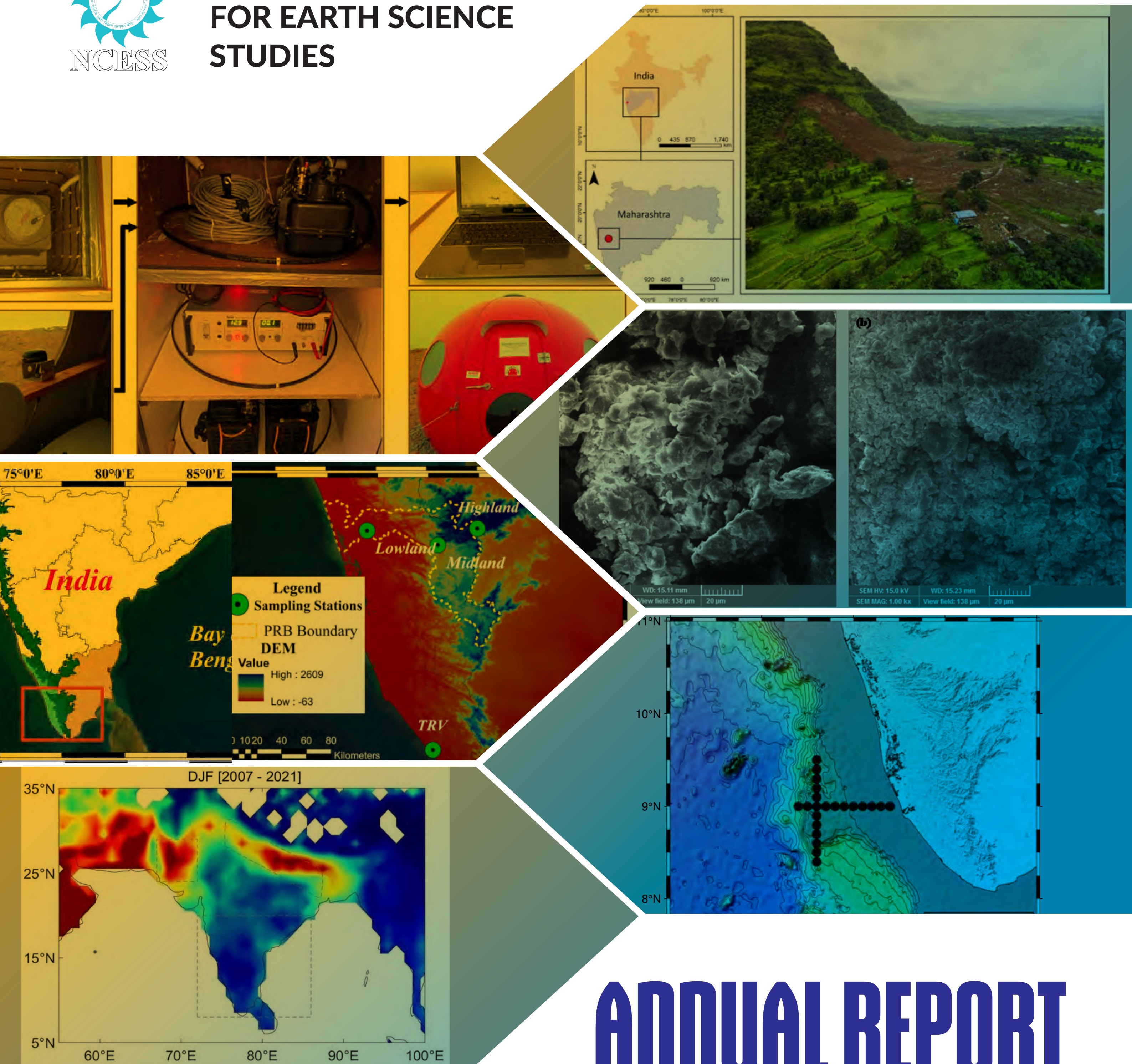
एम ओ ई एस - राष्ट्रीय पृथ्वी विज्ञान अध्ययन केन्द्र

Azadi Ka Amrit Mahotsav

NCESS

MoES - NATIONAL CENTRE FOR EARTH SCIENCE STUDIES



ANNUAL REPORT 2021-2022

Committed to Earth and its Future

पृथ्वी और उसके भविष्य के लिए प्रतिबद्ध

FRONT COVER

Left Panel (from top):

1. Establishment of a broadband seismological observatory at Larsemann Hills, Antarctica.
2. Map and Digital Elevation Model (DEM) of hydrological study area (Periyar basin) in Western Ghats with location of sampling stations.
3. Spatial distribution of PM2.5 mass concentration during the winter season of 2007–2021 over India.

Right Panel (from top):

1. Location and panoramic view of Taliye landslide in Maharashtra, India.
2. SEM images of activated carbon prepared from pistachio shell, before and after adsorption of malachite green dye.
3. Map of the hydrographic study area in Eastern Arabian Sea indicating the Conductivity – Temperature - Depth (CTD) measurement locations.

Annual Report 2021 – 2022

Published by	Director, National Centre for Earth Science Studies
Coordination & Compilation	Dr. A. Krishnakumar Dr. C. K. Unnikrishnan Shri. S. R. Unnikrishnan

वार्षिक प्रतिवेदन
ANNUAL REPORT

2021-2022

एम ओ ई एस – राष्ट्रीय पृथ्वी विज्ञान अध्ययन केन्द्र
(पृथ्वी विज्ञान मंत्रालय, भारत सरकार)
पी.बी. नं. 7250, आक्कुलम, तिरुवनंतपुरम – 695011, भारत

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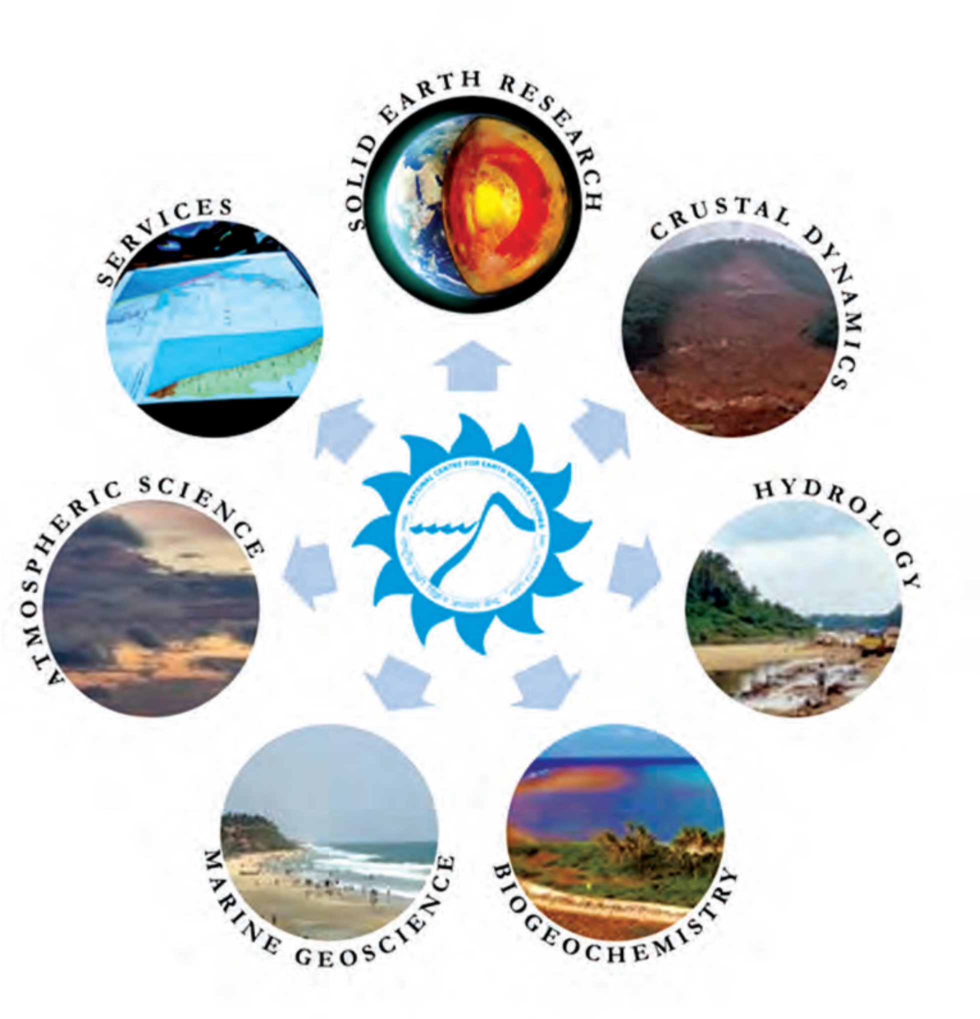
RESEARCH AND DEVELOPMENT ACTIVITIES



Vision: To excel in solid earth research and its applications.

Mission: Foster multi-disciplinary research in emerging areas of solid earth science and provide services by utilizing the knowledge for earth sciences applications and generate leadership capabilities in selected areas.

Contents

From the Director's Desk

When the future generations look back on the events of the year 2021-2022, they will not only see the entire world in the grip of a novel coronavirus but also witness the power of indomitable human spirit. Future Indians would particularly feel proud for the nation's effort in successfully tackling the pandemic by producing, administering, and distributing vaccines. We at NCESS made sure that the spread is contained and everybody was vaccinated. Except for the first few months of the year, we were back to the normal mode of working. I applaud my colleagues for navigating through those difficult times and producing some excellent scientific results.

Mandated to carry out research and development in Solid Earth Sciences, NCESS is funded through the Seismology and Geoscience (SAGE) scheme of the Ministry of Earth Sciences (MoES). In the new Plan period that began in the Financial Year 2020-2021, the six research groups of NCESS began implementing 15 research projects under the theme of "Geodynamics and Surface Processes (GSP)". The year 2021-2022 probably was one the most productive years for NCESS in recent times. Our researchers had published a total of 83 peer-reviewed research articles and 3 books. Four research scholars were awarded PhD degrees, a scientist own the certificate of merit award from MoES, and two young researchers got best paper awards in conferences. Several colleagues were invited to serve as Chair/Member in editorial boards of journals, board of studies of universities, various national expert/advisory committees. Our scientists delivered 24 invited talks in various institutes/conferences/symposia.

In the research front, the following important results had been reported by the researchers of NCESS. LA-ICPMS U-Pb geochronological studies on zircons and monazites from granulite of Southern Granulite Terrane revealed two distinct thermal events; a Paleoproterozoic high-T event and associated crustal anatexis at ~2.5 Ga, and a Neoproterozoic Ultra high-T event at ~550 Ma, with the latter monazite data hinting at a prolonged (50-60 Ma) thermal event, attributed to collisional orogenesis. Mineralogical, geochemical and Sr-Nd-Pb isotopic study of mud breccia, ejected at the mud volcanoes of the Andaman accretionary prism, located at the Indian Plate-Burma Plate convergent margin, suggested that these mud volcanoes originate from the tectonic mélanges located near the décollement, thus providing a window to the fore-arc processes. The water isotopic compositions of precipitation in the humid regions of the Western Ghats showed limited altitude effect; however, these rains did contain an appreciable amount of recycled moisture (~8.5%). NCESS, in collaboration with nine working groups, had successfully completed the Phase-I of the national network program on Submarine Groundwater Discharge (SGD). This project had identified nine perennial fresh SGD zones along the southwest coast of India that leaked about 6% of the rainwater into the sea. The evaluation of project proposals from various institutes are in progress for the implementation of Phase-II of the project, which envisages to quantify the amount of SGD long the entire Indian coast and understand its impact on the coastal ecosystems.

NCESS had established a Broad Band

Seismometer (BBS) at the Bharti Station in Antarctica, during the 41st ISEA to study the crust/mantle structures of East Antarctica. Partnering with NCPOR, NCESS had initiated a study on the polar region air-ice-sea exchange, at Prydz Bay of Antarctica. NCESS had undertaken two scientific cruises during the year 2021-22; one to the Arabia Sea (SK-369) to study the coastal processes along the west coast of India and one to the Bay of Bengal and the Andaman Sea (SK-373) to study palaeoceanography, paleoclimate, and subduction zone processes using sediment (core) and (volcanic) rock samples.

To improve the academic activities within the institute, a seminar series called the "Earth Science Forum" was revived with weekly seminars by scientists/scholars of the institute as well as by invited speakers. NCESS celebrated Azadi Ka Amrit Mahotsav, the 75th year of Indian Independence, with a webinar lecture by Padma Shri Michel Danino of IIT Gandhinagar on "The Sarasvati River's Decline in the Holocene", on 22nd April 2021. NCESS observed its 8th Foundation Day on 3rd January 2022 with an online lecture by the Chairman of the Research Advisory Committee of NCESS, Prof. S.K. Tandon, on "The Anthropocene Concept: Focus on the Terrestrial Hydrosphere". Dr. Satish C. Tripathi, General Secretary, The Society of Earth Scientists, delivered an online talk on "Geo-conservation and Geo-tourism" in Hindi to commemorate the World Hindi Day on 10th January 2022.

In the organizational front, several objectives were achieved during the year 2021-2022. Three scientists were recruited and action was initiated to fill the vacancy in another three posts. The National Geosciences Data Centre (NGDC) was established in NCESS and the portal will be open to users upon completion of the security audit by the National Informatics Centre. Although the renovation of the administrative block was delayed due to various reasons including the pandemic, a state-of-the-art transformer could be brought in for NCESS to cater to the requirements of all sophisticated laboratories. Through limited consultancy activities, NCESS could generate some amount of corpus funds, which shall be utilized for various welfare schemes for the staff.

In spite of the pandemic related difficulties during early part of the year, NCESS had made significant progress in terms of scientific research during the year 2021-2022. Each member of the institute contributed to this effort. We are proud to be part of an institute that not only works toward achieving the mandate set by the central government, but also caters to the local/state needs. On behalf of NCESS, I am extremely happy to place this Annual Report before all well-wishers of the institute.

Dr. Jyotiranjan S. Ray
Director, NCESS

Committees

Statutory Committees

1. The General Body (GB)

Secretary Ministry of Earth Sciences, Government of India Prithvi Bhavan, New Delhi	President
Advisor Ministry of Earth Sciences, Government of India Prithvi Bhavan, New Delhi	Member
Additional Secretary & Finance Advisor Ministry of Earth Sciences, Government of India Prithvi Bhavan, New Delhi	Member
Joint Secretary (Admin) Ministry of Earth Sciences, Government of India Prithvi Bhavan, New Delhi	Member
Programme Head (NCESS) Ministry of Earth Sciences, Government of India Prithvi Bhavan, New Delhi	Member
Director National Centre for Polar & Ocean Research Vasco-da-Gama, Goa	Member
Director National Institute of Ocean Technology Pallikaranai, Chennai	Member
Director National Centre for Earth Science Studies Akkulam, Thiruvananthapuram	Member Secretary

2. The Governing Council (GC)

Secretary Ministry of Earth Sciences, Government of India Prithvi Bhavan, New Delhi	Chairman
Additional Secretary & Finance Advisor Ministry of Earth Sciences, Government of India Prithvi Bhavan, New Delhi	Member

Joint Secretary (Admin) Ministry of Earth Sciences, Government of India Prithvi Bhavan, New Delhi	Member
Chairman, RAC National Centre for Earth Science Studies Akkulam, Thiruvananthapuram	Member
Dr. Suresh Das Emeritus Professor Indian Institute of Science Education and Research Thiruvananthapuram	Member
Dr. Anil Bhardwaj Director Physical Research Laboratory, Ahmedabad	Member
Director National Centre for Polar and Ocean Research Vasco-da-Gama, Goa	Member
Dr. Radhika Ramachandran Former Director Space Physics Laboratory, Thiruvananthapuram	Member
Director National Center for Seismology Lodhi Road, New Delhi	Member
Programme Head (NCESS) Ministry of Earth Sciences, Government of India Prithvi Bhavan, New Delhi	Permanent Invitee
Representative, NITI Aayog	Invitee
Director National Centre for Earth Science Studies Akkulam, Thiruvananthapuram	Member Secretary

3. The Finance Committee (FC)

Additional Secretary & Finance Advisor Ministry of Earth Sciences, Government of India Prithvi Bhavan, New Delhi	Chairman
Joint Secretary (Admin) Ministry of Earth Sciences, Government of India Prithvi Bhavan, New Delhi	Member

Programme Head (NCESS) Ministry of Earth Sciences, Government of India Prithvi Bhavan, New Delhi	Member
Director National Centre for Earth Science Studies Akkulam, Thiruvananthapuram	Member
Director (Finance) Ministry of Earth Sciences, Government of India Prithvi Bhavan, New Delhi	Member
Manager (F&A) National Centre for Earth Science Studies Akkulam, Thiruvananthapuram	Member
Senior Manager National Centre for Earth Science Studies Akkulam, Thiruvananthapuram	Member Secretary

4. The Research Advisory Committee (RAC)

Dr. S. K. Tandon Professor Emeritus University of Delhi Delhi	Chairman
Dr. P. P. Mujumdar Professor Indian Institute of Science Bengaluru	Member
Dr. S. Balakrishnan Professor Pondicherry University Puducherry	Member
Dr. Kanchan Pande Professor Indian Institute of Technology Mumbai	Member
Dr. N. P. Kurian Former Director National Centre for Earth Science Studies Thiruvananthapuram	Member

Dr. S. K. Satheesh Professor Indian Institute of Science Bengaluru	Member
Dr. V. K. Gahalaut Chief Scientist National Geophysical Research Institute Hyderabad	Member
Dr. Rajiv Sinha Professor Indian Institute of Technology Kanpur	Member
Director National Centre for Earth Science Studies Thiruvananthapuram	Member
Dr. Tomson J. Kallukalam Scientist-D National Centre for Earth Science Studies Thiruvananthapuram	Member Secretary

Preface

The research activities of NCESS are carried out under the theme "Geodynamics and Surface Processes (GSP)", which focusses on Geodynamic Evolution of the Indian Plate, Complexities of Coastal Processes, Surface and Groundwater Hydrology, Critical Zone Processes and Natural Hazards. Fifteen research projects are currently being implemented by the six Research Groups of the Centre; Solid Earth Research Group (SERG), Crustal Dynamics Group (CDG), Hydrology Group (HyG), Biogeochemistry Group (BgG), Marine Geoscience Group (MGG), and Atmospheric Science Group (ASG).

The projects under "Geodynamics and Surface Processes" are:

1. Geodynamic evolution of Archean cratons, Proterozoic mobile belts, and Active subduction zones
2. Internal structure of volcanic eruptive centers by Muon Tomography
3. Deep lithospheric and Asthenospheric structures and Origin of shear zones
4. Early Earth Differentiation Processes
5. Hydrocarbon Fluid Inclusions in Sedimentary Basins of India
6. Slope Stability and Landslide
7. Coastal ocean dynamics and boundary exchanges, their role on climate regulations
8. Origin, evolution and paleoclimatic implications of estuarine-continental margin sediments
9. Submarine Groundwater Discharge
10. Critical zone studies of Peninsular India
11. River and Groundwater hydrology of Peninsular India
12. Evolution and water potential of natural springs of India
13. Bio-geochemistry and nutrient fluxes of rivers and coastal environments
14. Thermodynamical and microphysical processes of Clouds & Cloud-aerosol feedback processes and its influence on weather systems
15. Dynamics of thunderstorms and lightning

Solid Earth Research Group (SERG): The main research objective of the Solid Earth Research Group is to understand the origin and evolution of the planet Earth and its various reservoirs such as the crust, mantle and the core. To achieve this the group focuses on deciphering the timescales and understanding the processes of geodynamic evolution of the Archean cratons, Proterozoic mobile belts, Purana Basins and mountain belts of Peninsular India. In addition, the research of the group aims at understanding the chemical evolution of the Earth's mantle since the earliest differentiation events by studying mantle derived rocks of different ages, at different tectonic settings, including active subduction zones. Other activities of the group include delineation of lithospheric structures under various Indian crustal blocks and shear zones, evolution of Quaternary landscapes, and muon tomography of Indian volcanoes.

Crustal Dynamics Group (CDG): This Group addresses scientific issues related to near surface dynamic processes on land. The focus has been understanding the causes and effects of slope failures. With the help of satellite imagery, field studies and geochemical characterization of soil/rock, the group attempts to help predict landslides and suggest mitigation. The activities of the group also include understanding of hydrocarbon fluid movements in sedimentary basins leading to mineralization.

Hydrology Group (HyG): The Hydrology Group focuses on basic and applied aspects of research in hydrology and water resources with specific reference to Earth's Critical Zone. Earth's Critical Zone is a complex natural environment where rock, soil, water, air, aerosols, solar energy and living organisms interact and shape the Earth's surface. The Critical Zone is experiencing ever increasing pressure from rapid economic developments. A better understanding of the processes taking place from tree to the aquifer bottom is very essential in the context of India's rapid economic developments and global climate change scenario.

Biogeochemistry Group (BgG): Biogeochemistry Group focuses on the study of physicochemical, geological and biological processes and reactions that govern the characteristics of natural environment. The Group also studies the changes in the biogeochemical cycles of elements in the current climate change scenario. The group employs geochemical/isotopic and microbiological modeling to interpret environmental processes and their effects on the global biogeochemical cycles. The thrust areas of research include biogeochemical studies is waters of estuaries, coastal oceans, springs and fresh water bodies on land with an emphasis on solute fluxes/dynamics and speciation, pesticide/organics fragmentation and degradation, water quality monitoring, pollution assessment and mitigation strategies.

Marine Geoscience Group (MGG): The focus of the Marine Geoscience Group has been the understanding of waves, currents and sediment transport and their effects on beaches and nearshore environment, with a special emphasis on modelling of coastal processes along the west coast of India. The activities include running high-resolution numerical models capable of simulating coastal ocean dynamics and boundary exchanges, establishing video based Coastal Monitoring network and investigating the evolution coastal ocean terraces. The national network project on Submarine Groundwater Discharge, aimed at quantifying the amount and understanding the impact of fresh groundwater discharge to the Bay of Bengal and the Arabian Sea, also forms a major activity of the group.

Atmospheric Science Group (ASG): The Atmospheric Science Group in NCESS is actively engaged in the basic and applied research on atmospheric clouds, aerosol-cloud interaction, thunderstorms, lightning and atmospheric electricity, and regional climate over Western Ghats to improve the forecasting of meteorological hazards.

1. Research Highlights

1.1 A new broadband seismological observatory at Larsemann Hills, Antarctica

A new Broadband Seismological Observatory near the Bharati station, East Antarctica was successfully established. Continuous time series data were collected and analysed to check the quality. These data along with global seismological data will be utilized for a detailed mapping of crustal and mid-to-upper mantle structures beneath the Prydz Bay region of Princess Elizabeth Land of Antarctica and Eastern Ghats Belt of India to decipher the patterns of crust/mantle deformation. Combining this information with the geological data sets attempts will be made to understand the geodynamic evolution of Antarctica and India, since the time of Gondwanaland, when both the continents were together.

1.2 Development of analytical protocol for chemical dating of monazites in NCESS

The calibration and quantification set-up conditions for monazite geochronology (analytical protocol for U-Th-total Pb) using an SXFive Tactis EPMA have been successfully established at NCESS. Consistency in the chemical-chronological data from monazites of known ages confirms the reliability of the NCESS-EPMA facility for the U-Th-Pb chemical age dating. By applying the same analytical setup, monazites from metapelites of the Madurai Block of Southern Granulite Terrain, India yield two peak ages in probability density diagram; ~505 Ma and ~590 Ma, which are similar to the $^{206}Pb/^{238}U$ ages (ca. 506 Ma and ca. 585 Ma) obtained using LA-ICPMS at NCESS.

https://doi.org/10.1007/s12040-021-01738-4

1.3 Timings of heating and cooling episodes in the Southern Granulite Terrain (SGT)

A significant amount of high to ultrahigh-temperature (HT-UHT) metamorphic rocks occur the Kambam belt in the central part of the SGT in the Madurai block. Geothermo-barometry and pseudo-section modelling of the granulite using mineral chemistry, zircon geochronology and Lu-Hf isotopic data reveal that the HT-UHT metamorphic conditions in these rocks had a clockwise P-T path, which suggests significant decompression and cooling. The results classify the Madurai block as a classic slow cooled granulite terrane with long lived UHT orogenic history. This has significant implications for the presently proposed tectonic models for SGT and its linkage with other continental fragments of the East Gondwana.

https://doi.org/10.1016/j.precamres.2022.106582

1.4 Understanding fore-arc processes from mud volcanoes of the Andaman Islands

A detailed mineralogical, geochemical and Sr-Nd-Pb isotopic study of the matrix of the mud breccia ejected at the mud volcanoes of the Andaman accretionary prism, located at the Indian Plate-Burma Plate convergent margin suggests that the mud volcanoes originate from the tectonic mélanges located near the décollement. The mud matrix is made up of argillaceous material derived from the altered oceanic crust and terrigenous sediment of the slab, with the former contributing more than 80%. All data point to a scenario that only a small fraction of the terrigenous sediment of the slab gets recycled into the mantle at the Andaman subduction zone.

https://doi.org/10.1016/j.chemgeo.2021.120595

1.5 Weathering and solute transport in small catchment rivers of southern Western Ghats

Over 600 small rivers originate from the Western Ghats and contribute ~18% of the total discharge from the Indian peninsula. Weathering process in these river basins produces saprolite and soil in the subsurface domain of the Critical Zone. The computed CO_2 consumption rate (CCR), for a west flowing river, the Thuthapuzha (1030 km^2/ 1821 MCM), and an east flowing river, the Bhavani (6200 km^2/1615 MCM), reveals that the former river accounts for a CCR of 2.18 x105 mol.km^{-2}.y^{-1} and the latter for 1.39 x105 mol. km^{-2}.y^{-1}. This study reveals that the interplay between the climatic factors and the geologic factors of the catchments assumes a significant role in determining the solute transfer and hydrochemical composition of the rivers.

https://doi.org/10.1007/s12665-021-09862-6

1.6 Moisture recycling and evaporation processes along the Western Ghats

The water isotopic composition (δ18O and δ2H) of the rains in the humid regions of the Western Ghats has limited influence from isotopic elevation (altitude) effect due to low temperature gradient, high relative humidity, and moisture feedback processes operating there. However, a pseudo effect is observed across the south-western flank of the Ghats due to moisture supply from reservoirs and lakes. The contribution of recycled moisture, estimated using back trajectories, does not exceed 8.5% of the rainfall over the midland region. Although the study did not find any signature of recycling in the highlands, the lc-excess, and the d-excess of surface waters suggest higher rates of evaporation from lakes and reservoirs and their role in generating local rainfall. Statistically significant amount effects are visible only along coastal areas having lower precipitation and higher temperature, which in turn indicate that precipitation along the Ghats (midland and highland) is significantly controlled by both the orographic moisture uplift and locally recycled moisture.

https://doi.org/10.1016/j.atmosres.2021.105863

1.7 Holocene monsoon and sea-level variability from coastal lowlands of Kerala

The Holocene sea-level and climate variability were studied based on geochemical and palynological proxies supported by 10 AMS radiocarbon ages on a 32 m long sediment core (L7) raised from Upper Kuttanad Kole wetlands (Kuttoor), Kerala, Southwest India. The study demonstrates high sea-level along with warm and wet climate due to Indian summer monsoon (ISM) intensification during 9.69–7.56 ka corroborating with the Holocene Climate Optimum (HCO). However, a break in the sediment deposition is observed between 7.56 and 3.51 ka, the reason for which is yet to be fully understood. During 3.51–2.55 ka, the gradual weakening of ISM has been invoked with an intermittent monsoon spell during 3.20–3.40 ka. Presence of coarser clastics, after 2.55 ka, suggests sediment deposition by the migrating distributary channel of the Pamba-Manimala rivers. The high sea level during HCO attests that the core location plausibly represented the southward extension of the Vembanad lagoon which transformed into part of the terrestrial system due to the gradual sea regression during the mid-late Holocene period followed by deposition of alluvial sediments from the hinterland rivers.

https://doi.org/10.1016/j.quaint.2022.03.005

1.8 Wave analysis at Valiathura beach using coastal video monitoring techniques

NCESS has initiated a pilot project for continuous coastal monitoring, adopting the video-based monitoring method in India through an indigenous Video Beach Monitoring System (VBMS). The fist VBMS station, was installed at Valiathura, a typical high energy beach in SW coast of India. The open-source toolbox ULISES was found to be suitable for planview generation. A new modulated transfer function (MTF) designed through Thomson's multi tapered method has been introduced. With this non-linearities can be reduced to an acceptable level. The transformed intensity spectra are showing a reasonably good agreement with the *in-situ* measurements by giving a correlation of more than 90%, with low RMSD, throughout the day. Mean bias and RMS error have been brought to within the permissible limits by considering long-term variations. Tt is found that the use of multi-tapered methods in transfer function estimation can significantly reduce the noise and local influences in the estimation of nearshore wave parameters from video images.

https://doi.org/10.1016/j.rsma.2022.102205

1.9 Submarine Groundwater Discharge – Phase-I

NCESS, in collaboration with nine working groups, has successfully completed the Phase-I of the national network program on Submarine Groundwater Discharge (SGD). Multi-proxy methods (thermal imaging, hydraulic head, spatial, electrical resistivity surveys and temporal hydrochemical observations) were employed to identify the potential SGD zones along the Indian coastline. Along the southwest coast of India, nine perennial fresh SGD (FSGD) zones were delineated with a net coastal stretch of 103.22 km. The reverse mechanism of seawater intrusion zones was found to be concentrated towards the south in Kanyakumari district and in some parts of Malappuram and Kozhikode districts. Using water balance approach the average flux of groundwater per unit length of the shoreline was estimated to range from 36 to 1213 $m^3/y/m$, suggesting that an average of 6% of rainfall is lost through the SGD. Studies on estimation of SGD and solute flux, nutrients inputs to Indian Ocean through SGD and the environmental impacts of the SGD will be carried out in the Phase-II of the SGD program.

https://doi.org/10.1016/j.rsma.2021.101963

1.10 Assessment of PM2.5 using satellite lidar observations

The particulate matter with aerodynamic diameters less than 2.5 μm (PM2.5) was estimated over the Indian sub-continent using near-surface retrieval of aerosol extinction coefficient (2007–2021) of Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on board Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite. Climatology of wintertime PM2.5 during the last 15 years shows the highest concentration over the middle Indo-Gangetic Plain (IGP) and northwest India with a 3 to 4-fold increase in magnitude compared to the peninsular India. Surface-level PM2.5 mass concentration during winter (December to February) shows statistically significant positive trends over the Indian subcontinent. It increases at a rate of ~3% over the IGP and arid regions of northwest India, and ~4% over peninsular India during the last fifteen years (2006–2020). Inter-annual variability of average near-surface PM2.5 concentrations over the Indian sub-continent during the fog occurring season (December to February) shows a statistically significant correlation with the post-harvest agro-residue burning over the western IGP (Punjab and Haryana) during November.

https://doi.org/10.1016/j.scitotenv.2022.155215

2. Awards, Honours & Human Resource Development

2.1 Awards

Dr. Jyotiranjan S. Ray, Director, NCESS has been awarded the 'Lifetime Achievement Award - 2022' instituted by the Indian Society of Applied Geochemists (ISAG) to honour eminent earth scientists.

As a part of Nari Gyan Badhe Vigyan initiative, MoES celebrated the achievements of Dr. K. Maya, Scientist F, Biogeochemistry Group on 28th March 2022, whose research interests include Environmental Geology, Sedimentology and Geochemistry.

Dr. S. Kaliraj, Scientist-C, Crustal Dynamics Group has been awarded 'Certificate of Merit Award - 2021' by the Ministry of Earth Sciences, Govt. of India.

Ms. Harsha Mahadevan, has been awarded PhD degree under the Faculty of Science, University of Kerala for her thesis "Synthesis, characterization and application of surface tuned clays and activated carbons to control nutrients in urban drainages: focus on adsorptive kinetics and isotherm modelling" on 07th May 2021. Dr. K. Anoop Krishnan, Scientist-D, Biogeochemistry Group was her supervising guide.

Shri. M. Ratheesh Kumar, has been awarded PhD degree under the Faculty of Applied Sciences & Technology, University of Kerala for his thesis "Seasonal investigation and evaluation of water quality parameters of Mangalore coast, Karnataka, India: Hydrochemical, marine biological and microbiological approach" on 23rd July 2021. Dr. K. Anoop Krishnan, Scientist-D, Biogeochemistry Group was his supervising guide.

Ms. P. Saranya, has been awarded PhD degree under the Faculty of Applied Sciences & Technology, University of Kerala for her thesis "Stable isotope studies on moisture source variation and associated water cycle dynamics in Periyar river basin, Southern Western Ghats" on 28th October 2021. Dr. A. Krishnakumar, Scientist-D, Hydrology Group was her supervising guide.

Smt. Parvathy K. Nair, has been awarded PhD degree under the Faculty of Applied Sciences, University of Kerala for her thesis "Hydrogeological and hydrochemical appraisal of Vembanad wetland system" on 01st February 2022. Dr. D. S. Suresh Babu, Scientist-F, Marine Geoscience Group was her supervising guide.

Shri. Vipin T. Raj, DST-INSPIRE Research Scholar, Hydrology Group received the "Best Poster Award" in Earth and Planetary Sciences section of 34th Kerala Science Congress held during 10-12 February, 2022 at Thiruvananthapuram, Kerala for the poster titled "Chemical denudation of mountainous catchments in Southern Western Ghats - a case study using hydro chemical tools and modelling".

Shri. R. K. Sumesh, Project Scientist B, Atmospheric Science Group received the "Best Paper Award" in Earth and Planetary Sciences section of 34th Kerala Science Congress held during 10-12 February, 2022 at Thiruvananthapuram, Kerala for the paper titled "Tracing the precipitation microphysics of mesoscale weather events over Kerala".

2.2 Membership in Committees outside NCESS

Dr. Jyotiranjan S. Ray

Chairman, Expert Committee on Earth and Atmospheric Sciences, Science and Engineering Research Board, Govt. of India.

Member, Research Advisory Committee, Birbal Sahni Institute of Palaeosciences, Lucknow.

Member, Board of Studies, Faculty of Earth Sciences, Cotton University, Guwahati.

Dr. V. Nandakumar

Member, Scientific Advisory Committee, Geochronology Facility, Inter-University Accelerator Centre (IUAC), New Delhi.

Member, Editorial Board, Energy Geoscience Journal.

Dr. D. Padmalal

Member, Dam Safety Authority, Govt. of Kerala.

Member, Editorial Board, Journal of Coastal Sciences.

Member, Board of Studies in Earth Sciences, KUFOS.

Member, Expert Committee on Teachers Associateship for Research Excellence (TARE), SERB, DST.

Member, Expert Committee constituted for evaluating DPR for river rejuvenation of 5 Kerala Rivers, IRDB, Govt. of Kerala.

Member, Advisory Committee of the project 'Facilitating Multilevel Climate Governance in Kerala', World Institute of Sustainable Energy, Pune.

Dr. L. Sheela Nair

Member, Board of in Physical Oceanography, Cochin University of Science and Technology.

Member, Shoreline Monitoring Committee for the VISL Project - constituted as per the direction of NGT to study the impact due to the International Sea Port Construction at Vizhinjam, Thiruvananthapuram.

Nominated Member, Coastal Protection and Development Advisory Committee (CPDAC), Central Water Commission, Dept. of Water Resources, Ministry of Jal Shakti.

Member, Alappad Beach Wash Mining Environment Damage Assessment Committee - constituted by Govt. of Kerala to reassess the damage caused by M/s Kerala Minerals and Metals Limited (KMML) and M/s Indian Rare Earths Limited (IREL) as per the directions given by NGT.

Member, Technical Advisory Committee

appointed by Govt. of Kerala for overseeing all the coastal protection works in the State.

Dr. Tomson J. Kallukalam

Member, Board of Studies of Geology, Farook College (Autonomous), Kozhikode, Kerala.

Dr. A. Krishnakumar

Member, Doctoral Committee of Environmental Sciences, Faculty of Applied Sciences, University of Kerala.

Member, Academic Committee, Sree Narayana Guru Open University, Kerala.

Member, Editorial Board, Journal of Geoscience Research, Gondwana Geological Society.

Member, Academic and Research Team, River Centre Project for guidance, participation and financial support to Swadeshi Science Movement (SSMK), the Kerala Chapter of Vinjanabharati for implementing Nila Project as part of empowering the society to progress towards the Sustainable Development Goals (SDG).

Dr. E. A. Resmi

Member, Board of Studies, Department of Atmospheric Sciences, Cochin University of Science and Technology.

Dr. B. Padma Rao

Co-Scientist, Working Group on applications based on AI/ML/DL tools, constituted by MoES, Govt. of India.

Member, Technical committee for validation of the security schemes at Sree Padmanabha Swamy Temple, Kerala.

Dr. Chandra Prakash Dubey

Chair, Society of Exploration Geophysicists (SEG) - Student Leadership Symposium (SLS) / Student Education Program (SEP) Travel Grant Review Committee, USA

Chair, Society of Exploration Geophysicists (SEG) - Near Surface Research Grant Review Committee, USA

Chair, Society of Exploration Geophysicists (SEG) - Field Camp Grant Review Committee, USA.

Dr. S. Kaliraj

Life Member, Indian Society of Remote Sensing (ISRS).

Member, International Society for Photogrammetry and Remote Sensing (ISPRS).

Dr. C.K. Unnikrishnan

Member, Scientific Instrumentation Technical Committee, National Atmospheric Research Laboratory, ISRO.

2.3 Invited Lectures / Chairing of Technical Sessions

Dr. Jyotiranjan S. Ray

Delivered a talk on "Quaternary Volcanism in India" organized by Wadia Institute of Himalayan Geology, Dehradun on 18th June 2021.

Delivered a talk on "Outstanding Research Questions in Indian Ocean Tectonics" in the Ocean Society of India Conference held on 18th August 2021.

Delivered a talk on "Some Interesting Research Questions in Indian Geology" organized by Physical Research Laboratory, Ahmedabad on 27th September 2021.

Delivered the keynote address on "Retracing Sarasvati: the lost river of the Harappan Civilization" in the webinar conducted as part of Azadi ka Amrit Mahotsav celebrations jointly organized by Vikram Sarabhai Space Centre (VSSC) - Liquid Propulsion Systems Centre (LPSC) - ISRO Inertial Systems Unit (IISU) - Indian Institute of Space Science and Technology (IIST), Thiruvananthapuram on 07th November 2021.

Delivered a talk on "Retracing Sarasvati: the lost river of the Harappan Civilization" organized by Institute of Geoscientists of Odisha on 13th February 2022.

Delivered a talk on "Origin of Andaman Mud Volcanoes: A geochemical perspective" in the Annual General Body Meeting of the Indian

Society of Applied Geochemists (ISAG) on 17th March 2022.

Dr. L. Sheela Nair

Delivered a talk on "Coastal monitoring - data requirement, availability & gaps for coastal design with reference to Kerala coast" at the Virtual International Workshop on Coastal Information System - Management and Engineering organized by the Dept. of Ocean Engineering, IIT Madras on 06th May 2021.

Delivered a talk on "Coastal erosion and protective measures" as part of the online training program conducted by the Irrigation Department of Kerala for the engineers held on 25th June 2021.

Delivered a talk on "Coastal Structures" as guest speaker in the 5-day online Short-Term Training Programme (STTP) on 'Recent advances in marine vehicles and structures (RAMVS)', organized by Department of Civil Engineering, National Institute of Technology, Calicut during 04-08 October 2021.

Dr. K. Anoop Krishnan

Delivered a talk on "Applications of CHNS Analyzer in assessing the hydro-geochemical candidature of River Basins" in the 'National Workshop on NMR Spectroscopy, BET Surface Area Analyser, X-Ray Photoelectron Spectroscopy and CHNS/O Analyser organized' by CLIF, University of Kerala, Trivandrum on 17th March 2022.

Delivered a talk on "Methods of sampling and test (physical and chemical) for water and wastewater" in the 'VIT Quality Week 2022' lecture program organized by Vellore Institute of Technology, Tamil Nadu on 23rd February 2022.

Delivered a talk in the 'National Webinar on Research Opportunities in India and Abroad for Young Research Aspirants' organized by Nesamony Memorial Christian College, Tamil Nadu on 08th July 2021.

Delivered a talk on "Integrated monitoring and mitigation approaches in containing water pollution: An overview" in the 'Webinar on Advances in Civil Engineering' organised as part of the Faculty Development Programme by Department of Civil Engineering, Atria Institute of Technology, Bengaluru on 01st July 2021.

Delivered a talk on "Restoration Ecology and Chemistry" on the occasion of the 'World Earth Day-2021 Celebrations' organized by the Kerala State Biodiversity Board, Trivandrum on 22nd April 2021.

Dr. A. Krishnakumar

Delivered a talk on "Climate change and its consequences: Increasing concerns" aired by All India Radio, Thiruvananthapuram on 20th June 2021. The programme was organized by Department of Soil Survey & Soil Conservation, Govt. of Kerala.

Dr. E. A. Resmi

Delivered a talk on "Monsoon variability and rainfall pattern over the Western Ghats" in the training program on 'Rainfall and weather parameter analysis using geospatial technologies' organized by KSCSTE-CWRDM, as part of Water Resources Training Project at Kottayam on 26th October 2021.

Dr. Nilanjana Sorcar

Delivered a lecture on "Characterization of partial melting in the continental crust: An example from Kerala Khondalite Belt, India" in the two-day Symposium on 'Processes in the continental crust' organized by the Department of Earth Sciences, IISER Kolkata during 23-24 October 2021.

Dr. B. Padma Rao

Delivered an invited talk on "Seismological observatory at Bharati station" in the Decade of Bharati Station (2012-2022) programme organized by NCPOR as part of Indian Antarctica Programme on 07th February 2022.

Dr. Chandra Prakash Dubey

Delivered an invited lecture on "Forward modeling of gravity and magnetic data" as part of the training program for early career researchers entitled 'Inversion and Machine Learning applications for geoscience data analysis' organized by CSIR-NGRI, Hyderabad sponsored by the Ministry of Earth Sciences, Govt. of India on 14th June 2021.

Delivered an invited lecture on "Subsurface structural settings and density variations: Insights from gravity data" as part of weekly seminar of Earth and Climate Science, IISER, Pune on 16th November 2021.

Dr. K. Sreelash

Delivered an invited lecture on "Surface Water and Groundwater Interactions" as part of 2-day online workshop on 'Sustainable Water Resources Management' conducted by Dept. of Civil Engineering, Mepco Schlenk Engineering College, Sivakasi, Tamil Nadu on 16th November 2021.

Delivered seven lectures as a part of the 2-day course on 'Applications of Remote Sensing in Critical Zone Studies' conducted by Dept. of Civil Engineering, Mepco Schlenk Engineering College, Sivakasi, Tamil Nadu during 21-28 August 2021.

Dr. S. Kaliraj

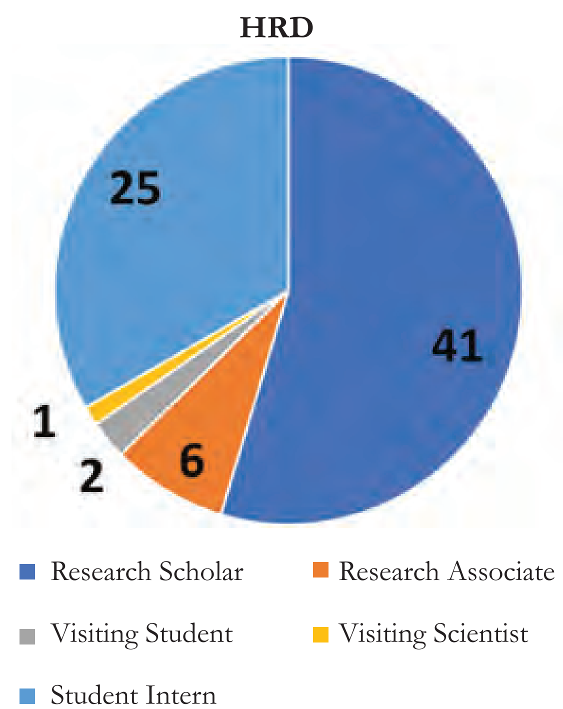
Delivered an invited lecture on "Identification of groundwater recharge potential zone and site-specific groundwater recharge structure" as part of the international training programme on 'Practical application of GIS tools in planning groundwater recharge activities' for the staffs of Uganda and Tanzania Water Resource Department, organized by Centre for Science and Environment (CSE), New Delhi on 11th March 2022.

Delivered an invited lecture on "Disaster risk with specific reference to coastal erosion" as part of the 'Spatial Information Technology in Understanding Disaster Risk' programme organized by Kerala State Disaster Management Authority (KSDMA) on 22nd March 2022.

2.4 Human Resource Development

NCESS has strong Human Resource Development scheme. The programs under this scheme are PhD program, Research Associateship, Visiting Scientist program, Visiting Student program and Student Internship. Currently 41 junior and senior research fellows are working for their PhD.

These fellows are registered in Cochin University of Science and Technology (CUSAT) / Kerala University through MoUs with NCESS. Six Research Associates are carrying out their postdoctoral research in NCESS at this time. NCESS trains about 50 M.Sc. / B.Sc. students each year as part of the internship program. Besides, many scientists of NCESS co-supervise Ph.D. / M.Sc. / M.Tech. students of other organizations / universities for their project / thesis works.



3. Research Activities

3.1 Solid Earth Research Group

3.1.1 Broadband Seismological Observatory at Larsemann Hills, Antarctica

The Antarctic continent and surrounding oceans are key parts of the Earth's System and can provide vital information on the crustal evolutionary processes operating on the Earth's surface. The basement of Antarctica comprises a suite of crustal blocks that were part of various supercontinents (e.g., Rodinia, Gondwana) and preserves distinct high-grade assemblages. Previous studies suggest that parts of eastern Antarctica and Eastern Ghats Belt (EGB), India were once adjacent to each other in pre-Permian continental reconstructions. Therefore, the terranes of East Antarctica and EGB play a very crucial role in the Rodinia / East Gondwana correlation. An interdisciplinary approach utilising geophysical investigations with igneous/metamorphic petrological studies can provide a window into the geodynamic evolution of the region in particular and of the Earth in general.

The crust and mid-to-upper mantle are characterized by discontinuities and strong special variations of their structure. The continental crust is extremely diversified as it indicates an assemblage of different terrains having the signatures of different tectonic episodes (e.g., Christensen and Mooney, 1995). Several studies have been carried out to understand the crustal and mid-to-upper structure of West Antarctica, however, the knowledge on the crustal and mid-to-upper mantle structure and deformation in the region of East Antarctica is limited due to the paucity of geophysical data sets. Thus, it is essential to understand the detailed crustal and mid-to-upper mantle structure and deformation along with the geological analysis to decipher the correlation between east Antarctica and EGB, India.

A detailed reconnaissance survey has been conducted (first phase of fieldwork) near the Bharati research station and finalized the location for the establishment of a seismological observatory (Fig. 3.1.1.1). Further, successfully established the Broadband Seismological Observatory near the Bharati station, East Antarctica. The broadband seismometer has been installed on the seismic pier within the Igloo, which was constructed from the bedrock. The instrument has covered with three layers of the insulated box and mounted the heat tracing cable on the walls of the insulated box to maintain the temperature (Fig. 3.1.1.2). Later, continuous time series data has been collected from the instrument and analyzed to check the quality of the data. An example of data recorded at our newly established observatory is shown in Fig. 3.1.1.3.

Generated data set along with the available BBS data will be utilized for the detailed understanding of crustal and mid-to-upper mantle structure (high-resolution structure) beneath the Prydz Bay region of PEL, east Antarctica and EGB of India i.e., to decipher the (i) crustal and mid-to-upper mantle structure; (ii) patterns of crustal and mantle deformation by utilizing the global and generated seismological data. These results will be integrated with the geological data sets, which will provide significant inputs in continental correlation and reconstruction in an integrative international approach. Therefore, the outcomes from this project will make a significant and novel contribution to our knowledge of the geodynamic evolution of East Antarctica and India.

Fig. 3.1.1.1: (a) Inverted triangle indicates the location of broadband seismological observatory. (b) Indicates the location of the observatory (red inverted triangle) and Bharati research station (red open circle).

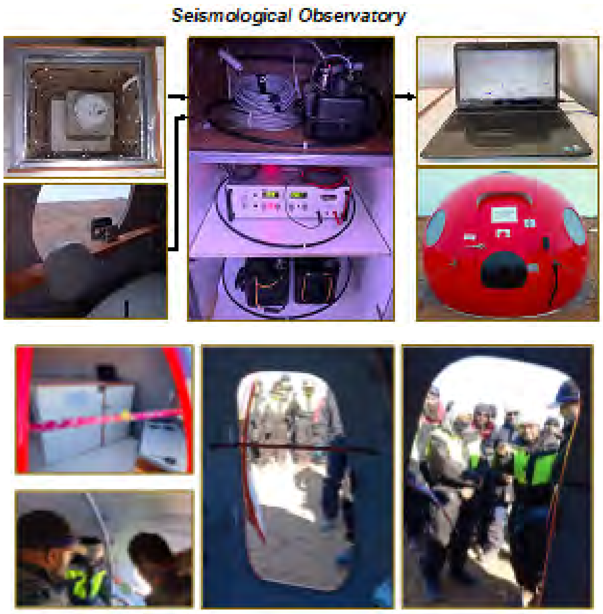


Fig. 3.1.1.2: Setup of the seismological observatory at Larsemann Hills, Antarctica and its inauguration.

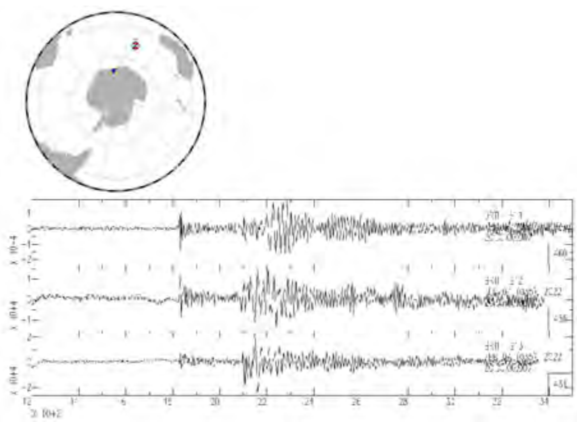


Fig. 3.1.1.3: Location of the earthquake (Mw6.4), recorded at our observatory (blue inverted triangle) (top panel) on 04-02-2022 and the corresponding three-component seismograms (bottom panel).

Padma Rao B., Krishna Jha

3.1.2 Chemical dating of monazite: Testing of analytical protocol for U–Th–total Pb using CAMECA SXFive Tactis EPMA at the National Centre for Earth Science Studies, Thiruvananthapuram, India

The calibration and quantification set-up conditions of monazite chronology (analytical protocol for U-Th-total Pb) using SXFive Tactis EPMA, at the National Centre for Earth Science Studies, Thiruvananthapuram, India has been successfully established. Consistency in the chemical-chronological data of the monazites starting from the Moacyr monazite (chronologically well-constrained) data followed by the analysis of monazite from the garnet-cordierite gneiss of the Kerala Khondalite Belt confirms the reliability of the NCESS-EPMA facility for the U–Th–total Pb chemical age dating of monazite. By applying the same analytical setup of chemical dating, the monazites from metapelites of Madurai Block of Southern Granulite Terrain, India yield two peak ages in probability density diagram of ca. 505 Ma and ca. 590 Ma (23 spots) which is similar to the 206Pb/238U age (ca. 506 Ma and ca. 585 Ma; 34 spots) obtained by LA-ICPMS (Fig. 3.1.2.1).

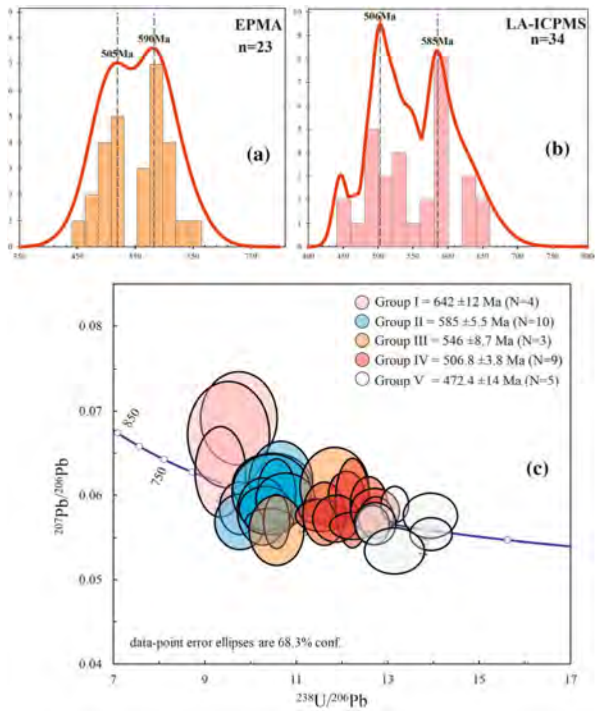


Fig. 3.1.2.1: Calculated ages of monazite grains from Madurai Block (a) Probability density plot shows a dominant peak at ca. 505 Ma and ca. 590 Ma, (b) represents the probability density plot of acquired data from LA-ICPMS showing a dominant peak at ca. 506 Ma and ca. 585 Ma and (c) represents the Terra-Wasserburg diagram, showing five major concordia age groups with two prominent populations at ca. 585 Ma and ca. 507 Ma.

https://doi.org/10.1007/s12040-021-01738-4

Nilanjana Sorcar, Sneha Mukherjee, Amal Dev J., Nishanth N.

3.1.3 Timing of metamorphism and cooling in south Indian granulites: New results from EPMA and LA-ICPMS/MC-ICPMS studies of HT-UHT rocks

The Precambrian granulite terrane of south India is known for the preservation of regional-scale high to ultrahigh-temperature (HT-UHT) metamorphic rocks. In the Madurai block, the largest crustal block in the terrane, a significant proportion of these HT-UHT rocks occur along a narrow belt referred to as the Kambam ultrahigh-temperature belt (KUB). Understanding the P-T-t evolution of these HT-UHT granulites is vital in decoding the spatial and temporal evolution of the Madurai block in relation to other crustal blocks. Detailed petrology, mineral chemistry, phase equilibrium modelling, and accessory mineral (zircon, monazite, rutile and apatite) geochronological and geochemical data of HT-UHT granulites from the Kambam ultrahigh-temperature belt were carried out. Combined mineral reaction and phase equilibrium modelling indicate extreme P-T conditions up to 1130 ºC at 11 kbar. The geometry of the P-T path is clockwise with initial isothermal decompression followed by near isobaric cooling (Fig. 3.1.3.1.a). LA-ICPMS U-Pb dating of zircon, monazite and rutile phases within these samples constrain the timing of metamorphism as well as cooling. U-Pb zircon ages of ~2500 Ma from the granulites points to new evidences for Paleoproterozoic high-grade metamorphism in the area where monazite U-Pb ages at ~593 and ~557 Ma throw light into the imprints on ~36 Ma prolonged Neoproterozoic thermal event attributed to Pan African collisional orogeny. LA-MC-ICPMS Hf isotopic record from zircon cores point to the role of significant juvenile crustal melting/anatexis during Paleoproterozoic. In addition, several cryptic metamorphic pulses are also identified evincing the polydeformed evolutionary history of these rocks. The ca. ~432 Ma cooling age record from rutile estimates an average cooling rate of ~3.0 ◦C/Ma over a time period of ~125 Ma. Additional metamorphic pulses are also identified, demonstrating the polydeformed crustal evolution history of the terrane. This suggests a complex history of slow cooling followed by ultraslow cooling (Fig. 3.1.3.1.b) The results bring forth the significance of the Kambam ultrahigh-temperature belt in understanding the tectonothermal evolution of Madurai block and provide additional evidence for long-lived Neoproterozoic UHT orogenesis in south India. The results also bring to the fore the importance of Kambam ultrahigh-temperature belt and Suruli shear zone which can be projected as a major terrane boundary within the Southern Granulite Terrane.

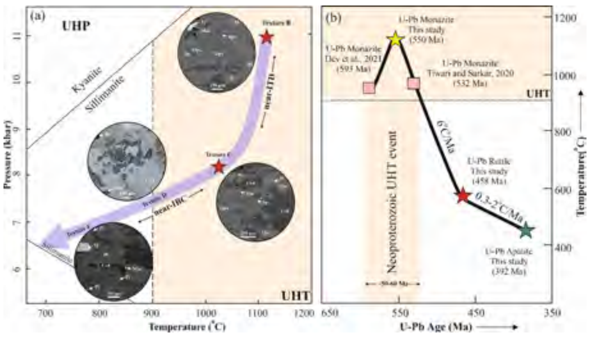


Fig. 3.1.3.1: (a) The Neoproterozoic clockwise P-T loop of UHT granulite with different stages of textural evolution. (b) Time vs. temperature (T-t) diagram illustrating the differential heating and cooling pattern for UHT granulites from KUB.

https://doi.org/10.1016/j.lithos.2021.106531
https://doi.org/10.1016/j.precamres.2022.106582

Tomson J. K., Nilanjana Sorcar, Amal Dev J.

3.1.4 Pulsed tectonic evolution in long-lived orogenic belts: An example from the Eastern Ghats Belt, India

This study characterizes two metamorphic cycles an aluminous granulite of the Eastern Ghats Belt (EGB), India using petrological, phase equilibria, geospeedometric, and, petrochronological data. The first metamorphic cycle ensued through dehydration melting of F-biotite along a shallow d*P*/d*T* prograde path reaching ultrahigh temperature (>950 ◦C) at 7–8 kbar pressure. The peak metamorphic assemblage is represented by sapphirine + spinel + Al-orthopyroxene + cordierite + ilmenite + plagioclase + quartz which constitute the coarse granoblastic assemblage. Reaction corona comprising orthopyroxene + sillimanite + garnet ± F-biotite over the peak phases imply near-isobaric cooling from the peak with the termination of the first cycle. The melt produced during the prograde stage has been lost to a large extent to stabilize the peak assemblage. The second metamorphic cycle ensued with the decomposition of cordierite by a skeletal intergrowth of orthopyroxene + sillimanite + quartz and a symplectic intergrowth of garnet + quartz between orthopyroxene and cordierite. A delicate symplectite comprising cordierite + quartz + K-feldspar ± plagioclase also formed at this stage within the leucocratic layers. These intergrowth textures resulted from reworking of the cooled granulite (increasing *P-T*) through incipient melting of F-biotite subsequent decompression, and melt-solid interaction during the terminal stage of the second metamorphic cycle. Contrary to the very slow post-peak cooling history proposed earlier Geospeedometric data involving garnet and biotite suggest the nonlinear nature of cooling with an initial fast cooling from the peak condition of the first metamorphic cycle. Monazite petrochronological data yield

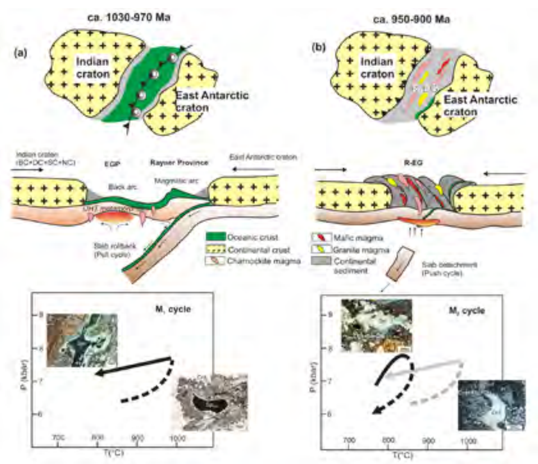


Fig. 3.1.4.1: Cartoon diagram illustrating the tectonic scenario involving the Indian and East Antarctic cratons during ca. 1030–900 Ma. (a) The M_1 cycle of metamorphism was initiated with the development of subduction-accretion system between the Indian and East Antarctic cratons at ca. 1030–970 Ma. Development of the back arc setting near the Indian side and high heat flow beneath the back arc basin resulted in UHT metamorphism. The process of subduction roll back was operative resulting in a counter-clockwise *P-T* path. (b) The M_2 metamorphic cycle started during ca. 950–900 Ma when slab detachment was complete below the composite Rayner-Eastern Ghats (R-EG) orogenic belt. The tectonic phase produced dominantly compressional structure leading to a possible clockwise *P-T* path. This tectonic mode switch could have given rise to several "pull–push" cycles.

1002 ± 3 Ma and 944 ± 6 Ma ages that belong to the peaks of first (ca. 1030–990 Ma) and the second (ca. 950–900 Ma) metamorphic cycles respectively of the central crustal province of the belt. This two-cycle evolution is related to several alternate extension (pull) and compression (push) cycles in an accretionary tectonic setting during ca. 1030–900 Ma. Identification of these two separate pulses of metamorphism within the period between ca. 1030 Ma and 900 Ma argues against the model of a single-cycle long-lived evolution of the EGP. Further, metamorphic pulses of the EGP can be correlated with the accretionary tectonics involving EGP and the Rayner Province (R-EG). The two cycles may be linked to several pull–push cycles (Fig. 3.1.4.1).

This work was done in collaboration with Prof. Sankar Bose of Department of Geology, Presidency University, Kolkata; Prof. Kaushik Das of Hiroshima Institute of Plate Convergence Regions Research, Japan; and Proloy Ganguly of Durgapur Government College, India.

https://doi.org/10.1016/j.precamres.2021.106522

Nilanjana Sorcar, Sneha Mukherjee

3.1.5 Structural variability and magnetization contrasts beneath SGT

The southern granulite terrain (SGT) is a large tract of exposed Archean continental crust, divided into the Madurai block (MB), Trivandrum block (TB) and Nagercoil block (NB). These crustal domains are linked with the NW-SE trending Achankovil Shear Zone (AKSZ). The gravity and magnetic data, along with previously published geological information were combined to re-evaluate the crustal architecture, evolution and possible extension of AKSZ into Madagascar (Fig. 3.1.5.1). Modeling analyses indicate that the long wavelengths trends of the magnetic anomalies originate at ~ 20 km depth of different SGT blocks (TB and MB). Whereas, the magnetic basement mapping shows that the prominent shallow magnetic features and furthermore associated with the newly identified faults at shallow depths that are corroborated with the gravity anomalies. The presence of Khondalites outcrops in Trivandrum block implies that high magnetization crust is the main source of positive magnetic anomalies. Furthermore, magnetic anomalies unveil, however, SGT that preserve the remanent of different block of crust in southern SGT. The NW-SE trending of AKSZ separating the two major lithological blocks (MB and TB) unveil different magnetic crust individually.

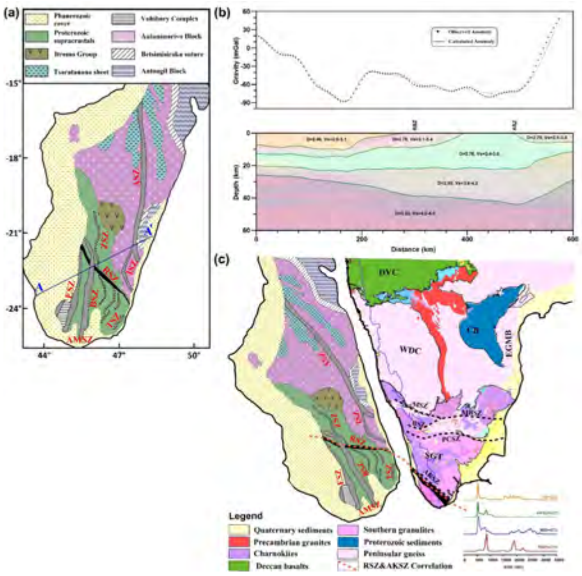


Fig. 3.1.5.1: (a) Geology map of Madagascar representing different shear zones. Available velocity model along profile AA' that crosses main shear zone of RSZ and ASZ (Profile AA' shown in blue colour). RSZ: Ranotsara Shear Zone, ASZ: Avango Shear Zone, ISZ: Ifanadiana Shear Zone, ZSZ: Zazafotsy Shear Zone, ESZ: Ejeda Shear Zone, BSZ: Beraketa Shear Zone, AMSZ: Ampanihy Shear Zone. (b) 2D Density model constrained with velocity model (background colour) along profile AA'. D: Density, Vs: Shear Velocity, RSZ: Ranotsara Shear Zone, ASZ: Avango Shear Zone. (c) The zircon age data.

This work was done in collaboration with Dr. V. M. Tiwari of CSIR-NGRI, Hyderabad

https://doi.org/10.2113/2021/6017801

Chandra Prakash Dubey, Kumar Batuk Joshi, Prasad M.

3.1.6 Sub-crustal mantle lithospheric modification beneath the thick sedimentary fan of Bay of Bengal

A comprehensive architecture of the BoB lithosphere is presented using a 3D density model constrained by gravity data and other relevant prior information. The newly derived three-dimensional density modeling of the Bay of Bengal improves the understanding of the geological structures and their tectonic process of lithospheric nature. The results of 3D density modeling show that the same density of the upper mantle cannot explain measured gravity over the northern part of the Bay of Bengal basin. In contrast, a model that incorporates modifications in upper mantle density variation laterally with a high density below the sedimentary load can explain the gravity anomalies associated with Moho deepening and thick lithosphere. Lithosphere thickness in the region of BoB varies 180 km to 72 km from north to south direction respectively (Fig. 3.1.6.1.c). Moreover, it appears from the mantle density interfaces that density anomalies in the mantle act as a stress concentrator under the prevailing tectonic and lithological loads (Fig. 3.1.6.1.b). A conceptual model is proposed to explain the lateral density changes in the sub-crustal where thickening of the lithosphere in north Bay of Bengal under the thick sedimentary fan leads mantle to flow.

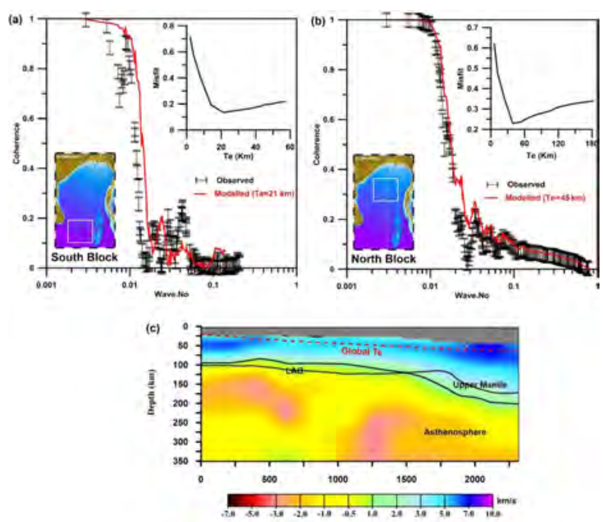


Fig. 3.1.6.1: (a) Estimated lithospheric elastic thickness (Te) for two different blocks from south and north region of the Bay of Bengal, and (b)Vertical section of S-wave tomography model along the 88 degrees of longitude (http://ciei.colorado.edu/~nshapiro/MODEL/). Global effective elastic thickness (Te) is plotted in red-dashed line along with predicted lithosphere thickness and the black dotted line is Lithosphere-Asthenosphere Boundary (LAB).

The long-term and complex geodynamic processes of the oceanic lithosphere of BoB could only be fully understood if model predictions are consistent with other results, and if demonstrated through plotting regional seismic tomographic and derived elastic lithosphere thickness. Gravity modeling suggests that the lateral changes in sub-crustal density such that the mantle underlying the thick sediment is denser than it is beneath the thin sediment region of the south. So interpreted these changes either due to change in the rifting style shearing or stretched or density has been changing as load increases to host the sedimentary load (Fig. 3.1.6.2). Sediment is being loaded on a relatively strong, dense, and, hence, cold lithosphere. Therefore, it is more likely that principal stress orientations would be in the direction of plate motion, which is consistent with fault plane solutions of earthquakes in the region. The focal mechanisms analysis of intraplate earthquakes in the oceanic lithosphere of Bay of Bengal region shows mainly normal faults with strike-slip motion reflecting compression stress in the interior of the plate. The above-mentioned observations also indicate that the upper mantle of the Bay of Bengal is rigid and contributes to the strength of the lithosphere.

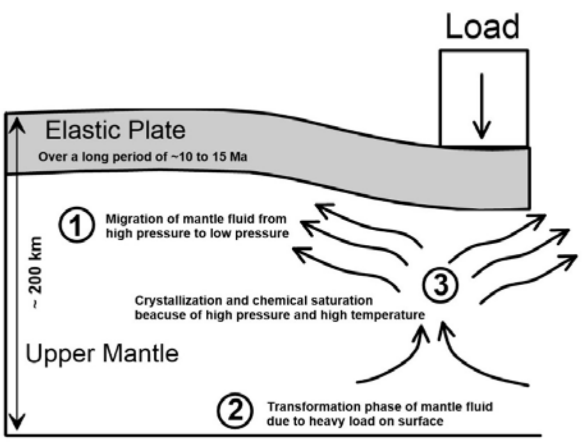


Fig. 3.1.6.2: The Proposed conceptual model for mass distribution in the upper mantle due to heavy load.

This work was done in collaboration with Dr. V. M. Tiwari of CSIR-NGRI, Hyderabad.

https://doi.org/10.1016/j.tecto.2022.229253

Chandra Prakash Dubey

3.1.7 Geochemistry of meta-sediments from Neoproterozoic Shimla and Chail Groups of Outer Lesser Himalaya: Implications for provenance, tectonic setting, and paleo-weathering conditions

The depositional history of the Himalayas has been overprinted by the tectonic activities during the Himalayan Orogeny. A detailed investigation of the sedimentary units can provide crucial information regarding their depositional history and provenance. This study aims at constraining the weathering history, tectonic setting, and provenance of meta-sediments from the Shimla and Chail Groups of Outer Lesser Himalaya. With similar major element chemistry, these meta-sediments comprise a low-silica group (avg. SiO_2/Al_2O_3 <3.29). Weathering intensity parameters chemical index of alteration (CIA), plagioclase index of alteration (PIA) and index of chemical variability (ICV) range from 62 to 78 (avg. = 69.41), 70 to 96 (avg. = 85.34), and 0.45 to 1.45 (avg. = 1.01), respectively indicating moderate to severe degrees of weathering. Transition element ratios [Cr/V (1.68–5.18), Ni/Co (1.47–30.99), and V/Ni (0.87–4.61)], and trace element bivariate plots suggest a recycled, felsic to intermediate provenance that has primarily been derived from Post-Archean sources with minor inputs from Archean units. A passive margin depositional setting

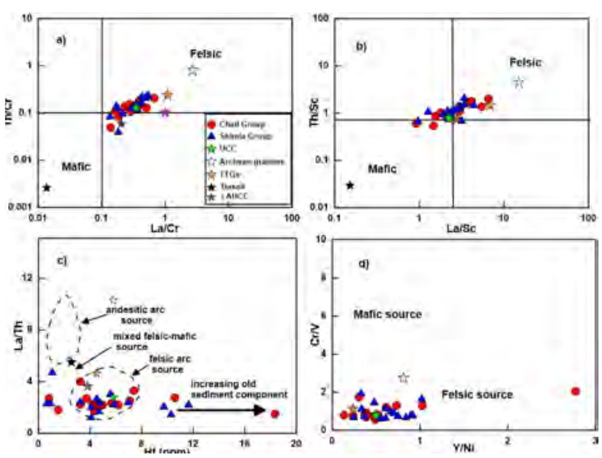


Fig. 3.1.7.1: Trace element discriminant plots of (a) and (b) Th/Cr versus La/Cr and Th/Sc versus La/Sc (after Bhatia & Crook, 1986); (c) La/Th versus Hf (after Floyd & Leveridge, 1987), and (d) Cr/V versus Y/Ni (after Ghosh, Jalal, & Islam, 2016) for the studied meta-sediments. Potential sources are plotted for comparison (Condie, 1993).

with arc derived sources is suggested for the Chail and Shimla meta-sediments. Rare-earth element patterns reveal similarities between the studied metasediments with TTG gneisses and sanukitoids from the Aravalli and Bundelkhand Cratons, as well as Chaur and Jutogh granitoids. Therefore, Neoproterozoic Himalayan granitoids and Archean Aravalli-Bundelkhand granitoids (TTGs and high-K granitoids) could be potential sources of these meta-sediments, as also suggested by the detrital zircon age distribution from the Beas-Satluj-Pabbar valleys and Shimla Group.

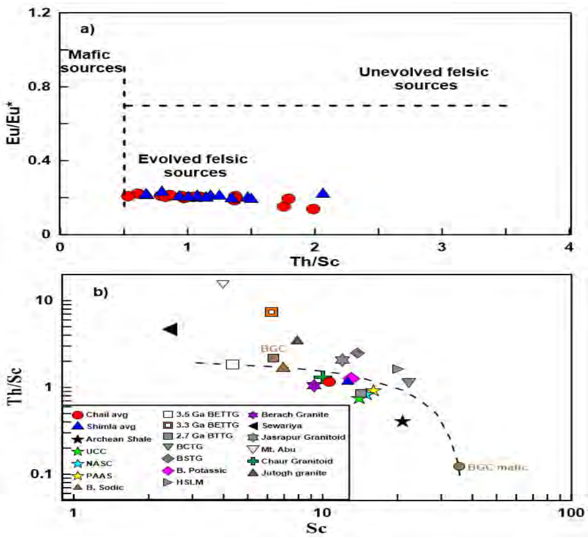


Fig. 3.1.7.2: (a) Eu/Eu* versus Th/Sc plot for Shimla and Chail meta-sediments and (b) Th/Sc versus Sc plot denoting probable source of Shimla and Chail metasediments.

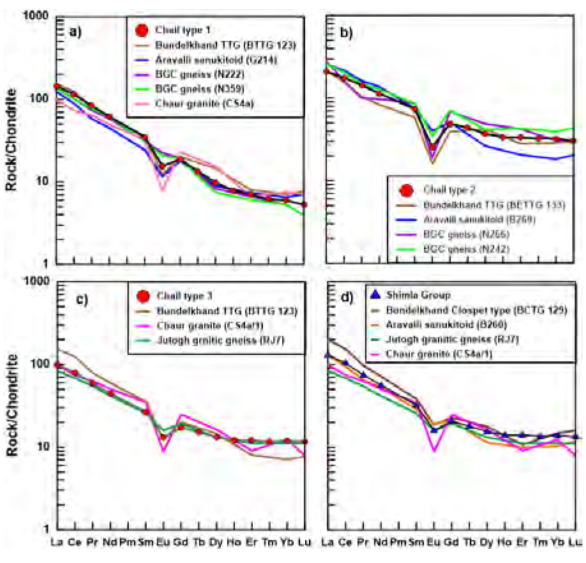


Fig. 3.1.7.3: (a) to (d) Average Chondrite-normalized REE patterns for Shimla and Chail meta-sediments.

This work was done in collaboration with Soumya Ray of Department of Geology, University of Delhi; Prof. Talat Ahmad, University of Kashmir, Srinagar and Dr. Keshav Krishna Aradhi of National Geophysical Research Institute, Hyderabad.

https://doi.org/10.1002/gj.4183

Kumar Batuk Joshi

3.1.8 C-Sr isotope stratigraphy of carbonate formations of the Late Neoproterozoic - Cambrian Marwar Supergroup, western India

The late Neoproterozoic – early Cambrian interval saw significant perturbations in the global carbon cycle, climate and weathering, and ocean chemistry. Simultaneously, this transition interval also witnessed the remarkable rise of complex multicellular life. The deposition of the Marwar Supergroup of western India took place during this time period. Sedimentation in the basin began in the late Neoproterozoic, following the ~750 Ma Malani volcanism, and continued at least until the early Cambrian, albeit intermittent breaks. Paleomagnetic data suggest an equatorial paleogeographic position for the Marwar Basin and position it adjacent to other Neoproterozoic – Cambrian ocean basins of Oman, south China and Australia; wherein copious evidence for the Neoproterozoic biogeochemical transitions have been found. The spatial and temporal dispositions of the Marwar Basin make it a strong candidate for preservation of signatures of the Neoproterozoic global events. Moreover, considering that all other Proterozoic Basins of India are either older or contain ambiguous evidence of these global events, the fluvio-marine sedimentary deposits of the Marwar Basin offer the best late Neoproterozoic – Cambrian rock record in the subcontinent for such an investigation. In this study, high resolution C-O-Sr isotope and trace element data for the carbonate formations of the Marwar Supergroup are presented to evaluate the primary nature of the geochemical signals, provide age constraints using C-Sr isotope stratigraphy and correlate the isotopic signals with the global Ediacaran - Cambrian record. The results show that the C and Sr isotopic compositions of the carbonate formations in the Bilara Group are similar to those observed in the late Ediacaran - early Cambrian successions elsewhere. This indicates that the Marwar Basin was connected to the global oceans during this time period. The variation observed in the $^{87}Sr/^{86}Sr$ of the Gotan Formation suggests an early Cambrian depositional age for the Bilara Group. Based on carbon isotope stratigraphy, two basin-wide $\delta^{13}C$ negative excursions of magnitudes ~6‰ and ~7‰, respectively, in the Gotan and the Dhanapa formations are identified. Results of the C and Sr isotope stratigraphy place the Ediacaran - Cambrian boundary in the Marwar Supergroup at the basal part of the Dhanapa Formation. These results also suggest that there was no major break between the sedimentation of the carbonates of Bilara Group and the overlying sandstones of the Nagaur Group.

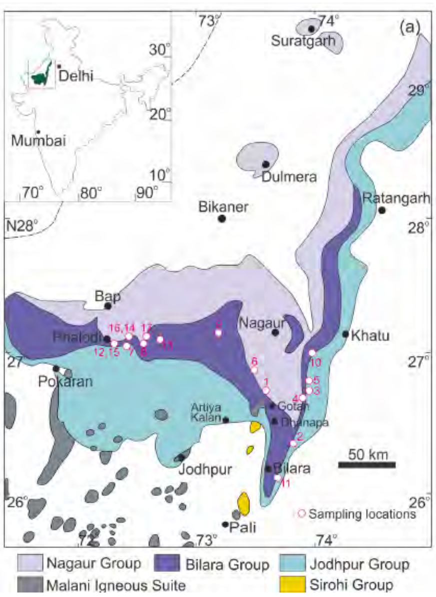


Fig. 3.1.8.1: Generalised geological map of Marwar basin with study locations.

This work was done in collaboration with Dr. Bivin Geo George and Dr. Sanjeev Kumar of PRL, Ahmedabad.

https://doi.org/10.1016/j.precamres.2021.106378

Jyotiranjan S. Ray

3.1.9 Origin of breccia in mud volcanoes of the Andaman accretionary prism: Implications for forearc processes

Mud volcanoes (MVs) are sedimentary structures whose surface morphology vaguely resembles that of a real volcano on a much smaller scale. They form as a result of the emission of depressurized multiphase fluid and argillaceous material from deep-seated sources. MVs either occur on top of surface-piercing shale diapirs or faults/fractures. The latter is more common in convergent margins, where lateral tectonic compression leads to the rise of fluidized mud, derived from subducting sediment and altered mafic/ultramafic rocks, along the slab-mantle wedge interface or décollement. Study of expelled fluids and mud breccia in MVs on accretionary wedges can provide much needed insight into the chemical transformation of slabs within forearcs. It would also be the first step towards a comprehensive understanding of the contributions of slabs to the chemical evolution of the Earth's mantle. In such an effort, the mineralogical, elemental and Sr-Nd-Pb isotopic compositions of mud breccia ejected at MVs of the Andaman accretionary prism, located at the India-Eurasia convergent plate boundary were carried out. Samples of mud breccia, essentially the clayey matrix component, were collected from two major mud volcano fields (MV-1 and MV-2) of the Andaman Islands. The main objectives were to understand the processes responsible for the origin and evolution of mud breccia, and to evaluate its potential as a proxy for crustal component getting recycled/ incorporated into the Andaman mantle wedge. In addition, with the help of radiocarbon dating of the mud matrix and characterization of rock clasts, determining the interaction of the mud breccia with the shallow subsurface environment before being ejected onto the surface was attempted. XRD, XRF, ICP-MS and TIMS analyses were carried out to identify the minerals present in these samples, and to determine major and trace element concentrations and Pb-isotopic composition respectively. Based on this mineralogical, geochemical and isotopic study and the earlier work on the mud breccia and fluids, including gases, discharged at the MVs of the Andaman Islands the following inferences were made about the origin of the breccia and its implication for the forearc processes, particularly in the Andaman subduction zone. The MVs of the Andaman Islands originate from a tectonic mélange, hosted by under-plated sediment in the décollement zone, located at depths exceeding 6 km. These MVs eject argillaceous sediment (quartz+clays) and fluids (water+methane) derived from the altered oceanic crust and highly pressurized sediment of the subducting slab. The study reveals that much of the terrigenous sediment of the slab gets accreted onto the prism through under-plating and that only a small fraction of it gets recycled into the mantle (Fig. 3.1.9.1). The primitive chemistry of arc lavas erupted at the currently active Barren Island volcano is a testimony of this process.

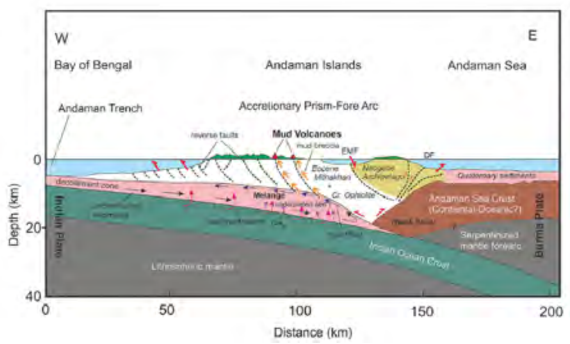


Fig. 3.1.9.1: A conceptualised cross section of the Andaman Subduction Zone, across the Middle Andaman Island, showing various lithological and structural architecture and inferred fluid and mud flow pathways.

This work was done in collaboration with Dr. Alok Kumar, Dr. N. Awasthi, Dr. M.G. Yadava and Dr. Bivin Geo George of PRL, Ahmedabad; Dr. P E Binusarama of VBSP University, Jaunpur; Prof. R. Bhutani and Prof. S. Balakrishnan of Pondicherry University; Prof. Kanchan Pande of IIT Mumbai.

https://doi.org/10.1016/j.chemgeo.2021.120595

Jyotiranjan S. Ray

3.1.10 Evaluating the connectivity of the Yamuna and the Sarasvati during the Holocene: Evidence from geochemical provenance of sediment in the Markanda River valley, India

The catchment of the Markanda River, the modern equivalent of a palaeochannel of Yamuna (Y1), is currently separated from that of the Yamuna River by a narrow drainage divide between the westward-flowing Markanda and the eastward-flowing Bata River, a tributary of the Yamuna. Interestingly, the Markanda catchment has several levels of fluvial terraces occupying a large valley with a misfit modern channel. The timing of formation of these terraces, during the Late Middle Pleistocene to the Holocene, led some workers to hypothesize that a large Himalayan sourced river was flowing in the WNW direction in the Markanda Valley and that the presence of clasts having sources in the Himalayan hinterland in this valley is a testimony of such a scenario. Alternatively, these clasts (high-grade metamorphic rocks and quartzite) could have been sourced locally, within the Sub-Himalaya. Irrespective of the point of origin, the presence of a distributary fan system in the plains and of multi-storied sand bodies suggests a high discharge of the river. Therefore, the major research questions that remain to be answered are: (1) Did the Yamuna flow through the Markanda Valley and the channel Y1 to join the ancient Ghaggar-Hakra (Sarasvati) River? (2) What implications did the fluvial evolution of the Markanda Valley have on the paleo-hydrography (and surface water availability) of the Harappan civilization downstream in the Ghaggar-Hakra system? This study attempts to answer these questions by studying the temporal changes in the provenance of the fluvial sediment in the Markanda Valley with the help of geochronology, geochemistry and Sr-Nd isotopic source fingerprinting.

The study in conjunction with the existing geochronological, geochemical, and isotopic data from sediment in the Ghaggar-Hakra plain, draw the following conclusions regarding the status of the Yamuna-Markanda-Sarasvati connection and its significance for the Harappan Civilization. The sediment deposited in the Markanda Valley during 13.1 to 3.8 ka was sourced from the concomitant Sub-Himalayan catchment of the river: the Siwalik Group, the Subathu Formation and the Dagshai-Kasauli Formations. This is also true for provenance of the fan sediment dating back to 57.7 ka. The Markanda Valley sediment is geochemically and isotopically similar to the sediment younger than 4.5 ka (silty clay and yellow sand) of the Ghaggar-Hakra plains/ paleo-channels; however, it is different from the sediment older than 4.5 ka (micaceous grey sand) of the plains, suggesting different depositional pathway for the latter. The study unequivocally established that the Markanda Valley was never connected to the Yamuna catchment during the last 13.2 ka. Albeit the age gap in the dated samples, results of this study indicate at lack of any connectivity between the Yamuna and the Markanda since 57.7 ka, which in turn suggests that the Yamuna River, contrary to earlier views, did not flowthrough the Channel-Y1. The micaceous grey sand of the Ghaggar-Hakra plains originating from the Higher and Lesser Himalayan sources was unquestionably deposited by the paleo-Sutlej and the paleo-Yamuna, with the latter possibly flowing through the Channel-Y2.

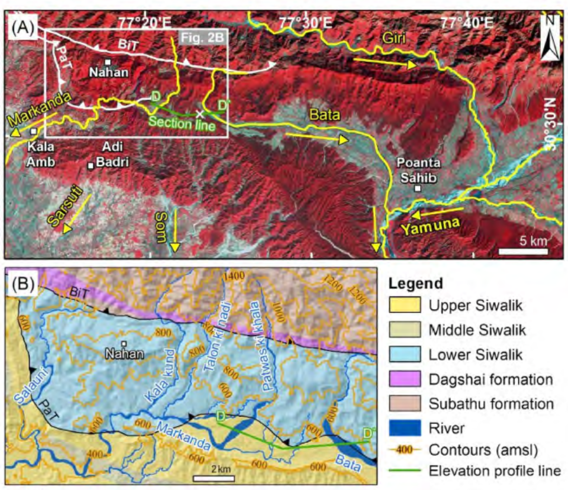


Fig. 3.1.10.1: (A) False colour composite using Landsat-7 imagery bands 234 showing the drainage divide (×) separating west-flowing Markanda and east-flowing Bata rivers. (B) Litho-tectonic map of the Upper Markanda Basin and its major tributaries showing major geological formations. BiT-Bilaspur Thrust, PaT-Paonta Thrust.

This work was done in collaboration with Dr. Ajit Singh and Dr. Vikrant Jain of IIT Gandhinagar and Dr. Milan Kumar Mahala of PRL, Ahmedabad.

https://doi.org/10.1016/j.geomorph.2022.108124

Jyotiranjan S. Ray

3.1.11 Heavy minerals in provenance studies: An overview

Over the past few decades, the advent of sophisticated imaging and *in-situ* measurements

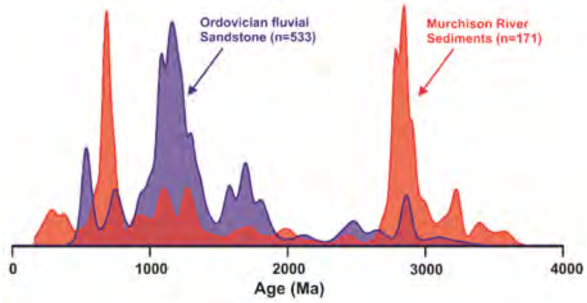


Fig. 3.1.11.1: KDE plots of U–Pb detrital zircons ages of Murchison River and Ordovician fluvial sediments, West Australia, showing significant variation in detrital zircon population from sandstones and modern river sediments (Markwitz et al. 2020).

as well as data deconvolution techniques have led to remarkable progress in the field of heavy mineral research. The prevalence of zircon in a wide range of igneous, sedimentary and metamorphic rocks has been used frequently in estimating provenance, depositional age, tectonic settings, drainage evolution and crustal evolution. However, the biased age spectra (induced by hydrodynamic fractionation, sampling and measurement protocol and inheritance) yielded by detrital zircons reinvigorated the need to utilise other heavy mineral phases (monazite, apatite, titanite and rutile) for addressing a range of geological processes. Different heavy minerals

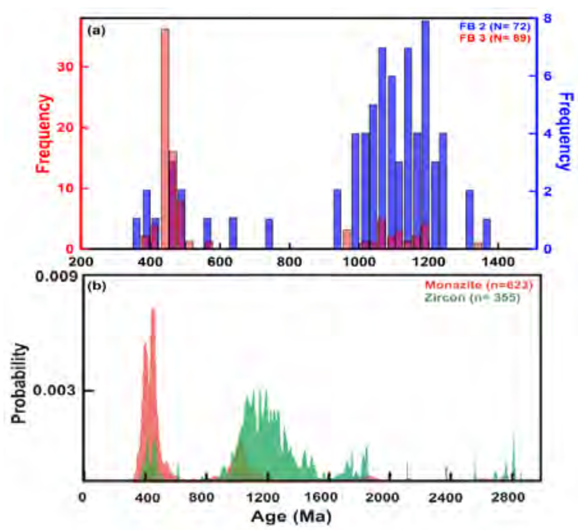


Fig. 3.1.11.2: (a) Histogram showing variation in U–Pb detrital zircon age spectra for two selected samples of French Broad River collected a few kilometres apart (Hietpas et al. 2011b). (b) Detrital zircon and monazite age spectra from Appalachian Foreland basin showing the impact of the chosen heavy mineral in provenance studies (Hietpas et al. 2011a).

are moderate to highly durable and provide variable response to magmatic and metamorphic events thereby providing clues that may be missed by single detrital grain analysis, thus emphasising the multi-mineral detrital approach as an indispensable method to investigate several geological processes. The present review highlights the role of detrital zircon and the associated limitations in using a single heavy mineral approach in geological studies. This review further emphasises the advantages of using multimineral/proxy studies and discusses the scope of heavy mineral research.

This work was done in collaboration with Elson P Oliveira of Department of Geology, Institute of Geoscience, University of Campinas, Campinas, Brazil

https://doi.org/10.1007/s12517-021-07687-y

Kumar Batuk Joshi, Upasana S. Banerji, Chandra Prakash Dubey

3.1.12 Gravity inversion for heterogeneous sedimentary basin with b-spline polynomial approximation using differential evolution algorithm

A MATLAB-based inversion program, b-spline polynomial approximation using the differential evolution algorithm (SPODEA), to recover the concealed basement geometry under heterogeneous sedimentary basins has been developed. Earlier inversion techniques used the discretized subsurface interface topography into a grid of juxtaposed elementary prisms to estimate the basement depth of a basin. Such discretization leads to the failure of the depth profile continuity and requires a higher number of inversion parameters for achieving the desired accuracy. The novel approach of SPODEA overcomes such limitations of earlier inversion techniques. SPODEA is based on the segment-wise b-spline optimization technique to estimate the basement depth by using high-order polynomials. Moreover, it can achieve an optimal misfit with minimal parametric information, which reduces the computational expense. Our inversion approach uses the differential evolution algorithm, which provides real parametric optimization and uses b-splines for accurate estimation of continuous depth profiles. The efficiency of our algorithm was determined with two complex synthetic sedimentary basin models comprised of constant and depth-varying density distributions. Furthermore, the uncertainty analysis of our inversion technique is evaluated by incorporating white Gaussian noise into the synthetic models. Finally, the utility of SPODEA is evaluated by inverting gravity anomalies for two different real sedimentary basins. It produces geologically reasonable outcomes that are in close agreement with basement structures from previously reported results.

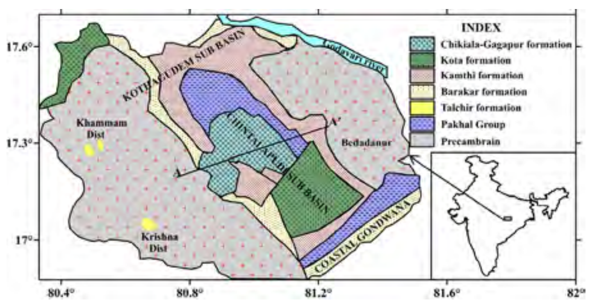


Fig. 3.1.12.1: Geology map of the Godavari Basin, India. AA' is the profile for the gravity anomaly.

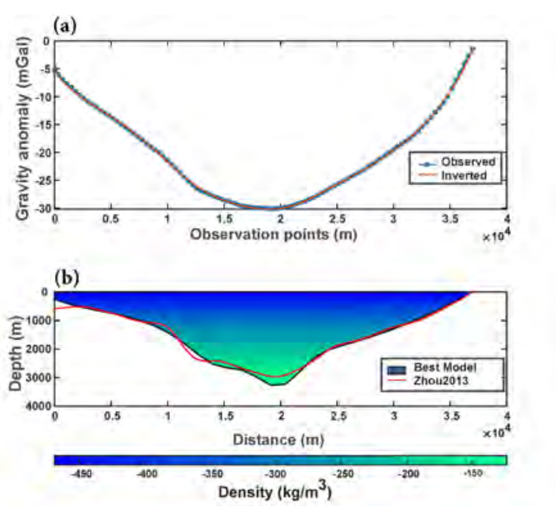


Fig. 3.1.12.2: Estimated basement depth profile from the Godavari Basin, India. The blue dotted curve in (a) represents the observed gravity anomaly, and the solid red line shows the inverted gravity anomaly. The solid red line in (b) represents the inverted depth profile from Zhou (2013), and the filled region represents the inverted sedimentary basin using SPODEA.

https://doi.org/10.1190/geo2019-0779.1

Arka Roy, Chandra Prakash Dubey, Muthyala Prasad

3.1.13 Gravity inversion of 2D fault having variable density contrast using particle swarm optimization

A Matlab-based optimization algorithm is introduced for inverting fault structures from observed gravity anomalies. A convenient graphical user interface is also presented for incorporating the input parameters without any technical complexity to any users. The inversion code uses particle swarm optimization, and all control parameters are tuned initially for faster convergence. There is no requirement of prior choice of an initial model, that is the advantage of using global optimization. The optimization technique is versatile enough to handle any depth-varying density distributions. The maximum number of iterations and stopping criterion is fixed initially for getting the best optimized solution. The inverted model's output in terms of fault structure, observed and inverted gravity

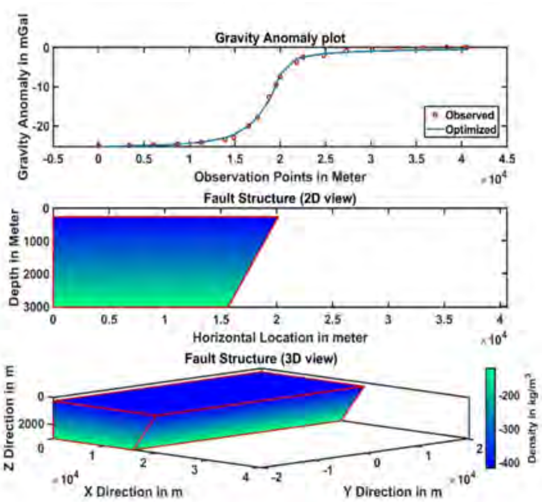


Fig. 3.1.13.1: Aswaraopet Boundary Fault, India having parabolic density distribution and corresponding observed gravity anomalies.

anomalies and dip, and vertex location of fault plane can be viewed in the graphical user interface at the end of the optimization process. The optimization algorithm is applied to different synthetic models with fixed and depth-varying density contrasts. All synthetic models are further contaminated with white Gaussian noise for sensitivity analysis, and detailed uncertainty appraisal was also performed for the reliability estimation. Finally, the optimization is implemented for fault structure inversion of the Aswaraopet boundary fault, India, and found that the optimized solution provides a good agreement with the previously published literature. Optimized results indicate that this novel optimization approach demonstrates a robust implementation of fault inversion for any depth-varying density distributions

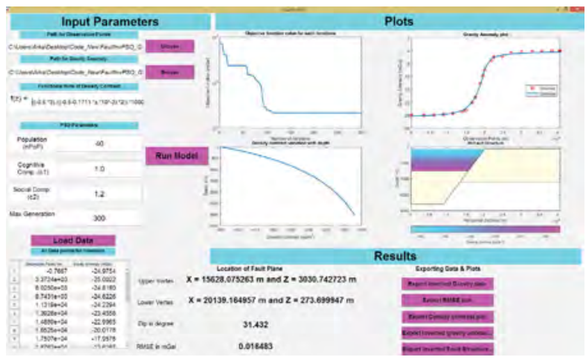


Fig. 3.1.13.2: Overview of FaultInvPSO graphical user interface.

https://doi.org/10.1111/1365-2478.13094

Arka Roy, Thatikonda Suresh Kumar

3.1.14 Gravity inversion of basement relief using Particle Swarm Optimization by automated parameter selection of Fourier coefficients

A global optimization technique using particle swarm optimization (PSO) is presented to estimate the depth to the basement of a heterogeneous sedimentary basin from the vertical component of the residual gravity anomalies. Inversion of basement relief for known density distributions has particular importance in many real applications such as mineral exploration, geothermal exploration, etc. Generally, gravity inversion in the Fourier domain allows a reduction in the optimization parameter. However, in the present study, an automated parameter selection criterion is developed for further reduction of optimizing parameters. A detailed uncertainty appraisal analysis is also performed for different configurations of synthetic models, which ensures the reliability of the optimization technique. All synthetic models are contaminated with white Gaussian noise, and an optimized depth profile is compared with noise-free data for sensitivity analysis. The result shows the robustness of the optimization method in the presence of noise. The technique is implemented on two real gravity anomaly profiles (1) Godavari basin, India, and (2) Sayula basin, Mexico. The optimized depth profile shows a good agreement with the published results using other optimization techniques. The method developed in the present work is a novel approach for the automatic selection of parameters as per the model's complexity. It provides an inversion technique that considers a small number of parameters with a minimum computational expense.

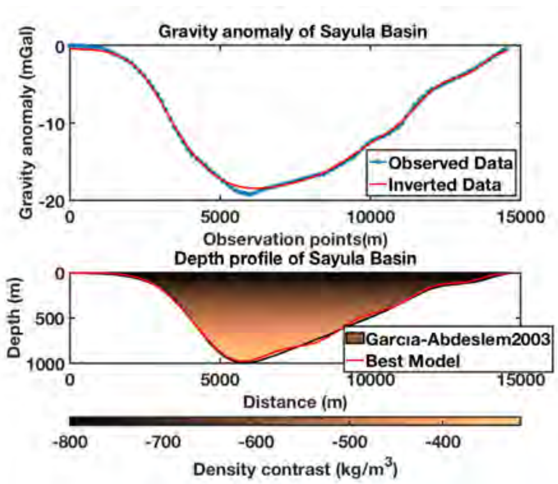


Fig. 3.1.14.1: Observed profile from Sayula basin, Mexico having depth varying density contrast. Blue dotted curve in upper panel represents the observed gravity field, solid red line shows inverted gravity field, and filled region in lower panel represents depth profile estimated by García-Abdeslem (2003) and red solid line represents inverted sedimentary basin using present Model.

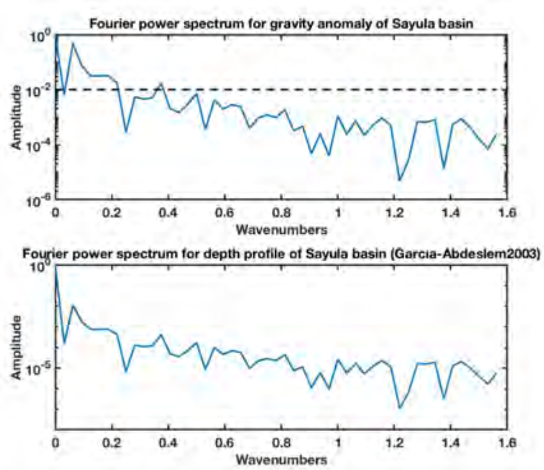


Fig. 3.1.14.2: Fourier power spectrum of gravity anomaly and depth profile for Sayula basin, Mexico. The upper depth bound for the inversion is 5660 m.

https://doi.org/10.1016/j.cageo.2021.104875

Arka Roy, Chandra Prakash Dubey, Muthyala Prasad

3.1.15 Structure estimation of 2D listric faults using Quadratic Bezier curve for depth varying density distributions

A contemporary and decisive optimization algorithm is developed for inverting gravity anomalies due to listric faults. The cross-section of listric faults is generally concave up, and the dip of the fault plane gradually decreases with depth. Quadratic Bezier curves are utilized to represent the curvature of the fault plane. The densities of sediment deposition are assumed to be known and can take any linear or non-linear functional form of depth. By constraining the density, a global optimization algorithm is adopted to estimate the fault structure by inverting control point parameters of Bezier curves. The presented algorithm is implemented in two different synthetic models having fixed and depth varying density contrasts. The robustness of the algorithm is authenticated by incorporating white Gaussian noise into synthetic gravity anomalies. A detailed uncertainty appraisal is also performed to justify the reliability of the algorithm. Finally, a real structure is reconstructed using observed gravity anomalies, and the estimated structure is verified with the structure obtained in previously published literature. Furthermore, a Matlab based GUI is developed such that any user can estimate real listric fault structure without any computational difficulties.

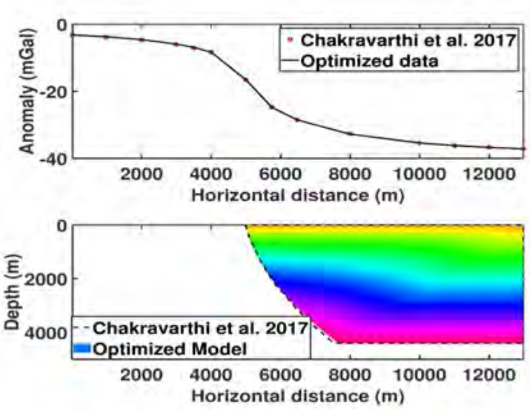


Fig. 3.1.15.1: Inverted Fault structure for Ahiri-Cherla master fault having parabolic density contrast.

Fig. 3.1.15.2: The user interface of ListricFaultInv GUI.

https://doi.org/10.1029/2021EA002061

Arka Roy, Thatikonda Suresh Kumar, Rajat Kumar Sharma

3.2 Crustal Dynamics Group

3.2.1 Slope stability and landslides: Runout modelling and detailed stability investigation of Taliye landslide, Maharashtra

The Taliye landslide (Fig. 3.2.1.1) that occurred in Maharashtra is a hill slope debris flow, one of the recent large-scale landslides in India in terms of mortality and socio-economic predicaments. A post-event engineering geological investigation and numerical modelling of this landslide have been carried out to have a closer look at its type and causes of failure, as well as to elicit its flow characteristics. In general, this area exhibits a moderately dissected plateau relief and the landslide has occurred on a north-westerly slope of a west trending major ridge. The in-situ rock was identified to be basalt of Diveghat Formation, which is dark grey in colour and fine-grained in texture. The debris present in the landslide zone is mostly comprised of unassorted, uncompacted basaltic rock fragments. The landslide initiated as a translational failure of shallow overburden, later transformed to a sheet type hill slope debris flow. The total runout of this landslide is 563 m and it has a maximum width of 230 m at the toe. The persistent downpour and presence of a small stream course are thought to be the prominent triggering factors; however, obstruction to surface runoff of rainwater and stream by improper terracing might have augmented the scale of initial translational failure. The numerical modelling package, rapid mass movements (RAMMS) was used to back analysis of this debris flow, using the flow shape. For the precise calibration of Voellmy frictional parameters (dry and turbulent frictional coefficients, μ and ξ respectively), this study introduces the popular receiver operative characteristics (ROC) technique as a model validation tool. Amongst the different combinations of frictional parameters experimented, the model with dry frictional coefficient of 0.06 and turbulent frictional coefficient of 1450 m/s2 has emerged as the best with an area under the curve value of 0.883 for the ROC assessment. With the best frictional parameters, the maximum flow velocity is simulated to be 5.26 m at the middle reaches (Fig. 3.2.1.2), and the maximum flow velocity and pressure are calibrated as 21 m/s and 0.92 kPa (Fig. 3.2.1.2), respectively in the hillock region.

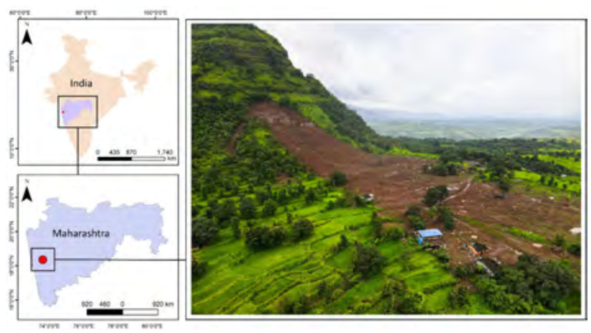


Fig. 3.2.1.1: Location and panoramic view of Taliye landslide.

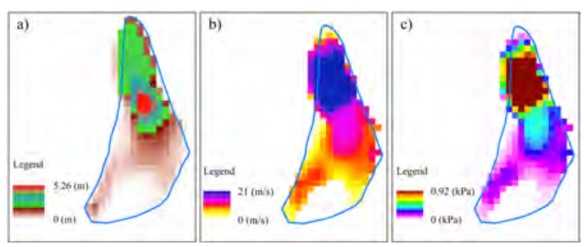


Fig. 3.2.1.2: Predicted flow parameters of debris flow, a) flow height, b) flow velocity and c) flow pressure.

Nandakumar V., Bipin Peethambaran

3.2.2 Paleo-fluids in the petroliferous basins of western offshore, India

First full-fledged facility to study the oil-bearing fluid inclusions in the various petroliferous basins established in NCESS. Special wafer preparation technique has been developed to visualize hydrocarbon fluid inclusions (HCFIs) without background interference. Also developed a technique to determine the American Petroleum Institute's (API) gravity- a measure of oil quality- present in micron sized HCFIs and patented the same. Identified the HCFIs constituents using Raman shifts and a 785 nm diode laser and it was the first of its kind effort internationally. Determined the oil window in sedimentary basins (Mumbai offshore and Kerala-Konkan) using micro-thermometric analysis. A potential fluid inclusion technique to determine the paleo temperature in petroliferous basins was established. Identified carrier beds in dry wells where hydrocarbon trails are observed signalling secondary migration.

The data obtained from micron sized fluid inclusions are valuable tools in reconstructing fluid flow histories through the carrier beds and its accumulation in the reservoirs. The Temperature of homogenisation (Th) data of coeval aqueous fluid inclusions as well as hydrocarbon fluid inclusions (HCFIs) obtained from microthermometric studies of fluid inclusions have been experimentally infused for the thermal history modelling in Petroleum System Model (PSM). The paleotemperature (Th) is a direct parameter that can be obtained through microthermometric measurements of fluid inclusions.

Integration of fluid inclusion data in Petroleum System Model for two wells RV-1 (proven) and KK4C-A1 (non-proven)- designated as dry wells from Mumbai offshore basin and Kerala Konkan basin initiated. For this study two sets of Petroleum System Models were considered and calibrated using Fluid Inclusion Temperature (FIT) and Bottom hole temperature (BHT) to find the generation and expulsion. The Mumbai offshore well (RV-1) is showing ~1.2Mtons of maximum generation starting from Early Eocene (~51Ma) to Pleistocene (1.8Ma) and zero expulsion in BHT calibration model, whereas FIT calibration model is showing a ~2.8Mtons of generation starting from Early Eocene (~51Ma) to Pleistocene (1.8Ma) and expulsion of ~2.4Mtons in Middle to Late Miocene (~10.1Ma) indicating an improved generation- expulsion history. However, the FIT calibration is indicating expulsion to a tune of almost generation and the presence of HCFIs especially in secondary fractures alone is indicating migration to other areas. The dry well from Kerala-Konkan basin is yielding ~0.2Mtons of generation (~32Ma, Early Oligocene) and zero expulsion for BHT calibration model and FIT calibration model. Nevertheless, the low API gravity obtained from our previous fluorescence-based studies and fluid inclusions indicate heavy to very heavy bitumen like hydrocarbon presence in the KK4C-A1well. The inference drawn from two well points to the need of migration studies using 2D modeling, which will be taken up in due course, using PetroMod software.

Mackenzie heat flow calibration using BHT is done in most of the oil exploration industry, but our new approach for the calibration using the paleotemperature (Th) from FIT is showing perfect fit into the curve suggesting that FIT is a reliable method.

Silpa Thankan, Nandakumar V., Shivapriya S.

3.3 Hydrology Group

3.3.1 Groundwater chemistry of a mountainous catchment with complex geologic and climate gradients, SW India

Mountainous catchments are one of the world's important water sources and sustains a major portion of global population and a rich biodiversity. The groundwater quantity and quality of mountainous watersheds depend generally on the geologic characteristics and climate gradients. Although many groundwater studies have been carried out in the midlands and lowlands of many river basins, not much attention has been paid to the mountainous catchments, especially of the tropical watersheds. Here we report a case study on the groundwater quality and its controlling factors of a mountainous catchment in the Western Ghats ranges of peninsular India - the Bhavani River basin, which is identified as a testbed for Critical Zone studies by the National Centre for Earth Science Studies (NCESS). A total of 88 water samples were collected seasonally for assessing various physico-chemical parameters, solute contents and scaling properties. The results of the study revealed the presence of higher pH and Total Dissolved Solids (TDS) in the talc-tremolite dominated central zone of the watershed whereas low values in the charnockite dominated areas. The major cations in the water samples are of the order $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ and the anions are of the order $HCO_3^{-} > Cl^{-} > SO_4^{2-}$. The content of Cl^{-} shows higher values in the samples close to agricultural/settlement areas. An overall evaluation shows that the hydrochemistry of groundwater in the studied watershed is influenced both by silicate and carbonate weathering. Principal Component Analysis and Agglomerative Hierarchical Clustering indicated that the water quality variations are mainly due to geogenic/natural processes. However anthropogenic factors also had significant effect in the agricultural/settlement dominated areas. Mineral stability indices computed for the groundwater reveal that 52% of the samples are supersaturated with carbonate minerals and often exhibit scaling due to solute overloading. Saturation Index and mineral stability diagram also support that the incongruent dissolution of aluminosilicate minerals (silicate weathering) is an important hydrochemical process influencing the chemistry of groundwater. Langelier saturation index (LSI) and Puckorius scaling index (PSI) worked out for the samples indicate that a significant number of open well and borewell samples exhibit scaling tendency. Among the contributing factors that determine water quality of groundwaters, chemical weathering and anthropogenic activities play a significant role. Long-term monitoring of the hydrochemical characteristics of the groundwater in the region could unravel the source contribution and future trends in hydrochemical characteristics of the groundwater systems in intensely managed agricultural areas in arid and semi-arid regions.

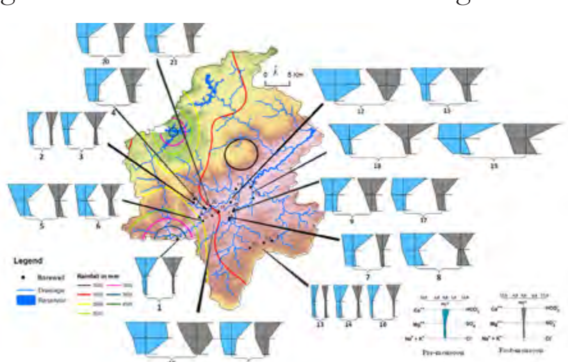


Fig. 3.3.1.1: Spatial variation of cations and anions in the pre-monsoon and post-monsoon seasons of borewell samples in the upper Bhavani River basin.

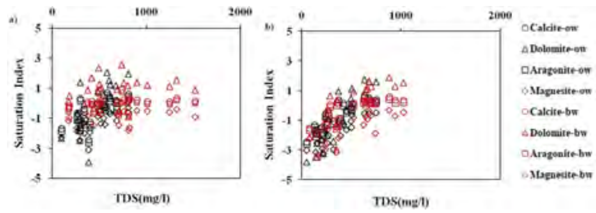


Fig. 3.3.1.2: Plots of Saturation Indexes with respect to TDS for (a) pre-monsoon and (b) post monsoon seasons.

https://doi.org/10.1007/s12665-021-09862-6

Gayathri J. A., Vipin T. Raj, Sreelash K., Maya K., Vandana M., Padmalal D.

3.3.2 Freshwater sources of Kerala – Hydrometeorological scenarios, environmental threats and management strategies

Kerala state in the southwest India receives an annual average rainfall of about 3000 mm. However, providing uninterrupted freshwater supply to the community round the year is a major challenge to the water managers in the state because of many factors including high population density, increased human interventions in the river catchments, environmental effects due to climate change, etc. It has now become more and more evident that the nature and contributions of rainfall, especially its pattern, have been changing drastically over the years, aggravating incidences of floods and landslides in wet (raining) season and water scarcity in dry (summer) season. Although such incidences were minimal in the pre-liberalization period (pre-1991), their recurrence and impacts are getting aggravated in the post-liberalization period (post-1991) - a period that witnessed severe environmental degradation due to rapid urbanization and economic development in the region. As per the records of the river gauging stations in the state, the number of no-flow/low flow days are increasing even in the lowland reaches of the major rivers. The adverse impacts of unabated groundwater abstraction/pumping are on the rise in many parts of the state, as the activity is being carried out without due regard to the safe yield and natural recharge capability of the aquifer systems. The rapidly changing water scenario of the state in the pre-and post-liberalization periods needs a thorough investigation, especially in regard to the structure and functions of its near surface terrestrial environment called the Critical Zone. It is certain that the stress in the Critical Zone will have a direct effect on the quality, quantity and availability of the freshwater resources in the surface and subsurface sources, which needs to be addressed adequately for laying down strategies for the conservation and management of the state's water sources.

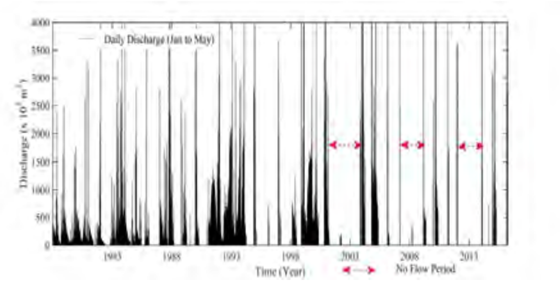


Fig. 3.3.2.1: Time series of the daily streamflow during the months of January to May of the Vamanapuram river depicting the increasing number of low flow days during the recent decade.

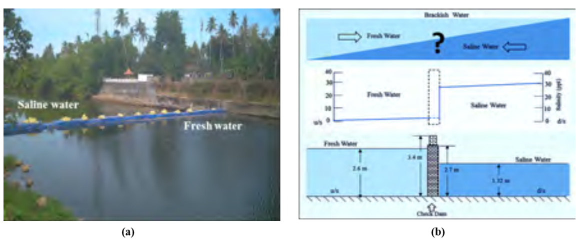


Fig. 3.3.2.2: (a) The existing check dam in the downstream reach of Vamanapuram river acting as a barrier between the freshwater and saline water and (b) Schematic of the freshwater-saline water mixing zone and the changes that has occurred due to the check dam.

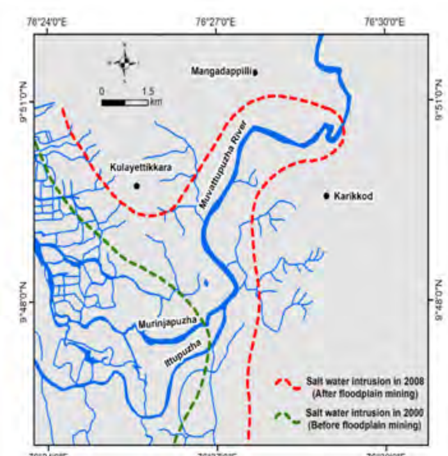


Fig. 3.3.2.3: Saltwater intrusion due to indiscriminate floodplain sand mining using high power get pumps- A case from the downstream reaches of Muvattupuzha River

Special Publication, Geological Society of India, No. 10, 2021.

Sreelash K., Arulbalaji P., Maya K., Padmalal D.

3.3.3 Major element chemistry of the Bhavani River, SW India – weathering processes and solute transport

Rivers are the natural pathway of geochemical signals from terrestrial environment to the ocean realm. However, this life sustaining system operating in tropics and subtropics is more reflexive to the adversities of urbanization, industrialization and other human interventions. The problem is severe in the case of small rivers that are more responsive to externalities. A study has been conducted to address the major ion chemistry and solute transport of one of the important east flowing rivers of Kerala, the Bhavani River that drains through different geologic and climate gradients. Hydrochemical data of the Bhavani River, in different stretches of the river, was obtained from field work, sampling and *in-situ* and laboratory analysis. In order to understand the spatio-temporal changes in the river water chemistry and causal mechanisms behind the changes in the long-term discharge characteristics, data from three gauging stations (Nellithurai, Thengumarahada and Savandpur) have been obtained from the Central Water Commission (CWC) via the surface water module of the India - WRIS (Water Resources Information System). The eastern part of the river basin experiences semi-arid/ arid climate with rainfall essentially predominated by the northeast monsoon, but the western most part of the river basin experiences humid climate with a dominant southwest monsoon. The controlling factor of the major ion chemistry of the river was studied using Gibbs's model and it indicates that the chemistry of the river water is controlled mainly by silicate weathering rather than precipitations. The river water chemistry of Bhavani River is dominated by Ca, Na and HCO_3. The hydrochemical analysis shows that majority of the water samples are of Ca-HCO_3 type. The particulate load/ dissolved load ratio of the Bhavani River is much less than that of the west flowing rivers of Kerala indicating the dominance of chemical weathering and evaporation over physical weathering.

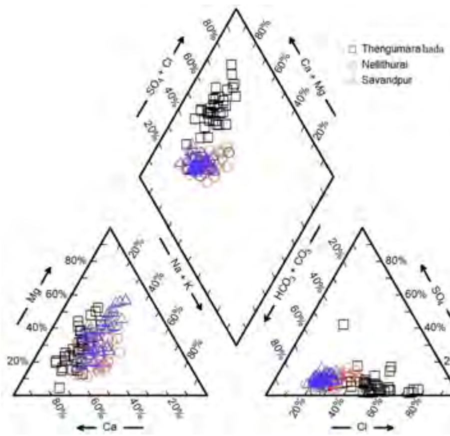


Fig. 3.3.3.1: Piper diagram showing the water chemistry in the gauging stations.

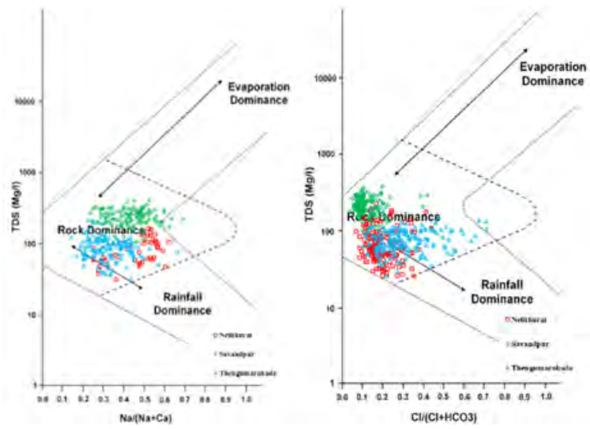


Fig. 3.3.3.2: Gibbs plot of Bhavani River at Nellithurai, Thengumarahada and Savandpur gauging stations.

This work was done in collaboration with Prof. K. Sajan, Cochin University of Science and Technology.

Special Publication, Geological Society of India, No. 10, 2021.

Vipin T. Raj, Gayathri J. A., Vandana M., Sreelash K., Padmalal D.

3.3.4 Spatiotemporal variability of rainfall and its effect on hydrological regime in a tropical monsoon-dominated domain of Western Ghats, India

Rainfall is an essential component of most hydrological processes and its spatiotemporal distribution and changing characteristics can have profound impact on agriculture, ecosystems and water resource management. With increasing concerns about intensification of climate change, it is essential to understand the nature and variability of rainfall and its changing patterns at different spatiotemporal scales, for effective management of water resources, especially, in regions with marked spatiotemporal variability in rainfall. A study has been conducted to assess the spatiotemporal changes in the rainfall pattern (trends in monthly, seasonal and annual rainfall, number of dry/wet days, total rainfall from dry/wet days, prolonged dry/wet spell, rainfall from low, moderate and high intensity daily rainfall events, and seasonality of rainfall) in six river basins of a tropical monsoon dominated state of Kerala, using a 28-year (1991- 2018) rainfall data. Further, the impact of changes in the rainfall and its characteristics on the hydrology (in terms of stream flow, groundwater level and evapotranspiration) of the river basins were analysed. The results in general shows a weakening of the monsoon rainfall over the Kerala region during the past two decades. A decreasing trend in rainfall was observed in the annual and monsoon seasons, while an increasing trend was observed in the pre-monsoon season. Significant decreasing trend in the rainfall was observed in the months of June and July followed by an insignificant increasing trend in the month of August and September. The magnitude of trends in rainfall during 1991- 2018 was found to be significantly higher than the trends over longer periods, indicating an accelerated change in the rainfall pattern during the recent decades. Analysis of rainfall characteristics indicates that the monsoon droughts are becoming more predominant throughout Kerala. This is evident from the decreasing trend in the total number of wet days, prolonged wet spells and the total rainfall from the wet days and increasing trends in the total number of the dry days, prolonged dry spells and the total rainfall from dry days in the case of annual rainfall and monsoon rainfall. The total rainfall from moderate and heavy rainfall events showed a decreasing trend, while the rainfall from low rainfall events showed an increasing trend in the studied basins. The decreasing trends in Seasonality Index (SI) reveals that the rainfall distribution has become more symmetric over the years. Controls of physiographic features on rainfall was evident. The declining trend in the monthly, seasonal and annual rainfall was found to be more predominant in the lowlands, followed by midland and highlands. The effect of the changes in the rainfall characteristics was evident on the hydrological regime of the studied river basins. The decline in stream flow both at seasonal and daily time scales and decline in groundwater levels indicate the effect of changing rainfall patterns on the hydrology of the studied river basins. The study calls for a revised plan for water management, adaptive cropping pattern and reservoir operations in the state of Kerala.

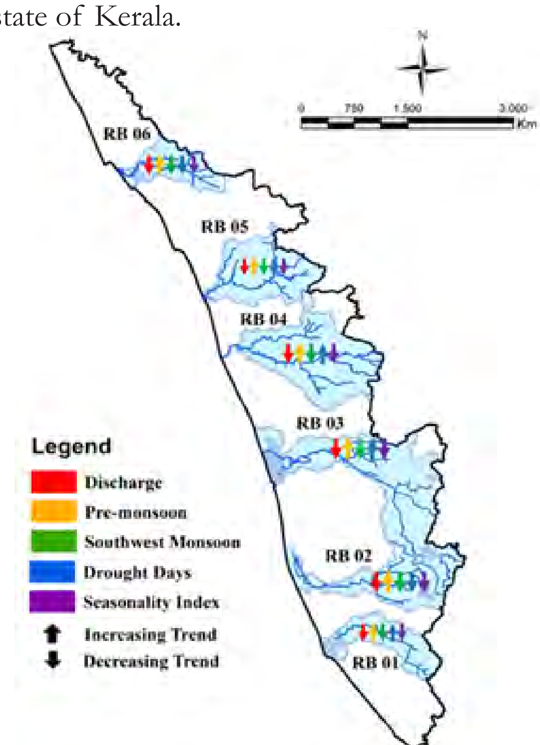


Fig. 3.3.4.1: Changes in the streamflow, seasonal rainfall, dry spells and seasonality index of the different river basins in Kerala (RB01 – Kallada, RB02-Pampa, RB03-Periyar, RB04-Bharathapuzha, RB05-Chaliyar and RB06-Valapatnam.

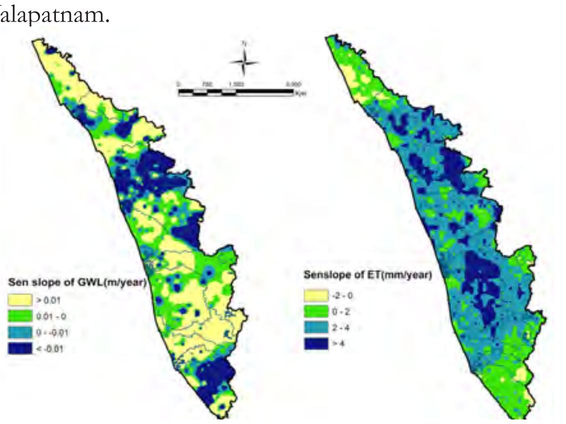


Fig. 3.3.4.2: Spatial variation of the trends in groundwater level and evapotranspiration of Kerala.

https://doi.org/10.1016/j.ejrh.2021.100861

Merin Mariam Mathew, Sreelash K., Micky Mathew, Arulbalaji P., Padmalal D.

3.3.5 Moisture recycling and evaporation processes along the Western Ghats orography

The present study is intended to improve understanding on the variation of precipitation isotopic composition along multiple stations located at different elevations of Periyar River Basin (PRB) and a coastal (TRV) station (Fig. 3.3.5.1). The $\delta^{18}O$ variation with elevation across PRB revealed an abrupt depletion at the highland station and a pseudo-elevation effect due to the supply of evaporated local moisture from reservoirs and lakes. The contribution of recycled precipitation estimated using back trajectories suggested a maximum of 8.5% of

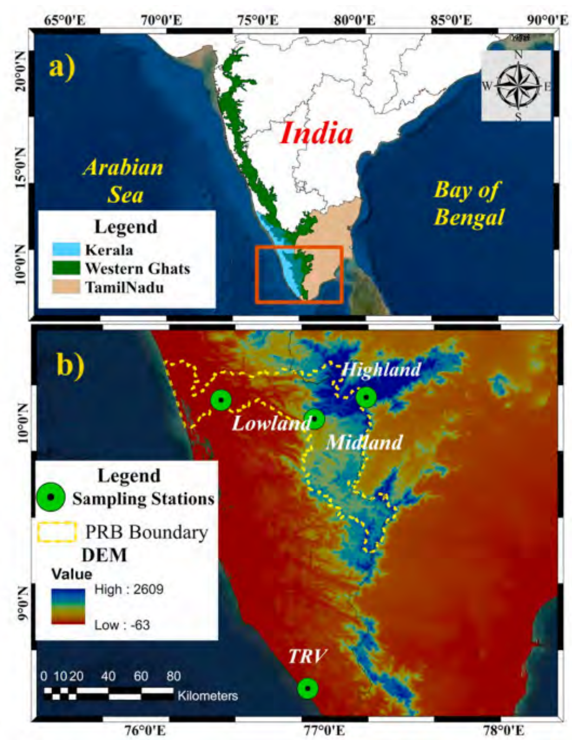


Fig. 3.3.5.1: (a) Study area in the Western Ghats Mountain range, (b) Digital Elevation Model (DEM) and location of sampling stations.

locally recycled rainfall over midland station towards September (Fig. 3.3.5.2). Though this approach did not show any signatures of moisture recycling in the highland station, the surface water (reservoirs and lakes) lc-excess (line-conditioned excess), and the d-excess (deuterium excess) values of precipitation suggested the higher rates of evaporation from large water bodies and their successive role in generating local rainfall. Statistically significant amount effects visible only along coastal stations with lower rates of precipitation and higher temperature indicate that precipitation along the Ghats region (midland and highland) is significantly controlled by orographic uplift of air moisture and the contribution from locally recycled moisture. This is further supported by the significant correlation of δ^{18}O with regional convective processes along the Arabian Sea till midland station and further decrease towards the highland. The study also provided an important information on the moisture feedback mechanism in the Western Ghats and the factors controlling the isotopic signatures over the region.

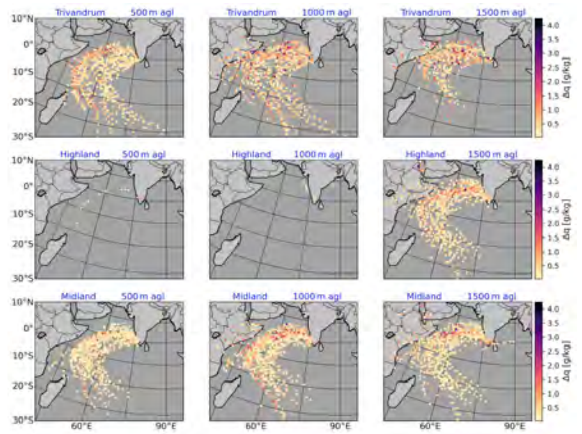


Fig. 3.3.5.2: Moisture uptake (Δq = +ve) locations along 168 h back trajectory reaching the sampling stations at different (500, 1000 and 1500 m agl) levels (Saranya et al., 2021).

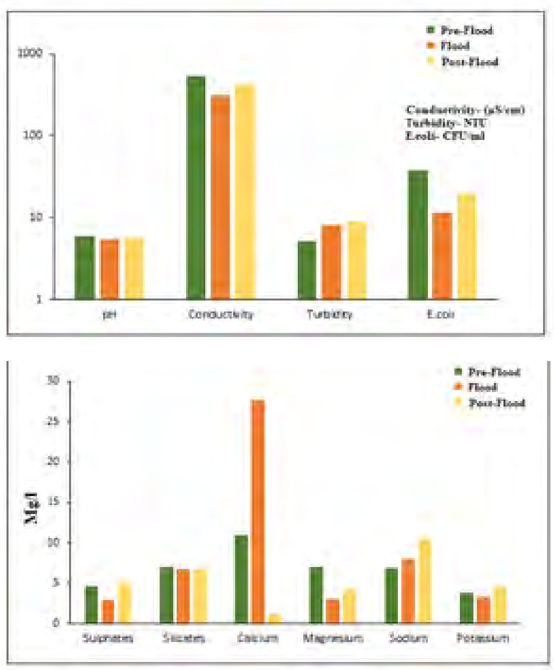
This work was done in collaboration with Nitesh Sinha, Center for Climate Physics, Institute for Basic Science, Busan, Republic of Korea and Sudhir Kumar, National Institute of Hydrology, Ministry of Water Resources, Roorkee

https://doi.org/10.1016/j.atmosres.2021.105863

Saranya P., Krishnakumar A., Anoop Krishnan K.

3.3.6 Impact of flood on groundwater hydrochemistry

Since the Periyar River Basin (PRB) is endowed with several reservoirs and dams, the basin had witnessed the impact of climate change and is reflected in many ways including flooding (2018 and 2019). The qualitative aspects of surface and ground water resources in the basin revealed that flooding has tremendously impacted the Surface Water (SW) resources while Ground Water (GW) was not much affected. The results of the impact of flood in the lowland reaches of GW resources of PRB showed that parameters like pH, TDS, EC, TH, NH_3^-, NO_2^-, HCO_3^-, SO_4^{2-}, SiO_4^{4-}, Mg^{2+}, and K^+ were decreased during flood time compared to pre-flood period. On the other hand, Ca^{2+}, Na^+, and Cl^-, turbidity values were increased during flood times. Values of pH, TDS, EC, turbidity, NH_3^-, HCO_3^-, SO_4^{2-}, SiO_4^{4-}, Mg^{2+}, Na^+, and K^+ were slightly increased in post-flood period compared to flood period. When compared to the pre-flood values, turbidity, NH_3^-, SO_4^{2-}, Na^+, and K^+ were slightly increased in post-flood period. It was also observed that pH, TDS, EC, TH, NO_2^-, Cl^-, HCO_3^-, SiO_4^{4-}, PO_4^{3-}, Ca^{2+}, Mg^{2+}, and E. coli values were higher in pre-flood periods compared to post-flood period (Fig. 3.3.6.1) (Discussed in detail in doi.org/10.1007/s11356-021-17596-y). The Piper plot indicates dominance of Ca–Mg–HCO_3 type in pre-flood, and mixing of Ca–Mg–HCO_3 type in both flood and post-flood periods. The USSL plot depicted that 92–96% of samples are



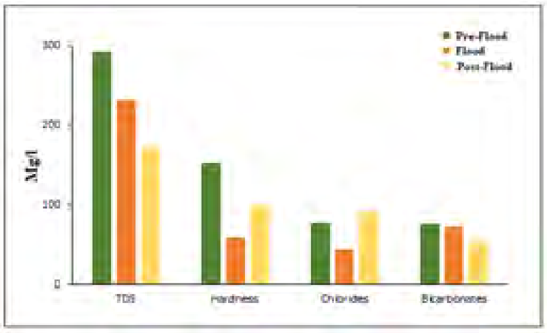


Fig. 3.3.6.1: Comparative variation of different hydrochemical parameters during pre-flood, flood and post-flood periods

noted as lower salinity and low sodium hazard; however, 4–11% of samples are noted as high salinity but low sodium hazard. The Wilcox diagram indicates that, 88–96% of groundwater was found as higher suitability for irrigation during the study periods. Based on WQI model, out of the 26 samples studied, 69% of wells showed improvement in water quality after flood; meanwhile, 19% well water samples in flood were observed for lower quality compared to pre-flood times and 12% of samples remain unchanged during flood (Fig. 3.3.6.2). Though floods are having positive and negative impacts, it is clear that quality of the groundwater in the RPLB is not severely affected, but they became diluted to permissible limits during flood and post-flood periods.

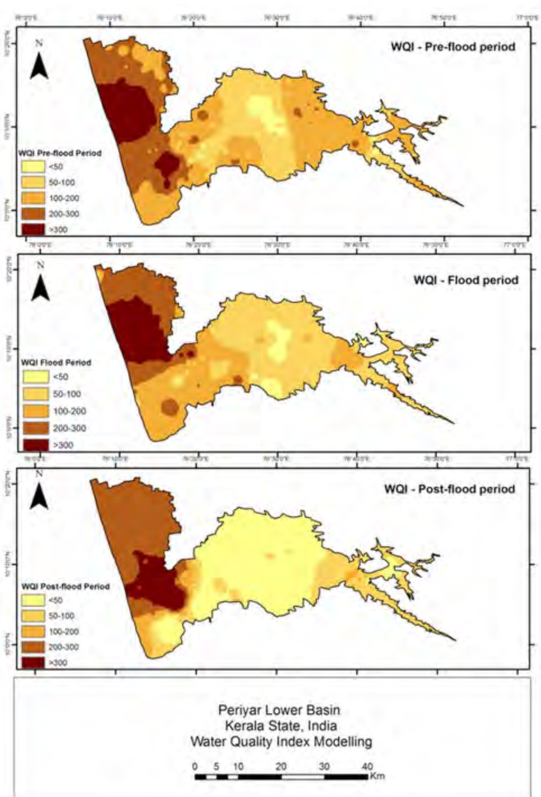


Fig. 3.3.6.2: Spatio-temporal variability of Water Quality Index for pre-flood, flood and post-flood periods.

https://www.doi.org/10.1007/s11356-021-17596-y

Krishnakumar A., Jeenu Jose, Kaliraj S., Aditya S. K., Anoop Krishnan K.

3.3.7 Water quality assessment of tropical freshwater lakes of Kerala

Besides the direct anthropogenic and climate change influence on riverine systems, lakes and wetlands are also under the threat of global environmental changes and human interventions. Therefore, the baseline data on water quality and their influencing factors in some of the important lakes were studied to strengthen our understanding on these systems. For this study, a total of 60 surface water samples, 20 samples each from the three lakes were collected from the Vellayani, Sasthamcotta and Pookot lakes (Fig. 3.3.7.1). The results of

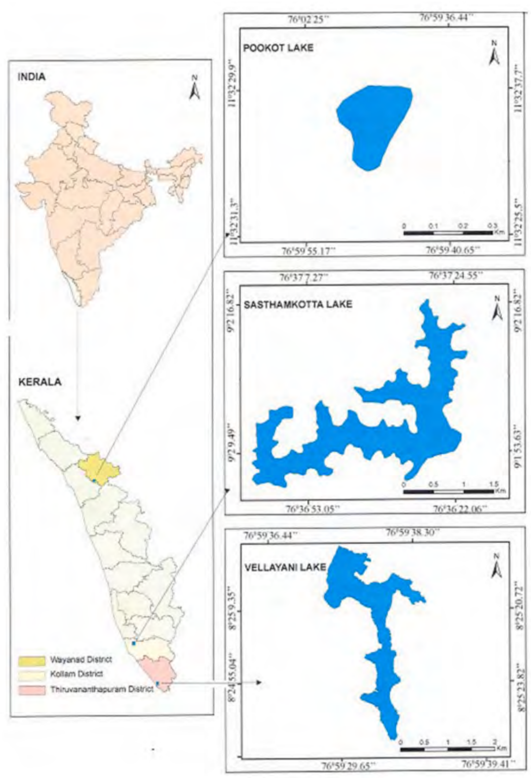
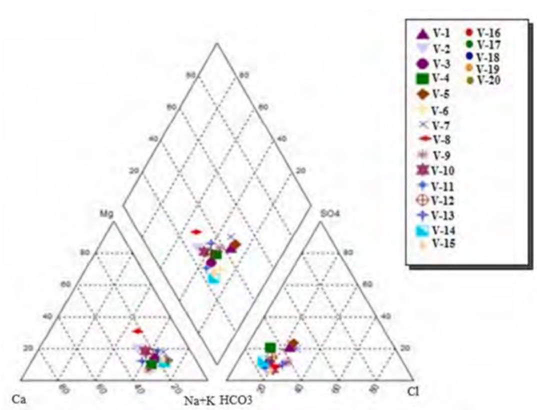
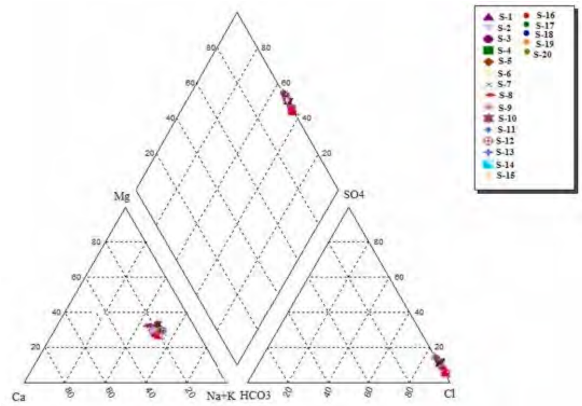


Fig. 3.3.7.1: Location map of the study area.

the analyses were compared with maximum permissible limit values recommended by World Health Organization (WHO) (2017) and Bureau of Indian standards (BIS) (2012). The annual concentration of majority of the constituent parameters showed an increasing trend. TDS values of Sasthamkotta (mean TDS > 500 mg/l) and Vellayani lakes (mean TDS > 500 mg/l) reflect the turbid and contamination scenario of the freshwater ecosystems. Increased concentration of primary nutrients like NO_3^- (mean >4 mg/l) and PO_4^{3-} (mean >3 mg/l) in Vellayani lake depict nutrient enrichment, both from anthropogenic influences and runoff from point and nonpoint sources. The observed hydro-chemical facies were $NaHCO_3$ for Pookot lake, NaCl with subordinates of Ca and Mg for Sasthamkotta lake and $NaHCO_3$ with subordinates of SO_4^{2-} for Vellayani lake, based on Piper trilinear diagrams (Fig. 3.3.7.2). Water Quality Index (WQI) were calculated for evaluating influence of natural and anthropogenic activities based on several key parameters (pH, EC, TDS, HCO_3^-, Cl^-, SO_4^{2-} , NO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+) in surface water chemistry. As per the WQI, majority of the samples in the three lakes, based on the observed chemical constituents were falling under 'good' category but the real havoc was existed due to bacteriological contamination. It was observed that there was an increased count of coliforms in the lake waters of Vellayani (140 MPN/ml), Sasthamkotta (260 MPN/ml) and Pookot (90 MPN/ml), which must be zero for drinking needs, according to WHO (2017) and BIS (2012) drinking water guidelines. The increased microbial population in all the three lakes indicate the unhealthy practices in the lake





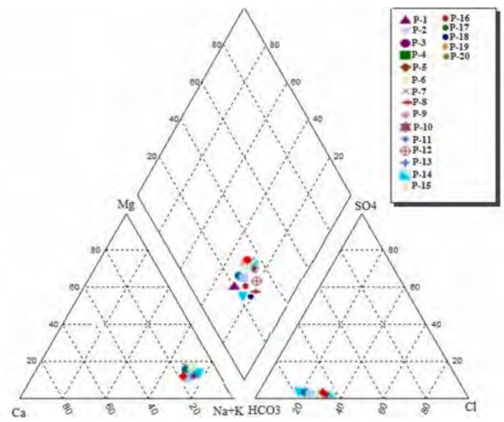


Fig. 3.3.7.2: Piper trilinear diagram showing ionic concentration in Vellayani, Sasthamkotta and Pookot lakes.

catchments. Therefore, sustainable management measures should be taken to improve the water quality of the fresh water resources of Kerala.

This work was done in collaboration with Dhanya Thulseedharan of Department of Physics, University of Kerala

https://doi.org/10.1016/j.enmm.2021.100588

Revathy Das, Krishnakumar A., Ratheesh Kumar M.

3.3.8 Implications of methane emissions in biogeochemical budgeting

Studies were conducted on freshwater lake ecosystems in Southern WGs for qualitative water analysis and their role in regulating the GHGs concentrations in the atmosphere. Investigation was done on measuring the daytime pattern of methane emissions during pre-monsoon, monsoon, and post monsoon seasons from a tropical wetland system, namely the Vellayani lake located in the urbanized area of Thiruvananthapuram city in Southern India (Fig. 3.3.8.1). The difference in the methane flux from the vegetated littoral zone and non-vegetated limnetic zone and the edaphic features controlling the production and emission of methane were also studied. Methane emissions were measured using static chamber, and analyses were performed using gas chromatograph. The methane emissions recorded in monsoon season from vegetated littoral zone was significantly higher compared with pre- and post-monsoon seasons, indicating seasonal fluctuations in methane emission from the wetland system (Fig. 3.3.8.2). CH_4 efflux in the zone of emergent vegetation in the littoral zone was significantly higher than from the non-vegetated limnetic zone indicating the importance of vegetation in methane transport to the atmosphere. Positive correlation of CH_4 efflux with edaphic factors like total organic carbon and total nitrogen showed that these factors largely determined the production and emission of methane. These results underlined the fact that the vegetated littoral zones of lake, especially the emergent plant zones were supersaturated with CH_4 compared with non-vegetated zones, by facilitating the production of carbon for CH_4 emission, and also enabled the release of CH_4 by diffusion through the intercellular gas lacunas. The study arrives at the conclusion that the atmospheric CH_4 emissions will be altered by the growth of exotic species and may be the reason for enhancing the climate warming in local/regional environment and may be even important globally.

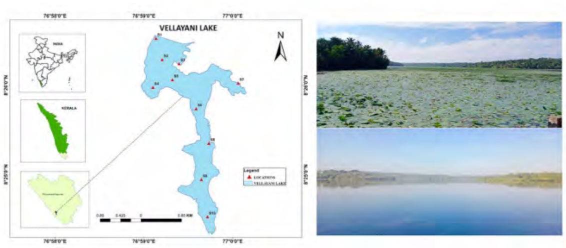


Fig. 3.3.8.1: Study area showing locations of samples collected, with photographs of vegetated littoral and open limnetic zone of Vellayani lake.

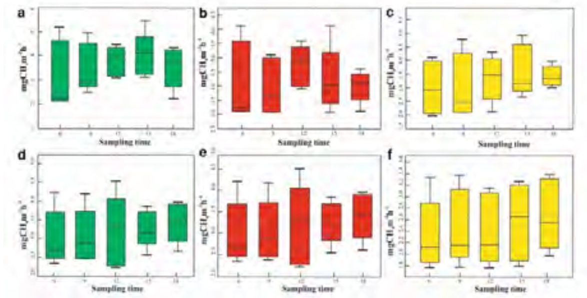


Fig. 3.3.8.2: Daytime variations of CH4 emissions from vegetated littoral and non-vegetated limnetic zone in different seasons.

https://doi.org/10.1089/ees.2021.0121

Revathy Das, Krishnakumar A.

3.3.9 Groundwater quality assessment using Entropy Water Quality Index

Studies were conducted in Kallada river basin (KRB) of WGs to assess the global environmental changes. The hydrochemical analysis of GW resources for studying the freshwater depletion and contamination indicates that the entire samples collected from the highland and midland stretches of the basin pertains to the desirable category for drinking purposes. The Entropy Water Quality Indices (EWQI) value indicates about 39% of samples as moderate quality water (rank-III) and 29% are of excellent quality (rank-I) confirming that the groundwater is nearly adequate for drinking targets during pre-monsoon while in monsoon and post monsoon seasons, EWQI values indicated 90% and 77% of total samples as excellent quality (rank –I) (Fig. 3.3.9.1). The groundwater samples procured from the lowland (estuarine) regions of the study area revealed that the prevalent cations are Na^+ and Ca^{2+}, and prevalent anion as Cl^-. This might have resulted from the man-made interventions and agricultural practices in the low-lying extents of the basin. The samples from majority of the open wells in KRB has been upgraded after the pre-monsoon season which points out the rainfall dominance in the monsoon season. The Principal Component Analysis (PCA) extracted three factors and the obtained results shows that Cl^-, TDS, Na^+, and Ca^{2+} ions contribute towards the moderate pollution load in groundwater (Fig. 3.3.9.2).

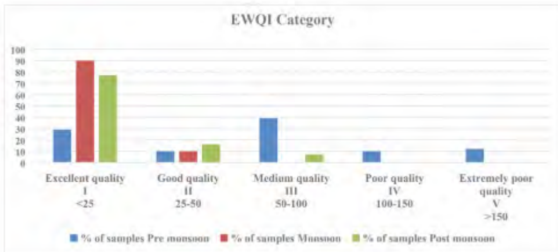


Fig. 3.3.9.1: EWQI category of Groundwater samples in the study region.

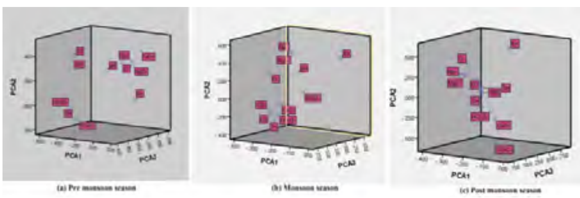


Fig. 3.3.9.2: PCA on 11 variables of groundwater samples during (a) pre-monsoon (b) monsoon and (c) post-monsoon seasons.

https://doi.org/10.1002/tqem.21840

Uma Mohan, Krishnakumar A.

3.3.10 Geochemical analysis of soils and sediments in Western Ghats

The geochemistry of soils and sediments are a topic of concern in contamination/ pollution purview to assess the potential impacts of anthropogenic interferences occurring in the environment since the soils of Sahyadri have a miraculous ability to absorb, and retain the rainwater and orient it to streams through the near surface springs. The highland regions of WGs are the largest producers of high yield cardamom, coffee, cocoa and spices and therefore as a result indiscriminate use of various pesticides, fertilizers and weedicides are observed in this region resulting in the deterioration of soil quality. The unscrupulous usage of agrochemicals in cardamom plantations, releases high levels of potentially toxic elements (PTEs) into the soils. The results of the soil samples collected from the highland regions of PRB revealed that the study area was contaminated with PTEs, and their observed average concentration was in the order Ba > Zr > V > Cr > Ni > Sr > Zn > Cu. Geochemical maps were generated to understand the hotspots in trace element contamination. Correlation matrix and factor analysis were applied to apportion the sources of PTEs. Enrichment factor and geochemical accumulation index indicated slight enrichment in all the elements analysed. The contamination factor varied from 15.41 to 25.58, signifying a considerable degree of contamination in the area with respect to soil pollution (Fig. 3.3.10.1). The pollution load index (PLI) values ranged from 0.97 to 1.99, indicating progressive deterioration of the sites (Fig. 3.3.10.1). High degree of contamination and PLI values implied that not only geogenic sources, but also intensified anthropogenic activities may contribute to trace element accumulation. This work provides insights on the accumulation of PTEs in the soils, which will pose a great health risk to the local population through the consumption of various agricultural products cultivated in the area. Moreover, the study identified the presence of acephate and fenvalerate as the major pesticide used while ethion is absent in all the samples. Accordingly, spatial variation diagrams were prepared.

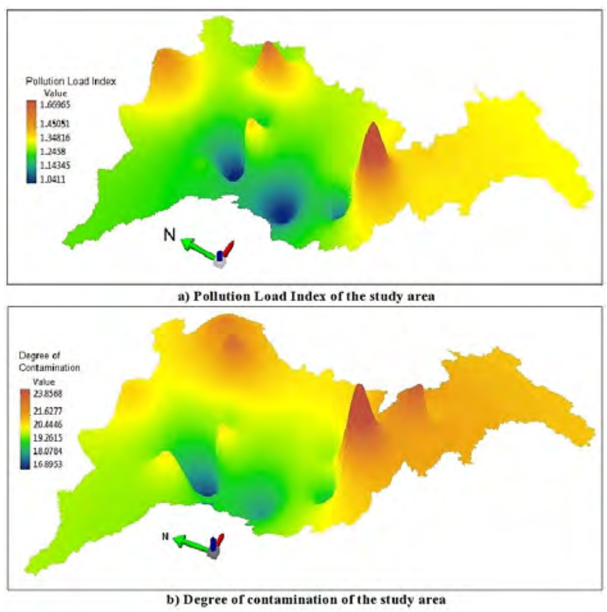


Fig. 3.3.10.1: Spatial variability maps showing distribution of PTEs in the agricultural soils of the study area.

https://doi.org/10.1002/tqem.21792

https://doi.org/10.1016/j.enmm.2021.100599

Krishnakumar A., Revathy Das, Aditya S. K., Anoop Krishnan K., Gayathri S., Vinu V. Dev, Shiny Raj R., Vishnu Maya T. M.

3.3.11 Geochemical aspects and contamination evaluation of major and trace elements in the sediments of Kallada river, southern Western Ghats, India

The sediment samples were analyzed from Kallada River Basin (KRB) to study the terrestrial biogeochemical cycling of elements and it was seen that the coastal sediments of KRB were polluted mainly by Zr which exhibits high values in the pre-monsoon season. Among the major elements, Ti is the only element which manifests slightly higher values in the pre-monsoon period. Zr showed exceptionally high values of geo accumulation index (Igeo) during all the seasons of study followed by Zn and Cr. The downstream stretches of the river showed very high degree of contamination (Cdeg) due to the discharge of untreated municipal sewage and waste from small-scale industries. Except Ti, Ca as well as Zr in coastal zones, the EFc values were less than 10 for all the minor elements during the three seasons of study. PLI values varied between 0 and 1.001 for the analyzed minor (trace) elements indicating non-polluted category. It was also observed that there are no substantial correlations among majority of the heavy metals, suggesting that the metals are independent with each other. Based on the textural analysis, it was observed that sediment samples predominantly come under sand and silty sand classifications and finds a strong association with Zr, Zn and Cr.

https://doi.org/10.1080/10934529.2022.2053450

Uma Mohan, Krishnakumar A.

3.3.12 Indian thermal springs

Thermal springs are important component of continental and submarine hydrothermal systems that involve the interconnected processes of heat and, chemical and aqueous fluid transport in the Earth's crust. Naturally heated waters emanating from thermal springs have been known to mankind and being used for recreational purposes for hundreds of years. These geothermally heated waters are also a clean, renewable resource that can be harnessed for use as heat and produce electricity. The prospect for geothermal energy in India is promising when considered the existence of large number of hot springs (more than 300) distributed in various physiographic/geologic domains of the country. A comprehensive review has been conducted on the widely distributed thermal springs in India from a hydrogeochemical and isotopic perspective. Detailed investigations over the last few decades culminated in the development of a vast geochemical database for thermal springs and associated gaseous phases. These representative datasets of thermal spring waters from different parts of the country have been evaluated following a classical approach, including water classifications that identified significant hydrogeochemical variations among different thermal spring clusters. Based on the geotectonic framework, the thermal springs have been classified into four groups: (a) Orogenic belt, (b) Areas of deep-seated faults and lineaments, (c) Rifts and grabens of Gondwana basin and (d) Deep sedimentary basin. Differences in rock-water interactions, and system characteristics such as water source, heat source, and topographic relief, were found to be the causes of observed variations. Thermal springs near the coast of western India have a high Cl content relative to Na, indicating that they have been influenced by seawater. Thermal springs in the northern territory have high HCO_3 and low Cl, suggesting that they have mixed with HCO_3-rich near-surface water. Due to their emergence from the periphery of Precambrian crystallines, most thermal springs in the central and eastern part of India are distributed within the Na-Cl and Na-Cl-HCO_3 type facies with low SO_4 content. Different geochemical thermometers such as silica, cation thermometers, and a combination of silica K-Mg systems were used to estimate reservoir temperatures, resulting in a temperature range of roughly 60-140°C. In general, the reservoir temperatures for thermal springs in India's northern and eastern parts are greater than

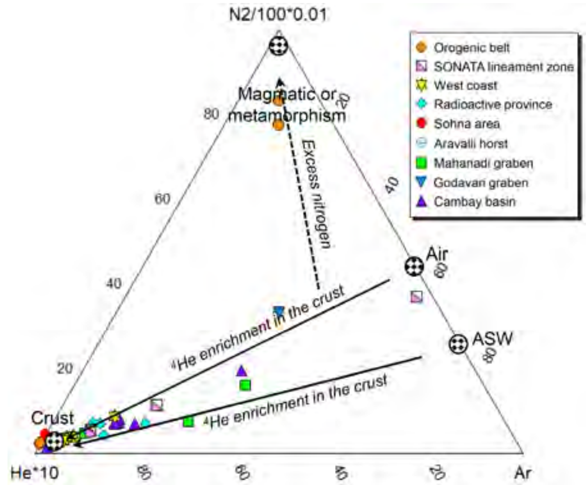


Fig. 3.3.12.1: N2-Ar-He ternary diagram for the gas samples of the Indian thermal springs. (ASW= air-saturated water).

those located in the southern and western continental margins. The chemistry of the associated gaseous discharges is dominated by atmospheric components. The exceptions are thermal springs from the Orogenic belt of Himalaya that are enriched with CO_2 possibly sourced from metamorphic decarbonation. The $^3He/^4He$ isotopic ratio in the gaseous discharge across all the groups and subgroups

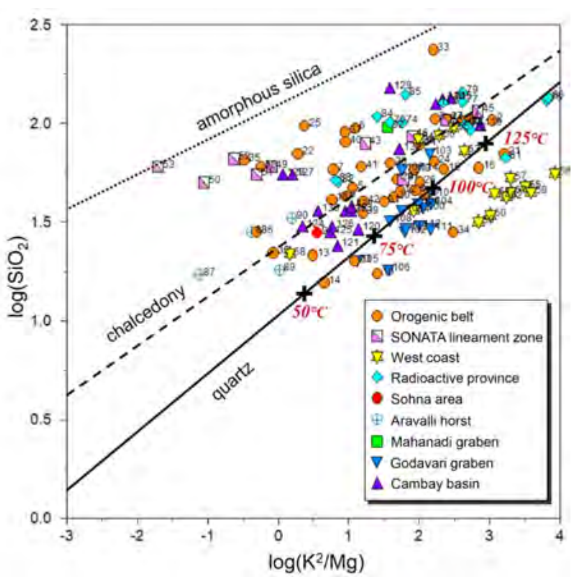


Fig. 3.3.12.2: The plot of log (SiO2) versus log (K2/Mg). The lines represent simultaneous attainment of equilibrium for the systems involving silica and K-Mg (Giggenbach and Glover, 1992).

predominantly bears signatures of crustal origin. Stable isotopic signatures strongly suggest that these hydrothermal systems are predominantly recharged by local meteoric waters. In contrast, a discernible positive oxygen-isotopic shift in thermal waters indicates the existence of high enthalpy reservoirs in the NW Himalayan region. Except for a few springs, long circulation time (>50 years) of meteoric waters within the conduit is indicated by low tritium values in the thermal waters.

https://doi.org/10.1016/j.earscirev.2021.103890

Prasenjit Das, Maya K., Padmalal D.

3.3.13 Paleoclimatic and paleoceanographic records from the Bay of Bengal sediments during the last 30 ka

The Bay of Bengal (BoB) is a semi-enclosed basin located in the north-eastern Indian Ocean which receives enormous fluvial sediment input primarily from the Himalayan and the Peninsular rivers depending on the Indian monsoon intensities. The seasonal reversal of monsoonal currents over the northern Indian Ocean leads to Indian monsoon which varies as a function of lateral migration of the Intertropical Convergence Zone (ITCZ) which in turn leads to both Indian Summer Monsoon (ISM) and Northeast Monsoon (NEM) over the BoB. Despite being such a dynamic region, the instrumental and oceanographic data for the BoB seldom goes beyond the last century which invigorated its long-term reconstruction of paleoclimate and paleoceanography, especially since last 30 ka, as it includes the most recent glacial period i.e., the Last Glacial Maxima (LGM: ~19–23 ka). Further, the last 30 ka also consists of several other globally recognized cold climatic events such as the Henrich events (H1: ~15–17 ka; H2: ~24–25 ka) and Younger Dryas (YD: ~12.9–11.8 ka) along with warm climatic events such as Bølling-Allerød (B/A: ~14.8–12.9 ka) and Holocene epoch (~11.8 ka - Present). In this work, a synthesis of paleoclimate and paleoceanographic reconstruction exclusively from the BoB and its nearby regions has been made with specific focus on the climatic events of last 30 ka. The study suggests that intensified NEM with simultaneous weakening of ISM during LGM was accompanied by a marked decline in Sea Surface Temperature (SST) of nearly 2–3°C, while strengthened ISM during B/A and Holocene with an intermittent ISM weakening during H1 and YD has been inferred. The NEM strengthening during LGM, led to enhanced sediment and water discharge from the peninsular rivers and reduced discharge from the Himalayan rivers in the northern and western BoB. Further, the weakening of Atlantic Meridional Overturning Circulation (AMOC) during YD and H1 led to diminishing water column stratification in the north-eastern BoB causing enhanced productivity.

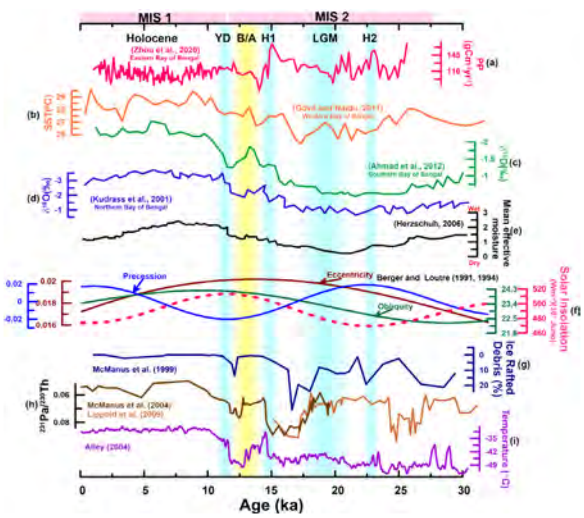


Fig. 3.3.13.1: (a-d) Paleoceanographic reconstruction from the Bay of Bengal and its comparison with the effective mean moisture reconstruction (e), solar and orbital forcing (f), ice rafted debris (g), Strength of Atlantic meridional ocean circulation (h) and temperature reconstruction (i).

https://doi.org/10.1016/j.jseaes.2022.105169

Nayana V. Haridas, Upasana S. Banerji, Maya K., Padmalal D.

3.3.14 Linkage of Indian monsoon with the North Atlantic climate during the Holocene: an emphasis on the Bond events

The high frequency of climate instability for the late Pleistocene has revealed the recurrence of Dansgaard-Oeschger (D/O) and Heinrich events (H). During the Holocene period, the Ice Rafted Debris (IRD) from the North Atlantic was identified as the Bond Event (BE) and were considered equivalent of D/O cycles. A close knitted association of the millennial-scale North Atlantic climate and the Indian Summer Monsoon (ISM) demonstrated a mechanistic link during the last ice age. However, a stable climate persisted during Holocene that witnessed trivial amplitude of North Atlantic climate influence compared to late D/O and H-events. Thus, it necessitates to address the linkage of ISM with the BE in order to exclusively investigate response of Indian monsoon towards the cold event of the North Atlantic Ocean during Holocene epoch. The BE has been numbered from 0 to 8 wherein 0 corresponds to Little Ice Age (LIA: ~0.4 ka) and 1 corresponds to Dark Age Cold Period (DACP: ~1.4 ka), while 2, 3, 4, 5a, 5b, 6, 7 and 8 correspond to ~2.8 ka, ~4.4 ka, ~5.5 ka, ~7.5 ka, ~8.1 ka, ~9.4 ka, ~10.3 ka, and ~11.1 ka of the BE climate events. Though the driving mechanism of BE remains uncertain, the reduced solar forcing and thermohaline circulation have been associated with the BE which in turn have hemispheric scale teleconnections. The ISM impacting the south Asian countries with significant rainfall over Indian landmass and nearby areas, has expounded a teleconnection with other climate variables and forcing factors. Despite having extensive studies on ISM reconstruction and reviews on the Holocene period, its climatic association with BE remains almost poorly understood. Here we reviewed the published marine and continental records that varied in accordance with the Indian monsoon system. The study revealed that the BE-5, 3, 2, 1, and 0 are well identified as weak ISM phases while enhanced winter precipitation was observed during BE-0 and possibly during BE-2. Despite the fact that limited studies have deciphered weak ISM during BE-4, 6, 7, and 8, further studies need to be explored address the response of ISM towards these north Atlantic climatic events. The study attempts to pave an understanding of the link and/or teleconnection of the ISM during each spell of the Bond events from 0 to 8 and highlights the response of marine and terrestrial archives from northern Indian Ocean and the Indian subcontinent to the BE during the Holocene epoch.

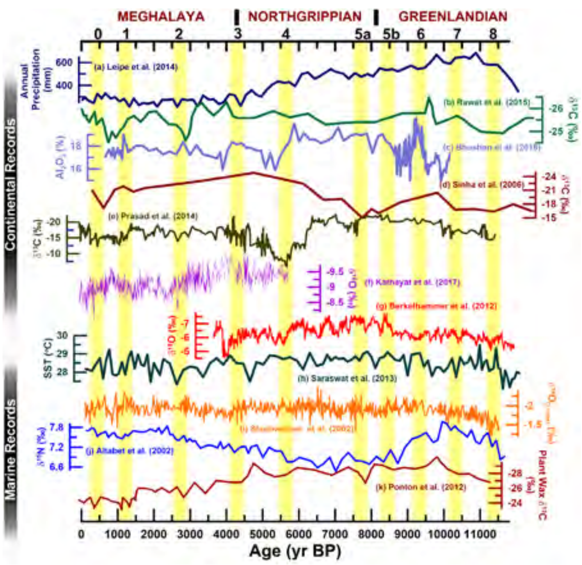


Fig. 3.3.14.1: Comparison of the continental and marine records from the Indian subcontinent and northern Indian ocean wherein the yellow bands represent the Bond Events from 0-8.

https://doi.org/10.1016/B978-0-323-90085-0.00016-4

Upasana S. Banerji, Padmalal D.

3.3.15 Holocene monsoon and sea-level variability from coastal lowlands of Kerala, SW India

The widespread Early Holocene sea-level rise observed along the global coastal realms reinvigorated the need to decipher sea-level variability on a local and regional scale, yet limited attempts were made on simultaneously addressing sea-level and climate variability. The southwest coast of India is endowed with several geomorphic features providing cues on the paleo-sea level and climate variability engrossed with its sedimentary sequence in the lowlands. The study demonstrated high sea-level along with warm and wet climate due to Indian summer monsoon (ISM) intensification during 9.69 – 7.56 ka corroborating with the Holocene Climate Optimum (HCO). However, a break in the sediment deposition is observed between 7.56 and 3.51 ka, the reason for which is yet to be fully understood. During 3.51–2.55 ka, the gradual weakening of ISM has been invoked with an intermittent monsoon spell during 3.20–3.40 ka. After 2.55 ka the sediment core records occurrence of coarser clastics indicating sediment deposition by the migrating distributary channel of the Pamba-Manimala rivers. The high sea level during HCO attests that the core location plausibly represented the southward extension of the Vembanad lagoon which transformed into part of the terrestrial system due to the gradual sea regression during the mid-late Holocene period followed by deposition of alluvial sediments from the hinterland rivers.

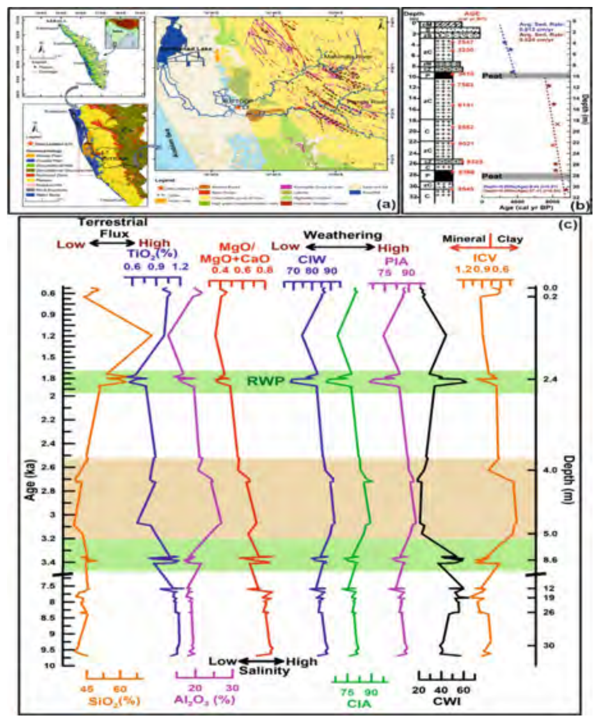


Fig. 3.3.15.1: (a) Location of the core along with its geology and geomorphology of the study area; (b) Age-depth plot and sedimentation rate for the core L7; (c) Downcore variations of the geochemical proxies for the L7 sediment core.

This work was done in collaboration with Prof. Ravi Bhushan, Ankur J Dabhi and Nisha Bharti of Physical Research Laboratory, Ahmedabad, Gujarat.

https://doi.org/10.1016/j.quaint.2022.03.005

Jithu Shaji, Upasana S. Banerji, Maya K., Padmalal D., Kumar Batuk Joshi

3.3.16 Holocene changes in fluvial geomorphology, depositional environments, and evolution of coastal wetlands - A multiproxy study from Southwest India

The Kuttanad Kole Wetlands (KKW) in Southern Vembanad basin, SW India is a unique wetland system, where paddy cultivation is being carried out 1.0–2.0 m below mean sea level. The fertile soil in the KKW in its upper, eastern part (upper Kuttanad) is formed essentially from deposition of fluvial sediments from the hinterland rivers. The wetlands host one of the largest subfossil shell deposits in India. The present study has been undertaken to use the spatial distribution and geochronology of the lime shell deposits along with multiparametric study of the borehole data collected through various projects to decode the depositional processes and coastal evolution of KKW – an important Ramsar wetland system of international importance in India. Except the top 2.0–3.0 m riverine sediments, the rest of the core sediments is of lagoonal nature with occasional presence of molluscan shells. The top riverine sediments are yellowish brown with heavy minerals derived from charnockite provenance. However, the heavy mineral suite in the lagoonal sediments of early–middle-Holocene age is dominated by sillimanite—an indicator mineral of the khondalite that occur in areas south of the Achankovil Shear Zone. This shows that, during early–middle-Holocene, the KKW was not influenced by the hinterland rivers draining the charnockite provenance, instead was influenced by sediments derived from the Kerala Khondalite Belt. This together with the occurrence of subfossil shells of Villoritta sp. in the lagoonal sediments with radiocarbon dates of 3.0–4.0 k yr BP reiterate that the hinterland rivers that drain the charnockite provenance joined the KKW only during late-Holocene. The following are some of the major highlights of the study:

The Achankovil, Pamba, and Manimala rivers when entering into the KKW get branches out and takes a northwesterly course and flows a long distance, before joining with the Vembanad Lake, instead of flowing straight to the Arabian Sea just covering a few kilometres. The river influenced, southeastern part (Upper Kuttanad) of KKW is blanketed 2–5 m thick alluvial sands and clays over a fairly thick deposit of lagoonal clays often with molluscan shells. The entire sequence lies either above lateritized crystallines or above Neogene sediments.

Heavy mineralogical study of the borehole cores retrieved from the Upper Kuttanad areas reveals that the riverine sediments are dominated by inosilicates (pyroxenes and amphiboles) which is indicative of sediment inputs from charnockitic source rocks in the hinterlands. On the contrary the sand fraction separated out from the lagoonal sediments is dominated by opaques and sillimanites indicating sediment source south of ASZ and brought up by littoral currents. Radio-carbon dates of the lagoonal sediments in KKW and southern Vembanad lagoon (1670 ± 70 yrs BP to 10,560 ± 90 yrs BP) give Holocene age. The dating of lime shell deposit (essentially composed of Villoritta sp.) varies from 3130 ± 100 yrs BP to 4780 ± 80 yrs BP. The bivalve Villoritta sp. thrives usually in the freshwater end of an estuary. This clearly indicates that freshwater from rivers reached the southern Vembanad lagoon and the KKW during the beginning of the late-Holocene.

The content of palynological and NPP elements in the sediment archive shows records of heavy rainfall and sea-level rise during the early–middle-Holocene period. During pre-Holocene, the KKW was an embayment boarded on the east by lateritized hillocks. Further, the Achankovil, Pamba and Manimala rivers were flowing through the southern side of a topographic high that acted as a divide between the river course and the embayment. During the early–middle-Holocene, the topographic high might have eroded due to the continuous wave impinging of the transgressive waters. Also, the sea-level rise and subsequent build-up of a barrier spit by the long shore drift have separated out the landward part of the embayment into a lagoon. The sedimentary record of the KKW and the adjoining coastal lands as well as the frequent flood events to which the region is subjected during every heavy monsoon period reveal that the KKW is not yet turned into a full-fledged deltaic system, but a delta is in the making in the Kuttanad region.

This work was done in collaboration with S. Vishnu Mohan, Department of Geology, Sree Narayana College, Chempazhanth; Ruta B. Limaye and K.P.N. Kumaran of PalynoVision, Mon Amour, Erandaane, Pune, Maharashtra, India

https://doi.org/10.1016/B978-0-323-90085-0.00026-7

Maya K., Padmalal D., Vandana M., Vivek V. R.

3.3.17 Holocene climate and sea-level changes and their impact on ecology, vegetation and landforms in South Kerala Sedimentary Basin, India

The South Kerala Sedimentary Basin (SKSB) is a curvilinear landward extension of the offshore sedimentary basin (Kerala – Konkan basin) in the coastal plain between Kollam and Kodungallur (8°45[1] and 10°15[1]N latitude) in the southwestern part of India. In the absence of outcrops, stratigraphic information has been derived from the subsurface sediments. Holocene sedimentary sequences are clay-dominated in the Vembanad lagoon and its adjoining areas. The Holocene epoch witnessed a rise in sea level from approximately 80.0 m below the present position to 4.0–6.0 m above. The rainfall varied from highly excessive (~2–3 times the current rate) to deficient. There have been noticeable tectonic movements, which have influenced the sedimentary environments to a considerable extent. These three factors acting in tandem have produced a complex combination of situations affecting the ecology and shaping the landforms. Most of the coastal landforms have been developed or substantially modified due to Holocene climate and sea-level changes. Similarly, the drainage system has undergone drastic modifications due to excessive rainfall coupled with rising and fall of sea level. There are pieces of evidence to prove that tectonic movements too have influenced drainage systems and landforms. The evergreen forests were converted into wetlands, water bodies got shrunken, aquifers and groundwater resources were severely affected, and sensitive ecosystems like the mangroves and the freshwater swamps of Myristica are becoming relics as a result of the changing scenario brought in by the hydrological processes and climate variability in the past 11 ka years. Holocene events are also responsible for generating mineral resources like beach placers, tile-brick clays, and glass sand. The role of sandy aquifers is worth mentioning as it is a significant aspect of the environmental process. The sand of the ridge–runnel system and various other landforms supply water to lakhs of households all over Kerala's coastal areas. These aquifers are recharged from the runnels, which are generally underwater for most parts of the year. Given the fast-declining areas under paddy cultivation, a significant recharge source of the life-sustaining aquifer is likely to face problems sooner than later. A major part of the land, water, and mineral resources are the gifts of Holocene events.

This work was done in collaboration with Ruta B. Limaye and K.P.N. Kumaran of PalynoVision, Mon Amour, Erandaane, Pune, Maharashtra, India

https://doi.org/10.1016/B978-0-323-90085-0.00010-3

Padmalal D.

3.3.18 Holocene evolution of coastal wetlands - A case study from Southern Kerala, India

The state of Kerala in southwest India is a geologically important narrow strip of land located on the western flank of southern Western Ghats. The region constitutes a part of the Peninsular craton and is characterized by unique physiographic, geologic, and geomorphologic settings. The present investigation aims to decode the evolution of coastal wetlands in southern Kerala between Kazhakuttom and Kaniyapuram, using textural, mineralogical, and geochemical characteristics of two borehole cores and surface sediment samples collected from the coastal lands of the Kazhakuttom–Kaniyapuram belt. The coastal wetlands of the study area have been evolved due to Holocene sea-level fluctuations. The heavy rainfall and river discharges during the early–middle-Holocene together with sea-level rise of ~6000 yrs BP might have aggravated deposition of alluvial sediments at the river confluence of Kulathur Thodu. Later, the lowering of sea level in the beginning of the Meghalayan time might have exposed many elevated areas in the form of ridges and runnels of the present strandlines. The process of formation of the Kadinamkulam lagoon dates back to middle–late-Holocene period. The present geomorphic configuration is the outcome of interplay of late Quaternary climatic and sea-level changes, especially during the later phases of the Last Glacial Maximum. The geological evolution of the area has been interpreted by collating the information acquired from various sources, such as, physiography of the coastal plain, geologic correlation, and chronology with adjacent dated borehole, sea-level changes, and evidences from textural, mineralogical and geochemical studies. The study explains the origin and evolution of coastal wetlands in the Kazhakuttom–Kaniyapuram belt and provides an evolution model for the coast. The most important coastal wetland in the area is Kadinamkulam lagoon or locally known as Kadinamkulam Kayal. The coastal wetlands in the Kazhakuttom–Kaniyapuram belt has been evolved and modified due to Holocene sea-level fluctuations. The heavy rainfall and river discharges during the early–middle- Holocene together with sea-level rise of ~6000 yrs BP might have aggravated deposition of alluvial sediments at the river confluence of Kulathur Thodu. Later, the lowering of sea level in the middle- and late-Holocene might have exposed many elevated areas in the form of ridges and runnels of the present strandlines. The process of formation of the Kadinamkulam lagoon dates back to middle–late-Holocene. The present geomorphic configuration is the outcome of the interplay of late Quaternary climatic and sea-level changes, especially during the later phases of the LGM. The subsurface sedimentary architecture, geomorphology of the Kadinamkulam coast, and the chronology of samples from southern to the northern part indicate that the present-day lagoon has evolved from an embayment of the Arabian Sea that existed prior to the Holocene. Although the process of lagoon development was initiated by natural events of pre-Holocene, sea-level and climate changes have transformed it considerably into its present form during the Holocene. Sediment supply and sea-level fluctuations have been the dominant factors responsible for the development of various geomorphic features along the coastal plains of southern Kerala. The different units detected by means of sedimentological and mineralogical approaches and by SEM surface texture analysis and X-ray fluorescence studies have been found to be useful for developing a three-fold model for the evolution of the wetland systems of the study area during the Holocene. The presence of a marine embayment and altitude of the location almost near to the ambient sea level facilitated the earliest marine influence during the early-Holocene. The subsequent formation of sand barrier spits and beach ridges across the pre-Holocene embayment paved the way for development of the Pallipuram wetland and then the Kadinamkulam lagoon. The Akathumuri lagoon (kayal) and the beach barrier systems might be the youngest wetland developed in the region. The northward shift of the Pallipuram wetland, the Kadinamkulam lagoon, and the Akathumuri lagoon indicate the northward drift of coastal sediments since early-Holocene.

This work was done in collaboration with S. Vishnu Mohan, Department of Geology, Sree Narayana College, Chempazhanthy and K.P.N. Kumaran, PalynoVision, Mon Amour, Erandaane, Pune, Maharashtra, India

https://doi.org/10.1016/B978-0-323-90085-0.00024-3

Aneesh M. S., Maya K., Padmalal D.

3.3.19 Dating techniques used in late Quaternary Period

The continuous quest to understand the past climatic, ecological and oceanographic conditions led to the extensive developments in dating techniques of Quaternary materials. The Quaternary Period is the most recent and shortest geological period that commenced around 2.58 My ago and is characterized by prominent climate instabilities. Unlike the other natural archives that grows in specific zones, the sediment remains ubiquitous and thus widely used as a paleoclimatic archive to infer the past climate and ecological conditions.

The sediment accumulation over time in various water bodies thus act as an imperative archive whose deposition rates may vary depending on its depositional environment and thus the applicable radiometric dating technique can be selected. The present study aims to provide an overview of the selected radiometric dating techniques frequently used in estimating the age, sedimentation rates, exposure age and denudation rates of the sediments depositing in various environments. The radiometric dating methods include cosmogenic radionuclides such as radiocarbon (14C), beryllium-10 (10Be) and Aluminium-26 (26Al) and lead-210 (210Pb) supported by artificial radionuclides such as Caesium-137 (137Cs). The frequent human encroachment in natural systems instigated the need to develop the dating technique that can provide the sediment chronology for the last few decades. Thus, the 210Pb dating technique was explored and implemented while the 137Cs acted as supporting evidence as it was the artificially induced isotope incorporated in to the atmosphere during the nuclear tests conducted between 1952 to 1962. The pervasive presence of carbon in sediments in the form of organic and inorganic fraction and the uniformity in 14C atmospheric distribution promoted the implications of 14C dating method. Further, the transition from conventional spectroscopic method (beta counting) to Accelerator Mass Spectrometer (AMS) for the estimation extended the 14C datable range from ~30000 yr to a maximum of 40,000–60,000 yr. Moreover, the introduction of the AMS also elevated the need to address the exposure ages and erosion/ denudation rates promoting the applicability of the 10Be and 26Al.

Despite the extensive application of these dating techniques (210Pb, 137Cs, 14C, 10Be and 26Al) they have their own limitations and drawback. Such as the sediment mixing and/or remobilization and sample from distal location may lead to restricted applicability of 210Pb and 137Cs dating. While the 14C technique require an improved temporal resolution for the 14C calibration curve and a better understanding of the marine reservoir ages to yield accurate and reliable radiocarbon ages. Further, the utility of coupled *in-situ* 14C-10Be remains significantly unexplored which can provide cues on the chronologies to the complex surface exposures for the late Quaternary period. Overall, it can be suggested that the future of Quaternary studies relies on improved dating precision and accuracy with simultaneous developments in the instrumental along with sample processing and treatments.

This work was done in collaboration with Dr. Vineet Goswami, Physical Research Laboratory, Gujarat, India

https://doi.org/10.1016/j.jaesx.2022.100091

Upasana S. Banerji, Kumar Batuk Joshi

3.4 Biogeochemistry Group

3.4.1 Hydrogeochemistry of the Indian thermal springs: Current status

The thermal springs in India are classified into four groups based on the geotectonic framework, and are: (a) Orogenic belt, (b) Areas of deep-seated faults and lineaments, (c) Rifts and grabens of Gondwana basin and (d) Deep sedimentary basin. Detailed investigations over the last few decades culminated in the development of a vast geochemical database for thermal springs and associated gaseous phases, which are now available online since the late 1960s. After a careful evaluation of their quality and reliability, these data have been used in this study. Thermal springs near the coast of western India have a high Cl content relative to Na, indicating that they have been influenced by seawater. Most thermal springs in the northern territory have high HCO_3 and low Cl, suggesting that they have mixed with HCO_3 rich near-surface water. Due to their emergence from the Precambrian crystallines, most thermal springs in the central and eastern part of India (Fig. 3.4.1.1) are distributed within the Na-Cl and Na-Cl-HCO_3 type facies with low SO_4 content. Different geochemical thermometers such as silica, cation thermometers, and a combination of silica K-Mg systems were used to estimate reservoir temperatures, resulting in a temperature range of roughly 60–140° C.

Because of the lack of equilibrium, the values of reservoir temperatures between 200°C and 300°C obtained using Na-K geo-thermometers may not be reliable. Generally, the reservoir temperatures for thermal springs in India's northern and eastern parts are higher than that of southern and western regions. The chemistry of the associated gaseous discharges is dominated by atmospheric components. The exceptions are thermal springs from the Orogenic belt of Himalaya that are enriched with CO_2 possibly sourced from metamorphic decarbonation. The $^3He/^4He$ isotopic ratio in the gaseous discharge across all the groups and subgroups pre- dominantly bears signatures of crustal origin. Stable isotopic signatures strongly suggest that local meteoric waters predominantly recharge these hydrothermal systems. In contrast, a discernible positive oxygen-isotopic shift in thermal waters indicates the existence of high enthalpy reservoirs in the NW Himalayan region. With the exception of a few springs, long circulation time (>50 years) of meteoric waters within the conduit is indicated by low tritium values in the thermal waters.

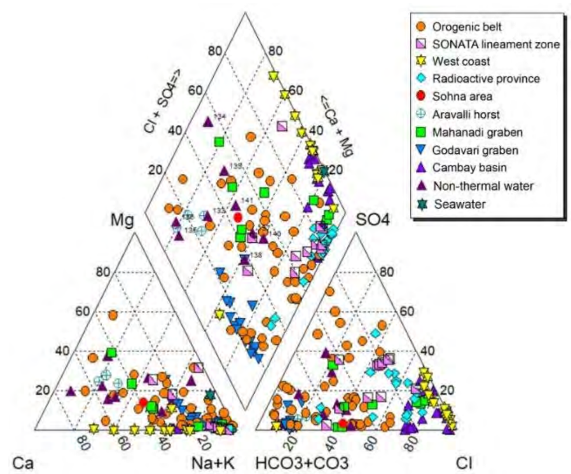


Fig. 3.4.1.1: Piper diagram showing plots of the thermal springs and non-thermal waters from the different geothermal provinces in India.

https://doi.org/10.1016/j.earscirev.2021.103890

Prasenjit Das, Maya K., Padmalal D.

3.4.2 Mechanisms controlling the dissolved load, chemical weathering and CO_2 consumption rates of Cauvery River, South India: Role of secondary soil minerals

Dissolved solutes in river waters are acquired by various natural and anthropogenic sources as a result of diverse biogeochemical processes. Hydrochemical assessment of the Cauvery River Basin (CRB), an east flowing Western Ghats (WG) river is carried out to understand the dissolved load sources and controlling mechanisms along with quantification of source-wise input to the dissolved load. Silicate weathering rates (SWR) and associated CO_2 consumption rates (CCR) are evaluated on account of silicate basement of CRB comprising of granulites and supracrustal rocks. The source-wise solute load contributions estimated using the chemical mass balance model signify that 68% of total load is from chemical weathering followed by 18.5% and 13.5% from anthropogenic and atmospheric inputs respectively, implying that chemical weathering is the major solute load controlling mechanism for CRB. The intensity of silicate chemical weathering occurring in the CRB is measured by index (Re) and found to be > 3, suggesting an incomplete weathering of drainage rocks (primary minerals) resulting in formation of soils comprising of secondary minerals including oxides, alumino-silicates and clay minerals (smectite, kaolinite and montmorillonite). Detailed understanding of chemical weathering mechanisms is carried out using Ca/Na and Mg/Na elemental ratios of different end-members including primary minerals from rocks and secondary minerals from soils. The Na-normalized mixing diagram (Fig. 3.4.2.1) reveals that chemical weathering of secondary minerals is dominating and the solute load contribution to the total dissolved load is significantly higher from secondary minerals (35.5%) than primary minerals (23.5%). The SWR and associated CCR are estimated to be 13 $t.km^{-2}.y^{-1}$ and 3.3×10^5 $mole.km^{-2}.y^{-1}$ respectively at outlet (Musiri) of the CRB. Results also indicate that SWR of the east flowing WG river, Cauvery are several times (~4) lower than the average SWR of west flowing WG rivers even though the associated CCR are comparable for both river systems.

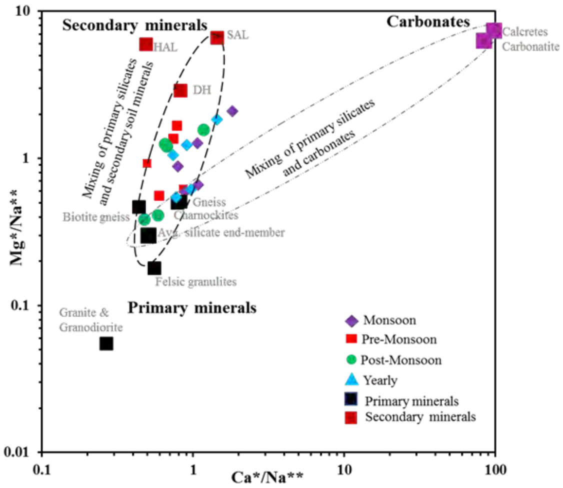


Fig. 3.4.2.1: End-member mixing diagram for '3' different end-members in terms of Ca/Na and Mg/Na ratios for CRB; primary silicate minerals from rocks, secondary silicate minerals in soils and sparsely available carbonate minerals, describing a mixing trend between primary minerals and secondary minerals for CRB water samples. *HAL, SAL and DH refer to soil samples from Halgur, Salem and Dharmapuri respectively.

https://doi.org/10.1007/s12665-022-10222-1

Upendra B., Anoop Krishnan K., Ciba M., Aiswarya A., Vinu Dev V., Sreenivasulu G.

3.4.3 Identification of groundwater potential zones in southern India using geospatial and decision-making approaches

Groundwater is the important resources for industries, communities, and irrigation purposes in the world. For water resource investigation, the conventional geophysical techniques and boring soil tests are costly and time-consuming. Now, complex groundwater studies are being made easier using the RS and GIS applications, and comes out with more success in the delineation of Ground Water Potential (GWP). The present study was carried out to identify of the groundwater potential zones (GWPZ) in the northern part of the Anantapur district of Andhra Pradesh State, India using Remote Sensing (RS), Geographical information system (GIS), and Analytical Hierarchy Process (AHP) approaches. In this study, various thematic maps categorized viz. geomorphology (GM), lineament density (LD), drainage density (DD), geology, land use/land cover (LULC), soils, slope, and rainfall for assessment of GWPZs, which is generated using RS and GIS technique. Furthermore, the relative weights were allocated to various thematic maps using the AHP approach and the relative rank assigned to each sub-criterion based on expert advice. The combination of the eight thematic layers in ArcGIS resulted in a groundwater potential map, providing the information about very good 2.45% (87.06 km^2), good 12.76 (452.56 km^2), moderate 63.47% (2250.75 km^2), poor 15.99% (567.16 km^2), and very poor 5.32% (188.73 km^2) groundwater possible zones. The acquired outcomes were validated with the area under the curve (AUC/ROC) method. The results show that there is a strong positive correlation between the GWPZs with 78% validation high performance and decreases to the low yield potential with poor areas. This study concludes that the AHP model will be a more reliable for the assessment of the GWP.

This work was done in collaboration with M. Rajasekhar and G. Sudarsana Raju of Department of Geology, Yogi Vemana University and Anand of Guru Gobind Singh Indraprastha University.

https://doi.org/10.1007/s13201-022-01603-9

Upendra B.

3.4.4 Assessment of land degradation vulnerability in Kasaragod, Kerala (humid tropics) and Virudhunagar, Tamil Nadu (sub-tropics) regions of Southern India

National Centre for Earth Science Studies (NCESS) signed an MOU with ISRO-SAC, Ahmedabad for National Network Project entitled "Desertification and Land Degradation: Monitoring, Vulnerability Assessment and Combating Plans 2018 – 2021 using integrated remote sensing and GIS techniques. The land degradation status for two districts in Kerala and Tamil Nadu was investigated as part of this study. The GIS-based DVI (Desertification Vulnerability Index) model has been used for mapping and assessment of potential vulnerability to desertification and land degradation in the two sites prevailing different climatic conditions, namely Kasaragod district in Kerala (humid tropics) and Virudhunagar district in Tamil Nadu (sub-tropics). The

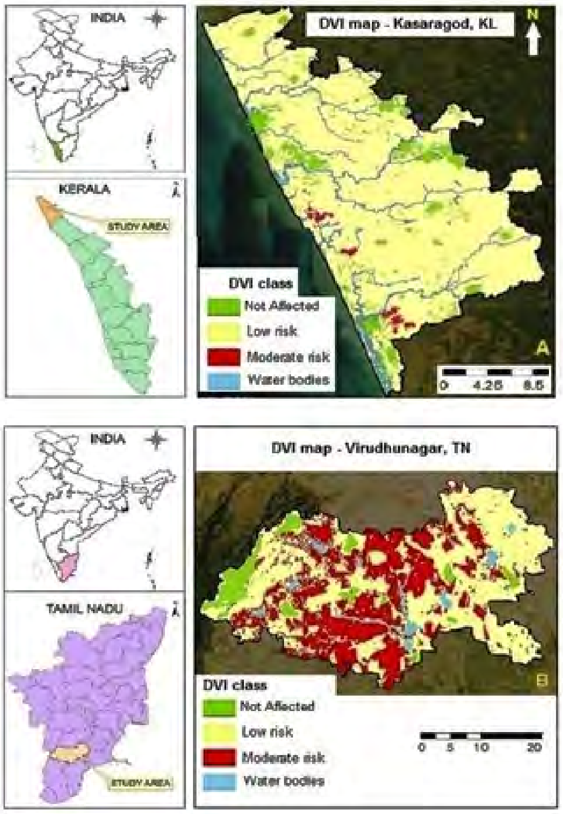


Fig. 3.4.4.1: Land degradation vulnerable zones of Kasaragod district (A) in Kerala and Virudhunagar district (B) in Tamil Nadu generated using GIS based LDI model.

DVI model is executed multivariate statistical indices, namely Climate Index (CI), Soil Index (SI), Vegetation Index (VI), Land Use Index (LUI), and Socio-Economic Index (SEI). These multivariate indices are estimated using multiple geo-environmental and demographical parameters like land use/ land cover (LULC), rainfall, soil properties, topography (slope), geomorphic landforms, geological settings, climatic factors. The result shows that the Kasaragod district in Kerala is not identified with a higher category of desertification vulnerability, and 8.3% of the total area has no significant exposure. The areal extend of 91.4% has been found under lower vulnerability conditions, and 0.23% of the area under moderate susceptibility to land degradation in the site-specific areas namely, Kodakkad, Timiri, Kilalode, Pullur, Panayal, Pallikere, and Bare due to human-induced activities like deforestation, and LULC changes. The sub-tropical Virudhunagar district in Tamil Nadu shows that 1.4% of the total area has not fall under land degradation; however, 65.4% of the area falls under low vulnerability and 33.2% under the moderately vulnerable zone. The spatially estimated area of 1428 km^2 (33.2%) is found with moderate vulnerability to desertification. Land degradation is affected in various parts of the district includes Vembakottai, Panaikudi, Narikudi, Sivakasi, Virudhunagar urban proximity, and Aruppukottai, due to severe soil erosion and increasing soil salinity conditions. About 65.5 % of the area is noticed as low vulnerability to land degradation; however, the land resources of the various sites are gradually undergoing degradation status due to both natural and anthropogenic activities that causing adverse impacts to environmental ecosystems.

This work was done in collaboration with SAC-ISRO, Ahmadabad.

https://vedas.sac.gov.in/static/atlas/dsm/DLD_Atlas_SAC_2021.pdf

Kaliraj S., K. K. Ramachandran, Arun R. Nath, Jyoti Joseph

3.4.5 Groundwater hydrochemical characteristics and saltwater intrusion in Cauvery deltaic fluvial plains of Southern India

The deltaic fluvial deposits cover the River Cauvery lower basin located in the Thiruvarur district of Tamil Nadu, India. The majority of agricultural lands are irrigated from river, canal, and groundwater (GW) sources. 50 bore well samples were collected and analysed using APHA (2012) standard protocols. Fig. 3.4.5.1 shows the spatial distribution of GW properties. In many places, the GW sources are found with suitability for drinking and irrigation purposes except in a few sites that are noted at higher Na^+ and Cl^- content due to the mixing of salt contents from fertilizers and fluvio-marine interactions. GW samples in many sites were estimated with a pH value of 6.9 to 8.2 which indicates marginally alkaline conditions. GW samples were estimated EC (375 - 2290 μS/cm) and TDS (120 - 1700 meq/L) respectively. Based on this, GW sources are classified as type I (EC < 1500 μS/cm) and type II (EC 1500 – 3000 μS/cm). Cation properties are estimated

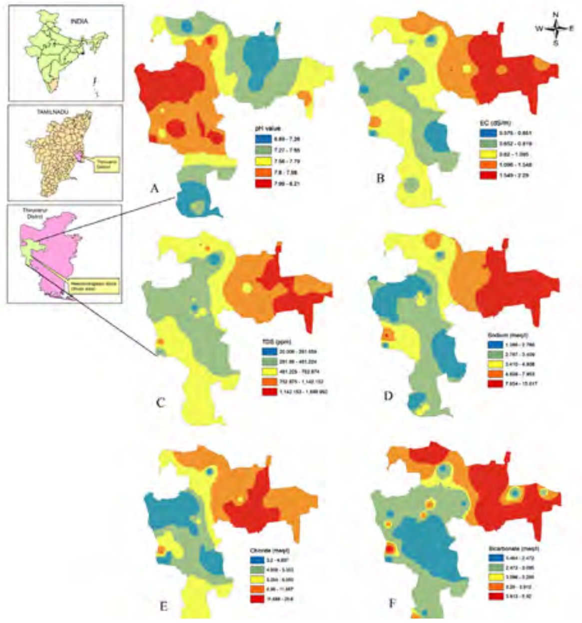


Fig. 3.4.5.1: Spatial distribution of groundwater hydrochemical properties in deltaic fluvial deposits of the River Cauvery lower basin; pH (A); EC (B), TDS (C), Sodium (D), Chloride (E), Bicarbonate (F).

as Ca^{2+} (0.60 - 2.97 meq/L); Mg^{2+} (0.40 - 5.96 meq/L); K^{+} (0.03 - 0.82 meq/L) and Na^{2+} (1.39 - 15.02 meq/L); whereas the Ca^{2+} and K^{+} found within desirable limit of drinking water quality, but samples 5 and 9 with excess of Mg^{2+} and Na^{2+}, and their observed values are 75 mg/L and 30 mg/L respectively. Anion properties were estimated as Cl^{-} (3.20 - 25.6 meq/L), CO_2^{3} (0.5 - 3.02 meq/L), HCO_3^{-} (0.46 - 5.92 meq/L) and SO_4^{2-} (0.10 - 2.34 meq/L). The Cl^{-} was found at a higher concentration in 20 samples compared to the permissible limit of WHO (World Health Organization), similarly, the higher Na^{2+} was noted in many samples that affected soil hydraulic properties and nutrients. Fig. 3.4.5.2A shows the HFE (hydro-chemical facies evolution) diagram denoting the dynamics of freshwater-saltwater mixing due to the seepage flow. About 38% of samples were observed in the mixing zone towards path (III). Among the 62% of samples experienced saltwater intrusion by increasing of Na-Cl facies and mixed Na-Cl facies. Gibbs plot (Fig. 3.4.5.2B) shows the rock weathering and evaporation factors are controlling GW quality and the plot reveals many GW samples fall under the evaporation and rock-water dominance region. Piper diagram **(**Fig. 3.4.5.2C**)** shows GW facies the 40% of sequences at $Na^{2+} \rightarrow Cl^{-} \rightarrow HCO_3^{-}$, and the 23% at $Na^{2+} \rightarrow Mg^{2+} \rightarrow Cl^{-} \rightarrow HCO_3^{-}$, and mostly mixed with residual carbonate in many samples. Fig. 3.4.5.2D shows the scatter plot indicating the GW ionic relationship. The Na^{2+}/Cl^{-} ratio remains constant against the increase of EC except for a few samples; About 81% of samples were noted at higher Cl^{-} compared to Na^{2+} due to base exchange activities. The relation of $Ca^{2+} + Mg^{2+}$ and $SO_4^{2-} + HCO_3^{-}$) shows the regression line at a 1:1 ratio due to ion exchange of $SO_4^{2-} + HCO_3^{-}$, and this indicates the dissolution of silicate minerals in many GW samples. Moreover, the GW samples in some lowlands show the relation of $Cl^{-} + SO_4^{2-}$, and $Na^{2+} + K^{+,}$ and they are dominated by chloride and sulphate contents due to base exchange from agricultural return flow, i.e., fertilizer used for agricultural activities.

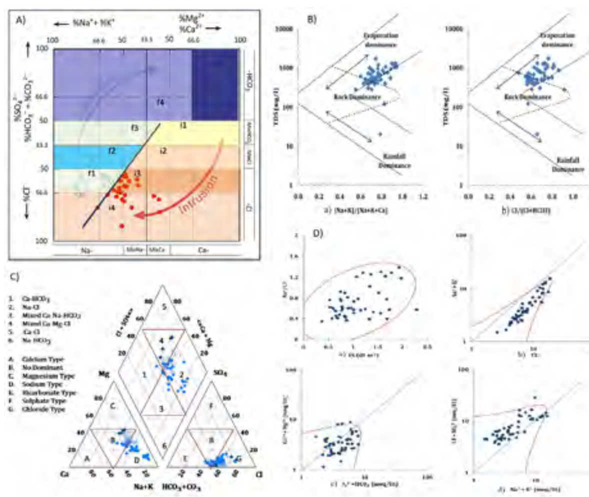


Fig. 3.4.5.2: Hydro-geochemical indices of GW properties: A) HFE diagram of freshwater - saltwater mixing interface; B) Gibbs plot for cations and anions relations; C) Piper diagram of GW major ionic compositions; D) Scatter diagram of GW ionic relationship.

This work was done in collaboration with Lalitha M., Dharumarajan S., Kalaiselvi B., Shivanand K., Koyal A., Hegde R. of National Bureau of Soil Survey and Land Use Planning.

https://doi.org/10.1007/s11356-021-13467-8

Kaliraj S.

3.4.6 Identification of groundwater potential zones in Karumeniyar river basin (semi-arid region) of Southern India

The Karumeniyar basin is a non-perennial and semi-arid landscape located in southeastern part of Tamil Nadu state, India. The basin covers the total area of 976 km^2 with the length of 56.5 km, found with dry-land agricultural activities and rural settlements. Groundwater is a major resource drinking and irrigation activities, but from past two decades, groundwater table is drastically decreasing due to both natural and anthropogenic activities. GIS based Analytical Hierarchy Process (AHP) modelling of multiple geo-environmental parameters for mapping GW potential zone is carried out for sustainable livelihood management. GW potential map is demarcated the 10.7% of area only exhibits higher GW potential zone; whereas, the 26.8% of area indicates good GW potential mainly around the streams and paleochannels. About 33.6% of area is noted at moderately GW potential, whereas, the GW table are getting recharged from monsoonal rainfall. The 28.9% of area fall under lower GW potential resulting of lower recharge by sub-surface settings of geological formations. *In-situ* geophysical survey of Vertical Electrical Sounding (VES) and groundwater yield data are cross-verified for the preparation of GW potential map and it indicates the higher GW potential in aquifers underlying unconfined and semi-confined formations. Whereas, the sedimentary formations found at higher porosity that leads good permeability compares to hard rock formations. Moreover, these formations consist of fault, lineaments support to greatly increasing of GW flow in and around the sub-surface even under the confined aquifers of crystalline rock formations. Vertical Electrical Sounding (VES) and groundwater potentiality indicates the relation of sub-surface settings and groundwater table based on its geophysical characteristics. Fig. 3.4.6.1B shows the VES curve of various locations that indicates that the curves of VES 1, VES2, VES 3, VES 4 are noted as low resistivity and high thickness of weathered and fracture zone in the second layer which revealed the occurrence of good GW potential zones. The 'A' type VES curve indicates the occurrence of typical hard rock formation; whereas the resistivity increase towards deeper formation with depth (A-type curve) that indicates the very poor groundwater potential zones. However, the curves of VES 5, VES 6 are noted at dominated A-type curve that indicates the poor GW potential in the area. GW is cross-validated using CGWB - groundwater yield data of 14 wells, and it shows the higher GW yield rate is strongly correlated with higher GW potential zones. Within the basin, the higher GW potential found mainly in unconfined and weathered semi-confined aquifers of sedimentary formations than the other hard rock formations. However, in the alluvium deposits found along the riverbanks, higher groundwater yield was observed due to recharging of river flow and runoff. This study provides a primary database for plaining rainwater harvesting at suitable sites and very much helpful for watershed management in semi-arid region.

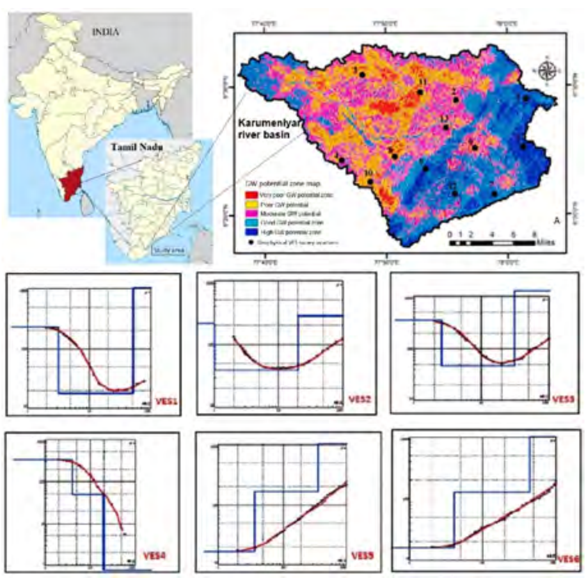


Fig. 3.4.6.1: Groundwater Potential Zone in Karumeniyar river basin (semi-arid region) of Southern India generated using GIS based AHP model.

This work was done in collaboration with Arunbose S., Srinivas Y., Rajkumar S., Nithya C. Nair of Manonmaniam Sundaranar University.

https://doi.org/10.1016/j.gsd.2021.100586

Kaliraj S.

3.4.7 Effect of trace metal contamination in sediments on the bioaccumulation of bivalve Meretrix meretrix

A quinquennial seasonal study (2015–2019) has been conducted to evaluate the bioaccumulation pattern of trace metals in *Meretrix meretrix*. The concentration of trace metals in the clam was observed as Cr > Cu > Ni > Zn > Pb > Cd > Hg, (Body> Mantle > Gills), similar to sediments. Contamination Factor of Cu and Cr in sediments showed strong association with the corresponding metal concentration in the body (r = 0.687, r = 0.962), mantle (r = 0.880, r = 0.956) and gills (r = 0.937, r = 0.863). Bioconcentration Factor was high for Cr followed by Ni. Mean Metal Concentration Rate (MMCR) of Cr was high and Hg was low (Body>Mantle>Gills). The study establishes that the trace metal intake by *Meretrix meretrix* is associated with seasonal variation, physicochemical factors, sediment texture, chemical speciation and the metabolic stress created within the species induced from increased demand for protein synthesis. The latter resulted in the augmented rate of accumulation of Cu and Cr.

https://doi.org/10.1016/j.marpolbul.2022.113422

Ratheesh Kumar M., Anoop Krishnan K., Vimexen V.

3.4.8 An environmental green approach for the effective removal of malachite green from estuarine waters using Pistacia Vera L. shell based active carbon

The study aims in developing strategies for containing dye pollution in water resources, which is a global threat in the current industrial era. The development of ecofriendly and cost-effective materials in dye removal processes are not yet fully explored. Thus, the present work describes the green approach in developing and applying activated carbon prepared from pistachio shell (PisAC) for the removal of malachite green (MG), a cationic dye, from wastewaters. The surface characteristics and properties of the adsorbent were studied using Fourier-transform infrared spectroscopy, Scanning electron microscopy, X-ray diffraction, Elemental analysis and Nitrogen adsorption-desorption. The effect of influential experimental parameters such as pH, initial dye concentration, temperature and ionic strength were carried out in batch mode for investigating the conditions apt for maximum removal of cationic dye pollutant. The optimum solution pH for the dye removal was found to be at 7.0. The adsorption process reached equilibrium in 30 min with a maximum removal of 96.7 % of MG from aqueous solution for an initial concentration of 75 mg/L. Pseudo-second-order kinetics was found to be the best fitted model to explain the kinetics of the adsorption. The maximum adsorption capacity obtained from Langmuir isotherm model was 76.92 mg/g. Thermodynamic studies revealed the adsorption of MG onto PisAC was spontaneous and endothermic. The reusability studies of spent adsorbent were also performed. The application of the adsorbent was carried out successfully in removing MG from estuarine water samples and found that 4.0 g/L of PisAC was sufficient for almost 99.9 % removal of MG.

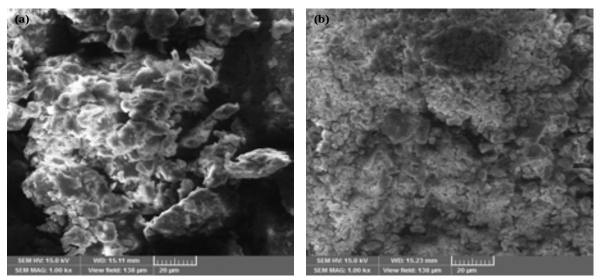


Fig. 3.4.8.1: SEM images of PisAC (a) before adsorption (b) after adsorption.

The adsorptive nature of activated carbon prepared from the shells of pistachio (PisAC) was found very fruitful for the effective removal of MG from aqueous solution. The synthetic route involved in the preparation of PisAC was environmentally friendly in nature. The surface morphology, functional group availability and crystallographic information of the precursor was confirmed from SEM, FTIR and XRD. The adsorption phenomenon was pH dependent at an optimum pH of 7.0 and the adsorption reached equilibrium within 30 min. The adsorption capacity increased with increased in temperature, indicating endothermic nature of the adsorption. The adsorption kinetics well fitted to pseudo-second-order kinetics and the adsorption isotherm well described using Langmuir isotherm model. The values obtained from Gibbs free energy and standard enthalpy depicted the spontaneous and endothermic nature of adsorption. The regeneration studies showed the potential ability of the adsorbent to adsorb more than 80 % MG even after 4 cycles. Finally, the activated carbon from the natural adsorbent were successfully applied on to estuarine water samples for the targeted removal of malachite green.

https://doi.org/10.1007/s40899-022-00612-5

Harsha Mahadevan, Nimina P. V. M., Anoop Krishnan K.

3.5 Marine Geoscience Group

3.5.1 Nearshore wave analysis from coastal video monitoring techniques at high energy micro tidal beach under sunlight dominance conditions: A case study from Valiathura beach in southwest coast of India

Video based remote sensing methods for continuous monitoring are advantageous due to its low risk and cost-effective features and ability to provide data during extreme events. In this connection, National Centre for Earth Science Studies (NCESS) has initiated a pilot project for continuous coastal monitoring, adopting the video-based monitoring method in India through an indigenous Video Beach Monitoring System (VBMS). The fist VBMS station, was installed at Valiathura, a typical high energy beach in SW coast of India and the software tools for deriving coastal morpho-hydro dynamic characteristics from video imagery are being developed. As part of this, attempts have been made to modify the open-source tools available for adapting to the Indian coastal conditions. The open-source toolbox ULISES was found to be suitable for planview generation, especially when the camera stations installed at lower heights. One of the defects observed in the earlier stages of development of the Indian system was the errors introduced due to the variations in sunlight intensity. This has been overcome with the introduction of a new modulated transfer function (MTF) designed through Thomson's multi tapered method. With the use of the new MTF, non-linearities, the spectral noise introduced from sunlight variations and other local contaminants could be reduced to an acceptable level. The transformed intensity spectra (Fig. 3.5.1.1) are

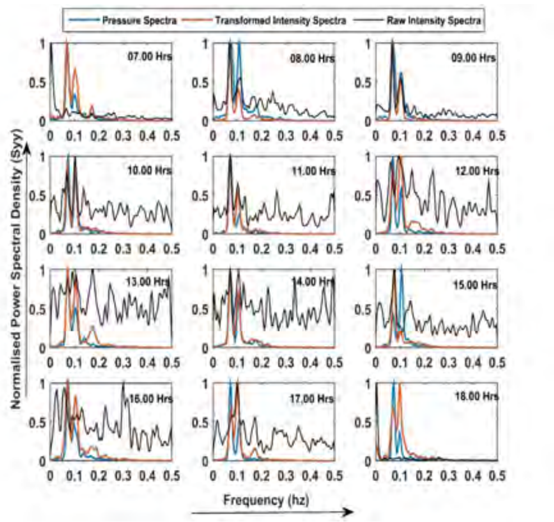


Fig. 3.5.1.1: Power Spectra computations at one hour interval on 10/04/2017.

showing a reasonably good agreement with the *in-situ* measurements by giving a correlation of more than 90% throughout the day. The corresponding RMSD values obtained also were low. While estimating the wave parameters (Fig. 3.5.1.2) it was observed that once long-term

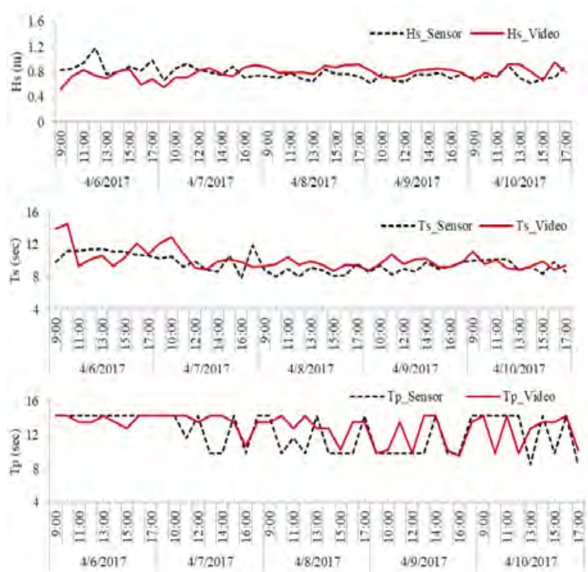


Fig. 3.5.1.2: Validation of video derived parameters: (a) Beach width and (b) Surfzone width.

variations are taken into consideration, mean bias and RMS error are within the permissible limit. Based on this study, it is found that the use of multi-tapered methods in transfer function estimation can significantly reduce the noise and local influences in the estimation of nearshore wave parameters from video images.

https://doi.org/10.1016/j.rsma.2022.102205

Ramesh M., Sheela Nair L., Anoop T. R., Prakash T. N.

3.5.2 Reconstruction of the paleoenvironment of the Late Quaternary sediments of the Kerala coast, SW India

Recurrent sea-level changes are reflected in the formation of coastal landforms; estuary, lakes, lagoons and barrier beaches during the late Quaternary period along the Kerala coast, SW India. The sediment core from these landforms was addressed for sediment lithofacies, geochemical parameters and associated foraminiferal assemblages to reconstruct the late Quaternary environment. The textural characteristics of the sediment (Fig. 3.5.2.1) indicate a shallow marine to lagoon and swampy/marsh environment. A layer of coarse sandy sediment (7–9 m thickness) is overlying the late Pleistocene (40 Kyrs BP) sediment sequence. The sediment was deposited under violent to the calm environment attributing its deposition in diverse energy regimes. This is also corroborated with the micro-textures of quartz grains. The geochemical elemental relationship (Rb vs K_2O, Ni vs TiO_2, K_2O/Na_2O vs SiO_2/Al_2O_3, discriminant function) is established with paleoweathering, provenance and tectonic setting. An abundant population of *Ammonia beccarii, A. tepida, E. discoidale, N. scaphum. A. beccarii* in the sediments reveals their high tolerance and adaptability to the changing environment. The multiproxy studies on sediments, support a stronger monsoon in the early Holocene leading to the incursion of high-water levels, increased flow discharge and bottom scouring but, there was a weak monsoon and arid climate prevailed during the Last Glacial Maximum (LGM). A conceptual model (Fig. 3.5.2.2) is also proposed to depict the shoreline evolution and its climate.

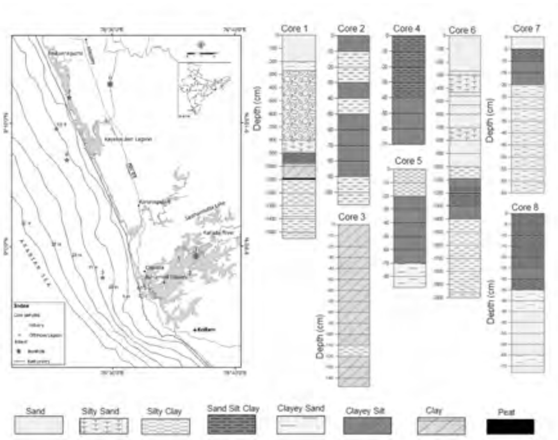


Fig. 3.5.2.1. Litho-log variations in the coastal plain, estuary and offshore region of the sediment cores.

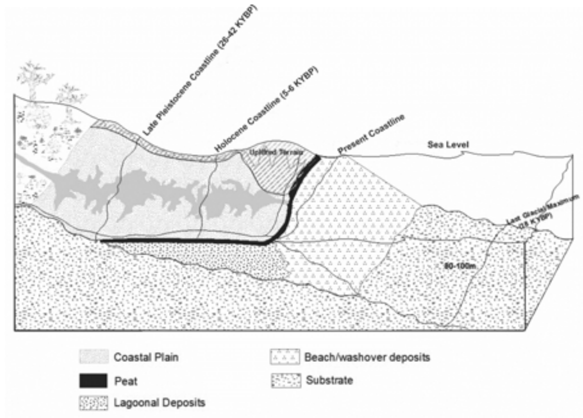


Fig. 3.5.2.2: A conceptual model showing the evolution of Kerala coast during the late Quaternary period.

This work was done in collaboration with Nagendra R. of Department of Geology, Anna University.

https://doi.org/10.1016/j.jseaes.2021.104952

Tiju I. Varghese, Prakash T. N., Sheela Nair L., Sreenivasulu G.

3.5.3 Palaeoredox reconstruction in the eastern Arabian Sea since the late Miocene

Investigation on oxygenation history of the northeastern Arabian Sea since the late Miocene was carried out using redox sensitive elemental and metal stable isotopic signatures in the deep-sea sediments. For this study, the sediment core samples collected at Site U1457 (67°55.80' E, 17°9.95' N, water depth 3534 m) of Laxmi Basin in the northeastern Arabian Sea during the International Ocean Discovery

Program (IODP) Expedition 355 were analyzed for a suite of elemental (Mo, W, U, V, Ba, Cd and P) as well as stable molybdenum (Mo) isotope ($\delta^{98/95}$Mo relative to NIST SRM 3134 lot No. 130418) and stable tungsten (W) isotope ($\delta^{186/184}$W relative to NIST SRM 3163 lot No. 080331) compositions. Sedimentary $\delta^{98/95}$Mo values (-0.70‰ to +1.18‰) at IODP Site U1457 in the northeastern Arabian Sea indicated partial authigenic Mo component. Sedimentary $\delta^{186/184}$W values (-0.02‰ to +0.21‰) were in the range similar to that of lithogenous material suggesting dominance of detrital composition. The study revealed that the water column in the northeastern Arabian Sea was oxic during the late Miocene and Pliocene while oxic to suboxic condition prevailed during the Pleistocene. The study also explored that under oxic to suboxic condition with limited particle shuttling, the W isotopes did not undergo significant fractionation, and their isotope ratios reflect the detrital source signature. This work reported the first results on isotopic compositions of Mo and W in sediments of the northeastern Arabian Sea since the late Miocene to investigate the palaeoredox conditions on a million-year time scale.

This work was done in collaboration with Alam M., Gurumurthy G. P. from Birbal Sahni Institute of Palaeosciences; Sohrin Y., Tsujisaka M., Takano S. of Institute for Chemical Research, Kyoto University; and Singh A. D., Verma K. of D*epartment of Geology, Banaras Hindu University.*

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Tripti M.

3.5.4 Salinity and temperature profiling for the submarine groundwater discharge simulations: Quantification through heat and solute transport model

Interaction between two hydrological masses, i.e., seawater and groundwater, manifests as seawater intrusion (SWI) or submarine groundwater discharge (SGD) in the coastal regions. SGD has been recognised as a potential pathway that introduces solutes/contaminants from the land to the sea. Developed coastal regions are the hotspots for contaminated groundwater discharge, affecting sensitive marine ecosystems. A study has been conducted to identify SGD locations and quantify the contaminant load reaching to the western coast of India (Gujarat coast, Fig. 3.5.4.1) using stable isotopes, seepage

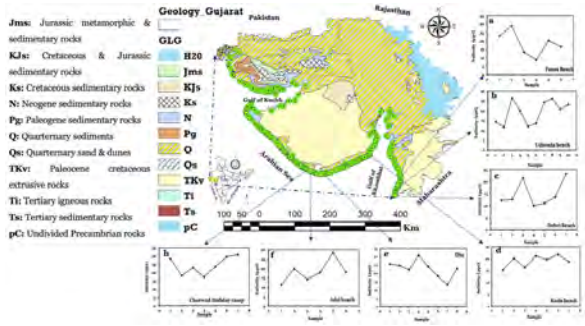

Fig. 3.5.4.1: Sampling locations in study area and geological setup and salinity gradient at seven potential SGD locations (a-g).

meter, heat and solute transport model. In the heat mixing model, temperature is used as a physical tracer to simulate porewater velocity in a vertical direction by employing the 1-D heat conduction-advection equation (Fig. 3.5.4.2). Additionally, to understand the process of SGD through the lens of solute transport, a 1-D advection-dispersion model was used for the quantification of hydrological flux using salinity as a tracer. The estimated SGD flux across the coast ranged between 1.04 and 181.1 $m^3.year^{-1}$ using seepage meter. Simulated flux using heat transport model and solute transport model varies from 0 to 774.7 $m^3.m^{-2}.year^{-1}$. SGD flux reported in the Gujarat coast was relatively lower than the fluxes reported in the Bay of Bengal, Western Bengal basin, South coast of India and Mumbai Harbour coast of Western India. In contrast, it was comparable to flux reported in the South-East coast of India. It was observed that the coastal aquifers are highly enriched in trace metals due to various active natural processes and anthropogenic activities across the coast. Terrestrial and recirculated SGD was a significant contributor to flow and metal load, which ranged from 1.04 to 181.1 $m^3.\ year^{-1}$ and 0–77.41 $kg.\ year^{-1}$, respectively. The highest estimated SGD in the Gujarat coast was relatively less than the SGD reported in the Bay of Bengal and comparable to the

South Chennai coast. Higher micronutrients (Fe and Zn) load in the southern coast leads to increased vulnerability of eutrophication, algal blooms and biotic ligand formation in aquatic species. This enrichment of micronutrients in the coastal ecosystem was evident by the growth of seaweeds on the seabed at SGD identified locations.

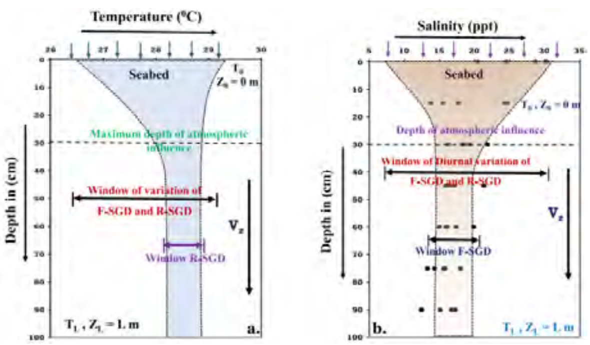

Fig. 3.5.4.2: Schematic diagram of the relationship between fresh/terrestrial SGD (F-SGD) and recirculated SGD (R-SGD) with variations in porewater (a) temperature and (b) salinity variation along the depth of the seabed. (Vz - vertical porewater velocity which is a function of depth (z), temperature (T), thermal conductivity and heat capacity of porewater and sediments).

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Suresh Babu D. S.

3.5.5 Numerical modelling of submarine groundwater discharge in the coastal catchments of SW India

Quantification of SGD across coastal catchments will help in the better management of water resources and enhancement of coastal productivity. Owing to spatial and temporal variations and complexities in the factors affecting SGD, it is often difficult to quantify and estimate SGD. Various terrestrial and marine factors affect spatial and temporal variations in SGD. Along with the discharge of fresh groundwater into the coastal system (fresh SGD), the recirculated seawater (recirculated SGD) also forms an integral part of SGD. Researchers have utilized different tracers, piezometers, water balance calculations, and numerical modeling to evaluate SGD. Numerical modelling approach has been employed in two costal catchments with different geomorphological characteristics on the southwest coast of India to quantify the fresh SGD fluxes in these aquifers. Two coastal catchments of Thiruvananthapuram district, Kerala, India namely Varkala (184 km^2) and Kadinamkulam (186 km^2), have been selected to compute SGD. The catchments are bounded by the Arabian Sea on the west and subtropical terrain in the other directions. The area enjoys a tropical humid climate with average annual precipitation that ranges from 1800 to 2000 mm. Finite element modeling approach using Groundwater Modeling Software (GMS) by Aquaveo has been utilized to estimate the SGD flux over the catchments (Fig. 3.5.5.1). A specific

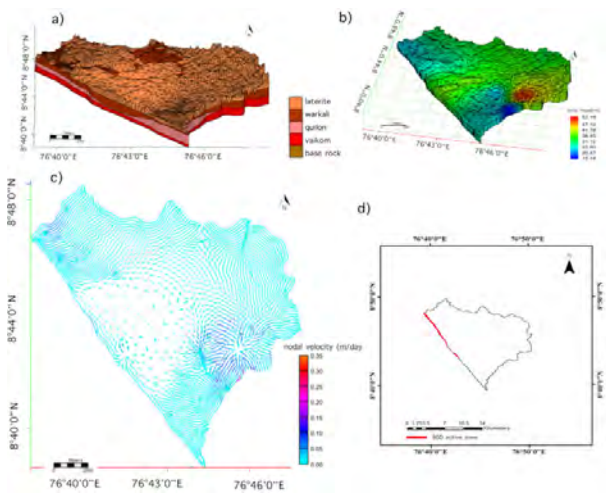

Fig. 3.5.5.1: (a) Varkala Catchment model, (b) Simulated total head and (c) the velocity of flow across the catchment and (d) Active SGD zones identified in the catchment.

head boundary condition is administered to the coastline boundary while other boundaries were modeled as zero flux boundaries. The bottom of the aquifer system was assumed to be impermeable to flow. Any flow across this boundary should be negligible due to the thick Khondalite regional confining unit at the base. The results of the study confirmed that the SGD flux from the catchments differs in a great way across its multiple layers as well as in comparison to one another. The fresh SGD flux from Varkala catchment is found to be 0.1 m^3/day/m and from Kadinamkulam catchment is 6 m^3/m/day. The cliff formations in the Varkala catchment are found to have influenced the SGD pathways in the catchment. It was observed that the SGD flux is heavily influenced by the geology, coastal geomorphology, land use, and topography of the location. The study showed that numerical modelling approaches can yield reliable estimates of SGD with low computational cost and time and is a potent method for quantifying SGD.

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3.6 Atmospheric Science Group

3.6.1 Assessment of PM2.5 using satellite lidar observations: Effect of bio-mass burning emissions over India

Regional aerosol loading over India is alarmingly increasing, poising concern due to its potential impacts on changing regional climate and human health. Wintertime pollution over India has been associated with adverse weather conditions such as extreme haze and fog events over the Indo-Gangetic Plain (IGP). The present study estimates particulate matter of diameter less than 2.5 µm (PM2.5) over India, during the winter season, using near-surface observations of the space-borne lidar, Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) during the last fifteen years (2007–2021) which assumes importance in the context of degrading air quality over India and potential health risks in the future.

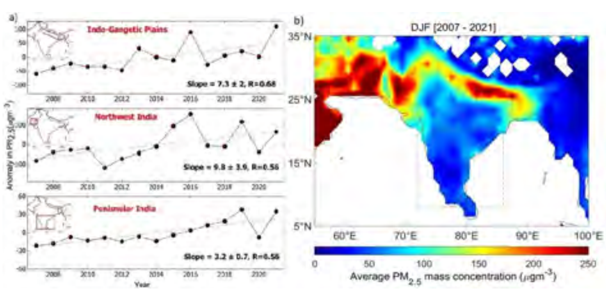

Fig. 3.6.1.1: a) The anomaly of average PM2.5 concentration near to surface during winter (December–February) of 2007 to 2021 over the study regions shown in the insets. The red dotted lines represent the fitted linear regression curve. The year corresponds to the January and February months of the season, and b) Spatial distribution of PM2.5 mass concentration at 1° × 1° grid resolution during the winter season (December to February) of 2007–2021. Dotted lines represent the regions under study.

The present study uses a bulk-mass-modelling method to retrieve surface-level PM2.5 over the Indian region using, near-surface retrievals of aerosol extinction coefficient, mass scattering efficiency, and mass absorption efficiency estimated using Mie calculations based on reanalysis-based aerosol composition, and satellite-based relative humidity observations to account for hygroscopic growth of the pollutants. An intercomparison analysis of collocated observations of CALIOP-derived PM2.5 and *in-situ* measurements over stations under the Central Board of Pollution Control shows a correlation with each other with an R2 of 0.42, a slope of 0.76, and a root mean square error of 51.4 μgm^{-3}.

Climatology of wintertime PM2.5 during the last 15 years shows the highest concentration over the middle IGP and northwest India with a 3-to-4-fold increase in magnitude compared to peninsular India. Over most parts of India except the southern part of the peninsula, PM2.5 concentrations exceed 40 μgm^{-3} as recommended by the National Ambient Air Quality Standards. Surface-level PM2.5 mass concentration during winter (December to February) shows statistically significant positive trends over the Indian subcontinent. It increases at a rate of~3%over the IGP and arid regions of northwest India, and~4% over peninsular India during the last fifteen years (2006–2020), which assumes significance in the context of deteriorating air quality and increasing occurrences of winter fog events over India. Large-scale agricultural crop-residue burning activities over the western part of IGP (Punjab and Haryana) during the post-monsoon season emit a large number of aerosols into the atmosphere and have been linked with air quality over the IGP during the following winter. The present study establishes a statistically significant correlation (95% confidence) between fire activity during November with wintertime PM2.5 concentration near the surface on the interannual scale. To compare the relative role of wintertime meteorology with anthropogenic fire activity in enhancing the air pollution over the study regions, linear regression analysis is carried out between wintertime PM2.5 concentrations with different meteorological parameters over the study regions. It showed that PM2.5 in winter is controlled by variability in agro-residue burning emission strength rather than meteorological conditions. Interannual variability of agro-residue burning over western IGP (Punjab and Haryana) shows a statistically significant correlation with wintertime AOD over IGP, northwestern part of India, and the eastern part of peninsular India, indicating the role of synoptic winds in dispersing the pollutants over large distances throughout the sub-continent Even though most of the studies on the role of post-harvest agro-residue-burning focus on the downwind regions over the IGP, our analysis shows that the influence of these pollutants extends up to peninsular India through long-range transport and can contribute to continental pollution outflow over to the Northern Indian Ocean.

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Lakshmi N. B., Resmi E. A., Padmalal D.

3.6.2 Raindrop size distribution of stratiform precipitation over southwest India – The gateway of Indian Summer Monsoon

The study focuses on exploring the bright band (BB) characteristics, using Micro Rain Radar and ceilometer during the monsoon season of 2019 over three stations - coastal (20 m above mean sea level (MSL), mid (400 m above MSL), and high (1820 m above MSL) altitude cloud physics observatories. The raindrop spectral characteristics are analyzed by classifying the BB events into three time periods, (i) prior to the occurrence of the bright band (pre-BB), (ii) during bright band (BB), and (iii) the subsequent hours after the dissipation of bright band (post-BB). In this study, reflectivity gradient between 4 km and 6 km measured with MRR is used for identifying the BB. Prominent BBs sustained for 10 min or more have been considered for the analysis. The analysis is further extended by classifying the BB event time as, pre- BB, BB, and post-BB hours.

The rain events are classified to 4 bins according to the rain rate (R): (i) $0.1 \leq R < 1$ (R1), (ii) $1 \leq R < 5$ (R2), (iii) $5 \leq R < 10$ (R3) and (vi) $R \geq 10$ (R4) mm hr^{-1}. Different classification criteria are adopted for rain rates to better explain the microphysical properties of tropical rainfall.

Stronger BB events are noted in the high-altitude station with reflectivity of 33 dBZ at the melting layer while the occurrence of high duration (~2 h) events are noted at the mid-altitude station. Pre-BB hours are contributing the highest surface rainfall from all stages of BB evolution at the coastal and mid-altitude stations. The vertical profile of high rain rates indicates the presence of shallow and mixed-phase precipitating systems during pre-BB hours. At the coastal station, light to moderate rainfall with narrow raindrop spectra having dominance of mid-size drops are noticed (Fig. 3.6.2.1). At the coastal station, from the melting layer to the surface, the R1 and R2 rain classes show dominant contribution in RSD spectra. In pre-BB hours, the drops spectra are mixed with shallow precipitating systems and faint BB signals which are evolved during the initial stages of stratiform precipitation. In BB and post-BB hours, the RSD spectra are observed with a slight variation in the number concentration of smaller drops from 4 to 1 km level in the R1 rain category. During BB hours, the RSD spectra of R1 and R2 mainly contribute to the total rainfall however, the spectra of R2 show dominant variation in the drop size range from 0.4 to 1.2 mm.

The RSD spectra at the mid-altitude station are evident with a uniform number concentration of smaller drops for all rain rate classes. The high-altitude station over the Western Ghats is conducive for the generation of stratiform precipitation along with mixed-phase systems in the background of southwest monsoon circulation. The RSD evolved from all rain rate categories in pre-BB hours are registered with these factors. The very heavy rainfall events over high-altitude stations are noted with consistent BB events. The RSD spectra associated with these events in pre-BB and post-BB hours are mostly contributed by R3 and R4 rain categories. The ambient weather conditions and cloud layers are in favorable conditions for the generation of smaller raindrops during pre- BB and post- BB hours. These drops undergo a collision-coalescence-accretion process and lead to a higher number concentration of mid-size drops.

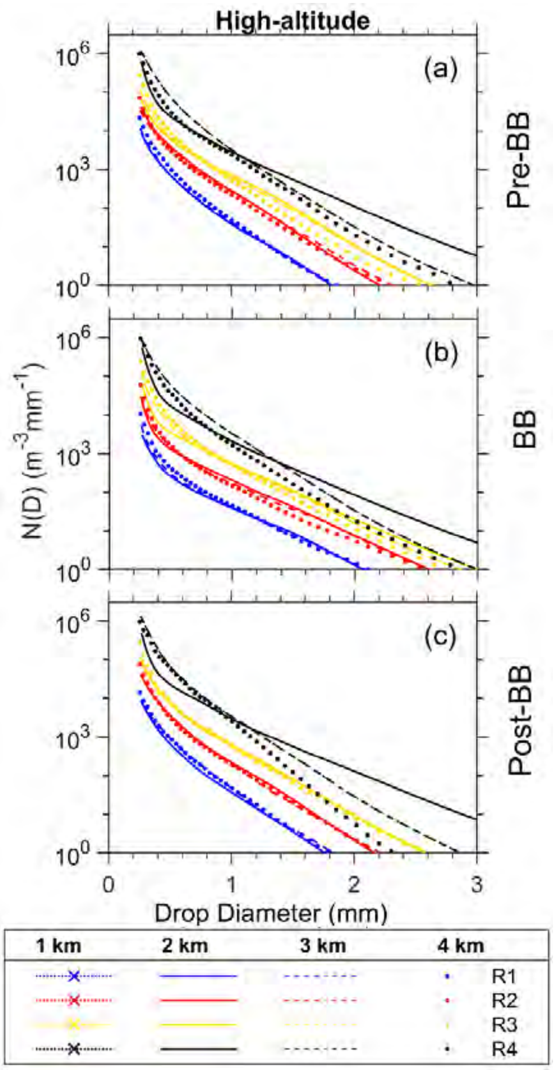

Fig. 3.6.2.1. Variation of mean raindrop concentration (N(D), m-3 mm-1) with drop diameter (D, mm) for pre-BB (a-c), BB (d-f) and post-BB (g-i) at high-altitude stations. The colour represents rain rates (R1 to R4) and three different lines represent altitude (1, 2, 3 and 4 km) above MSL.

The efficiency of collision-coalescence processes is relatively more at the mid- and high-altitude stations resulting in small to mid-size drops and larger drops respectively. The raindrops generated from the melting layer fall into the shallow feeder clouds formed at the saturated surface in the high-altitude station that creates a seeder feeder mechanism of orographic rain enhancement. The radar reflectivity-rain rate relations coherently explain the results concerning the evolution of drop spectra. There is significant vertical variation in both the coefficients and exponents values of Z-R relation in all three stations. Nearly equal coefficients and exponents (except at coastal station) for pre-BB and post-BB categories are detected. At the coastal station, the coefficient 'a' increase from 1 km to the surface implies that collision-coalescence leads to larger raindrops, further initiating the collision-coalescence-breakup processes representing a decrement in the exponent 'b' at the near-surface level. The exponent and coefficient values at the coastal and mid-altitude stations are higher in BB than in pre-BB and post-BB hours. Although the coefficient values are higher at the high-altitude station, exponent values are less in the case of BB than in pre-BB and post-BB hours. The distribution of mass-weighted mean diameter (Dm) varies from 0.5 to 1 mm with wider generalized intercept parameter (log10Nw) values at the mid- and high-altitude stations during pre-BB hours. In BB hours, the distribution of Dm values at the high-altitude station extends to 1.5 mm with high log10Nw values and the shape-slope (μ-Λ) relation also shows the extension of raindrop spectra to larger drops.

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4. Research Output

4.1 Publications

4.1.1 Papers in Journals (SCI)

1. **Ajith Kumar Behera**, Pradhan, R. M., Kumar, S., Chakrapani, G. J., Kumar, P. (2022). Assessment of groundwater flow dynamics using MODFLOW in shallow aquifer system of Mahanadi Delta (east coast), India. Water, Vol. 14 (4), Art. 611. https://doi.org/10.3390/w14040611
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4.1.2 Papers in Journals (non-SCI)

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4.3 Papers presented in Conferences / Seminars / Symposia

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3. **Anusha Andrews Resmi, E. A., Sumesh, R. K., Nita, S., Unnikrishnan, C. K., Padmalal D.** (2021). Confronting the challenges of precipitation microphysics over windward side of the southern Western Ghats. International Symposium on Tropical Meteorology 'Changing Climate: Consequences and Challenges', INTROMET-2021 held at Kochi during 23-26 November 2021.
4. **Anusha Andrews**, **Resmi, E. A., Sumesh, R. K., Unnikrishnan, C. K., Padmalal D.** (2021). Characteristics of shallow clouds and precipitation over Western Ghats region. 18th Annual Meeting of the Asia Oceania Geosciences Society (AOGS 2021) held at Singapore during 01-06 August 2021.
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7. **Jeenu Jose, Krishna Kumar, A., Anoop Krishnan, K.** (2021). Water quality and environmental implications of a tropical estuarine wetland system of international importance: study of Ashtamudi Lake, Kerala, India. International Conference in Geosciences with focus on Climate

Change Perspectives, organized by Mohanlal Sukhadia University, Udaipur, Rajasthan on 10th July 2021.

8. **Jeenu Jose, Krishna Kumar, A., Anoop Krishnan, K.** (2021). Assessment of toxic metal ions in Ashtamudi Ramsar wetland system, SW coast of India. National Seminar on Recent Advances in Geoscience Research held at University of Delhi during 1-2 July 2021.
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10. **Kumar Batuk Joshi, Upasana S. Banerji, Chandra Prakash Dubey,** Elson P. Oliveira (2021). Detrital zircon record from Indian subcontinent. National Seminar on Recent Advances in Geoscience Research held at University of Delhi during 1-2 July 2021.
11. **Lakshmi, N. B.** (2022). Retrieval of near-surface PM2.5 over India using satellite lidar observations. 21st National Space Science Symposium organized by Indian Institute of Science Education and Research held at Kolkata, 31 January - 04 February 2022.
12. **Lakshmi, N. B.**, **Resmi, E. A., Padmalal, D.** (2022). Spatio-temporal variability of PM2.5 over India using multi-year spaceborne lidar observations and its implications. 34th Kerala Science Congress held online during 10-12 February 2022.
13. **Micky Mathew, Sreelash, K., Padmalal, D.** (2021). Causes and consequences of intensive climate change on Kerala during the recent decades. 34th Kerala Science Congress held online during 10-12 February 2022.
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18. **Sneha Mukherjee**, Goutam Ghosh, **Nilanjana Sorcar** (2021). Geochronological and geochemical analyses of the rocks from the Baijnath Klippe, Kumaun Himalaya, North West India and its implications. American Geophysical Union Fall Meeting, 13-17 December 2021.
19. **Sreelash, K., Micky Mathew, Merin Mariam Mathew, Padmalal, D.** (2021). Decoding the role of climate change in the hydro-climatic disasters of south peninsular India. NATHAZARDS-2021 held online during 20-22 September 2021.
20. **Sribin, C., Padma Rao, B.,** Ravi Kumar, M., **Tomson, J. K.** (2021). Mantle deformation along the Western Ghats: Insights from core-refracted shear wave splitting analysis. Joint Scientific

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22. **Sumesh, R. K., Resmi E. A.**, **Unnikrishnan, C. K., Dharmadas Jash**, (2021). Macrophysics of clouds and precipitation microphysics over windward side of Western Ghats during pre and post monsoon seasons. International Conference on Clouds and Precipitation held at Pune during 02-06 August 2021.
23. **Sumit Kumar**, **Resmi E. A., Dharmadas Jash, Sumesh, R. K., Unnikrishnan, C. K.** (2021). Vertical raindrop size distribution of heavy to very heavy precipitation over western ghat: a case study. International Symposium on Tropical Meteorology 'Changing Climate: Consequences and Challenges', INTROMET-2021 held at Kochi during 23-26 November 2021.
24. **Sumit Kumar**, **Resmi E. A., Sumesh R. K., Unnikrishnan, C. K., Padmalal D.** (2021). Orographic evolution of raindrop size distributions associated with bright-bands over Western Ghat. 18th Annual Meeting of the Asia Oceania Geosciences Society (AOGS 2021) held at Singapore during 01-06 August 2021.
25. **Unnikrishnan, C. K.**, Pawar, S. D., Gopalakrishnan (2021). A study on lightning activity in south India using satellite and ground observations. International Symposium on Tropical Meteorology 'Changing Climate: Consequences and Challenges', INTROMET-2021 held at Kochi during 23-26 November 2021.
26. **Vipin T. Raj, Sreelash, K., Padmalal, D.** (2021). Chemical denudation of mountainous catchments in Southern Western Ghats - A case study using hydro chemical tools and modelling. 34th Kerala Science Congress held online during 10-12 February 2022.
27. **Vrinda Mukundan**, Smitha V. Thampi, Anil Bhardwaj (2021). Understanding the M3 layer in the Martian dayside ionosphere using MAVEN observations. 21st National Space Science Symposium organized by Indian Institute of Science Education and Research held at Kolkata, 31 January - 04 February 2022.
28. **Vrinda Mukundan**, Smitha V. Thampi, Anil Bhardwaj (2022). Unusual response of the Martian ionosphere to a moderate dust storm event of October 2016. 3rd Indian Planetary Science Conference held at Physical Research Laboratory, Ahmedabad in 14-16 March 2022.

5. External and Consultancy Projects

NCESS carried out few external grant-in-aid projects and a number of consultancy projects during the year 2021-2022. The externally funded projects were sponsored by Govt. of Kerala and Govt. of India agencies. The consultancy projects were undertaken mainly for the demarcation of HTL and LTL for Coastal Regulation Zone.

Coastal Zone Management

The coastal policy of the Government of India and the coastal states is to develop the coastal regions of the country within the framework. This will ensure the utilization of coastal resources to its optimum potential and to sustain the functional integrity of coastal ecosystems. This approach will also help to contain, to a certain extent, the impact of coastal hazards to coastal communities and properties. Regulating high impact activities in the coastal zone through CRZ is one of the effective tools in this endeavour.

As part of preparing the Coastal Zone Management Plan (CZMP) of Kerala as per 2019 Regulation, extensive ground truth has been collected in all the 10 districts of Kerala where CRZ is applicable and modifications are being made to the maps prepared on the GIS platform. GIS digital conversion of the CRZ maps of 1995 is being undertaken to achieve the maps and to compare with the new CZMP. The entire HTL and LTL geo data base of the State has been sent to National Centre for Sustainable Coastal Management (NCSCM) for its validation as per the direction of the Ministry of Environment, Forest and Climate Change, Government of India.

Around 12 consultancy projects were completed during the year and 14 consultancy works were in progress.

Table 5.1: List of ongoing external grand-in-aid projects

Sl. No.	Project Title	Funding Agency	Total Outlay (Rs. in lakh)
1.	Environmental monitoring of water and sediment quality parameters in the back waters of Cochin Port Trust	Cochin Port Trust, GoI	30.00
2.	DST Inspire Faculty Award - Innovation in science pursuit for inspired research - Dr. Tripti Muguli	Department of Science and Technology, GoI	35.00
3.	Teachers Associateship for Research Excellence (TARE) to Dr. Rajaveni S.P.	Department of Science and Technology, GoI	3.35
4.	Preparation of Coastal Zone Management Plan (CZMP) of Kerala with respect to the CRZ notification 2019	Kerala Coastal Zone Management Authority	198.55
5.	DST Inspire Faculty Award - Innovation in science pursuit for inspired research - Dr. Vrinda Mukundan	Department of Science and Technology, GoI	22.00
6.	"Back to Lab" – Post Doctoral Fellowship Programme – Project entitled "Socio economic and environmental viability of Pamba Achankovil - Vaippar Link" – Dr. Smitha P. S.	Kerala State Council for Science, Technology & Environment	14.17
7.	Sediment budgeting and studies on waves in the VISL project site and adjoining area	Vizhinjam International Seaport Limited	98.44
8.	Identification and monitoring of rip currents at Rushikonda blue-flag certified beach, Vishakapatnam SAMUDRA - TDP project at SAC	Space Applications Centre, ISRO, GoI	17.99

Table 5.2: List of completed CRZ consultancy projects

Sl. No.	Report No.	File No.	Project Name
1.	NCESS-CRZ-15-2021	CRZ/10/2021	KITCO Ltd., Ernakulam (For the construction of jetty and cruise vessel – under Kerala Shipping and Inland Navigation Corporation (KSINC) project at Foreshore Road, Ernakulam)
2.	NCESS-CRZ-03-2022	CRZ/14/2021	Nadapana V. Chanakya and Sreelekshmi Garikipathi, Kannur (For the proposed construction of a special residential building in Edakkad Village)
3.	NCESS-CRZ-17-2021	CRZ/22/2021	St. John d' Britto Church, Kollam (For the re-construction of existing old church in Sakthikulangara, Kollam)
4.	NCESS-CRZ-09-2022	CRZ/26/2021	Njandan Madath Kumman Sooraj, Kannur (For the construction of A2 residential (hotel) building in Pallikunnu Village, Kannur)
5.	NCESS-CRZ-07-2022	CRZ/30/2020	Public Works Department (Bridges Division), Ernakulam (For the construction of Azhikode - Munambam bridge)
6.	NCESS-CRZ-06-2022	CRZ/25/2021	Kerala State Housing Board, Division Office, Ernakulam (For the development of Government Maharaja's Taluk Hospital, Karuvellipady, Ernakulam)
7.	NCESS-CRZ-04-2022	CRZ/15/2021	Food Corporation of India, Divisional Office, Kochi (For the construction of district office building in Rameswaram Village, Ernakulam)
8.	NCESS-CRZ-01-2022	CRZ/24/2021	Kerala State Housing Board, Kottayam (For the development of Government Taluk Hospital, Vaikom, Kottayam)
9.	NCESS-CRZ-02-2022	CRZ/22/2019	Public Works Department (Bridges Division), Thiruvananthapuram (For the construction of Asramam Link Road Phase III)
10.	NCESS-CRZ-10-2022	CRZ/30/2021	Cochin Port Trust (For the installation of 1.5 MWp grid connected floating solar PV project in the backwaters near CoPT's walkway avenue between BOT junction and Kannangatt bridge)
11.	NCESS-CRZ-08-2022	CRZ/08/2022	Indian Coast Guard (via KITCO Ltd.) (For the construction of facilitation centre for ICG Operations at Palluruthy, Ernakulam)
12.	NCESS-CRZ-13-2022	CRZ/09/2022	Goshree Island Development Authority (GIDA) via M/s KITCO Ltd., Ernakulam (For the proposed construction of 350m approach road in Kadamakkudy Village, Ernakulam)

Table 5.3: List of ongoing CRZ consultancy projects

Sl. No.	Project Title	Funding Agency	Total Outlay (Rs. in lakh)
1.	Delineation of HTL/ LTL and preparation of CRZ status report	Public Works Department (PWD) Road Division, Kollam (Construction of Perumon, Konnayil Kadavu, Kannankattu Kadavu, Kattilkadavu, Asramam Link Rd, Fathima Island - Arulappanthuruth bridges)	11.00
2.	-do-	Department of Tourism, Thiruvananthapuram (For the project "Rejuvenation of Akkulam Lake and its watershed, Rebuilding Kerala, the sustainable way")	3.15
3.	-do-	Kerala Tourism Infrastructure Ltd. (KTIL), Thiruvananthapuram (For the development of Kadinamkulam – Anchuthengu backwater tourism corridor)	5.15
4.	-do-	Public Works Department (Bridges Division), Ernakulam (For the construction of Pullut parallel bridges across Kodungallur Kayal in Thrissur District)	3.15
5.	-do-	AW hospitality Pvt. Ltd., Thycaud, Thiruvananthapuram (For the construction of hotel cum residential apartment project at Chowara, Kottakal Village, Thiruvananthapuram)	6.15
6.	-do-	Public Works Department (Bridges Division), Thrikkakara, Ernakulam (For the construction of Kumbalanghi - Keltron ferry bridge across Vembanad Lake connecting Ernakulam and Alappuzha districts)	3.15
7.	-do-	KRFB-PMU, Ernakulam/Thrissur Unit, O/o The Executive Engineer, Edapally, Ernakulam (For the construction of Thriprayar bridge across Canoli Canal in Nattika LAC in Thrissur)	3.15
8.	-do-	Travancore Titanium Products Limited, Thiruvananthapuram District (For the construction of Travancore Titanium Products Ltd at Kadakampally Village, Thiruvananthapuram)	3.15
9.	-do-	Public Works Department (Bridges Division), Ernakulam (For the construction of Nayarambalam Herbert bridge in Ernakulam District, Kerala)	3.15
10.	-do-	Harbour Engineering Sub Division, Muthalappozhy (For the development of Perumathura Beach in Thiruvananthapuram District)	3.15
11.	-do-	Mohd Salih KV & others, Calicut (For the construction of commercial cum residential building in Feroke Municipality of Kozhikode District, Kerala)	3.15
12.	-do-	Harbour Engineering Department, Thiruvananthapuram (For the construction of Fishing Harbour at Pozhiyoor (Kulathur Panchayath) in Thiruvananthapuram District)	3.15
13.	-do-	Harbour Engineering Division, Kasaragod (For the construction of fishing harbour in Ajanoor Grama Panchayat in Kanhangad LOC, Kasaragod District, Kerala)	3.15
14.	-do-	Adani Ports and Special Economic Zone, Gujarat (For the construction of two desalination plants and associated intake & outfall facilities as part of the development of 1576.81 Industrial Park/SEZ at Mundra, Kutch, Gujarat)	9.88

6. New Facilities

NCESS procured many sophisticated analytical facilities for carrying out front-line research in the field of earth science studies during the financial year. The instruments procured and their key characteristics are furnished below.

Sl. No.	Name of the equipment / facility	Make / Model	Application	Photograph of the facility/ instrument
1.	Broadband Seismometer established at Larsemann Hills, Antarctica	REF TEK 151B-120	A continuous record of the ground motion - used to detect the earthquakes/ icequakes and to decipher the subsurface structure and deformation patterns.	
2.	Automatic Weather Station installed at Vattavada, (Munnar Critical Zone Observatory) and Aduthurai (Aduthurai Critical Zone Observatory).	Campbell Scientific	2-level weather station to continuously record the basic meteorological variables such as rainfall, solar radiation, wind speed, wind direction, relative humidity, atmospheric pressure, air temperature.	
3.	Field Lysimeter installed at Attappadi, Munnar and Aduthurai CZOs	Eijkelkamp, Smart Field Lysimeter	A weighing type lysimeter for direct measurements of actual evapotranspiration in vegetated areas.	
4.	Automatic Digital Pan Evaporimeters installed at Munnar and Aduthurai CZOs	Virtual Instruments	Self-recording and automatic filling pan evaporimeter to record daily values of potential evaporation.	

5.	Ground water level monitoring system (and daily record pf ground water level, and rainfall)	Encardio	Understanding river-water and groundwater interaction.	

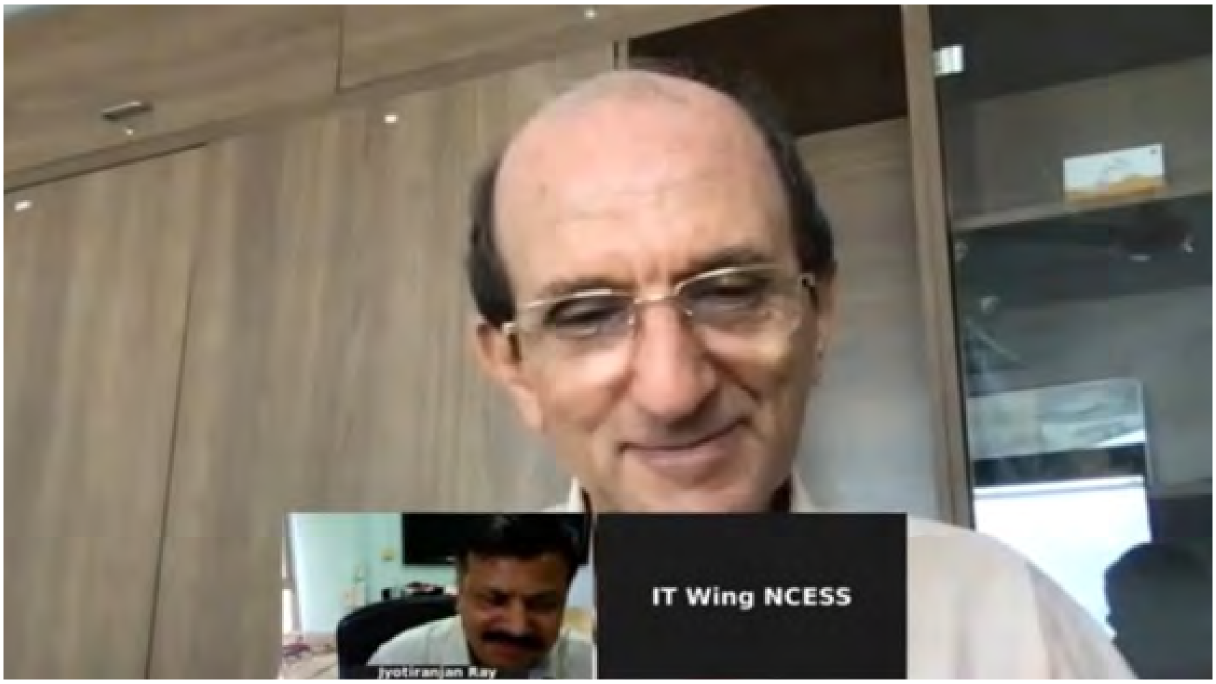
7. Conference, Seminar & Workshop

7.1 Webinar on Recent Advances in Atmospheric Sciences

NCESS organised a one-day webinar on "Invited Lectures on Recent Advances in Atmospheric Sciences" on 30th April 2021 as a part of 'Bharat ka Amrit Mahotsav' celebrations. Dr. K. Rajeev, Director, Space Physics Laboratory, delivered a talk on "Understanding tropical clouds". Dr. T. Narayana Rao, Head (CCSG), National Atmospheric Research Laboratory, delivered a talk on "Atmospheric radars". Dr. S. Suresh Babu, Head (ATRF), Space Physics Laboratory, delivered a talk on "Advances in aerosol research". Dr. Thara Prabhakaran, Project Director (CAIPEEX), Indian Institute of Tropical Meteorology delivered a talk on "Microphysics and precipitation pathways in monsoon clouds". Dr. K. Kishore Kumar, Head (Atmospheric Dynamics Branch), Space Physics Laboratory, delivered a talk on "Are the large-scale atmospheric circulations accelerating in the present climate?". Dr. S. Siji Kumar, Scientist SF (Numerical Atmospheric Modelling Branch), Space Physics Laboratory, delivered a talk on "Atmospheric inverse modelling for greenhouse gas flux estimation".

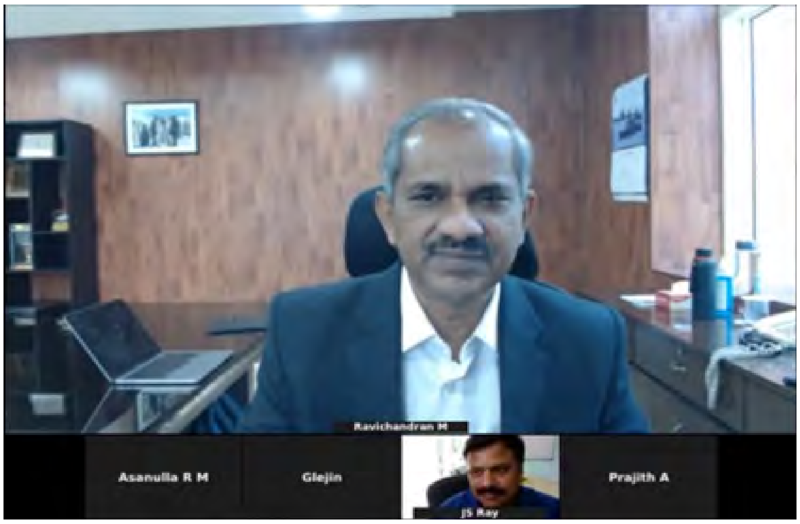
7.2 Webinar as part of Azadi ka Amrit Mahotsav celebrations

As part of Azadi ka Amrit Mahotsav celebrations, an online talk was organized on 26th August 2021. Padma Shri Michel Danino, Visiting Professor, Humanities and Social Sciences, IIT Gandhinagar delivered a talk on "The Sarasvati River's decline in the Holocene".



7.3 NCESS Foundation Day 2022

National Centre for Earth Science Studies (NCESS) celebrated its 8th Foundation Day on 03rd January 2022. The online function was presided by Dr. M. Ravichandran, Hon'ble Secretary, MoES. The Foundation Day lecture was delivered by Prof. S. K. Tandon, Chairman, Research Advisory Committee (RAC), NCESS titled "The Anthropocene concept: focus on the terrestrial hydrosphere". Dr. Jyotiranjan S. Ray, Director, NCESS gave the welcome address.



8. Extension Activities

8.1 Inauguration of New Entrance Gate

The newly constructed Automatic Entrance Gate, Boom Barrier and Security Complex of NCESS was inaugurated by Dr. M. Rajeevan, Hon'ble Secretary, MoES and Chairman, Governing Council, NCESS on 22nd April 2021 through video conference. Prof. J. S. Ray, Director, NCESS gave the welcome address.

8.2 Swachhata Pakhwada

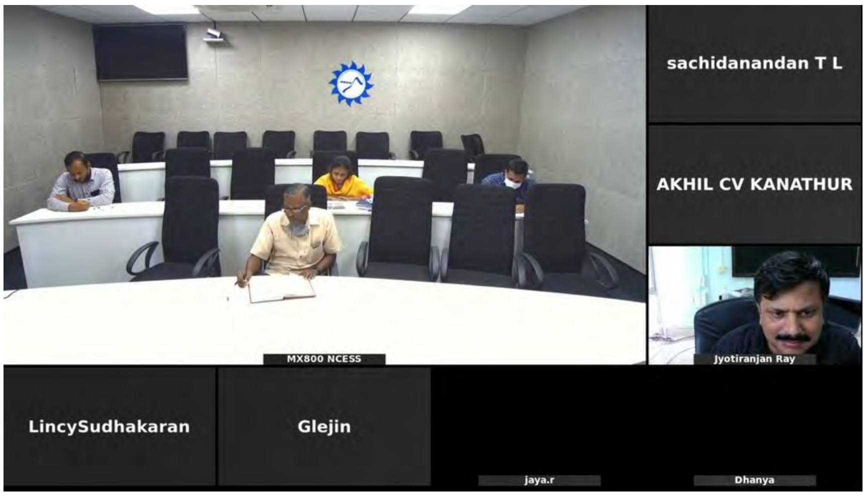
As part of Swachhata Pakhwada, cleaning of office premises was carried out during 01-15 July, 2021. An online gathering was organised on 15th July 2021 to take the Swachhata Pledge. It was followed by the distribution of cleaning materials/kits to various divisions for cleaning of office space/laboratories. Also, to mark the conclusion of Swachhata Pakhwada, an online invited talk on "Statutes on Waste Management" was delivered by Dr. A. M. Sheela, Chief Environmental Engineer, Kerala State Pollution Control Board.

8.3 Hindi Fortnight Celebrations

The programme was inaugurated by Dr. Som Kumar Sharma, Associate Professor, Space and Atmospheric Sciences Division, Physical Research Laboratory, Ahmedabad on 14th September 2021 through video conference. As part of the programme various online competitions viz. essay writing, short story writing, etc. were conducted. The valedictory function was held on 26th October 2021. Prof. Jyotiranjan S. Ray, Director NCESS inaugurated the function and distributed the prizes to the winners of the competitions.

8.4 Vigilance Awareness Week

As per the circular from Central Vigilance Commission, the Vigilance Awareness week was observed from 26th October to 01st November 2021 with the theme 'Independent India @ 75: Self Reliance with Integrity. NCESS employees took the integrity pledge on 26th October 2021 to mark the solidarity with the vision of corruption-free India and to emphasize the importance of integrity in public life. As part of the programme, Shri. R. Sukesan IPS, Superintendent of Police (Retd.) delivered an online talk on "The need and importance of vigilance in official life" on 29th October 2021.



8.5 World Hindi Day

World Hindi Day 2022 was celebrated on 10th January, 2022 at NCESS. Dr. Satish C Tripathi, General Secretary, The Society of Earth Scientists, was the chief guest and delivered a talk on "Geo-conservation and Geo-tourism potential of India (status & future roadmap)".

8.6 India International Science Festival (IISF) 2021

National Centre for Earth Science Studies participated in the 7th edition of 'India International Science Festival (IISF)' held at Panaji, Goa during 10-13 December 2021. NCESS exhibited posters on research activities in the Mega Science, Technology & Industry Expo pavilion of Ministry of Earth Sciences.

8.7 Earth Science Forum

The Earth Science Forum (ESF) of NCESS organized 6 online lectures during 2021-22 on different themes of Earth Sciences by scientists and researchers from NCESS. The first talk of this period was given by Ms. Mintu Elezebath George, Research Scholar, Marine Geoscience Group on the topic "Assessment of Submarine Groundwater Discharge from the Kozhikode coastal segment, Kerala, SW India" on 09th April 2021. Dr. Manab Kumar Dutta, Research Associate, Hydrology Group delivered the first talk of 2022 on "Carbon biogeochemistry of contrasting Indian estuaries" on 18th February 2022. Dr. Prajith A., Scientist B, Marine Geoscience Group delivered a talk on "Factors controlling sedimentation in the Bay of Bengal: Implications of southwest monsoon and turbidity current activities" on 25th February 2022. In March 2022, Dr. Lakshmi N. B., Research Associate, Atmospheric Science Group delivered a talk on "Lidar-based characterization of atmospheric aerosols over India" and Dr. B. Padma Rao, Scientist C, Solid Earth Research Group provided a brief presentation on "Seismological Observatory at Bharati Station, Antarctica - Overview of NCESS Antarctica Expedition". Dr. Bivin Geo George, Scientist B, Solid Earth Research Group delivered a talk on "Fluvio-aeolian dynamics in the Thar Desert" on 18th March 2022.

9. Staff Details

9.1 Director's Office

Dr. Jyotiranjan S. Ray	Director
Dr. D. S. Suresh Babu	Scientist-F & Head, DTC
Smt. Jinitha Madhavan	Coordinator Gr. III
Shri. S. R. Unnikrishnan	Scientific Asst. Gr. A
Smt. T. Remani	MTS
Shri. R. Binu Kumar	MTS

9.2 Solid Earth Research Group

Dr. Jyotiranjan S. Ray	Head (addl. charge)
Dr. Tomson J. Kallukalam	Scientist-E & Deputy Head
Dr. Chandra Prakash Dubey	Scientist-C
Dr. B. Padma Rao	Scientist-C
Dr. Nilanjana Sorcar	Scientist-C
Dr. Kumar Batuk Joshi	Scientist-C
Shri. Arka Roy	Scientist-C
Dr. Bivin Geo George	Scientist-B (from 01.10.2021)
Shri. N. Nishanth	Scientific Asst. Gr. B
Smt. G. Lakshmi	Scientific Asst. Gr. A
Shri. Krishna Jha	Scientific Asst. Gr. A
Shri. K. Eldhose	Technician Gr. B

9.3 Crustal Dynamics Group

Dr. V. Nandakumar	Scientist-G & Head
Shri. Thatikonda Suresh Kumar	Scientist-C
Ms. Alka Gond	Scientist-C
Shri. S. Shivapriya	Scientific Asst. Gr. A

9.4 Hydrology Group

Dr. D. Padmalal	Scientist-G & Head
Dr. A. Krishnakumar	Scientist-D
Shri. Rajat Kumar Sharma	Scientist-C
Dr. K. Sreelash	Scientist-C
Shri. Prasenjit Das	Scientist-C

9.5 Biogeochemistry Group

Dr. K. Maya	Scientist-F & Head
Dr. K. Anoop Krishnan	Scientist-E
Shri. Badimela Upendra	Scientist-C
Dr. S. Kaliraj	Scientist-C
Smt. T. M. Liji	Scientific Asst. Gr. B
Ms. P. V. Vinitha	Scientific Asst. Gr. A

9.6 Marine Geoscience Group

Dr. L. Sheela Nair	Scientist-G & Head
Dr. D. S. Suresh Babu	Scientist-F
Dr. Reji Srinivas	Scientist-D
Shri. Ramesh Madipally	Scientist-C
Dr. A. Prajith	Scientist-B (from 01.09.2021)
Dr. Ajit Kumar Behera	Scientist-B (from 02.09.2021)
Shri. S. S. Salaj	Scientific Asst. Gr. B
Shri. M. K. Rafeeque	Scientific Asst. Gr. B
Shri. M. K. Sreeraj	Scientific Asst. Gr. B
Shri. Shibu Sasi	Scientific Asst. Gr. A
Shri. N. Sreejith	Scientific Asst. Gr. A

9.7 Atmospheric Science Group

Dr. D. Padmalal	Scientist-G & Head (addl. charge)
Dr. E. A. Resmi	Scientist-D & Deputy Head

Shri. Dharmadas Jash	Scientist-C
Dr. C. K. Unnikrishnan	Scientist-C
Smt. Nita Sukumar	Scientific Asst. Gr. B

9.8 Central Geomatics Laboratory

Dr. Reji Srinivas	Scientist-D & Co-ordinator
Shri. S. S. Salaj	Scientific Asst. Gr. B
Shri. P. B. Vibin	Scientific Asst. Gr. B
Shri. M. K. Rafeeque	Scientific Asst. Gr. B
Smt. M. Lincy Sudhakaran	Scientific Asst. Gr. A

9.9 Library

Dr. D. S. Suresh Babu	Scientist-F & Co-ordinator
Smt. K. Reshma	Scientific Asst. Gr. B

9.10 Administration

Shri. D. P. Maret	Senior Manager
Shri. A. Saji	Manager
Shri. M. Madhu Madhavan	Deputy Manager
Smt. R. Jaya	Deputy Manager
Smt. G. Lavanya	Deputy Manager
Smt. Indu Janardanan	Scientific Asst. Gr. B
Shri. P. Rajesh	Executive
Smt. P. C. Rasi	Executive
Smt. Femi R. Srinivasan	Executive
Smt. Smitha Vijayan	Executive
Smt. D. Shimla	Junior Executive
Shri. P. H. Shinaj	Junior Executive
Smt. K. S. Anju	Junior Executive
Smt. V. Sajitha Kumary	Junior Executive
Smt. Seeja Vijayan	Junior Executive
Shri. M. K. Adarsh	Technician Gr. A
Shri. P. Saseendran Nair	MTS (till 31.05.2021)
Shri. P. S. Anoop	MTS
Smt. P. S. Divya	MTS
Shri. K. Sudheer Kumar	MTS
Shri. M. R. Murukan	MTS

9.11 Retirements

Shri. P. Saseendran Nair
MTS
Estate Administration & Management
Superannuated on 31 May 2021

9.12 New Appointments

Dr. A. Prajith
Scientist-B
Marine Geoscience Group

Dr. Ajit Kumar Behera
Scientist-B
Marine Geoscience Group

Dr. Bivin Geo George
Scientist-B
Solid Earth Research Group

10. Balance Sheet

NATIONAL CENTRE FOR EARTH SCIENCE STUDIES

(Ministry of Earth Sciences, Government of India)

Akkulam, Trivandrum

Audit for the Period

2021 – 2022

A J Mohan & Associates

Chartered Accountants

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[See Rule 238 (1)]

UTILIZATION CERTIFICATE FOR THE YEAR 2021-22
IN RESPECT OF RECURRING/NON RECURRING
GRANTS-IN-AID CREATION OF CAPITAL ASSETS

1. Name of the Scheme: National Centre for Earth Science Studies(Autonomous Bodies)
2. Whether recurring or non recurring grants: Both
3. Grants position at the beginning of the Financial year:
   (i) Cash in Hand/Bank : Rs.2,77,34,551.00
   (ii) Unadjusted advances: Rs.3,85,82,238.00
   (iii) Total: Rs.6,63,16,789.00

Details of grants received, expenditure incurred and closing balances: (Actual)

(Amount in Rupees)

Unspent Balances of Grant Received (Figure as at Sl. No. 3(iii))	Interest earned thereon	Interest Deposited back to the Govt	Grant received during the year			Total Available Funds	Expenditure Incurred	Closing Balance
1	2	3	4			5	6	7
			Sanction No.	Date	Amount	(1+2+3+4)		(5-6)
6,63,16,789.00	0.00	0.00	-	-	0.00	6,63,16,789.00	99,90,349.00	5,63,26,440.00

Grants position at the end of the financial year

a. Cash in Hand/ Bank : Rs 2,77,13,522.00
b. Unadjusted advances : Rs.2,86,12,918.00
c. Total : Rs. 5,63,26,440.00

Certified that I have satisfied myself that the conditions on which grants were sanctioned have been duly fulfilled/are being fulfilled and that I have exercised following checks to see that the money has been actually utilized for the purpose for which it was sanctioned:

(i) The main accounts and other subsidiary accounts and registers (including assets registers) are maintained as prescribed in the relevant Act/Rules/Standing instructions (mention the Act/Rules) and have been duly

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audited by designated auditors. The figures depicted above tally with the audited figures mentioned in financial statements/accounts.

(ii) There exist internal controls for safeguarding public funds/assets, watching outcomes and achievements of physical targets against the financial inputs, ensuring quality in asset creation etc. & the periodic evaluation of internal controls is exercised to ensure their effectiveness.

(iii) To the best of our knowledge and belief, no transactions have been entered that are in violation of relevant Act/Rules/standing instructions and scheme guidelines.

(iv) The responsibilities among the key functionaries for execution of the scheme have been assigned in clear terms and are not general in nature.

(v) The benefits were extended to the intended beneficiaries and only such areas/districts were covered where the scheme was intended to operate.

(vi) The expenditure on various components of the scheme was in the proportions authorized as per the scheme guidelines and terms and conditions of the grants-in-aid.

(vii) It has been ensured that the physical and financial performance under National Centre For Earth Science Studies has been according to the requirements, as prescribed in the guidelines issued by Govt. of India and the performance/targets achieved statement for the year to which the utilization of the fund resulted in outcomes given in the financial statements duly enclosed.

(viii) The utilization of the fund resulted in outcomes given in the financial statements duly enclosed.

(ix) Details of various schemes executed by the agency through grants-in-aid received from the same Ministry or from other Ministries is enclosed.

Trivandrum
06.09.2022

For AJ Mohan & Associates
Chartered Accountants
FRN 002468N

Manager (F&A) **Senior Manager** **Director**

CA ANITH PA
Partner
Membership No :226894
UDIN : 22226894ARDILW5028

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[See Rule 238 (1)]

UTILIZATION CERTIFICATE FOR THE YEAR 2021-22 IN RESPECT OF RECURRING/NON RECURRING GRANTS-IN-AID SEISMOLOGY AND GEODYNAMICS (SAGE)/R&D PROGRAMMES

1. Name of the Scheme : Seismology And Geosciences (SAGE)
2. Whether recurring or non-recurring grants : Both
3. Grants position at the beginning of the Financial year :
   (i) Cash in Hand/Bank: Rs. 0.90
   (ii) Fund Diversion: Rs. (3,16,55,236.00)
   (iii) Unadjusted advances: Rs.3,06,82,030.26
   (iv) Total: Rs.(9,73,204.84)

Details of grants received, expenditure incurred and closing balances: (Actual)

(Amount in Rupees)

Unspent Balances of Grant Received (Figure as at Sl. No. 3(iv))	Interest earned thereon	Interest Deposited back to the Govt	Grant received during the year			Opening Balance Adjustment *	Total Available Funds	Expenditure Incurred	Closing Balance
1	2	3	4			5	6	7	8
			Sanction No.	Date	Amount		(1+2-3+4+5)		(6-7)
(9,73,204.84)	3,70,723.00	3,70,723.00	#	#	13,20,00,000.00	(1,65,315.00)	13,08,61,480.16	9,36,72,754.06	3,71,88,726.10

*The part of balance shown in SAGE fund instead of OPMA (Operations & Maintenance) fund in the years 2015-16, 2016-2017 and 2017-18, now corrected.

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MOHAN & ASSOCIATES CHARTERED ACCOUNTANTS

MOES/P.O.(Seismo)/8/(14)-A/2017 dated 24.06.2021 – Rs.4,00,00,000/-
MOES/P.O.(Seismo)/8/(14)-A/2017 dated 09.09.2021 – Rs.3,20,00,000/-
MOES/P.O.(Seismo)/8/(14)-A/2017 dated 27.10.2021 – Rs.5,00,00,000/-
MOES/P.O (Seismo)/8/ (14)-A/2017 dated 27.10.2021 – Rs.1,00,00,000/-

Component wise utilization of grants :

Non -Recurring	Recurring	Total
Rs.4,01,35,186.00	Rs. 5,35,37,568.06	Rs.9,36,72,754.06

Grants position at the end of the financial year

a. Cash in Hand/ Bank : Rs. 7,39,936.75
b. Unadjusted advances : Rs. 3,64,48,789.35
c. Total : Rs. 3,71,88,726.10

Certified that I have satisfied myself that the conditions on which grants were sanctioned have been duly fulfilled/are being fulfilled and that I have exercised following checks to see that the money has been actually utilized for the purpose for which it was sanctioned:

(i) The main accounts and other subsidiary accounts and registers (including assets registers) are maintained as prescribed in the relevant Act/Rules/Standing instructions (mention the Act/Rules) and have been duly audited by designated auditors. The figures depicted above tally with the audited figures mentioned in financial statements/accounts.

(ii) There exist internal controls for safeguarding public funds/assets, watching outcomes and achievements of physical targets against the financial inputs, ensuring quality in asset creation etc. & the periodic evaluation of internal controls is exercised to ensure their effectiveness.

(iii) To the best of our knowledge and belief, no transactions have been entered that are in violation of relevant Act/Rules/standing instructions and scheme guidelines.

(iv) The responsibilities among the key functionaries for execution of the scheme have been assigned in clear terms and are not general in nature.

(v) The benefits were extended to the intended beneficiaries and only such areas/districts were covered where the scheme was intended to operate.

(vi) The expenditure on various components of the scheme was in the proportions authorized as per the scheme guidelines and terms and conditions of the grants-in-aid.

(vii) It has been ensured that the physical and financial performance under National Centre for Earth Science Studies has been according to the requirements, as prescribed in the guidelines issued by Govt.

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A.J. MOHAN & ASSOCIATES
CHARTERED ACCOUNTANTS

of India and the performance/targets achieved statement for the year to which the utilization of the fund resulted in outcomes given in the financial statements duly enclosed.

(viii) The utilization of the fund resulted in outcomes given in the financial statements duly enclosed.

(ix) Details of various schemes executed by the agency through grants-in-aid received from the same Ministry or from other Ministries is enclosed.

Trivandrum
06.09.2022

CA ANITH. P.A. M. No: 226894 B.Com, FCA

For AJ Mohan & Associates
Chartered Accountants
FRN 002468N

Manager (F&A) **Senior Manager** **Director** **CA ANITH PA**

Partner
Membership No :226894
UDIN : 22226894ARDILW5028

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AJ MOHAN & ASSOCIATES CHARTERED ACCOUNTANTS

GFR 12 - A

[See Rule 238 (1)]

UTILIZATION CERTIFICATE FOR THE YEAR 2021-22
IN RESPECT OF RECURRING/NON RECURRING
GRANTS-IN-AID SALARIES AND GENERAL

1. Name of the Scheme : National Centre for Earth Science Studies(Autonomous Bodies)
2. Whether recurring or non-recurring grants : Both
3. Grants position at the beginning of the Financial year :
   - (i) Cash in Hand/Bank : Rs. 1,44,91,236.12
   - (ii) Unadjusted advances : Rs. (67,85,931.00)
   - (iii) Total : Rs. 77,05,305.12

Details of grants received, expenditure incurred and closing balances: (Actual)

(Amount in Rupees)

Unspent Balances of Grant Received (Figure as at Sl. No. 3(iii))	Interest/Other Receipts earned thereon	Interest Deposited back to the Govt	Grant received during the year			Opening Balance adjustment *	Total Available Funds	Expenditure Incurred	Closing Balance
1	2	3	4			5	6	7	8
			Sanction No.	Date	Amount		(1+2-3+4+5)		(6-7)
77,05,305.12	23,85,891.00	17,37,750.00	#	#	13,00,00,000.00	1,65,315.00	13,85,18,761.12	12,89,94,772.00	95,23,989.12

*The part of balance shown in SAGE fund instead of OPMA (Operations & Maintenance) fund in the years 2015-16, 2016-2017 and 2017-18, now corrected.

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AJ MOHAN & ASSOCIATES CHARTERED ACCOUNTANTS *

MoES/P.O(NCESS)/3/2015-PT dated 24.06.2021 - Rs.1,00,00,000.00
MoES/P.O(NCESS)/3/2015-PT dated 24.06.2021 – Rs.1,40,00,000.00
MoES/P.O(NCESS)/3/2015-PT dated 29.09.2021 – Rs.2,65,00,000.00
MoES/P.O(NCESS)/3/2015-PT dated 29.09.2021 – Rs. 35,00,000.00
MoES/P.O(NCESS)/3/2015-PT dated 17.12.2021 – Rs.2,68,00,000.00
MoES/P.O(NCESS)/3/2015-PT dated 17.12.2021 – Rs.1,00,00,000.00
MoES/P.O(NCESS)/3/2015-PT dated 07.02.2022 – Rs.2,99,20,000.00
MoES/P.O(NCESS)/3/2015-PT dated 30.03.2022 – Rs. 45,00,000.00
MoES/P.O(NCESS)/3/2015-PT dated 30.03.2022 – Rs. 47,80,000.00

Component wise utilization of grants :

Grant in aid General	Grant in aid Salary	Total
Rs. 2,36,19,248.00	Rs. 10,53,75,524.00	Rs. 12,89,94,772.00

Grants position at the end of the financial year

a. Cash in Hand/ Bank: Rs. 1,69,90,338.12
b. Unadjusted advances: Rs. (74,66,349.00)
c. Total: Rs 95,23,989.12

Certified that I have satisfied myself that the conditions on which grants were sanctioned have been duly fulfilled/are being fulfilled and that I have exercised following checks to see that the money has been actually utilized for the purpose for which it was sanctioned:

(i) The main accounts and other subsidiary accounts and registers (including assets registers) are maintained as prescribed in the relevant Act/Rules/Standing instructions (mention the Act/Rules) and have been duly audited by designated auditors. The figures depicted above tally with the audited figures mentioned in financial statements/accounts.

(viii) There exist internal controls for safeguarding public funds/assets, watching outcomes and achievements of physical targets against the financial inputs, ensuring quality in asset creation etc. & the periodic evaluation of internal controls is exercised to ensure their effectiveness.

(ix) To the best of our knowledge and belief, no transactions have been entered that are in violation of relevant Act/Rules/standing instructions and scheme guidelines.

(x) The responsibilities among the key functionaries for execution of the scheme have been assigned in clear terms and are not general in nature.

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AJ MOHAN & ASSOCIATES CHARTERED ACCOUNTANTS

(xi) The benefits were extended to the intended beneficiaries and only such areas/districts were covered where the scheme was intended to operate.

(xii) The expenditure on various components of the scheme was in the proportions authorized as per the scheme guidelines and terms and conditions of the grants-in-aid.

(xiii) It has been ensured that the physical and financial performance under National Centre For Earth Science Studies has been according to the requirements, as prescribed in the guidelines issued by Govt. of India and the performance/targets achieved statement for the year to which the utilization of the fund resulted in outcomes given in the financial statements duly enclosed.

(viii)The utilization of the fund resulted in outcomes given in the financial statements duly enclosed.

(x) Details of various schemes executed by the agency through grants-in-aid received from the same Ministry or from other Ministries is enclosed.

Trivandrum
06.09.2022

CA ANITH. P.A. M. No: 226894 B.Com, FCA

For AJ Mohan & Associates
Chartered Accountants
FRN 002468N

Manager (F&A) **Senior Manager** **Director**

CA ANITH PA
Partner
Membership No :226894
UDIN : 22226894ARDILW5028

AJ MOHAN & ASSOCIATES CHARTERED ACCOUNTANTS

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A J Mohan & Associates
Chartered Accountants
FRN: 002468N

5th Floor, Flair Al Rahma,
Panavel - Kochi Hwy Toll Junction,
Edappally, Kochi, Kerala – 682024
anith.pa@ajmohan.com/+8828171868

INDEPENDENT AUDITORS REPORT

To,

The Director

National Centre for Earth Science,

Thiruvananthapuram, 695011

REPORT ON THE FINANCIAL STATEMENTS

Qualified Opinion

We have audited the accompanying financial statements of National Centre for Earth Science Studies, Thiruvananthapuram, 695011 which comprise the balance sheet as at 31.03.2022, and the income and expenditure account for the year then ended, and a summary of significant accounting policies and other explanatory information

In our opinion and to the best of our information and according to the explanation given to us, except for the effects of the matter described in the Basis for Qualified Opinion section of our report, financial statements give a true and fair view and prepared in conformity with the accounting principles generally accepted in India:

a) In the case of the Balance Sheet, of the state of affairs of the National Centre for Science as at 31st March, 2022

b) In the case of Income and Expenditure Account, of the expenditure over Income /Income over expenditure for the year ended on that date

Basis for Qualified Opinion

1. Provision for the month of march 2022 has not been provided for expenses "security services , Cleaning services and Vehicle Hire Charges" citing that the amounts will be determined only after due approval from competent authority. This practice is not in conformity with AS – 29 "Provisions, contingent liabilities, and contingent assets". If the society had complied with AS-29, Expense and Provisions would have increased by Rs.5,34,060.00/-.

2. There are long outstanding receivables which are subject to Confirmation

A J MOHAN & ASSOCIATES CHARTERED ACCOUNTANTS

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- Advance to Suppliers – NCESS – Rs.6,42,99,989.00 Dr.
- Leave Salary Receivable – Rs.1,35,990.00 Dr.
- Salary receivable – Rs.6,40,079.00 Dr.
- Grants to Other Institutes – Rs.1,12,17,224.00 Dr.
- Gratuity Receivable KSCTSE – Rs.29,98,600.00 Dr.
- Service Tax Interest Receivable – Rs.10163.00 Dr.
- Service Tax Receivable – Rs.1,84,870.00 Dr.
- General Reserve – Rs.3,13,74,204.00 Dr. (This account represents amount receivable from Government of Kerala.)

We conducted our audit in accordance with standards on auditing issued by the Institute of Chartered Accountants of India. Our responsibilities under those Standards are further described in the Auditor's Responsibilities for the Audit of the Financial Statements section of our report. We are independent of the Auditee in accordance with the Code of Ethics issued by the Institute of Chartered Accountants of India. We have fulfilled our other ethical responsibilities in accordance with these requirements and the ICAI's Code of Ethics. We believe that the audit evidence we have obtained is sufficient and appropriate to provide a basis for our qualified opinion.

Emphasis of Matter Paragraph

We draw attention to the Subheading contingent liabilities in the Notes to Financial Statements; that the management is unable to predict the outcome of the cases filed against the NCESS, which will be known only at the time of final judgement. Hence amount of contingent liability is not estimated and disclosed by the management.

We draw attention to the Subheading Retirement benefits in the Notes to Financial Statements; that the Leave encashment is accounted for on cash basis, no provision for leave encashment is made in the accounts.

Our opinion is not modified in respect of these matters.

RESPONSIBILITIES OF MANAGEMENT AND THOSE CHARGED WITH GOVERNANCE FOR THE FINANCIAL STATEMENTS

The management is responsible for the preparation of these financial statements that give a true and fair view of the financial position and financial performance of the entity in accordance with Accounting Standards issued by the Institute of Chartered Accountants of India and in accordance with accounting principles generally accepted in India and for such, internal control as management determines is necessary to enable the preparation of financial statements that are free from material misstatement, whether due to fraud or error.

Those charged with governance are responsible for overseeing the entity's financial reporting.

AUDITORS RESPONSIBILITY FOR THE AUDIT OF FINANCIAL STATEMENTS

Our responsibility is to express an opinion on these financial statements based on our audit. We have conducted our audit in accordance with standards on auditing issued by the Institute of Chartered Accountants of India. Those Standards require that we have complied with the ethical requirements and plan and perform the audit to

AJ MOHAN & ASSOCIATES CHARTERED ACCOUNTANTS

obtain reasonable assurance about whether the financial statements as a whole are free from material misstatement, whether due to fraud or error and to issue an auditor's report that includes our opinion.

As part of an audit in accordance with standards on audit, we exercise professional judgment and maintain professional; skepticism throughout the audit:

We also obtain an understanding of internal control relevant to the audit in order to design audit procedures that are appropriate in the circumstances, but not for the purpose of expressing an opinion on the effectiveness of the entity's internal control.

Evaluate the appropriateness of accounting policies used and the reasonableness of accounting estimates and related disclosures made by management.

We believe that the audit evidence obtained by us is sufficient and appropriate to provide a basis for our audit opinion on the financial statements.

OTHER MATTERS

(a) We have sought and obtained all the information and explanations which to the best of our knowledge and belief were necessary for the purpose of our audit

(b) The balance sheet and the income and expenditure dealt by this report are in agreement with the books of account

Place: Trivandrum
Date: 06.09.2022

For A J Mohan & Associates
Chartered Accountants
FRN :002468N

CA ANITH. P.A. M. No: 226894 B.Com, FCA

CA ANITH PA
Chartered Accountants
Partner
Membership No: 226894
UDIN: 22226894ARDILW5028

A J MOHAN & ASSOCIATES CHARTERED ACCOUNTANTS

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NATIONAL CENTRE FOR EARTH SCIENCE STUDIES
Ministry of Earth Sciences, Government of India

Balance Sheet as on 31st March, 2022

Particulars	Sch No.	2021-2022	2020-2021
		Rs.	Rs.
Liabilities			
Capital Reserve	1	43,15,34,320.43	45,92,96,121.84
General Reserve	2	(3,13,74,204.00)	(3,13,74,204.00)
Unspent Balance GOI - MoES	3	10,30,39,155.22	7,30,48,889.28
Unspent Balance of Projects	4	16,45,36,571.64	16,26,73,777.64
Corpus Fund	5	20,44,32,417.73	18,09,32,191.23
Current Liabilities	6	2,43,83,302.00	1,47,84,931.00
Total		**89,65,51,563.02**	**85,93,61,706.99**
Assets			
Fixed Assets	7	43,15,34,320.43	45,92,96,121.84
Current Assets, Loans & Advances	8	46,50,17,242.59	40,00,65,585.15
Total		**89,65,51,563.02**	**85,93,61,706.99**
Notes forming part of Accounts	16		

Trivandrum
06.09.2022

For AJ Mohan & Associates
Chartered Accountants
FRN 002468N

Manager (F&A) **Senior Manager** **Director**

ANITH PA
Partner
Membership No :226894
UDIN : 22226894ARDILW5028

CA ANITH. P.A. M. No: 226894 B.Com FCA

AJ MOHAN & ASSOCIATES CHARTERED ACCOUNTANTS

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NATIONAL CENTRE FOR EARTH SCIENCE STUDIES

Ministry of Earth Sciences, Government of India

Income & Expenditure for the year ended 31st March, 2022

Particulars		Sch No.	2021-22	2020-21
			Rs.	Rs.
Income	-			
Operation and Maintenance Grant				
Grant Received	13,00,00,000.00	9		
Less: Capital Expenditure	4,57,103.00		12,95,42,897.00	12,24,18,306.00
Income from Consultancy Project			1,25,250.00	-
Other Income		10	5,22,891.00	4,00,996.00
Depreciation Written Back			7,86,05,514.00	8,65,64,248.09
Total - A			**20,87,96,552.00**	**20,93,83,550.09**
Expenditure				
Staff Salary & Benefits		11	10,53,75,524.00	9,38,98,556.00
Other Institutional Expenses				
Total of Other Institutional Expenses	2,36,19,248.00			
Less: Capital Expenditure	4,57,103.00	12	2,31,62,145.00	2,39,17,391.38
Depreciation			7,86,05,514.00	8,65,64,248.09
Total - B			**20,71,43,183.00**	**20,43,80,195.47**
Excess of Income over expenditure (A-B)			16,53,369.00	50,03,354.62
Excess of Income over expenditure of Prev. Year			77,05,305.12	27,01,950.50
Total			**93,58,674.12**	**77,05,305.12**
Notes forming part of Accounts		16		

CA ANITH. P.A. M. No: 226894 B.Com, FCA

Trivandrum

06.09.2022

For AJ Mohan & Associates

Chartered Accountants

FRN 002468N

Manager (F&A) Senior Manager Director

ANITH PA

Partner

Membership No :226894

UDIN : 22226894ARDILW5028

AJ MOHAN & ASSOCIATES CHARTERED ACCOUNTANTS

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NATIONAL CENTRE FOR EARTH SCIENCE STUDIES

Ministry of Earth Sciences, Government of India

Receipts & Payments Account for The Year Ended 31st March, 2022

Receipts	Amount		Payments	Amount
Opening Bank Balance	42225788.02		Consumables	7715719.48
Opening Stock:	0.00		Printing & Stationery	435245.00
Printing & Stationery	70462.00		Previous Years Salary	96142.00
Consumables	1541797.00		Salaries-Director	3619546.00
Stamp	0.00		Salaries-Others	78842648.00
Grant From Government	262000000.00		Leave Salary & Pension Contrib	136512.00
Interest From Deposits	29044.00		LIC Gg Scheme For Staff	1429859.00
Receipts From Cony Projects	125250.00		Sitting Fee/ Honor-Visiting Ex	321320.00
Miscellaneous Receipts	492833.00		Children Education Allowance	864000.00
Application Fee (Right to Info	1014.00		Contribution To EPF	3767488.00
Co-Operative Recovery	-3000.00		Salary-Other Institutes	8085371.00
Subscription to NCESS Rec-Club	-25.00		Contribution To EPFIF	25650.00
EPF Staff	49678.00		EPF Administrative Charges	174045.00
NPS Staff	59127.00		Contribution to Pension Scheme	406250.00
GSLIS	-140.00		Medical Expense Reimbursement	637156.00
Income Tax Staff	176500.00		Leave Travel Concession	238107.00
Income Tax Contractors	249073.00		Travelling Expense to Visiting	61274.00
LIC	-1291.00		Travelling Expense	2223420.99
CGST TDS	-1859.00		Electricity Charges	4189513.00
SGST TDS	-1859.00		Water Charges	119845.00
IGST TDS	-39542.00		Repairs & Maintenance-Vehicles	43278.00
NCESS Co-Operative Society	-441.00		Repairs & Maintenance-Others	1867379.00
Sundry Creditors for Expenses	-1740997.00		Repairs & Maint Of Building	730433.00
Sundry Creditors for Supplies	10373225.00		Petrol Diesel & Oil	127502.00
CGST	317807.00		Taxes & Insurance-Vehicles	21524.00
SGST	317808.00		Hospitality Expenses	103996.00
IGST	6584.00		Remuneration Proj Staff(Cont)	22994824.00
KFC	-1050.00		Advertisement	211054.00
Security Deposit Received	434918.00		Audit Fees	29181.00
Emd Received	-476000.00		Vehicle Hire Charges	1710592.00
Fund Diversion	-31655236.00		Legal Charges	269670.00
			News Paper & Periodicals	1898.00
			Postage & Communication	2676468.00
			Prior Period Expenses-Others	3716079.06
			Contingency	7731145.00
			Semi/Conf/Wkshp/Trng/Brstmng	217514.00
			Contribution to NPS	7048292.00
			Consultant Fee/ Charges	924000.00

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A J MOHAN & ASSOCIATES CHARTERED ACCOUNTANTS

NATIONAL CENTRE FOR EARTH SCIENCE STUDIES
Ministry of Earth Sciences, Government of India

			NPS Service Charges	4458.00
			SB-Swachtha Pakhwada	11975.00
			SB-Housekeeping	1122842.00
			SB-Gardening	61140.00
			SB-Swachtha Mission	24839.00
			Subscription Of Journals	2511846.00
			Equipment Repair Charges/AMC	1709918.00
			Boat Hire Charges	18950.00
			Bank Charges	18605.36
			Field Expenses	1843969.74
			Rent	840720.00
			Insurance Labs & Equipment	50117.00
			Membership/Registration	114460.25
			Printing & Publication Cost	558891.98
			Analytical Charges	161256.00
			Remuntion-Proj Staf-Other Institute	4805762.00
			Field Expenses-Other Institute	1517148.00
			Chemi/Consum-Other Institution	954536.00
			Contingency-Other Institutions	896798.20
			Overhead Charg-Other Institute	1043835.00
			Computer System & Accessories	3288058.00
			Canteen Equipment	10750.00
			Electrical/Ups Installations	446249.00
			Furniture	253116.00
			Laboratory Equipment	35696509.00
			Books & Journals	2120.00
			Office Equipment	107765.00
			Air Conditioners	297488.00
			Major Software	490234.00
			Work In Progress - Capital	4080084.00
			Roads	5899494.00
			Other Receivables	-330419.00
			CGST-TDS Receivable	26505.00
			SGST-TDS Receivable	26505.00
			Margin Money on LC - NCESS	-1569707.00
			Rolling Contingent Advance	56460.00
			Tour Advance	-1376092.54
			Other Advance	-2295369.17
			Imprest	-4389.00
			Prepaid Taxes & Insurance-Vehicle	-1383.00

A J MOHAN & ASSOCIATES
CHARTERED ACCOUNTANTS

NATIONAL CENTRE FOR EARTH SCIENCE STUDIES

Ministry of Earth Sciences, Government of India

		Prepaid Expenses-Others	242247.00
		Prepaid Expenses- Postage and Telegram and Telephone	69895.00
		TDS Receivable	125722.00
		Leave Salary Receivable	0.00
		Central Public Works Dept	-10405365.00
		Tescan Brno, Czech Republic	-90214.00
		Geometrics Inc.,USA	-1020517.00
		IDS Georadar S.R.L, ITALY	-3279668.00
		Star One IT Solutions	10281415.00
		Elementar UK LTD	20756111.00
		IIT	-693877.00
		National Institute Of Oceanogr	-567241.00
		NIH	-1908137.00
		Manipal Academy Of Higher Education	-657256.00
		NIT, Karnataka	-487662.00
		KU	-370768.20
		CUSAT	-1100000.00
		CWRDM	677336.00
		Anna University	81173.00
		Pondicherry University	-435880.00
		V.O.Chidambaram College	-937400.00
		Closing Bank Balance	45443796.87
		Closing Stock:	
		Printing & Stationery	96315.00
		Consumables	1536578.00
		Stamp	2879.00
Total	**28,45,49,468.02**	**Total**	**28,45,49,468.02**

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A J MOHAN & ASSOCIATES CHARTERED ACCOUNTANTS

NATIONAL CENTRE FOR EARTH SCIENCE STUDIES
Ministry of Earth Sciences, Government of India

Schedules Forming part of Balance Sheet

Schedule 1 - Capital Reserve

Particulars	Sch.No	As at 31.3.2022	As at 31.3.2021
		Rs.	Rs.
Opening Balance		45,92,96,121.84	46,62,43,759.49
Less:Fixed Assets Rounded off		2.41	-
Add: Addition to Capital Asset		5,59,21,439.00	8,17,33,602.00
Add: Transfer from External Projects		2,71,848.00	6,25,598.43
Less: Depreciation		7,86,05,514.00	8,65,64,248.09
Less: Sale of Fixed Assets/ Capitalisation of WIP		53,49,572.00	27,42,590.00
Closing balance		**43,15,34,320.43**	**45,92,96,121.84**

Schedule 2 - General Reserve

Particulars	Sch.No	As at 31.3.2022	As at 31.3.2021
		Rs.	Rs.
Plan fund from GOK			
Opening Balance		58,56,830.00	59,67,205.00
Add: Receipts for R&D from operations and maintenance fund		-	-
Less: Plan Revenue Expenditure for the year		-	1,10,375.00
Less: Plan Capital Expenditure for the year		-	-
Add: Interest Received and other income		-	-
Add: Previous Year Adjustments		-	-
Closing Balance		**58,56,830.00**	**58,56,830.00**

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A J MOHAN & ASSOCIATES CHARTERED ACCOUNTANTS

NATIONAL CENTRE FOR EARTH SCIENCE STUDIES
Ministry of Earth Sciences, Government of India

Non Plan Fund from GOK			
Opening Balance		(3,72,31,034.00)	(3,69,90,687.00)
Add: Receipts during the year		-	-
Less: Non Plan Revenue Expenditure for the year			2,40,347.00
Closing Balance		**(3,72,31,034.00)**	**(3,72,31,034.00)**
Total		**(3,13,74,204.00)**	**(3,13,74,204.00)**

Schedule 3 - Unspent Balance GOI - MoES

Particulars	Sch.No	As at 31.3.2022	As at 31.3.2021
Operation and Maintenance Fund		**Rs.**	**Rs.**
-			
Grant in aid for salaries and general (OPMA)			
Opening Balance		77,05,305.12	27,01,950.50
Add: Incorrect classification in Previous Audit Report		1,65,315.00	-
Add: Grant Received during the year	9	13,00,00,000.00	12,50,00,000.00
Less: Revenue Expenditure	11 & 12	12,85,37,669.00	11,78,15,947.38
Less: Capital Expenditure	11 & 12	4,57,103.00	25,81,694.00
Add: Income from Interest & Other Income	10	5,22,891.00	4,00,996.00
Add: Income from consultancy		1,25,250.00	-
Closing Unspent Balance of Grant		**95,23,989.12**	**77,05,305.12**
Grant in aid for creation of capital assets (Major works)			
Opening Balance		6,63,16,789.00	8,20,64,504.00
Add: Grant Received during the year		-	-
Less: Revenue Expenditure		-10,771.00	69,570.00

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A J MOHAN & ASSOCIATES CHARTERED ACCOUNTANTS

NATIONAL CENTRE FOR EARTH SCIENCE STUDIES
Ministry of Earth Sciences, Government of India

Less: Capital Expenditure	15	-99,79,578.00	1,56,78,145.00
Add: Income from Interest & Other Income		-	-
Closing Unspent Balance of Grant		**5,63,26,440.00**	**6,63,16,789.00**

Seismological and Geoscience (SAGE)			
(Research & Development Programme)			
Opening Balance		-9,73,204.84	3,34,29,714.64
Less: Incorrect Classification in the Previous Financial statements		-1,65,315.00	-
Add: Grant Received during the year		13,20,00,000.00	10,25,00,000.00
Less: Revenue Expenditure	13	-5,35,37,568.06	7,36,45,027.48
Less: Capital Expenditure	14	-4,01,35,186.00	6,32,96,307.00
Add: Income from Interest & Other Income		-	346.00
Add: Income from sale of assets		-	38,069.00
Closing Unspent Balance of Grant		**3,71,88,726.10**	**- 9,73,204.84**
Closing Unspent Balance		**10,30,39,155.22**	**7,30,48,889.28**

Schedule 4 - Unspent Balance of Projects

Particulars	**Sub Sch No.**	**As at 31.3.2022**	**As at 31.3.2021**
		Rs.	**Rs.**
Research Projects	A	66,67,739.14	1,47,79,740.14
Divisional Core Research Projects	A	2,28,74,823.04	1,74,83,397.54
Service Component Projects	A	43,99,481.00	- 3,41,850.00
Consultancy Projects	B	13,05,94,528.46	13,07,52,489.96
Total		**16,45,36,571.64**	**16,26,73,777.64**

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Schedule 5 - Corpus Fund

Particulars	Sch.No	As at 31.3.2022	As at 31.3.2021
		Rs.	Rs.
Opening Balance		18,09,32,191.23	17,19,94,366.71
Add: Interest Received Fixed Deposit		1,53,54,126.00	19,01,103.00
Add: Income from Consultancy Projects		43,09,915.50	36,43,213.02
Add: Overhead Charges		22,50,618.00	18,10,124.00
Add: Other Receipts		15,85,567.00	15,83,384.50
Closing Unspent		**20,44,32,417.73**	**18,09,32,191.23**

Schedule 6 - Current Liabilities

Particulars	Sch.No	As at 31.3.2022	As at 31.3.2021
		Rs.	Rs.
Common Fund		35,668.00	35,668.00
EMD		23,18,467.00	27,94,467.00
Tax Deducted at Source Payable Contractors		2,49,073.00	1,20,145.00
Tax Deducted at Source Payable Staff		6,50,000.00	4,73,500.00
Security Deposit		7,76,186.00	3,41,268.00
EPF Staff		5,35,993.00	4,86,315.00
Subscription to NCESS Rec- Club		1,475.00	1,500.00
Co-Operative Recovery		10,000.00	13,000.00
NPS Staff		3,00,608.00	2,41,481.00
GPF Central		-	-
GSLIS		4,330.00	4,470.00
KFC		-	1,050.00

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LIC		58,261.00	59,552.00
NCESS Co-Operative Society		4,000.00	4,441.00
Sundry creditors for expenses		70,80,092.00	88,21,089.00
Sundry creditors for supplies		1,16,79,505.00	13,06,280.00
GST payable		6,17,028.00	- 25,171.00
GST TDS Payable		62,616.00	1,05,876.00
Total		**2,43,83,302.00**	**1,47,84,931.00**

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Schedule 7- Fixed Assets

Sl No.	Particulars	Balance as on 1st April 2021	Additions		Deletion / Adjustments	Balance as on 31st March 2021	Rate %	Depreciation Provided during the year	Balance as on 31st March 2022
			More than 180 days	Less than 180 days					
		Rs.	Rs.	Rs.	Rs.	Rs.		Rs.	Rs.
1	Buildings	1,50,40,690.00	-	58,99,494.00	-	2,09,40,184.00	10.00	17,99,044.00	1,91,41,140.00
2	Library Books	45,72,401.00	-	2,120.00	-	45,74,521.00	40.00	18,29,384.00	27,45,137.00
3	Computers	1,15,37,991.00	11,03,506.00	22,05,959.00	-	1,48,47,456.00	40.00	54,97,791.00	93,49,665.00
4	Furnitures & Fixtures	1,03,06,274.00	-	2,53,116.00	-	1,05,59,390.00	10.00	10,43,283.20	95,16,107.00
5	Laboratory Equipment	36,84,77,117.43	1,41,07,337.00	2,18,39,613.00	-	40,44,24,067.43	15.00	5,90,25,639.00	34,53,98,428.43
6	Office Equipment	78,92,970.00	-	1,18,515.00	-	80,11,485.00	15.00	11,92,835.00	68,18,650.00
7	Plant & Machinery	20,996.00	-	-	-	20,996.00	15.00	3,150.00	17,846.00
8	Electrical Installations	1,05,17,307.00	2,32,674.00	5,11,063.00	-	1,12,61,044.00	15.00	16,50,827.00	96,10,217.00
9	Vehicles	4,19,311.00	-	-	-	4,19,311.00	15.00	62,897.00	3,56,414.00
10	Research Boats	1,181.00	-	-	-	1,181.00	20.00	236.00	945.00
11	Softwares	1,62,69,255.00	2,49,610.00	2,40,624.00	-	1,67,59,489.00	40.00	65,00,428.00	1,02,59,061.00
12	Work In Progress	1,42,40,626.00	-	94,29,656.00	53,49,572.00	1,83,20,710.00	-	-	1,83,20,710.00
	Total	**45,92,96,119.43**	**1,56,93,127.00**	**4,05,00,160.00**	**53,49,572.00**	**51,01,39,834.43**		**7,86,05,514.00**	**43,15,34,320.43**

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Schedule 8 - Current Assets, Loans & Advances

Particulars	As at 31.3.2022	As at 31.3.2021
	Rs.	Rs.
A. Current Assets		
1. Stock - in - hand	16,32,893.00	16,12,259.00
2. Cash & Bank Balance		
SBI - Consultancy Projects	10,69,08,411.46	7,55,54,960.96
SBI - External Projects	3,30,51,256.18	3,08,99,369.68
SBI - NCESS	4,54,43,796.87	4,22,25,788.02
SBI - Corpus Fund	30,61,555.73	6,220.23
Treasury Accounts (GOK)	11,000.00	11,000.00
SBI - NCESS E-TAX	1,000.00	1,21,145.00
Term Deposits	18,65,54,540.00	16,04,72,419.00
Imprest Balances	5,777.00	7,287.00
		30,92,98,189.89
Total A (1+2)	**37,66,70,230.24**	**31,09,10,448.89**
B. Loans, Advances & Other Assets		
1.Deposits		
Deposit with KSEB	6,24,610.00	6,24,610.00
Deposit with T K Varghese and Son	6,000.00	6,000.00
Deposit with BSNL	3,000.00	3,000.00
Deposit with drinking water	300.00	300.00
Cylinder deposit	1,900.00	1,900.00
Caution deposit	3,000.00	3,000.00
2. Advances & other amount recoverable in cash or in kind or for value to be recovered		
Tour Advance	4,76,979.35	18,53,071.89
Other Advance	1,05,945.00	24,01,314.17
Rolling Contingent Advance	1,69,175.00	1,12,715.00
Margin Money on LC NCESS	37,76,334.00	53,46,041.00
Advance to staff - External/Consultancy Projects	94,472.00	7,96,416.00
Advance to Suppliers - NCESS	6,42,99,989.00	4,80,58,227.00
Leave Salary Receivable	1,35,990.00	1,35,990.00
Salary Receivable	6,40,079.00	6,40,079.00

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Accrued Interest- CORFU		19,16,322.00	75,53,552.00
TDS Receivable - External Projects		7,96,815.00	2,41,215.00
TDS Receivable - Consultancy Projects		3,47,037.00	1,88,000.00
TDS Receivable - NCESS		1,25,722.00	-
Grants to Other Institutes		1,12,17,224.00	1,76,16,936.20
Gratuity Recievable KSCTSE		29,98,600.00	29,98,600.00
GST TDS Receivable		93,810.00	40,800.00
Prepaid expenses		3,18,676.00	7,917.00
Service Tax Interest Receivable		10,163.00	10,163.00
Service Tax Receivable		1,84,870.00	1,84,870.00
Other Receivable		-	3,30,419.00
Total B (1+2)		**8,83,47,012.35**	**8,91,55,136.26**
Total (A+B)		**46,50,17,242.59**	**40,00,65,585.15**

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AJ MOHAN & ASSOCIATES CHARTERED ACCOUNTANTS

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Schedules Forming Part of Income and Expenditure

Schedule 9 - Grant Received

Particulars	As at 31.3.2022	As at 31.3.2021
	Rs.	Rs.
Grant in aid salaries and general (OPMA)		
Add: Grant Received During the Year	13,00,00,000.00	12,50,00,000.00
Total	**13,00,00,000.00**	**12,50,00,000.00**

Schedule 10 - Other income

Particulars	As at 31.3.2022	As at 31.3.2021
	Rs.	Rs.
Miscellaneous Receipts	4,92,833.00	3,61,474.00
Application Fee (Right to Information Act)	1,014.00	190.00
Interest from deposit	29,044.00	39,332.00
Total	**5,22,891.00**	**4,00,996.00**

Schedule 11 - Staff Salary & Benefits

Particulars	As at 31.3.2022	As at 31.3.2021
	Rs.	Rs.
Salary Director	36,19,546.00	20,15,179.00
Salaries Others	7,88,42,648.00	7,10,35,545.00
Salary Other Institutes	80,85,371.00	94,36,601.00
Contribution to EPF	37,67,488.00	33,53,315.00
Contribution to EPS	4,06,250.00	3,80,000.00
EPF Administrative Charges	1,74,045.00	1,55,174.00
Contribution to EPF IF	25,650.00	25,425.00
Contribution to NPS	70,48,292.00	28,11,276.00
Children Education Allowance	8,64,000.00	9,45,000.00
Leave Salary & Pension Contribution	1,36,512.00	70,487.00
Leave Travel Concession	2,38,107.00	24,01,900.00
Incentives to Staff	-	32,500.00
LIC GG Scheme for Staff	14,29,859.00	7,24,423.00
Medical Expenses Reimbursement	6,37,156.00	4,27,268.00

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Previous Year Salary	96,142.00	76,608.00
Nps Service Charges	4,458.00	7,855.00
Total	**10,53,75,524.00**	**9,38,98,556.00**

Schedule 12 - Other Institutional Expenses

Particulars	As at 31.3.2022	As at 31.3.2021
	Rs.	Rs.
Computer System & Accessories	2,39,204.00	2,42,497.00
Electrical /UPS Installations	67,137.00	3,144.00
Air Coditioners		
Canteen Equipment	10,750.00	
Electrical fittings to buildings	-	6,400.00
Library Books & Journals	2,120.00	22,92,927.00
Major software	32,982.00	
Furniture	17,995.00	
Office Equipments	86,915.00	36,726.00
Advertisement	1,33,686.00	1,69,554.00
Audit Fee	29,181.00	94,400.00
Bank charges	-	2.38
Consultant fee	5,43,375.00	4,89,667.00
Consumables	5,95,336.00	14,92,988.00
Contingency	76,33,473.00	51,52,126.00
Electricity Charges	40,28,448.00	38,65,663.00
Hospitality Expenses	1,03,996.00	1,34,733.00
Legal Charges	2,69,670.00	2,17,800.00
News Papers & Periodicals	1,898.00	999.00
Petrol , Diesel & Oil	1,27,502.00	2,25,849.00
Postage & Communication	5,71,359.00	3,85,910.00
Printing & Stationery	3,95,166.00	5,48,527.00
Prior Period Expenses	1,01,242.00	7,84,802.00
Remuneration to Project Staff	23,78,356.00	29,77,886.00
Repairs & Maintenance - Others	10,68,838.00	15,30,752.00
Repairs & Maintenance - Building	7,30,433.00	23,05,745.00
Repairs & Maintenance - Vehicle	43,278.00	76,931.00
Seminar/Conference	94,514.00	84,289.00
Sitting Fee/Honor-Visiting Expenses	1,35,320.00	1,05,740.00
Swachh Bharath- Gardening	61,140.00	67,200.00
Swachh Bharath- House Keeping	11,22,842.00	14,85,144.00
Swachh Bharath Pakhwada	11,975.00	2,81,204.00

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Taxes & Insurance Vehicles	21,524.00	12,670.00
Travelling Expenses	1,251.00	1,09,930.00
Travelling Expenses for Visiting Experts	61,274.00	1,149.00
Vehicle Hire Charges	2,40,538.00	11,98,453.00
Water Charges	1,19,845.00	64,962.00
SB-Swachtha Mission	24,839.00	52,218.00
Land Lease	-	98.00
Subscription to Journals	25,11,846.00	-
Total	**2,36,19,248.00**	**2,64,99,085.38**

Schedule 13 - Research & Development Revenue Expenses

Particulars	As at 31.3.2022	As at 31.3.2021
	Rs.	Rs.
Advertisement charges for R&D	77,368.00	81,845.00
Bank charges	18,605.36	55,392.48
Boat hire charges	18,950.00	49,324.00
Chemicals/ consumables	71,20,383.48	1,91,94,110.00
Chemicals/ consumables - Other Institutes	9,54,536.00	18,30,451.00
Cost Of Power/Electricity - Labs	1,61,065.00	29,746.00
Contingency	97,672.00	2,06,244.00
Contingency other institutes	8,96,798.20	5,95,741.00
Consultants charges	3,80,625.00	12,12,606.00
Communication /postage charges	21,05,109.00	1,451.00
Equipments repair charges/ AMC	17,09,918.00	17,19,543.00
Field expenses	18,43,969.74	10,34,490.00
Field expenses - Other Institutes	15,17,148.00	19,14,205.00
Hire charges of vehicles	14,70,054.00	35,49,333.00
Insurance labs & equipments	50,117.00	2,23,850.00
Membership / Registration	1,14,460.25	73,208.00
Over head charges - Other Institutes	10,43,835.00	7,95,763.00
Printing & publication cost	5,58,891.98	2,24,068.02
Printing & stationery	40,079.00	8,96,258.00
Prior period expenses	36,14,837.06	83,82,724.98
Repairs and maintenance	7,87,770.00	35,12,331.00
Remuneration to project staff	2,06,16,468.00	2,37,10,190.00
Remuneration - Project Staff- Other Institute	48,05,762.00	23,10,833.00
Rent	8,40,720.00	11,98,345.00
Seminar,symposium & workshop	1,23,000.00	
Sitting fee Visiting Experts	1,86,000.00	3,600.00

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Travelling expense	22,22,169.99	3,05,737.00
Training Expenses	-	4,49,400.00
Analytical Charges	1,61,256.00	84,238.00
Total	**5,35,37,568.06**	**7,36,45,027.48**

Schedule 14 - Research & Development Capital Expenses

Particulars	As at 31.3.2022	As at 31.3.2021
	Rs.	Rs.
Computer System & Accessories	30,48,854.00	44,41,632.00
Electrical /UPS Installations	3,79,112.00	9,39,312.00
Major Software	4,57,252.00	8,53,971.00
Furniture	2,35,121.00	10,04,580.00
Office equipment	20,850.00	36,503.00
Laboratory equipment	3,56,96,509.00	5,46,63,803.00
Air conditioners	2,97,488.00	13,56,506.00
Total	**4,01,35,186.00**	**6,32,96,307.00**

Schedule 15 -Creation of capital assets (Major Works)

Particulars	As at 31.3.2022	As at 31.3.2021
	Rs.	Rs.
(a) Revenue Expenditure:		
Minor Civil Works (Repairs & Maintenance)	10,771.00	69,570.00
(b) Capital Expenditure:		
Major Civil Works- Roads	58,99,494.00	14,37,519.00
Work In Progress	40,80,084.00	1,42,40,626.00
Total	**99,90,349.00**	**1,57,47,715.00**

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Sub Schedule A

Statement of Unspent Balance in respect of Grant in Aid received for Research from Ministries/Departments/ Organisations of Central/State Governments, Divisional Core Research Projects and Service Component Projects from 01/04/2020 to 31/03/2021

	Project	Opening Balance Rs.	Amount Received Rs.	Amount Refunded Rs.	Net Amount Received Rs.	Net Amount Available Rs.	Amount Utilised Rs.	Closing Balance Rs.
	Research Projects							
								-
1	CSIR25	11,537.00	-	-	-	11,537.00	-	11,537.00
2	CSIR27	-	20,000.00	-	20,000.00	20,000.00	-	20,000.00
3	DST82	4,995.00	-	4,995.00	(4,995.00)	-	-	-
4	DST85	13,18,733.00	-	13,18,733.00	(13,18,733.00)	-	-	-
5	DST86	5,828.00	4,47,099.00	-	4,47,099.00	4,52,927.00	4,51,520.00	1,407.00
6	DST87	5,43,637.00	3,621.00	-	3,621.00	5,47,258.00	5,42,936.00	4,322.00
7	DST89	8,17,443.14	22,96,915.00	45,642.00	22,51,273.00	30,68,716.14	18,18,089.00	12,50,627.14
8	DST90	1,95,676.00	5,280.00	-	5,280.00	2,00,956.00	-	2,00,956.00
9	DST91	2,03,487.00	5,58,275.00	-	5,58,275.00	7,61,762.00	4,92,045.00	2,69,717.00
10	DST92		22,55,497.00		22,42,813.00			

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		10,24,559.00		12,684.00		32,67,372.00	17,56,702.00	15,10,670.00
11	DST93	-	4,52,279.00	-	4,52,279.00	4,52,279.00	4,35,280.00	16,999.00
12	FC	1.00	-	-	-	1.00	1.00	-
13	IDRB1	2,55,257.00	-	-	-	2,55,257.00	2,55,257.00	-
14	KCZMA	2,12,226.00	30,00,000.00	-	30,00,000.00	32,12,226.00	6,24,113.00	25,88,113.00
15	KSCS28	4,90,235.00	-	4,90,235.00	(4,90,235.00)	-	-	-
16	KSCS29	87,63,549.00	-	-	-	87,63,549.00	87,63,549.00	-
17	KSCS36	20,000.00	-	9,109.00	(9,109.00)	10,891.00	10,891.00	-
18	KSCS37	2,726.00	3,47,517.00	-	3,47,517.00	3,50,243.00	3,50,243.00	-
19	KSCS38	20,000.00	-	-	-	20,000.00	-	20,000.00
20	KSCS40	44,252.00	-	15,420.00	(15,420.00)	28,832.00	28,832.00	-
21	KSCS41	20,000.00	-	-	-	20,000.00	20,000.00	-
22	KSCS42	4,72,400.00	-	-	-	4,72,400.00	4,25,806.00	46,594.00
23	SAC15	3,53,199.00	-	22,246.00	(22,246.00)	3,30,953.00	3,30,953.00	-
24	SAC16	-	8,07,560.00	-	8,07,560.00	8,07,560.00	1,28,072.00	6,79,488.00
25	DECC2	(2,97,768.00)	-	-	-	(2,97,768.00)	-	(2,97,768.00)
26	DECC3		7,60,000.00	-	7,60,000.00			

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		(3,64,366.00)				3,95,634.00	50,557.00	3,45,077.00
	Total	**1,41,17,606.14**	**1,09,54,043.00**	**19,19,064.00**	**90,34,979.00**	**2,31,52,585.14**	**1,64,84,846.00**	**66,67,739.14**
	Divisional Core Research Projects							
1	GEOMAT	42,60,885.00	-	-	-	42,60,885.00	-	42,60,885.00
2	MACIS	1,32,22,512.54	1,14,92,299.00	-	1,14,92,299.00	2,47,14,811.54	61,00,873.50	1,86,13,938.04
	Total	**1,74,83,397.54**	**1,14,92,299.00**	**-**	**1,14,92,299.00**	**2,89,75,696.54**	**61,00,873.50**	**2,28,74,823.04**
	Service Component Projects							
2	AAS	1,215.00	81,070.00	-	81,070.00	82,285.00	81,070.00	1,215.00
3	CPT4	3,14,669.00	4,60,000.00	-	4,60,000.00	7,74,669.00	4,29,046.00	3,45,623.00
4	VISL	-	50,00,000.00	-	50,00,000.00	50,00,000.00	9,47,957.00	40,52,043.00
5	LRSA	-	3,200.00	-	3,200.00	3,200.00	3,200.00	-
6	PSA	-	51,620.00	-	51,620.00	51,620.00	51,620.00	-
7	SEM	-	11,600.00	-	11,600.00	11,600.00	11,600.00	-
8	XRF	4,400.00	2,36,320.00	-	2,36,320.00	2,40,720.00	2,40,120.00	600.00
	Total	**3,20,284.00**	**58,43,810.00**	**-**	**58,43,810.00**	**61,64,094.00**	**17,64,613.00**	**43,99,481.00**
	Grand Total	**3,19,21,287.68**	**2,82,90,152.00**	**19,19,064.00**	**2,63,71,088.00**	**5,82,92,375.68**	**2,43,50,332.50**	**3,39,42,043.18**

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NATIONAL CENTRE FOR EARTH SCIENCE STUDIES
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Sub Schedule B

Statement of Unspent Balance of Consultancy Projects for the year 2020-2021

	Project	Opening Balance	Consultancy Fee Received	Consultancy Expenses	Incentive Money to Staff	Transferred to Corpus Fund	Transferred to CESS Fund	Transferred to Common Fund	Total Expense	Closing Balance
1	CONY	-	20,75,974.00			20,75,974.00			20,75,974.00	-
2	CONY196	12,26,857.00	-	-	-	-	-	-	-	12,26,857.00
3	CONY201	11,82,248.00	-	-	-	-	-	-	-	11,82,248.00
4	CONY281	4,95,088.00	-	-	-	-	-	-	-	4,95,088.00
6	CONY308	25,500.00	-	-	-	-	-	-	-	25,500.00
7	CONY309	2,32,879.00	-	-		-			-	2,32,879.00
8	CONY312	97,059.00	-	-	-	-	-	-	-	97,059.00
9	CONY315	1,86,145.00	-	-	-	-	-	-	-	1,86,145.00
10	CONY317	6,63,588.00	-	-	-	-	-	-	-	6,63,588.00
11	CONY329	7,35,944.00	-	-	-	-	-	-	-	7,35,944.00
12	CONY330	5,24,537.00	-	-	-	-	-	-	-	5,24,537.00
13								-	-	

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	CONY334	15,58,102.00	-	-	-	-	-			15,58,102.00
14	CONY343	7,81,831.00	-	-	-	-	-	-	-	7,81,831.00
15	CONY344	10,22,999.00	-	-		-			-	10,22,999.00
16	CONY345	2,98,592.00	-	-	-	-	-	-	-	2,98,592.00
17	CONY346	2,51,375.00	-	-	-	-	-	-	-	2,51,375.00
18	CONY349	5,53,429.00	-	-	-	-	-	-	-	5,53,429.00
19	CONY355	2,29,338.00	-	-	-	-	-	-	-	2,29,338.00
20	CONY356	5,83,332.00	-	-	-	-	-	-	-	5,83,332.00
21	CONY360	1,84,812.00	-	-	-	-	-	-	-	1,84,812.00
22	CONY361	1,80,75,977.00	-			-				1,80,75,977.00
23	CONY363	3,37,391.00	-	-	-	-	-	-	-	3,37,391.00
24	CONY365	2,29,166.00	-	-		-			-	2,29,166.00
25	CONY369	12,89,318.00	-	-		-			-	12,89,318.00
26	CONY370	8,88,532.00	-	-		-			-	8,88,532.00
27	CONY371	2,24,143.00	-	-		-			-	2,24,143.00
28	CONY372	2,05,925.00	-	-		-			-	2,05,925.00
29	CONY374	2,10,000.00	-	-		-			-	2,10,000.00
31	CONY378	8,96,71,427.00	-							8,96,71,427.00

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32	CONY379	85,829.00	-							85,829.00
33	CONY380	2,52,460.00	-	-		-			-	2,52,460.00
34	CONY381	2,64,841.00	-	-		-			-	2,64,841.00
35	CONY383	99,904.00	-	-		-			-	99,904.00
36	CONY384	2,51,605.00	-	-		-			-	2,51,605.00
37	CONY385	2,80,099.00	-	-		-			-	2,80,099.00
38	CONY386	10,19,850.00	-	-		-			-	10,19,850.00
50	CONY447	80,500.00	-	-		-			-	80,500.00
51	CONY465	2,09,400.00	-							2,09,400.00
54	CONY466	2,09,400.00	-	2,09,400.00		-			2,09,400.00	-
55	CONY467	2,09,400.00	-	2,09,400.00		-			2,09,400.00	-
56	CONY468	2,09,400.00	-	2,09,400.00		-			2,09,400.00	-
58	CONY469	2,09,400.00	-	2,09,400.00		-			2,09,400.00	-
59	CONY473	2,09,400.00	(2,09,400.00)	-		-			-	-
60	CONY484	5,05,294.00	-						-	5,05,294.00
61	CONY488	2,06,195.00	-	2,06,195.00					2,06,195.00	-
62	CONY490	5,56,156.00	-	5,56,156.00					5,56,156.00	-
63	CONY492	2,09,825.00	-	-					-	2,09,825.00

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64	CONY495	1,98,740.00	-	-					-	1,98,740.00
65	CONY497	1,87,195.46	-	-					-	1,87,195.46
66	CONY502	2,10,000.00	-	2,10,000.00					2,10,000.00	-
67	CONY504	2,07,353.00	-	2,07,353.00					2,07,353.00	-
68	CONY505	2,04,346.00	-	2,04,346.00					2,04,346.00	-
69	CONY506	2,02,653.00	-	3,596.00					3,596.00	1,99,057.00
70	CONY512	2,87,730.00	-	2,87,730.00					2,87,730.00	-
71	CONY513	2,10,000.00	-	2,10,000.00					2,10,000.00	-
72	CONY514	1,13,964.50	-	1,13,964.50					1,13,964.50	-
73	CONY515	2,00,000.00	-	2,00,000.00					2,00,000.00	-
74	CONY516	2,10,000.00	-	2,10,000.00					2,10,000.00	-
75	CONY517	2,28,562.00	-	-					-	2,28,562.00
76	CONY518	2,07,353.00	-	-					-	2,07,353.00
77	CONY519	4,82,000.00	-	-					-	4,82,000.00
78	CONY520	1,48,101.00	-	1,48,101.00					1,48,101.00	-
79	CONY521	2,10,000.00	-	2,10,000.00					2,10,000.00	-
80	CONY522	2,10,000.00	-	2,10,000.00					2,10,000.00	-
81	CONY523	-	3,15,000.00	3,15,000.00					3,15,000.00	-

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82	CONY524	-	3,15,000.00	1,16,100.00					1,16,100.00	1,98,900.00
83	CONY525	-	3,15,000.00	3,15,000.00					3,15,000.00	-
84	CONY526	-	10,60,500.00	-					-	10,60,500.00
85	CONY527	-	3,15,000.00	-					-	3,15,000.00
86	CONY528	-	6,15,000.00	6,15,000.00					6,15,000.00	-
87	CONY529	-	3,17,670.00	3,17,670.00					3,17,670.00	-
88	CONY530	-	3,15,000.00	1,05,000.00					1,05,000.00	2,10,000.00
89	CONY531	-	3,15,000.00	3,15,000.00					3,15,000.00	-
90	CONY532	-	3,15,000.00	3,15,000.00					3,15,000.00	-
91	CONY533	-	3,17,670.00	1,05,000.00					1,05,000.00	2,12,670.00
92	CONY534	-	3,17,670.00	1,05,000.00					1,05,000.00	2,12,670.00
93	CONY535	-	3,17,670.00	3,17,670.00					3,17,670.00	-
94	CONY536	-	3,17,670.00	1,05,000.00					1,05,000.00	2,12,670.00
95	CONY537	-	5,15,000.00	1,23,600.00					1,23,600.00	3,91,400.00
96	CONY538	-	3,15,000.00	1,05,000.00					1,05,000.00	2,10,000.00
97	CONY539	-	3,15,000.00	1,05,000.00					1,05,000.00	2,10,000.00
98	CONY540	-	3,15,000.00	3,15,000.00					3,15,000.00	-
99	CONY541	-	3,17,670.00	3,17,670.00					3,17,670.00	

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100	CONY542	-	3,17,670.00	3,17,670.00					3,17,670.00	-
101	CONY543	-	3,17,670.00	3,17,670.00					3,17,670.00	-
102	CONY544	-	3,17,670.00	3,17,670.00					3,17,670.00	-
103	CONY545	-	3,15,000.00	1,05,000.00					1,05,000.00	2,10,000.00
104	CONY546	-	3,17,670.00	3,17,670.00					3,17,670.00	-
105	CONY547	-	2,10,000.00	2,10,000.00					2,10,000.00	-
106	CONY548	-	3,15,000.00	3,15,000.00					3,15,000.00	-
107	CONY549	-	3,17,670.00	1,05,000.00					1,05,000.00	2,12,670.00
108	CONY550	-	3,17,670.00	3,17,670.00					3,17,670.00	-
109	CONY551	-	3,15,000.00	1,05,000.00					1,05,000.00	2,10,000.00
	TOTAL	**13,07,52,489.96**	**1,21,74,114.00**	**1,02,56,101.50**	-	**20,75,974.00**	-	-	**1,23,32,075.50**	**13,05,94,528.46**

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Schedule 16

Notes on Financial Statement for the Financial Year ended 31st march 2022

Organizational Information

National Centre for Earth Science Studies is a Society taken over by the Ministry of Earth Sciences, Government of India on 1st January 2014 for perusing and promoting basic and applied advanced research in the frontier areas of Earth Sciences. The Centre has been registered under Travancore Cochin Literary, Scientific and Charitable Societies Registration Act, 1955 as an autonomous institution under the Ministry of Earth Sciences, Government of India.

Accounting Policies

The society follows mercantile system of accounting and recognizes income and expenditure on accrual basis except for government grants and other income.

Fixed Assets and Depreciation

All the fixed assets of the Centre of Earth Sciences as on 31.12.2013 have been taken over by National Centre for Earth Studies (NCESS) other than land owned by the Government of Kerala. As per GO (Ms) no 468/2013 dated 24-10-2013 , the Government of Kerala has accorded sanction in principle for leasing out an extent of 13.95 acres of land possessed by the Centre for Earth Studies (CESS) to the Ministry of Earth Sciences, Government of India for 99 years at Rs 1 /- Acre per year for the operation of the Centre.

The additions of fixed assets during the period are stated at cost. Fixed assets of the Centre are acquired out of grants received. Assets acquired for the sponsored projects (Grant in aid) are capitalized on completion of the project/receipt of permission from the concerned Government Department. Funds utilized for acquiring fixed assets from Grants received are transferred to Capital Reserve.

Depreciation is charged to the fixed assets on the Written Value Method as per the rates prescribed under the Income Tax Rules. Depreciation has also been charged on fixed assets on written down value method for assets transferred from the externally funded projects on the closure of projects / or on receipt of permission from concerned department /ministry. Depreciation on assets acquired out of grants has been written back from the capital reserve.

The center has not conducted physical verification of fixed assets during the year. The book value of the fixed assets as per books of accounts is pending to be reconciled with value as per the asset register.

Current Assets

Cash and Bank balance represent the balances with the society, grant in aid projects, and consultancy project Accounts. Closing Stock of chemicals, glassware, consumables and stationery items are at cost as certified by the management. Cash equivalents like term deposits and bank balances are as per the confirmations provided.

Loans and advances

Advance to staff represents balance with them for meeting the expenses in connection with the conduct of research programs and are considered good and secured.

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Capital Work in Progress

Work in Progress is treated as Capital Expenditure and is shown in the Utilization Certificate. This will be adjusted in due course against respective heads of account, once the work is fully completed.

Capital Reserve

The amount received from the Ministry of Earth Sciences and other institutions utilized for acquiring the fixed assets is credited to capital reserve and the depreciation charged in the income and expenditure statement is written back by debiting the capital reserve.

The capital reserves as on date of taking over are carried forward after deducting the value of land not taken over.

General Reserve

The negative figure of Rs 3.14 Crores was due to the non -receipt of non-plan funds from the Kerala State Council for Science, Technology and Environment (KSCTSE) and overspent during erstwhile CESS period.

Corpus Fund

In order to maintain corpus fund approval from the Administrative Ministry is required, however no such approval has been obtained from MOES. Since receipts accrued to NCESS is utilized as main source of receipts for Corpus Fund, obtaining approval from MOES is mandatory. The unspent balances of Consultancy projects that are concluded and closed are transferred to Corpus Fund and MACIS (Divisional Core research project).

Research Program Funds

The balance of the grant for the research programs remaining unspent is stated as Research program under Unspent balance GOI -MOES. During the year, the society has received Rs 13.20 Crores funds towards Research Program Grant from the Ministry of Earth sciences. Unspent balance at the end of the period amounts to Rs 3.71 Crores.

Unspent Balance of Projects

The unspent balances of grant received for the conduct of sponsored R&D projects sanctioned by Ministries /Departments of Government of India /Kerala, Consolidated service projects from various agencies are carried forward as unspent balance of projects.

Operation and Maintenance Fund

Unspent balance of Grant received from the Ministry of Earth Sciences (MOES) for operation and maintenance expenditure and other income of NCESS is stated as the balance of operation and Maintenance Fund. The excess of income over expenditure or deficit over expenditure in the statement of Income and Expenditure is credited or debited in the account. Unspent balance as on 31st March 2022 is 95.24 Lakhs.

Projects

The Committees consisting the heads of respective projects and other technical personnel are monitoring the status of various projects, including the financial budgets and noting down the minutes of the output of such meeting. The various assets of the project purchased by NCESS are located at such projects. Income and

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Expenditure of External/Consultancy projects are accounted on cash basis. The unspent amount on the completion of consultancy projects is transferred to NCESS.

Retirement benefits

Leave encashment is accounted for on cash basis, no provision for leave encashment is made in the accounts

Interest received

The society parks fund in short term deposit with bank and also in Savings bank accounts with State Bank of India. The interest received in the said accounts is refunded to Ministry of Earth Sciences. Interest earned on corpus fund is added to the corpus fund itself and not included in the income of the society

Contingent Liabilities

Contingent liability is possible obligation that may arise in the future depending on occurrence or non-occurrence of one more uncertain event. In the matter of cases in court, the outcome can be known only upon the final judgment. Due to this factor estimation of contingent liability is difficult, wherever possible liability has been estimated and disclosed.

Details of court case as on 31st March 2022 with their present status as on 27.07.2022 are as follows:

Sl No	Writ Petition/ Case Number	Case Particulars	Present Status (as on 29.07.2022)	Likely financial Obligation
1	ATA No: 698 (07) 2013 before the EPF Appellate Tribunal, New Delhi	Petition filed by former employees of CESS seeking payment of Employers share of PF Contribution to the EPF on the pay revision arrears	Dismissed on 13.09.2021	
2	WP © No: 13704/2016 filed K.V.Thomas & others	Pension Case	Judgement awaited	Not known at present
3	Appeal filed on 10-08-2015 before the Appellate Tribunal, Bangalore	Demand to remit service tax against fund received towards grant-in-aid during period from 2002-05 and 2010-11	Case is pending before Customs Excise and Service Tax Appellate Tribunal, Bangalore	Against the Order-in-Appeal, NCESS had filed Appeals (A. Nos. ST/21752 & 21754/2015-DB) before the Customs, Excise and Service Tax Appellate Tribunal, Bangalore. The Registry of the Tribunal had raised a defect notice. The defect notice was to deposit 10% of the disputed tax as mandatory pre-deposit as per amended Section 35F of the

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				Central Excise Act, 1944. The Appeals were posted for hearing on the defect before the Hon'ble Tribunal on 18.02.2016. After noting the submission, the Hon'ble Tribunal has directed NCESS to deposit 10% of the disputed tax amount within 4 weeks and report compliance on 11.04.2016. Against A.No. 21752, NCESS had deposited Rs.3,70,740/- on 30.03.2016 and against A. No. 21754 deposited to Rs. 35,224/- on 28.03.2016. Outcome of the case is awaited
4	WP © No: 32888 of 2017 filed by Rajesh P and others before the Honourable High Court of Kerala	Consider placing the petitioners in PB 2 i.e. 9300-34800 with GP 4200/- and for other reliefs.	Counter Affidavit filed.	Not Known
5	WP © No: 23371 of 2018 filed by Anju K S and others before the Honourable High Court of Kerala	Consider placing the petitioners in PB 2 i.e. 9300-34800 with GP 4200/- and for other reliefs.	Counter Affidavit filed	Not Known
6	WP © No: 8515 of 2019 filed by Dr. C N Mohanan and others before the Honourable High Court of Kerala	Requesting unlimited gratuity as per KSCSTE rules	As per Judgement dated 26 April 2022 the liability is with KSCSTE	--
7	WP © No: 8960 of 2019 filed by Shri.John Mathai and others before the Honourable High Court of Kerala	Requesting unlimited gratuity as per KSCSTE rules	Judgement dated 26 April 2022. MoES has advised to file appeal.	Approximate Liability of Rs.2.5 crore.
8	WA No.269 filed by P.Girija before the before the Honourable High Court of Kerala in 2020	Requesting promotion as Scientist B from July 2008 and permit to continue till attaining 60 years of age ie 31.03.2011	Judgement awaited	Not known

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9	WPC 2181/2019 filed by M/s Summer Cabs before the Honourable High Court of Kerala.	To stay the retender process and to award the vehicle contract to M/s Summer Cabs	Counter Affidavit filed	Decision awaited
10	WA No.2259 of 2019 filed by Smt.Sreelekshmi and others before Hon'ble High Court	Quash the direction dated 26th August 2019 and extention of contract engagement beyond 30.06.2019 and regularization in the services of NCESS.	Judgement awaited	Not known