facilities that are available in a luxurious hotel.
2. Development of geothermal parlour or small pools with soaking tubs with or without snack bar and camping facilities.
3. The primitive undeveloped springs within the nature's lap without any services.

The first two are becoming popular in modern world; the third one still has significance to the trekkers and explorers.

11. Indian Hot Springs and Practice of Balneotherapy in India

India has a few numbers of hot springs and surprisingly, all are somehow related to Hindu mythology. The peculiarity of the nature of those springs draws attention since the historic past and associates them to mythological facts. The Rig Veda, a religious text of ancient India, described hydrotherapy treatments used for healing (Wardle 2013). Rudimentary health tourism in the form of pilgrimage has already been developed surrounding these hot springs. For example, at the temples of Manikaran and Badrinath in north India, thermal water forms the basis of the religious ritual carried out there, as well as the spiritual meaning attached to these places (Boekstein 2014). A balneotherapic practice in a primitive form has been practiced by the local 'pandits' of these areas. In Odisha, Taptapani thermal water is used for the treatment of skin, stomach and Rheumatic disorders.

It is apparent that the many hundreds of Indian hot springs might be utilised in balneotherapy and tourism, an aspect so far rather neglected except in Bihar, Himachal Pradesh and the West Coast area (Bowen 1989). A case study conducted by the Apollo Group of Hospitals showed that there are tremendous opportunities in India as far as medical tourism is concerned (Smith & Puczkó 2009). Detailed study and discussions are required to understand the possibilities of geotourism, health tourism and practice of balneotherapy surrounding the pilgrimage.

Geologically, nine potential areas are recognised in the subcontinent of India to develop geothermal and balneological services (Figure 6). These are:

1. The zone of subduction or Himalayan suture zone
2. North Indian Precambrian region or Sohana province
3. The zone in middle India associated with mid-continental rifts i.e. SONATA (SonNarmada-Tapi) Rift.

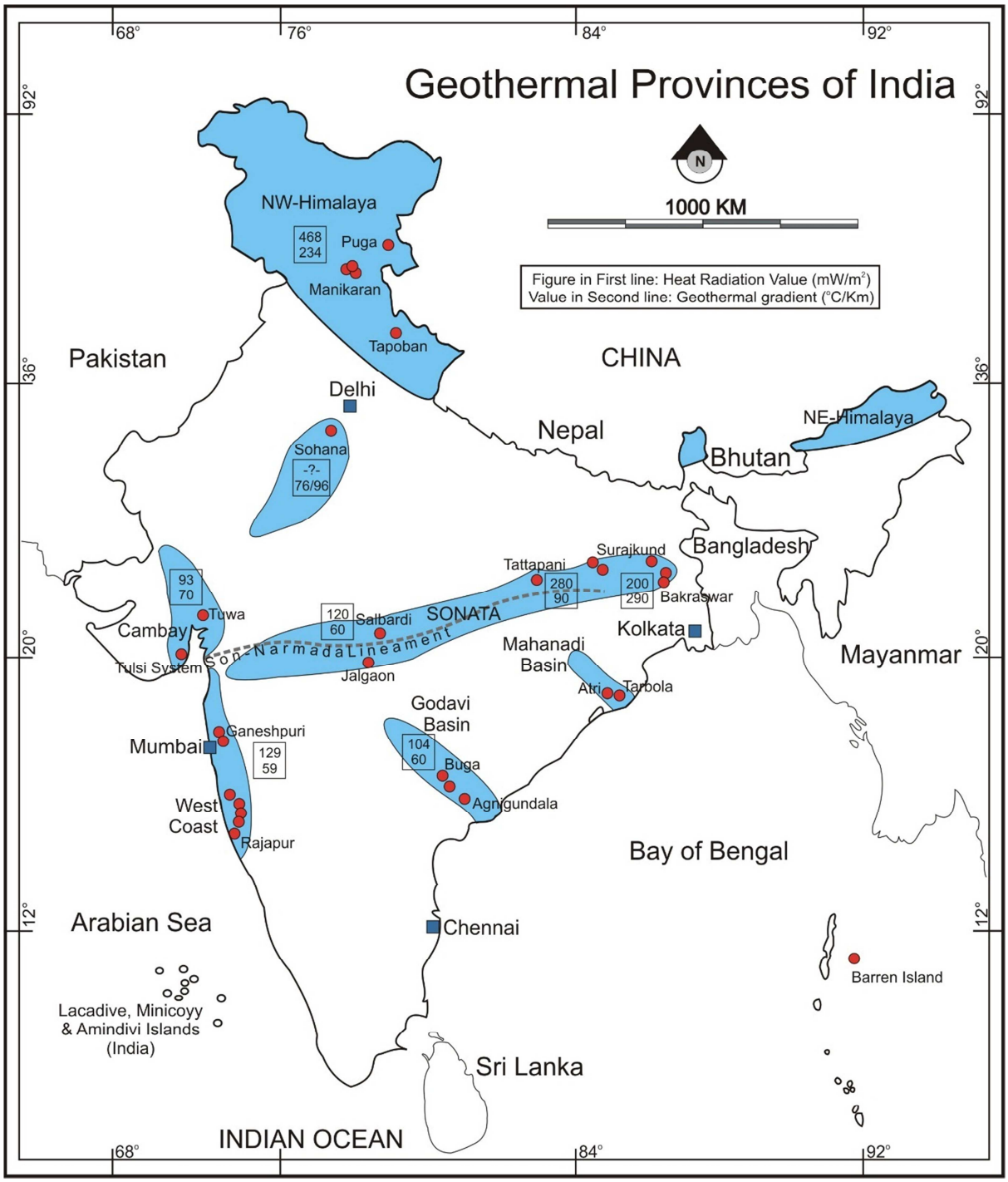


Figure 6: Major and representative Geothermal Provinces of India. (Modified after Chandrasekharam & Chandrasekhar 2010, 2015).

4. Sedimentary basin of Cambay and surrounding areas (Gujarat-Rajasthan Geothermal Province)
5. The thermal accumulation associated with Cretaceous-Tertiary volcanism below the Deccan Trap near west coast.
6. Mahanadi Basin
7. Godavari Basin

8. The Bay islands of Andaman & Nicobar and
9. North-east Himalayan subprovince.

Though Andaman and Nicobar islands is promising site for the development of spa and health resort, the close-door policy for the purchase of land in the area repels the investors. On the other hand, Kerala has developed health resort services based on Ayurveda, massage and traditional herbal medicine, but there is no notable thermal spring in the state.

A detailed state-wise list of hot spring sites is given in Table 5. The governments of Odisha, Himachal Pradesh and Maharashtra have taken the initiative to develop the hydrothermal sites. Bihar and Jharkhand are also interested in developing geotourism surrounding the hot-spring areas. In Birbhum district of West Bengal, Bakreshwar is famous for pilgrimage. However, most of the geothermal and hydrothermal sites in India are neglected. Except Puga and Chumathang in northern Himalaya, most of the geothermal reservoirs are low-temperature, mid to low-enthalpy type. Hence, it is not possible to harness electricity from those sites without the advancement of technology. The only possible ideas we can adopt is to convert them to geotourism sites with the facilities of health resorts, spas and balneotherapic centres. To draw the attention of foreign tourist and earn foreign revenue, the idea should be modern one, with the design of international standard.

Table 5: State-wise geothermal resources in India which have potential for balneotherapic use.

State	Name of the Geothermal Spot	Source of information
Andhra Pradesh	Mahandishwara Swamy temple at Mahanandi (Kurnool district [Dt.]), Bugga and Manuguru (Godavari valley)	Shanker et al. 1991, Chandrasekharam & Bundschuh 2002
Arunachal Pradesh	Dirang (West Kameng Dt.), Kitpi (Tawang Dt.), Bhalukpong (East Kameng Dt.), Thingbu and Tsachu (Tawang Dt.)	Shanker et al. 1991, Bora et al. 2006, Shanmugasundaram 2015
Assam	Gelepung (Dibrugarh Dt.) Garampani, Barpung (Karbi Anglong Dt.)	Shanker et al. 1991 and personal information
Bihar	Rajgir, Hot-springs of Munger dt. (Bharani, Bhimbandth Group; Hingania Group; Remeshwar-Lakshmiswar-Bhowarh Kund Groups; Rishikund Group; Sitakund-Phillips Kund Group; Sringrishi Group)	Shanker et al. 1991
Chattisgarh	Tattapani (Balrampur Dt.) and Surajkund (Faridabad Dt.)	Shanmugasundaram 2015, Roy 2008
Goa	No information available; assets remain untapped	Shanmugasundaram 2015
Gujarat	Tulsishyam (Junagarh Dt.),	Shanker et al. 1991, Mahala 2019

State	Name of the Geothermal Spot	Source of information
	Tuwa, Unani (Surat Dt.), (Cambay basin of Gujrat)	
Haryana	Sohana (near Gurgaon)	Shanker et al. 1991
Himachal Pradesh	Spread over Parbati, Beas, Satluj and Spiti valleys. Parvati Valley: Manikaran, Khirganga, Kasol, Awas. Satluj and Spiti valleys: Tapri, Chuza-Sumdo, Tattapani, Garam Kund and Vasisht (Bank of River Ravi)	Shanker et al. 1991, Chandrasekharam & Bundschuh 2002, Suryawanshi et al. 2019, Shanmugasundaram 2015, Chandrasekharam & Chandrasekhar 2008
Jharkhand	Tatta and Jarom in Palamau Dt. Surajkund, Lakshmi Kund, Brahma Kund, Ram Kund, Sitakund and Bagodar in Hazaribagh Dt. Tantloi, Dalahi and Bara Palasi (Dumka Dt.)	Shanker et al. 1991, Mukhopadhyay & Sarolkar 2012
Karnataka	Bendruteertha	Shanker et al. 1991
Kerala	Varkala	Shanker et al. 1991
Madhya Pradesh	Dhuni Pani, Salbardi	Shanker et al. 1991
Maharashtra	Rajapur-Unhale, Palghar, Anjaneri-Math, Rajwadi, Tural, Aravli, Khed, Unhavare-Farare, Vadvil, Pali, Akloli, Ganeshpuri, Satvili, Vajreshwari, Nimboli, Banganga, Nandni Gaygotha, Padusupada, Haloli, Sangh and Koknere	Shanker et al. 1991, Chandrasekhar et al. 2016, Suryawanshi et al. 2019
Manipur	Ukhrul	Personal information
Meghalaya	Jakrem	Shanker et al. 1991
Mizoram	No information available	
Nagaland	No information available	
Odisha	Atri, Taptapani, Deluajhari, Tarabalo	Shanker et al. 1991, Mahala 2019
Punjab	No Database on Hot-water Springs	Shanker et al. 1991
Rajasthan	Lalsot-Toda Bhim belt Jhunjhunu and Siwana area	Shanker et al. 1991, Moon & Dharam 1988, Singh et al. 2016
Sikkim	About 14 hot springs – all are of temp. >65°C; Phurchachu, Yumthang, Borang, Ralang, Taram Chu, Polat, Rishi and Yumesamdong (Yumey-Samdong)	Shanker et al. 1991, Kundu 2018, Shanmugasundaram 2015

State	Name of the Geothermal Spot	Source of information
Tamil Nadu	Mannargudi-Thiruthuraipundi area Costal tract of Arantangi	Shanker et al. 1991, Shanmugasundaram 2015
Telangana	Ushnagundam (Agnigundala) (near Bhadrachalam area)	
Tripura	No information available	
Uttar Pradesh	Most of the hotsprings are now located in Uttarakhand. No information available for Uttar Pradesh	Shanker et al. 1991
Uttarakhand	Sastradhara (Dehradun), Surya Kund (Near Rudra Prayag), Tapt Kund (on the bank of Alakananda), Gauri Kund (05 kms from Sonprayag) Bhagirathi Valley (Uttarkashi Dt.): 6 hot-water spring *viz.* Gangnani, Bhukki and Songarh; Darma Valley (Pithaurgarh Dt.): 1 hot-water spring; Madhya Maheswar Valley: 1 hot-water spring	Shanker et al. 1991, Suryawanshi et al. 2019
West Bengal	Bakreshwar, Dalahi and in Birbhum Dt.	Shanker et al. 1991, Ghose et al. 2002, Chandrasekharam & Bundschuh 2002
Jammu-Kashmir & Ladakh	Puga, Ladakh Dt., Chhumathang, Ladakh Dt., Panamik (Nubra Valley)	Shanker et al. 1991, Suryawanshi et al. 2019
Andaman and Nicobar Island	Barren Island & Batang	Shanker et al. 1991

12. Conclusion

Balneotherapy is a type of hydrotherapy. Balneology (lat. balneum: bath) is the science that deals with the healing effects of natural thermal waters, and their use in the treatment of diseases. Balneotherapy has a wide role in the management of various medical conditions. The geothermal waters of varied chemical composition can be used in balneotherapy treatment. The hot springs are distributed in different geological provinces all over India and provide low-enthalpy geothermal resources. Apart from space heating at many resorts, the introduction of balneotherapy makes the resort more attractive. Due to the multidisciplinary character of balneotherapy, there are ample opportunities to conduct research on the subject, especially in a country like India, and lots of innovative ideas may be developed and introduced in the field of geotourism and balneology.

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Constraints and possibilities in the changing teaching-learning paradigms of tertiary level formal ESL classroom teaching in Kolkata due to COVID-19: A case study

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Abstract: This paper intends to study the changing teaching-learning contexts that the COVID-19 crisis has suddenly forced the teacher and student communities to reckon with. Adapting a case study approach, the paper bases itself on a questionnaire study circulated among and answered by a sample group of 20 teachers and 160 students of English and Communicative English in two undergraduate colleges in Kolkata. The findings focus on the aspects of the teaching-learning process adapted by the teachers in the lock-down period; the teaching tools used in the process, the infrastructure available to the teachers and lists the challenges faced while taking online classes. On the other hand, the paper tries to gauge students' attitude to online classes, the degree of satisfaction and the overall achievement in comparison to the bricks and mortar classroom. Using this data, as we gradually emerge out of the pandemic era, this paper tries to layout the implications of the post-COVID educational paradigm, with special reference to training, flexibility of teaching methodology in taking synchronous and asynchronous classes in order to ensure safe and quality sustenance of higher education, specifically with reference to collaborative language teaching and learning.

Keywords: online teaching, case study, teaching tools, resources, synchronous and asynchronous teaching.

1. Introduction

Online teaching is not a novel concept and our educational systems have been consistently albeit slowly shifting towards greater inclusion and focus on online teaching, especially in the field of adult education and independent learner development. However, the COVID-19 pandemic has created an imposed world wherein teachers and students find themselves suddenly in various forms of adaptations to continue and sustain educational practices despite the challenges of accessing a collective learning environment and a bricks and mortar setting. Academia has shifted completely online because of a situational demand that has called for greater teacher-learner adaptability in shifting from a real to a virtual classroom overnight. As a part of action research and professional development, this paper seeks to understand the means of online teaching-learning paradigm for tertiary level learners of English language in two colleges in Kolkata; predict patterns in teaching methodologies; learning strategies adopted by the students and the implications of real and virtual learning, as we evolve and accept the new normal of the education process in the last three months.

In this context, the paper deals specifically with Communicative Language Teaching (CLT) as a popular approach to English as a Second Language (ESL) teaching and discusses the

considerations about enabling the method to be adapted online. It is hoped that the findings of this paper will not only generate professional development but also focus on the gaps in educational process that need a closer inspection.

To that end, this paper, which is based on a survey on a sample group of 20 teachers and 160 students of English and Communicative English, worked with the following research objectives:

- Finding out the accessibility to the learning platforms and the regularity of the students in online classrooms.
- To understand the infrastructure preparedness and adequacy of both teachers and learners.
- To gauge the degree of satisfaction with the teaching content, methodology and overall online teaching-learning experience.
- To know the preference for the mode of class as an experience.
- To list the challenges and constraints in this process.

2. Theoretical Background:

This section considers the tenets of Communicative Language Teaching (henceforth to be referred as CLT) that are central to the teaching of Communicative English, a Major course run under the University of Calcutta. As an approach CLT is a task-based, collaborative learning methodology that primarily focusses on the functional use of English language in society, media and commerce. The learners are exposed to the theoretical frameworks and practical uses of the English language through a predominantly interactive teaching approach. English, which is the target language, is the primary vehicle of classroom instruction and overall learning experience, not merely an academic subject. Richards and Rodgers (2016:87) site two predominant aspects of CLT- first, that it studies language in the 'broader socio-cultural context of its use' and second, it is a 'learner-centered and experience-based view of second language teaching'. The key to this methodology is the active use of the target language in various situations that are built and generated to emulate real life circumstances that would enable the learners to not only master the language forms but also to understand the theories behind that particular use. So, the language used in the classroom is original and authentic. The emphasis in this approach is on consistent communication between the teachers and learners and among the learners themselves through various simulations and role-plays, discussions and debates, interactions through which the students socially negotiate and co-construct meaning. The students in this process are given active agency to elaborate on their thoughts and opinions, to agree or disagree to build and put forward a point of view.

The role of the teacher is to act mainly as a facilitator of learning in creating situations where the learners can actively engage in communication in a social context, especially ones requiring active negotiation. He/she arranges activities in pairs, triads or groups and acts as an advisor monitoring progress of learning and giving feedback. The errors that result are seen as developmental and feedback is instantaneous. The learning process is supported by

extensive feedback and scaffolding from the teachers as well as from the peers. The assessment that takes place is summative, but more importantly, formative in nature with a lot of student participation.

An extension of CLT, Cooperative Language Learning (CLL) finds comprehensive use in the methodology of teaching tertiary level ESL learners. Richards and Rodgers (2016:244) cite Olsen and Kagan's (1992) definition of this approach:

> *Cooperative learning is a group learning activity organized so that learning is dependent on the socially structured exchange of information between learners in groups and in which each learner is held accountable for his or her own learning and is motivated to increase the learning of others.*

This approach has been welcomed by language experts and professionals alike for its sustained adaptation to communicative possibilities. It also provides opportunities for teachers to realize the goals of interactive teaching that is the cornerstone of the CLT approach. It enables teachers to focus both on particular linguistic structures and rules as well as communicative functions, promoting both accuracy, fluency and critical thinking among adult learners, unlike CLT which often prioritizes fluency over accuracy. However, this approach builds by reducing the affective filter of the learners during participation in pair or group activities. The peer scaffolding and situational cues provide the learners support, motivation and resources to accomplish the interactive task. Richards and Rodgers (2016:245) accurately point out:

> *CLL is thus an approach that crosses both mainstream education and second and foreign language teaching.*

3. Methodology:

The paper aimed to study the various adaptations made by the teachers to sustain education through online platforms and after preliminary study of the English teachers' experiences in the first two months of such classes note down the areas of training and improvement necessitated by the process as well as highlight the concerns put forward by the students and teachers. To this end, two sets of questionnaires have been circulated among teachers and students of English and Communicative English of two undergraduate colleges in Kolkata. The focus is on teaching tools, infrastructure, challenges faced and overall teaching-learning experience. The sample size of teachers is 20 and that of students is 160. Their responses have been analyzed and put forward in a tabular format; that will help in the estimation, inference and prediction of the overall experience of the population. The broad objective of this paper is that it be treated as a case study of a specific microcosm of people. The findings will also be used to comprehend the resources required in order to offer a blended format of learning using the CLT approach to ESL students, to offer both synchronous and asynchronous modes of learning.

4. Data Analysis and Discussion:

The data gathered from the student and teacher responses have been comprehensive and are presented in a tabular format in this section. 70% of the students surveyed have never been a part of any online course before this lockdown. None of the teachers surveyed have actively taken an extensive online teaching course. However, they are familiar with ICT methods, use google groups and social media platforms like social media chat group to pass on handouts, worksheets and added reading material as a form of asynchronous learning. Following the lockdown, the platforms used for teaching are predominantly Whats App chat groups, google classrooms, google groups for uploading pdfs, audio and video lectures, links to further resources, and worksheets. The mode of teaching is mostly asynchronous, that is not face-to-face and lacks the simultaneity of a face-to-face classroom. However, in some cases, Zoom and skype have been used to a lesser extent for synchronous lessons. 84% of the students surveyed have agreed that the routine mostly resembles usual college routine, classes being arranged six days a week. Both the teachers and the students have noted a fair regularity in such classes.

4.1 Regularity of learners:

Students		Teachers	
Yes	73.58%	Very regular	43.75%
No	8.81%	Moderately regular	50%
Maybe	13.84%	Mostly irregular	0%
Not answered	3.77%	Not answered	6.25%

Most of the teachers and students surveyed have been able to access the basic infrastructure required to take asynchronous online classes. Most of them are heavily reliant on their smart phones for the purpose. The teachers have uploaded supporting materials, audio and video lectures on the respective platforms of choice, followed by discussion on the classroom page. However, this preparedness mostly extends to online asynchronous classes, as synchronous classes require far more digital support and network availability on a regular basis, which is problematic for most students.

4.2 Infrastructure Readiness:

Students		Teachers	
Yes	70.44%	Yes	50%
No	5.66%	No	31.25%
Unsure	20.13%	Unsure	18.75%
Not answered	3.77%	Not answered	0%

As the table testifies, most of the students and teachers possess the basic infrastructure readiness to conduct and participate in online classes, in form of smart phones and laptops and a reliable internet connection.

4.3 Class accessibility for students

Yes	79.25%
No	4.40%
Sometimes	12.58%
Not answered	3.77%

As the table above shows, most of these online classes have been accessible to the students, possibly more so due to the asynchronous nature of the class, which does not require taxing amounts of data. Despite attending blended synchronous and asynchronous teaching-learning environments, most students prefer face-to-face interaction in classrooms as a more satisfactory learning experience. The teachers are also of a similar opinion because online teaching requires breaking the classroom teaching into even smaller units for greater intelligibility and ease of comprehension. Further, the asynchronous classes and synchronous classes have not offered much scope for learner-learner interaction, which is a hallmark of the Cooperative Language Learning approach, followed in most classes. The teachers have gradually become adept at using multiple synchronous and asynchronous teaching platforms like google jamboard and padlet. However, due to accessibility problems, they refrain from active usage of such platforms, resulting in mostly asynchronous teaching. The students surveyed have also asserted their overall satisfaction in gaining access to adequate study materials, mentorship and guidance from their teachers. However, they are concerned with the lack of peer interaction, which is the norm for them and are unsure about their own understanding of the syllabus and individual skill development. Additionally, the nature of content delivery in the virtual classrooms has changed from CLT and CLL to mostly lecture based methods, which defeats the intrinsic purpose of the syllabus outline.

4.4 Preferred mode of classroom teaching:

Online mode	13.84%
Offline mode	83.02%
Not answered	3.14%

As this table demonstrates, preferred mode of classroom teaching for most students is offline teaching, which offers them greater opportunities to engage with the subject matter, their teacher and their co-learners.

4.5 Coverage of syllabus:

Yes	60.38%

No	8.18%
Unsure	28.30%
Not answered	3.14%

Most of the students surveyed have asserted that there is a satisfactory completion of the syllabus. However, quite a significant percentage of learners are also not sure of the completion of the syllabus, which points to the problematic nature of subject understanding developed among the average or weaker learners.

4.6 Adequacy of T-L & L-L interaction:

Yes	37.11%
No	24.53%
Unsure	33.33%
Not answered	5.03%

As the table displays, a significant number of students surveyed have pointed out to the uncertainty and lack of adequate teacher-learner (T-L) or learner-learner (L-L) interaction which the cornerstone of any form of Communicative Language Teaching. This calls for a greater exploration of various online resources and techniques and approaches that can veer both teachers and learners towards greater participation and interaction-based teaching-learning methodologies.

4.7 Satisfaction with online classes and teaching methodology:

Very satisfied	32.70%
Moderately satisfied	58.49%
Rarely satisfied	5.031%
Not answered	3.77%

This table also demonstrates that the degree of satisfaction with online classes is moderate among the students, again iterating the veracity and efficiency of a bricks and mortar classroom.

4.8 Students' understanding of the delivery of lesson plans:

At all times	25%
Mostly	68.75%
Rarely	6.25%
Not at all	0%

This table verifies the success of the teacher adaptation since most of the students surveyed have understood the delivery of the subject matter.

While online teaching has had its share of advantages, primarily rooted in the flexibility of work hours, 87.5% of the teachers have noted that it is more difficult than face-to-face teaching, requiring more preparation. 81% of the teachers surveyed have said that their students have been cooperative in this process. However, they have raised concerns about maintaining student motivation through the length of the class, as well as in online formative assessment, especially with the notions of copying and cheating being rampant due to monitoring impossibility. This is a cause of concern for the teachers. Due to the lack of face-to-face, human teaching-learning environment and a relaxed and supportive classroom atmosphere, the teachers feel that they have not been able to engage students adequately in activity-based, task-based and interaction-based learning. Some of the other constraints listed by the teachers are:

- Lack of detailed institutional guidelines in taking these online classes
- Lack of simultaneous and interactive learning
- Weak students, slow learners and remedial teaching
- Error and immediate feedback
- Requisite infrastructure, uniform accessibility and poor internet connectivity
- Problems in computer hardware
- Slow teaching progress
- Authenticity of student participation and performance
- Reluctance among students to use zoom and other synchronous learning apps due to privacy issues

All the teachers surveyed have agreed that a blended approach using online and offline modes of learning, will be the new norm in the post-pandemic era. However, in order to adapt to that changed normal, an extensive technical know-how and training is essential both at the macro and micro level. The approaches of Communicative Language Teaching and Cooperative Language Learning also need to evolve in order to be brought into an online platform. There needs to be sustainable infrastructure development and support to both teacher and student communities for tangible results and sustainable development in the education and skill development of ESL learners, especially at the tertiary level.

5. Conclusion:

In summarizing the findings of the paper, a reference can be made to Bashir and Newton's statement (2020):

> *Remote learning can be difficult for everyone, but it can be especially difficult for vulnerable communities. These communities already experience many inequalities and switching to remote learning can create new issues.*

Bringing English Language learning into a stable blended learning platform in the post-pandemic normal in the higher education sector of our country invariably calls for the following implications:

- Extensive digital literacies and training for both teachers and students
- Institutional responsibility in deliberate planning and support
- Recognizing and appreciating the socio-economic background of the learners
- Detailed guidelines for active use and uniformity of platforms
- A planned and consistent move towards synchronous online teaching
- Strengthening of infrastructure
- Bridging the digital divide- affordable and accessible

The COVID-19 pandemic has undoubtedly enforced substantial changes in the work culture universally. But what has been primarily a constraint, has also been laudably adapted by both teachers and students. This experience has become an opportunity to promote twenty-first century skills among teachers and learners, greater need for self-regulated discipline and continuous professional development and training.

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Changing trends in environmental education of India in 20th and 21st century: an overview

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Abstract: Environmental education gained its recognition after the United Nations Conference on the Human Environment held in Stockholm, Sweden in 1972. Awareness and education for environment is thought to have evolved after 1977, when world's first intergovernmental conference was organized by UNESCO in cooperation with the UNEP in Tbilisi, Georgia (USSR). After the Rio Earth Summit in 1992, environmental education for sustainable development (EESD) has emerged as an important approach to encourage students to conserve and protect the natural environment in their schools and in their neighbourhoods. Thereafter, environmental education became identified as potential breeding ground for innovative reforms in Schools and Colleges in India, though awareness for environment is thought to have evolved thousands of years ago in ancient India. This education was introduced in formal secondary school level curriculum after the influence of policy, National Curriculum Framework 2005 of NCERT and directive of honourable Supreme court in response to a 1991 petition. In present scenario every High School, undergraduate and graduate level Institution is being assisted in designing environmental activity work plans with participation of students, staff and teachers. This article aims to reveal the changing trends of thoughts and perspectives related to environmental education of India and their implementation in formal education system in 20th and 21st century. The trends of environmental education flourished through decades, from outdoor education to conservation education, to global and values education and action-competence, to education for a sustainable future and building of community partners, though the decade of 1970s was marked as prolific growth era. The article also emphasizes the vital role of education and awareness in sustainable development and achieving sustainable lifestyle. Thus, the prime goal of environmental education is to motivate and empower every citizen to bring about marked changes within their community and societies.

Keywords: Environmental education, awareness, sustainability.

1. Introduction

Education to understand environment is a means for generating proper awareness and adequate knowledge and skills regarding environmental protection. 'Environmental education' encompasses raising awareness, acquiring new perspectives, values, knowledge and skills leading to changed behaviour in support of an ecologically sustainable environment. The definition of 'Environmental education', which became widely accepted after framing of 'The Belgrade Charter' on the framework of Stockholm is as follows:

> *"Environmental education is a process aimed at developing a world population that is aware of and concerned about the total environment and its associated problems, and which has the knowledge, attitudes, motivations, commitments, and skills to work individually and collectively toward solutions of current problems and the prevention of new ones"* (UNESCO-UNEP 1976).

According to UNESCO, Environmental education has got three key dimensions, i.e., education in the environment, education about the environment and education for the environment. Education in the environment focuses on students' understanding of important facts, concepts and theories. Education about the environment involves students in direct contact with a forest, beach, street or any location to develop awareness and concern for the environment. Education for the environment aims to promote a willingness and ability to adopt lifestyles that are compatible with the wise use of environmental resources (URL: https://www.ilearnlot.com/environmental-education-aim-principles-and-concept/55271/).
Thus, education on environment can create awareness about the natural and anthropogenic changes taking place in the environment, understand some of the reasons for these changes and find out solutions to these problems. Education about environment adopts a holistic perspective which examines the ecological, social, cultural and other aspects of particular problems.

Awareness and education for environment in India is thought to have evolved thousands of years ago in ancient times. The development of the discipline 'the Environmental education' began after the construction of formal body, International Union for Conservation of Nature or IUCN in 1949, which was the consequence of International Union for Conservation of Nature and Natural Resources Conference (IUCN) held in Paris in 1948. Further, observation of British Indian laws indicate the traces of environmental concern through Legislations like, Shore Nuisance Act, 1853; The Oriental Gas Companies Act, 1857; Indian Easements Act, 1882; Fisheries Act, 1870; Indian Ports Act, 1908; Hailey National Park Act, 1936; Motor Vehicles Act, 1939; Factories Act, 1948 etc. (URL:https://shodhganga.inflibnet.ac.in/). Attitude towards environmental education in 20th century continued to evolve during 1970's and in 1972, when the first United Nations Conference on Human Environment held in Stockholm gained international recognition. In Stockholm Conference, "educational, informational, social and cultural aspects of environmental issues" was one of the five important aspects where more than 100 proposals were placed from different countries (UNEP 1972). Consequently in January 1975, United Nations Environmental Programme (UNEP) was formed and International Programme in Environmental Education (IEEP) was launched by UNESCO and UNEP. In October of 1975, the Belgrade Charter was framed by the participants of the International Workshop held in Belgrade, Yugoslavia after proposal of a global framework for Environmental Education (UNESCO-UNEP 1975). Environmental education developed an impetus after the world's first International Governmental Conference on Environmental Education, organized by the UNESCO in cooperation with the UNEP in Tbilisi, Georgia (USSR) in 1977. The declaration constitutes the framework, goals, objectives, principles and guidelines for environmental education at all levels of local, regional and international for all age groups intrinsic and extrinsic of formal school system (UNESCO-UNEP 1977). The goals of environmental education were to foster clear awareness of, and concern about, economic, social, political and ecological interdependence in urban and rural areas, to provide every person with opportunities to acquire knowledge, values, attitudes, commitment and skills needed to protect and improve the environment, to create new patterns of behaviour of individuals, group and society as a whole towards the environment. Five objectives were attributed to the guidelines of environmental education,

viz. students to develop awareness and sensitivity to the environment and related issues, to develop attitudes and values that reflect feelings of concern for the environment, to develop knowledge and understanding of the environment and the impact of people on it, to develop skills involved in identifying, investigating and problem solving associated with environmental issues and finally to develop a sense of responsibility through participation and action as individuals or members of groups in addressing environmental issues. Environmental education started gaining momentum after the Rio Earth Summit in 1992 at Rio de Janeiro, where building on recommendations of Tbilisi Declaration on Environment and Development's Agenda 21 became the modern impetus for comprehensive and holistic environmental education. It was actually called for reorienting education towards sustainable development, increasing public awareness and promoting training (UNCED 1992). Thus, the definition of education for sustainable future became relevant, holistic, issue-based, value-oriented, and action-oriented. The aspect of action-orientation was the most widely accepted one and consequently became the influential concept of the new environmental education in the notion of 'action competence' (Breiting & Mogensen 1999). The 'action competence' approach emphasizes that environmental education must aim to involve students as active participants in all aspects of the environmental education experience (Jensen & Schnac 2006). The spectrum of environmental education of India is very wide, having four major interrelated components, i.e., awareness, real life situation, conservation and sustainable development.

The principles of environmental education set forth in the Tbilisi Declaration (UNESCO-UNEP 1977) also included the fundamental elements of sustainable development. According to UNESCO, sustainable development is the "ultimate goal of the Man-environment relationship". The concept of sustainable development was first given by The Brundtland Report–'Our Common Future' in 1987, which defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). After the Rio Earth Summit in 1992, environmental education and sustainable development had become one of the top agendas at national and global levels. Actually, the concept of sustainable development was promoted by the World Commission on environment and Development and was popularized by 1992's Rio Conference (Sauve 1996). Implementing environmental education for sustainability in schools requires the development of a shared vision, goals and objectives. The environmental education of 21st century has come up with new knowledge and techniques addressing the demands of a constantly evolving social and technological landscape, ensuring the needs and interests of the community. The ultimate requirement was to train the environmental professionals and educators, so as to communicate environmental information to the general public.

2. Environmental education in Indian institutions

The constitution of India already describes the fundamental duty of every citizen of India to protect and manage natural environment. Article 47 includes the protection and improvement

of environment as a part of its primary duties, whereas Article 48A states that state shall endeavour to protect and improve the environment, and safeguard the forests and wildlife of the country. The year 1972 was recorded as the marked shift in the understanding of environmental protection and environmental management in history of India through Stockholm Conference. The impetus towards environmental education developed after 'The Constitution Act, 1976 (42nd amendment), where environmental protection and improvement by safeguarding forests and wildlife were incorporated into the Constitution (URL:https://shodhganga.inflibnet.ac.in/). After incorporation of environmental concern in the Constitution in 1976 through 42nd amendment, its importance was recognized by the Government leading to various policies which resulted into incorporation of education in schools. But the standard of education and pattern of implementation in regular school curriculum was not uniform throughout the country, except the schools in Uttarakhand where environmental education was introduced as one of the regular subject up to class VIII (Sonowal 2009). Thereafter, a framework was formulated in 1988 by NCERT leading to infusion of environmental concerns into the NCERT model text books published between 1987 and 1989 (NCERT 1987-1989). In India over the last few years, environmental education has been incorporated as an integral part of the curriculum in schools, undergraduate and graduate courses, since the directive of Honourable Supreme Court of India on 18th December, 2003, and the enforcement of 1991 decision requiring environmental studies as a compulsory subject at all levels of Indian education (Kamble & Kazi 2016, URL: https://www.ecology.edu/environmentaleducation.html). Thereafter environmental education became identified as potential breeding ground for innovative reforms in schools and colleges, and became a compulsory curricular component at all levels of education. One of the proposed activities of reorientation of environmental education was to assist every school, college and institution in designing environmental activity work plans with participation of students and staff. It also gives special attention to children at school level where they are made aware of health, nutrition, hygiene, sanitation, and water and food contamination.

In India, the National Policy of Education (NPE) in 1986 had given a special place of significance to education and environment, in which 'Protection of the environment' was stated as a common core around which a National Curriculum Framework (NCF) was woven in 1988, 2000, 2005 respectively (URL:www.ncert.nic.in/chapter-3, URL:www.ncert.nic.in/eei). For experimental basis, an environmental course was introduced in rural schools of central Himalayas in 1987 by Uttaranchal Environment Education Centre discussing environmental and livelihood issues. It focussed on practical courses related to land degradation and management of their village ecosystem for ensuring maximum sustainable production (Pande 2010). Finally, environmental education was infused in NCERT syllabus in all class levels as per NCF, 2005 by redesigning their syllabus, text books, charts, kits etc. (Gopal & Anand 2006). The term EVS (Environmental Studies) was first introduced in NCF 2005, where role of a primary teacher in EVS teaching-learning was to develop a holistic understanding of the environment from different perspectives, viz. social, cultural, environmental, health etc. The aim of EVS was to introduce students to the natural, social and cultural life, enabling them to analyse, evaluate, draw inferences about environmental problems and concerns and finally finding out solutions. The outcome was

that 'Learning by doing' or 'experimental learning' gradually became popular engaging students in constructing knowledge, skills and values from direct experience, thereby connecting knowledge to life outside the school. Enriching curriculum beyond the text books and experience outside the classroom were well-practiced. Similarly, at undergraduate levels maximum emphasis was given on knowledge regarding sustainable development and conservation, which included participating in activities at environmental education centres, action-oriented field work by visiting National parks, heritage sites, farms, zoos, museums and other relevant sites. A wide range of data was collected from the local environment, including data on soil, air, water, energy and biodiversity. Such activities got the potential to link scientific ideas with community concern, and provided opportunities for students to actively participate on local issues. The National Environment Policy (NEP), introduced by Ministry of Environment and Forests on 2006, also focussed on resource conservation and management. The policy aims at mainstreaming environmental concerns into all developmental activities.

The present environmental education scenario of India enables participation and learning by all age groups involving two-way communication rather than contemporary paradigm of one-way flow of information. It includes three patterns of education based on different disciplines, viz. Environmental studies, dealing with environmental disturbances and mitigation of their impact; Environmental science, dealing with the study of processes in air, water, soil and organisms leading to environmental damage; and Environmental engineering, dealing with the study of technical processes to mitigate pollution. Since effectiveness of the education relies mainly on the knowledge, skills and attributes of the educator, subject related to Environmental education was introduced in pre-service and in-service training and orientation courses, like pre-service teacher education for primary school teachers, pre-service teacher training for secondary level offered by B. Ed, and in post graduate level M. Ed as special paper. In recent days technology mediated environmental education is of great concern, where teacher and learner are deprived of direct face to face contact making more dynamic and multimedia approach. The new emerging trends of pedagogy in environmental education are imparting a positive impact on teaching learning system bringing about positive attitudinal change among learners. Several online certificate courses are run by autonomous and government institutions.

3. Environmental education and sustainability

An environmental education for sustainability curriculum involves understanding the present environment; how it has been shaped, the value in which it is held and seeking to mitigate adverse effects on it. This involves an investigation of the present situation and accepting responsibility to work towards a sustainable future. Since last two decades environmental education for sustainability has not remained confined to any one learning area within a school, college or institution, it has been incorporated in numerous ways into the curriculum(Alexandar & Poyyamoli 2014). Since then appropriate strategies were implemented and negotiated with students, which were highly interactive within and beyond

the classroom. Students took the responsibility for collecting and analyzing data, and finally their creative thinking skills helped them develop a vision for a sustainable future. The long-term goals of environmental education for sustainability enhanced the abilities of student to develop attributes and skills which are conductive to the achievement of a sustainable future; to respect the intrinsic value of the whole environment, to understand and value the interdependence of social, cultural, economic and ecological dimensions at local, national and global levels, and to develop an ethic of personal responsibility towards all aspects of the environment and participation as active citizens in building a sustainable future (Bhat et al. 2017).

The most effective environmental education for sustainability programs developed learning opportunities outside classroom to support and extend the classroom program. Those included special environmental events and projects to complement classroom activities, using the community to investigate practical and real-life situations, involving students in investigating, maintaining and improving the school and local environment, participating in State or territory heritage festival programs.

4. Conclusion

The article presents an overview of changing trends in environmental education in India from 20^{th} to 21^{st} century. This article sheds light throughout the contemporary and present environmental education status in India. Teachers are the best mode of imparting environmental knowledge in classroom and creating awareness regarding environmental issues. Knowledge imparted should be regarding principles and strategies for conservation and sustainable utilization of natural resources for the existence of mother earth. Though environmental education in India has become an integral part of the whole system of formal education at all levels, it should be focused on practical problems related to real life. Our new generation's education on environment would be more practice-oriented than theoretical, involving better understanding of the environmental issues within their communities. Further, the whole education process which was reshaped for sustainable development should be implemented practically involving students, teachers, practitioners and every citizen to achieve the goal of sustainable lifestyle. This could be implemented by forming a network and discussing the means of learning and sharing at different levels by maximizing awareness and participation. In conclusion, the prime necessity of conservation and preservation of present environment requires study of Environmental science to built and grow awareness among students of schools and colleges.

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Feminism to ecofeminism

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Abstract: Feminism as a literary theory has embraced myriad disciplines and expanded to address the evolving social spectrum. It often intersects other categories to incorporate changing contours of cultural as well as social phenomenon. Emerging from the discourses of second wave feminism during the 1960s and 1970s, ecofeminism merges two heterogeneous realms-ecology and feminism. As a hybrid term it facilitates the formulation of a new strategy to articulate the problematic of marginalising both nature and women in the society. This paper intends to explore how ecofeminism emerged to address this marginalisation by the dominant patriarchal framework that sanctions the oppression of nature as well as women. In this process the paper will also address how ecofeminism as a theory will interrogate other discourses and generate new controversies. The paper ends with a note on the relevance of ecofeminism in the post infection era.

Key words: Feminism, Ecofeminism, Ecology

Nature, conceptualised as radically different from humans, is often conceived in terms of a mute entity and exploited as a repository of resources. Ecological movement targets the anthropocentric binary of nature/human which not only excludes nature but also makes it inferior to human identity. Feminist movement as a distant discipline from ecology has emerged to address the binary of man/woman as one of its centric positions. Emergence of ecofeminism as a part of feminist movement gave it an opportunity to include non-human nature in its theorising and thus merged two movements (Mac-Canty 2004). Ecology henceforth was also included and shared a common debate with feminism. Ecofeminism is altogether a new terminology which encompasses ecology and feminism and thus connects divergent areas. It attempts to trace the common aspect of domineering politics that sanctions the oppression of nature as well as women. In Garrard's observation while Deep ecology identifies the anthropocentric dualism (humanity/nature) as the ultimate source of anti-ecological beliefs and practices, ecofeminism takes into consideration the androcentric dualism of man/woman (Garrard 2007). Ariel Salleh points out that 'Ecofeminism investigates the very foundations of mainstream feminism, by pointing to its complicity with the Western androcentric colonisation of the life world by instrumental reason.'(Salleh 1997) Since its emergence ecofeminism has incited wide critical debate and intersected diverse disciplines. The paper will trace its emergence, how the new theory gradually opened up new critical enquiry within the feminist discourse and evolved to initiate an altogether new branch of literary as well as political doctrine.

Since its emergence as a literary theory to address women's issues feminism has incorporated myriad fields. First wave feminism emerged in the late 19th century as a reaction to women's exclusion from political domain and demanded voting rights with a focus on equity feminism.

On the other hand second-wave of feminism emerged in the 1960s to 1970s and disrupted the personal/ political domain with a motto 'personal is political' placing embodiment in its theorising. Ecofeminism originated in the second wave of the feminist movement, and initiated a new branch of studies including environment or nature in its theorisation. The dichotomy of nature/culture, man/woman attained a new dimension as the new theory investigated hierarchical position of one entity over the other.

Sherry B. Ortner's essay ' Is Female to Male as Nature is to Culture'(1974) analysed the two binaries nature/ culture, male /female and questioned the justification of hierarchical positioning of culture over nature and men over women. Ortner also focused on the rationale that identifies women with nature, which is perceived as inferior to culture. While discussing woman-nature alignment she has particularly focused on the significance of woman's body and its functions and observed that while man can transcend and transform nature woman is attributed an 'intermediate' position between nature and culture. The reference to nature or ecology in consonance with feminism is located in Shulamith Firestone's book '*The Dialectic of Sex: The Case for Feminist Revolution*'(1970). In the chapter 'Feminism and Ecology' she writes

> *'The best new currents in ecology and social planning agree with feminist aims. The way these two social phenomena, feminism and revolutionary ecology, have emerged with seeming coincidence illustrates a historical truth: new theories and new movements do not develop in a vacuum, they arise to spearhead the necessary social solutions to new problems resulting from contradictions in the environment.' (Firestone, 1970)*

Firestone has connected ecology with feminism as intersecting each other in two issues: reproduction and its control on one hand and cybernation on the other. But the idea was not further developed till 1973. This reference is taken up by the French feminist, Francoise d'Eaubonne in 1974, who points out that it is patriarchy which is the common dominant paradigm behind the oppression of women and ecology. The formation of Ecology-Feminism centre finally led to the formation of a new platform which Francoise d'Eaubonne first termed as 'ecofeminism'. In her essay 'This Time for Ecofeminism' she further develops this interconnection and offers the academia a new terminology- Ecofeminism- which opens up a new platform to address the issue. She posits that it is a 'male System' which is responsible for two destructive situations that engender creation: one is overpopulation and other is destruction of natural resources. According to her, man's dominance over 'agricultural and procreational' processes has resulted into exploitation of environment and women.

Ecofeminism, developed out of the contours of liberal, socialist and radical feminism, includes the oppression of non-human nature in its theorisation and posits that environmental concern is an inevitable part of feminist agenda. The interconnection between woman and nature was further pointed out by Mary Daly in her book *Gyn/Ecology: The Metaethics of Radical Feminism* (1978), by Carolyn Merchant in *The Death of Nature: Women, Ecology and the Scientific Revolution* (1980). Daly supported the emergence of the theory in its embryonic form but she places emphasis on 'all forms of pollution in phallocentric society'

(Daly 1978). Merchant observes that the advent of new mechanical rational scientific mind has disrupted the world order and had viewed nature as a resource to be exploited. This has violated nature's sanctity and had sanctioned the advent of mechanistic progressive technology. The market oriented economy led to the exploitation of both nature and women. In her words, 'we must re-examine the formation of a world view and a science that by reconceptualizing reality as a machine rather than a living organism, sanctioned the dominion of both nature and women' (Merchant 1980).

Val Plumwood has established a connection between phallocentrism and anthropocentrism which makes an important shift from second wave feminism to ecofeminism. Anthropocentrism primarily posits human species at the centre of the ecosphere while phallocentrism has been the centre of criticism for second wave feminism (Datar 2011). According to Plumwood ecofeminism as a theory also attempts to resolve problems in the concept of anthropocentrism which threatens the foundations of environmental philosophy (Plumwood 1997). Anthropocentrism primarily makes human beings the centre of the ecosphere and thus does not include non- human species within its boundary. This view poses that human beings maintain a hierarchical relationship with nature which is separated from humans. Conceptualised as the Other, nature is excluded from the cultural framework and inferiorised in the process. Similarly, in feminist discourse woman is the Other and often associated with the inferior part of the nature/culture hierarchy. Plumwood posits that as ecofeminist one identifies this commonality. She, therefore, envisages the scope for ecofeminism to address the oppression of both nature and women from a common paradigm. In her words,

> *'Our speech for the other is made possible by the commonality of the centric structure, for as ecofeminists we speak as those who are ourselves oppressed in a different area, as women, and we are able to transfer our understanding to the other's oppression.' (Plumwood 1997)*

In her book *Earthcare* Carolyn Merchant has studied how liberal, cultural, social, and socialist feminism contribute to the development of ecofeminist perspective in different ways. Liberal feminism has asserted that women are rational agents like men and therefore demanded equity for them. Liberal ecofeminism, Merchant argues, tries to implement laws in order to make social reproduction environmentally sound. It ensures that women can also join men in the cultural project of environmental conservation. Cultural ecofeminism analyses environmental problems from the perspective of patriarchy and endeavours to liberate both women and men. Social and socialist ecofeminism explores capitalist relations of production revealing the domination of nature by men (Merchant 1995).

Ynestra King has elucidated different responses to interconnection of ecology and feminism. She observes that 'An ecological perspective offers the possibility of moving beyond the radical (cultural) feminist/socialist feminist impasse. But it necessitates a feminism that holds out for a separate cultural and political activity so that we can imagine, theorize or envision from the vantage point of *critical otherness*'. She also argues that feminism will be

disembodied without ecological perspective because it asserts the interdependence of living beings (King 1996).

Ecofeminism as a theory draws two parallel strands of criticism as it addresses how patriarchy has aligned woman with nature. While some ecofeminists assert that this alignment can be revoked for positive implications, some others caution against it because it has inherent flaw of essentialism. According to the first strand, the identification of woman with nature can be reclaimed as an empowering strategy to construct feminist spirituality. On the other hand, the second strand observes that aligning women with nature and men with culture is a part of patriarchal strategy. Noel Sturgeon points out that 'the effort to make connections between women and nature rather than between feminism and environmentalism as political movements produces a theoretical context in which conceptions of both women and nature are frequently essentialist' (Sturgeon 1997). Susan Grifffin has attempted to correct the misreading of ecofeminism which has been criticised for inviting the flaw of essentialism. Ecological concepts, according to her, illuminate the ecofeminist understandings of both the oppression of women and the social construction of gender. She argues that by understanding how and why woman is associated with nature, one can decode many structures of injustice (Griffin 1997).

Thus emerging in 1970s ecofeminism inspired much critical debate in the academia and became so diverse and ever changing that it cannot be theorised in homogenizing agenda. It became an umbrella term or hybrid criticism to incorporate ideas from diverse fields and minds. In order to explain the ecofeminist philosophy Karen Warren has drawn three intersecting spheres representing feminism, technology (science and development) and local perspective. She points out how it is very crucial to think about the 'empirical connections between women and nature, and also between people of color, children, the poor, and nature.' (Warren 1997) This also highlights the web of interconnection and multiplicity that ecofeminist philosophy incorporates within its theorisation. Ecofeminist theoretical discourse expanded to include areas of theology, economics, sociology and other branches. On one hand it had invited discourse on essentialism or embodiment, on the other it became ever expanding as to include goddess feminism, colonial approaches. Third world ecofeminism became one of its offshoots that had opened up various discourses. Vandana Shiva, Maria Mies, Claudia Von Werlhof, Veronica Bennholdt-Thomsen had placed particular emphasis on third world perspectives. Shiva terms science and development as 'brutal expression of patriarchal ideology' which threatens to annihilate nature which has been transformed from *terra mater* to a machine and repository of resources. Shiva observes that women are victims of the violence of patriarchal form of development which she terms as 'maldevelopment' because it is 'bereft of the feminine, the conservation, the ecological principle'(Shiva 1998). She also points out how ecological struggle in India initiated by women aims at liberating nature as well as women from marginalisation (Shiva, 1988). Maria Mies adds the notion of 'catching-up development' according to which the poor countries are fascinated with the progress of industrialized countries and try to catch up. She finds a colonial relationship exists between the underdeveloped and overdeveloped countries. In her words: 'Today, a

similar colonial relationship exists between Man and Nature, between men and women, between urban and rural areas.' (Mies 1993)

Ecofeminism connecting divergent disciplines finds its expression in social movements too. Like the environmental movement and feminist movement this has also asserted the right of the women and focused the oppression of both women and environment. A large number of women gathered at Amherst, USA as a result of meltdown at Three Mile Island in the first ecofeminist conference – 'Women and Life on Earth: A Conference on Eco-Feminism in the Eighties'. Ecofeminist activists took part in demonstrations or direct actions, formed political platform for a U.S Green party and built various kinds of ecofeminist cultural projects. As a diverse field it has taken up issues such as toxic waste, deforestation, military and nuclear weapons policies, reproductive rights, domestic and international agricultural development. (Sturgeon 1997). Women in the third world countries have actively taken part in order to protect environment which is inextricably linked with their lives. In 1974, twenty-seven women of Reni in northern India protested to stop tree felling – the movement known as the Chipko reflected the inextricable connection of women and her land. Wangari Maathai, the founder of the Green Belt movement in Kenya, played an essential role in preserving and restoring nature. She worked with grassroots women who planted millions of trees and this planting contributed much to the development of the community. Her project not only provided economic development of the indigenous community but also ensured environmental sustainability. Ariel Salleh has observed that 'Despite cultural differences between women around the world, this new politics reflects a common intuition that somehow the struggle for a feminine voice to be heard is joined to the struggle for a nurturant, protective attitude towards our living environment.' (Salleh 1997) Ecofeminism thus interconnects with all forms of oppression and initiates grassroots movements in order to ensure a sustainable world.

As a philosophical critique ecofeminism aims to construct a discourse of equality and thus reconstructs the narrative of both nature and gender. In her paper 'Ecofeminism in the Twenty-first century' Susan Buckingham has revisited ecofeminism and attempted to traverse its trajectory to explore how the theory has changed and influenced environmental debate as well as feminist discourse. She has observed that though there is little change in the social roles or environmental degradation the platform has implemented changes in policy making (Buckingham 2004). The outbreak of Covid-19 as a pandemic will force humanity to reinvestigate the question of interconnectedness and our inevitable dependence on nature. Ecofeminism has always placed emphasis on care ethics and inclusivity of animate and inanimate world in its theorising. It is time that we reconsider the planet as a habitat for all and get rid of all hierarchical structures that sanction the interest of a few and negate the web of interconnection.

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