"Ecology, Environment, Earth Sciences, Ocean & Water"

CSIR Addressing Sustainability Science

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CSIR THEME DIRECTORATES

SUSTAINABILITY science is a solution-oriented discipline requiring fundamental research entrenched with multi/intra-disciplinary approaches. CSIR has created a thematic area – "Ecology, Environment, Earth Sciences, Ocean and Water" (E3OW) – to address issues of socio-economic and environmental importance for the country.

CSIR researchers working on the sustainability science are enhancing our knowledge of the functioning of the Earth system and its critical thresholds and also developing response strategies to global changes with focus on people, prosperity and planet. The theme E3OW becomes increasingly prominent as humanity confronts daunting challenges in finding natural resources to sustain the burgeoning population, in mitigating natural hazards that impact life and infrastructures, and in achieving sustainable environmental stewardship for the country.

The actions in the E3OW theme, therefore, are aimed at preserving:

a) **the water cycle,** altered by reservoir construction, agriculture, groundwater extraction, and urbanization, often leading to significant groundwater depletion;
b) **the carbon cycle,** central to climate but heavily affected by anthropogenic greenhouse gas emissions and land use, and also recent geo-engineering practices aimed at reducing the human impact on climate;
c) **the Earth's surface,** transforming in its physical, chemical, and biological state, with accelerated soil erosion, mobilization and deposition of metals and toxins;
d) **the coastal areas,** hosting >60% of the world's population and due to forcing from both ocean and land processes, experiencing coupling of geomorphic, hydrological, ecological, climatic, and biogeochemical phenomena.

Water

Source sustainability

The scarcity and deteriorating quality of water in several regions of the world, including in many Indian states, is alarming. Climate change impacts are likely to aggravate the water problems. India is one of the most water-intense economies and is one of the largest water users per unit of Gross Domestic Product (GDP).

Groundwater reserves source about 90% of the agricultural requirements, causing an imbalance between groundwater recharge and extraction resulting in rapid groundwater depletion in several parts of India. Groundwater overexploitation has economic and social consequences due to persistent excavation of deeper new wells, increased energy cost in lifting groundwater, spread of geogenic contaminants — arsenic, fluoride, salinity — and ingress of seawater in freshwater aquifers in coastal areas.

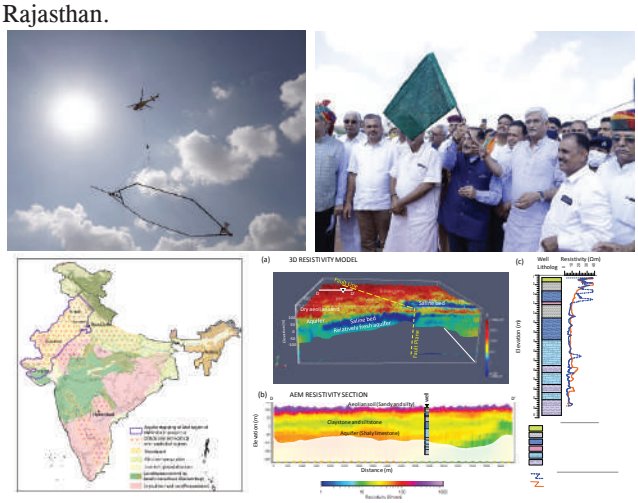
In addition to affecting the huge rural and urban population, water scarcity in India also extensively affects the river ecosystem. The enormity of the challenge requires well-informed science-based solutions as well as policy framework based on water management options.

Managed Aquifer Recharge (MAR) is a potential method to control over-abstraction, restore the groundwater balance and address the issues of contamination to certain extent. Information on the disposition of aquifer system is an essential requirement for managed recharge of aquifers.

CSIR-National Geophysical Research Institute (CSIR-NGRI) has demonstrated how MAR based on aquifer knowledge and community participation could bring a paradigm shift in agriculture-based income in the villages situated in Choutuppal Mandal of Telangana state.

For upscaling of geophysical mapping of aquifers and rapid survey over a large region, CSIR-NGRI has adopted a new technique of Heli-borne TEM, which has provided very promising results in aquifer mapping in India. With state-of-art ground and Heli-borne geophysical technologies, CSIR-NGRI in collaboration with Central Ground Water Board (CGWB), Ministry of Jal Shakti, Government of India has initiated a mega project of High-Resolution Aquifer Mapping & Management in arid regions of North Western India coving about 4 lakh square kilometres to identify potential groundwater bearing zones for water supply and recharge.

Hon'ble Union Minister of Jal Shakti Shri Gajendra Singh Shekhawat and Hon'ble Union Minister of Science and Technology Dr Jitendra Singh inaugurated the state-of-art heliborne geophysical investigations for groundwater management in arid regions on 5 October 2021 at Jodhpur, Rajasthan.



Launch of Heli-borne geophysical survey of arid regions of NW India (left); Planned survey area (middle), and right, 3D resistivity model of aquifer in the Thar desert, Jaisalmer, Rajasthan (Source: https://doi.org/10.1016/j.wasec.2022.100111).

A recent investigation using the Heli-borne technology in the Prayagraj region, Ganga river basin shows a pathway of an ancient river that has comparable dimensions to that of the rivers Ganga and Yamuna in Prayagraj region of Uttar Pradesh. The newly traced paleo-river can serve as reservoir of underground water in the depleting aquifers in the Ganga-Yamuna doab.

Treatment

Water desalination is a common practice to achieve the overarching goal of providing drinking water. Reverse Osmosis (RO) has been practiced commercially. During desalination, the salinity is lowered – which is desired – but the concentrations of nutritious constituents are also reduced excessively – which is undesirable. The development of a methodology that enables desalination to be conducted with better retention of nutritious ions would be of considerable interest.

CSIR developed the electrodialysis (ED) process for the separation of mono- and bivalent ions employing polyaniline (PANI)-modified interpolymer type of ion-exchange composite membranes (Thakur *et al.*, 2014). Due to sieving and hydrophobic effects, the PANI coating demonstrated improved retention of nutritious minerals in the desalinated water which is also a mineral-balanced alkaline water. The technology is scalable with productivity of desalinated water from 10 LPH to 500 LPH, and suitable for domestic as well as societal uses. The cost of such electrodialysis units may vary from Rs. 30,000 to Rs. 15,00,000 depending on productivity.

Plant capacity – 0.1 MLD (100 m^3 per day)
Raw water – 10000-12000 ppm
Product water – < 500 ppm (WHO standard)
Product recovery - ~50%

Electro-dialytic desalination plant (Plant capacity -0.1MLD (100m3 per day; Raw water -10000-12000 ppm; Product water < 500 ppm (WHO standard); Product recovery - ~ 50%) by CSIR-CSMCRI (Source: DOI: 10.1016/j.desal.2013.12.007).

Higher concentrations of Fluoride, Arsenic, Iron, Uranium, etc. in drinking water are a major problem for human health in various parts of the country. CSIR Laboratories have developed several water treatment technologies for these contaminants to enhance water potability. These include ceramic membranes technology, adsorbent based technologies which can operate without electrical power, gravitational based technology, and technology for removal of pathogens.

A low-cost purification media (disc/candle) produced from locally available materials like Red-clay, sand and saw dust is also developed to remove excess iron along with suspended particles. These technologies can be deployed at domestic to community levels and utilised across the country. Potable drinking water using gravitational based community level Fluoride, Arsenic and Iron Removal (FAIR) technology has been recognized by the West Bengal Pollution Control Board (WBPCB).

CSIR-NEERI's solar Electrolytic Defluoridation (EDF) based filter for the treatment of excessive fluoride in water sources has been successfully installed at 200 fluoride-affected villages in India. It was found that EDF plants produced the treated water with fluoride less than 1 mg/L and 90-99% reduction in bacterial load from the raw water with the fluoride in the range 2-5 mg/L and total coliform and faecal coliform counts in the range 120–630 CFU/100 ml and 70-100CFU/100 ml respectively in raw water. Reduction in hardness and nitrate was also observed in treated water. Till now, it is estimated that more than 1,00,000 people have been saved from fluorosis through application of the EDF technique developed by CSIR-NEERI.

Supply

Drinking water supply systems in Indian villages face multiple challenges of drying up of groundwater source, pump failures, irregular and inadequate water supply, etc. The need of the hour is to ensure and put in place systems to effectively monitor and manage rural water supply.

Six CSIR labs together developed and demonstrated an integrated IoT based SMART Water Management system comprising of Sensor-nodes, Gateways, Cloud & Analytics, and Dashboard-visualization for service delivery measurement and monitoring (quality, quantity and regularity). CSIR IoT technologies will be deployed at 115 clusters covering ~20 states as a model project in collaboration with Jal Jeevan Mission of Ministry of Jal Shakti.

CSIR-NEERI has developed a software RISK-PiNET for assessment of contamination in drinking water distribution system and to identify the exact contaminant intrusion point in the network of pipelines. The software assesses the pipe condition, hazard due to sewage and drain, and risk. The software also assesses the failure rate and remaining useful life of each pipe considering the year of pipe-installation, length, diameter and pressure therein the pipe. Accordingly, rehabilitation of the contaminated pipeline can be planned rather than changing the water distribution system at large scale. This software is useful for various Municipal Corporations in the country as the potable water is supplied to consumers through pipelines in urban areas.

A huge quantity of sewage is generated in ever expanding urban areas. With limited installed capacity of treatment in centralized manner, a large portion of this sewage remains untreated and is diverted to water bodies. To prevent water bodies from pollution CSIR-NEERI developed a PHYTORID technology, which is a constructed wetland exclusively designed for the treatment of municipal, urban, agricultural and industrial wastewater. PHYTORID is a subsurface flow constructed wetland system (SSFCW) with demonstrated continuous operation as a standalone sewage treatment system. It has a large potential for decentralized treatment of sewage in urban and rural areas of the country with concomitant advantage of water resource conservation. Till date about 80 such plants have been set-up across India and are providing treated water for reuse and recycle. The technology has been transferred to 15 agencies (private and government) for dissemination and implementation.

Environmental Solutions

In response to the emerging reality of environmental pollution and degraded ecosystems due to increasing anthropogenic pressure, rapidly shrinking ecosystems, depleting biodiversity and changing global climate, CSIR is addressing the scenario on a priority basis.

CSIR has developed environment-friendly firecrackers, which are made using less polluting raw materials, thus causing less pollution as compared to normal crackers. Their chemical composition also helps them suppress dust when they are burnt. The Indian Fireworks industry has an over rupees 6000-crore worth of annual turnover. At an annual growth rate of about 10 percent, it is providing employment opportunities to over 5 lakh families directly or indirectly. Thus, CSIR is aiming at providing solutions that not only address the pollution related concerns of firecrackers and fireworks, but also protect the economy and the livelihoods of the professionals involved in this trade.

Green firecrackers developed by CSIR laboratories (Source: CSIR-NEERI)

The treatment and safe disposal of effluents using High Rate Transpiration System (HRTS) has been demonstrated at various locations by CSIR-NEERI. HRTS involves the use of dynamic, multicomponent soil system as a live filtration device to rejuvenate the wastewater through adsorption, ion exchange, precipitation and stabilization of pollutants through microbial degradation. It is a land application system where the wastewater is applied in specially designed field layouts with wide ridges and furrows. In ridges, trees with much higher transpiration capacity are planted, while wastewater is allowed to flow through the furrows. The high transpiration capacity of plants enables the system to serve as a biopump through stomatal network. All the wastewater is utilized in this process, obviating the problem of ground water pollution. It is a cost effective and environmentally acceptable solution to manage the problem of coloured wastewaters. HRTS ensures

the reuse of effluent and its nutrient contents for biomass production. It prevents ground and surface water pollution.

Minerals and Hydrocarbon Resources

India and surrounding oceans are locales of rich mineral and hydrocarbon resources. Exploration and environmentally viable exploitation of these resources will be major steps towards sustainability.

The occurrence of placer minerals in the beaches and near shore zones around Manavalakuruchi and Midalam areas, Kanyakumari, south Tamil Nadu has been known since long. Economically workable deposits are reported for a stretch of 10 to 15 km along the coastal belt. Real-time observation and measurement of all beach profiles for a period of 15 months indicates the replenishing nature of sand in the Manavalakurichi to the tune of 5.7 Lakh tons along 5.8 km long stretch.

CSIR institutes are working extensively on non-conventional energy sources like gas hydrates, shale gas, coalbed methane, and geothermal. Gas hydrates, ice-like crystalline solids of gas, are considered as the future source of energy and will be of great economic importance if exploited properly. CSIR-NGRI has prepared a gas-hydrate stability thickness map along the Indian continental margin from available bathymetry, sea-bottom temperature and geothermal gradient data. The map is also useful for exploration scientists.

India has the fifth-largest proven coal reserves globally, and hence, it is likely to have significant prospects for CBM exploitation. According to Govt. of India's data, the prognosticated CBM resources in the country are approximately 92 Trillion Cubic Feet (TCF) in 12 states of India; however, the established reserves are only 9.9 TCF. The present-day major CBM projects exist only in the Damodar and Son valley coalfields, while other regions are yet to be fully explored (DGH, 2019).

An initiative by Coal India, CSIR-NGRI and Central Mine Planning and Design Institute (CMPDI) carried out 3D-high resolution seismic surveys to map coal seams suitable for CBM exploration. The Ib valley coalfield is one of the prospective regions of the Mahanadi basin, identified for exploring Coal Bed Methane.

Since the coal blocks are not well-explored using geophysical data in this region, CSIR-NGRI took up 3D seismic exploration studies in Belpahar Sector-III, Jharsuguda district, Odisha state of Ib valley. The seismic section revealed the roof and floor contour maps of the regional coal seams. Given the presence of shale-rich thick Barren Measures in the Damodar river valley basin, some of the sub-basins are being explored for shale gas prospects. According to an estimate given by CMPDI, 45 TCF of shale gas reserves are expected in Gondwana sub-basins (Jharia¸ Bokaro, North Karanpura, South Karanpura, Raniganj & Sohagpur); however, a detailed geophysical mapping of the prospective zones has not been done.

CSIR-NGRI has carried out 2D seismic studies for EOGEPL in Raniganj East to map different Gondwana Formations. Further, CSIR-NGRI carried out detailed 3D seismic surveys in two new blocks of the Raniganj and Jharia coalfields of Damodar valley basin, and the thickness of the prospective Barren Measures was mapped along with associated structural features. The preliminary investigations estimated more than 1.2 Billion Cubic Meters of shale gas potential in the studied coal blocks of Jharia and Raniganj coal fields.

In addition to exploration programmes CSIR institutes are working to enhance oil recovery. This was demonstrated in the Balol heavy-oil field in the Northern Cambay basin, using 4D seismic data.

Marine Living Resources

Fishery resources along the Indian coast vary due to driving forces such as physical mixing, nutrients availability and plankton diversity. The formation of temperature fronts enhances nutrient concentrations and biological production where fish is aggregated. These regions are transient in nature, unlike fronts found in the subtropical/subpolar region. Hence accurate prediction of the location of these regions is helpful for fishermen to identify the zone of fishing for better yield. Based on oceanographic surveys and mesocosm experiments, the development of fronts and ecosystem within them can be evaluated; this information can be included in the numerical models for better prediction of regions of potential fishing in the coastal waters along with India.

There are many regions along the Indian coastline, such as the Gulf of Mannar, Wadge Bank, Quilon Bank, etc., that are characterized by high fishing resource potential. Though these regions have been known to fishermen since long as important fishing areas, the key environmental mechanisms in such regions supporting rich fisheries are largely unknown. Comprehensive knowledge of the ocean processes and their bio-physical linkages are essential for understanding ecosystem functioning, which in turn, supports valuable living resources in a marine environment. Therefore, by adopting an ecosystem ecology approach, the water column and sea bottom characteristics of these high-fishery regions can be quantified to explain the major driving environmental mechanisms in these regions. This work falls under the Deep Ocean Mission and also Blue Economy of UN SGD 14.

Seaweed/macroalgae are one of the most important biological resources from rocky intertidal regions. They provide numerous ecosystem services like food, shelter and refuge to various organisms such as fish, crustaceans, etc. The macroalgal bed also serves as a nursery for fisheries and protects them from predators. Seaweeds are a great source of cosmeceutical, nutraceutical and pharmaceutical active ingredients due to myriad health benefit compounds like antioxidant, anti-allergy, anti-inflammatory, anti-diabetic, cytoprotective, photo-protective agents, vitamins, etc. However, despite the immense potential seaweeds entail, they are understudied. A step has been initiated to study seaweed diversity along the Konkan coast to explore the functional benefits of seaweed.

In recent years, consumers' preferences are shifting from synthetic to organic food. This is due to the perception that organic or natural source is safe and healthy. Food comes in a variety of colours. Food without the right colour is considered unappealing. The sensorial connection of food and colour has increased the demand for natural colour compounds in the food industry. Natural colour compounds are chlorophylls, carotene, anthocyanins, etc. Seaweeds are rich in these pigments.

Additionally, these natural colour pigments contain many biologically active ingredients beneficial to human health. The incorporation of these colourants will also provide the much-needed nutrients to those suffering from undernourishment. This undertaking can make a positive contribution to the National Mission 'Poshan Abhiyan' to alleviate malnutrition amongst the impoverished community and to the nation's blue economy policy.

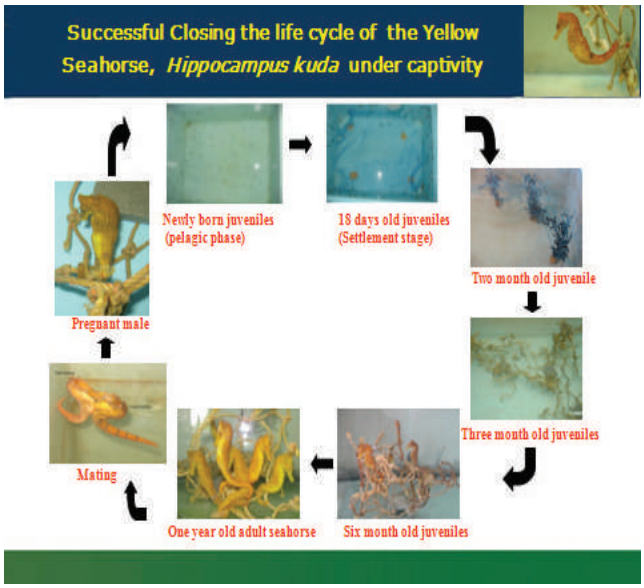
Green Mussel culture program: In the wake of ever-increasing demand for this gourmet seafood and the dwindling natural harvest, farming of green mussels, locally known as '*Xinanneo*', holds enormous potential. To bridge the vast gap between the supply and demand, recently CSIR-NIO successfully conducted a tech-demo of rack technique of farming of green mussels (area, 18 m^2) in a sheltered Bay at Madkai Village, Goa. This was carried out to complement CSIR's Integrated Skill Initiative.

Sustainably high production of 6120 green mussels (340 Nos./m^2) with a total biomass of 200 kg with shell-on (11 kg/m^2) was achieved during the culture period of five months. Monthly growth rates of 7.5 gm in weight and 13 mm in length were witnessed and an average weight of each cultured mussel at the time of harvest was 42 gm.

Acting as a knowledge-partner, the CSIR-NIO provided regular advisories to the skill trainees and information on environmental and growth parameters and the nutritive value of cultured mussels was also collected at fortnightly intervals. This technological diffusion could help in realising one of the Grand Challenges 'Doubling Fishermen's incomes by 2022' as envisioned by the Government of India.

Indian Yellow seahorse: Seahorses form an ingredient in traditional medicine, particularly in Southeast Asia where traditional Chinese medicine (TCM) and its derivatives (e.g. Japanese and Korean traditional medicine) are practised. In TCM, seahorses are credited with having a role in increasing and balancing vital energy flows within the body, as well as a curative role for ailments such as impotence and infertility, asthma, high cholesterol, goitre, kidney disorders, and skin afflictions such as severe acne and persistent nodules. They are also reported to facilitate parturition and act as a powerful genital tonic and as a potent aphrodisiac.

The current demand for seahorses appears to far exceed the supply, with at least 25 million seahorses (>70 tonnes dry weight) traded globally. Researchers at CSIR-NIO have successfully closed the life cycle of Yellow seahorse under captivity. This technology has great potential to integrate both conservation objectives and provide alternative livelihood options for fishers in the source countries, who in the absence of fishing alternatives, continue to exploit the declining seahorse populations.



Life cycle of seahorse (Source: CSIR-NIO)

Natural Hazards

The densely-populated Bay of Bengal (BoB) rim witnesses the deadliest Tropical Cyclones (TCs) globally before and after the summer monsoon. Earlier studies indicated enhanced salinity stratification and deeper thermocline reduce cooling under BoB TCs after the monsoon, suggesting that air-sea coupling may favour stronger TCs during that season.

Using observations and simulations from a regional ocean-atmosphere model, CSIR-NIO scientists show that BoB TCs are actually stronger before the monsoon due to a more favourable background atmospheric state (less vertical wind shear, larger maximum potential intensity, more humid mid-troposphere). Further they have developed two nonlinear Tropical Cyclones (TCs) intensity hindcast schemes, for the first time globally. These schemes are based on either Support Vector Machine (SVM) or Artificial Neural Network (ANN) algorithms. Contrary to linear schemes, which perform slightly better when trained individually over each TC basin, nonlinear methods perform best when trained globally. Globally trained nonlinear schemes improve TC intensity hindcasts relative to regionally trained linear schemes in all TC-prone basins, especially the SVM scheme for which this improvement reaches 10% globally. The SVM scheme, in particular, partially corrects the tendency of the linear scheme to underperform for moderate intensity (category 2 and less on the Saffir–Simpson scale) and decaying TCs. This improvement is sufficiently large to motivate more testing of nonlinear methods for statistical TC intensity prediction at operational centers.

The highly populated Indo-Gangetic-Plains (IGPs) are facing high seismic threat from impending large

earthquake(s) occurring in the Himalayan area. Towards making an earthquake resilient infrastructure, CSIR-NGRI has recently estimated the parameters viz. the thickness of the soft sediments and the Ground Motion Prediction Equations (GMPEs) of the IGPs and Himalayan region. Based on this research, earthquake risk maps of Lucknow and Dehradun cities, located in the IGPs and the Himalayan hinterland respectively, have been prepared by characterising the hazard and its uncertainty, to serve as input for risk assessment and earthquake resistant design for different applications – ranging from private homes to multi-storied buildings and critical infrastructures such as bridges or dams. Both the maps were shared with the main stakeholders – Uttarakhand and Uttar Pradesh State Disaster Management authorities. They agreed to use the outcome for revising land-use maps with revised hazard components and the building bye-laws to outlaw unsafe and vulnerable typologies of houses in both the cities.

Release of earthquake risk maps of Lucknow and Dehradun cities

Natural disasters such as landslides, Glacial Lake Outburst Floods (GLOFs), and other catastrophic flash flood events are major hazards in the Himalayas. They are a growing threat in a warming climate. Retreating glaciers and permafrost degradation causes the growth of glacial lakes and destabilization of mountain slopes, increasing the flash flood and landslide hazard in vulnerable mountainous regions. These events pose a large risk to downstream communities, causing loss of life and destruction of homes, businesses, roads, livestock and hydropower infrastructure. Catastrophic floods are of particular concern for hydropower development, a rapidly growing industry of increasing economic importance for India, especially in the Himalayan mountains. The 2013 Kedarnath and the 2021 Dhauli Ganga floods are stark examples.

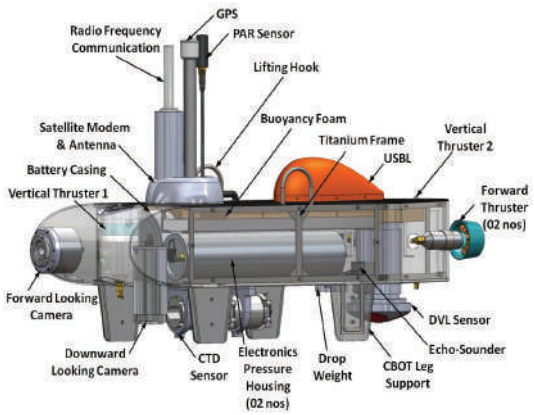
While glacial lakes can be identified through satellite data and can be equipped with ground-based warning systems for GLOF hazards, landslides and subsequently triggered flow cascades are extremely difficult to anticipate in both space and time. While some individual slopes may be monitored, this quickly becomes unfeasible across the population of potential failure sites along the entire belt. Similarly, monitoring of individual lakes or channels for flash floods becomes unfeasible for the entire region.

However, seismic recording of the ground shaking caused by landslides, GLOFs, and other catastrophic floods, which travel as elastic waves at high speeds of a few km per second, offers an alternative paradigm for early warning. The resulting seismic waves can be detected remotely, even at large distances from the flood source, thereby raising the possibility of a distributed early warning system based around networks of seismometers that could simultaneously monitor geomorphic hazards over large regions (Cook *et al.*, 2021).

Autonomous Vehicles

CSIR-NIO has recently developed an autonomous underwater vehicle to monitor coral reefs. The other applications include seabed photography, underwater pipeline inspections, harbour/ island surveillance, satellite validation and calibration, coastal/ocean/fresh water studies. Coral reef monitoring is considered by most climate scientists as a reliable proxy indicator of climate change because corals are sensitive to small changes in temperature and pH. The conventional diver approach involves high cost and strenuous human effort to survey the coral reef area. The C-Bot being developed at the CSIR-NIO shall address the challenge of large area coral reef bed monitoring.

For the first time in India, drone-borne magnetic measurements were recorded using the light weight potassium



(Left) CBOT with sensors and electronic modules. (Right) CBOT at Bambolim beach for field test (Source: CSIR-NIO).

magnetic sensor towed as under slung by an indigenously developed UAV. A survey over dolerite dyke intrusion in granitic-gneissic terrain, near Hyderabad was carried out to show the efficacy.

Acknowledgement

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