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Original Article

A Perspective on Chemistry Research in India

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Abstract:

Chemistry is a foundational scientific discipline that contributes directly to healthcare, agriculture, energy, environmental protection, advanced materials, biotechnology and industrial development. India has developed a large and diverse chemistry research ecosystem involving universities, national laboratories, Indian Institutes of Technology, Indian Institutes of Science Education and Research, the Indian Institute of Science and industrial research organizations. Over the last several decades, Indian chemistry research has expanded substantially in both volume and disciplinary diversity. Scientometric investigations have documented strong growth in Indian chemical research, particularly in organic, physical, inorganic, analytical, electrochemical, materials and medicinal chemistry. Varaprasad et al. (2011) demonstrated sustained growth in Indian chemical research between 1987 and 2007, while Arunachalam et al. (2017) reported a substantial increase in India's chemistry publications between 1991 and 2015. Organic chemistry has remained one of India's major strengths, with Indian researchers producing significant output across synthetic chemistry and related sub-disciplines (Salini et al., 2014; Dwivedi et al., 2015). At the same time, emerging fields such as nanoscience, nanotechnology, medicinal chemistry, analytical chemistry and sustainable chemistry are expanding the scope of Indian chemical research. Nanoscience research in India has shown strong interdisciplinary characteristics and substantial connections with chemistry and materials science (Karpagam et al., 2011). Medicinal chemistry has benefited from increased academic and industrial activity, particularly following changes in India's intellectual-property environment (Vishwakarma et al., 2017; Talukdar et al., 2023). Nevertheless, challenges remain in research quality, advanced instrumentation, international collaboration, translation of discoveries into technologies, and equitable distribution of research infrastructure. This review examines the evolution, present status, major research areas, strengths, challenges and future opportunities of chemistry research in India and argues that the next phase should emphasize interdisciplinary excellence, sustainable chemistry, high-quality research, innovation and stronger industry-academia partnerships.

Keywords:* *Chemistry, India, Chemical, Organic Chemistry, Medicinal Chemistry.

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Introduction:

Chemistry occupies a distinctive position among the natural sciences because it provides the molecular foundation for understanding matter and transforming it into useful products and technologies. Modern chemistry extends far beyond conventional laboratory synthesis. It encompasses molecular design, catalysis, spectroscopy, computational modelling, materials development, drug discovery, environmental monitoring, energy conversion and biological applications. Consequently, the strength of a country's chemistry research ecosystem has direct implications for its industrial competitiveness, healthcare system, environmental sustainability and technological development. India has a long tradition of chemical research and education. Following independence, the development of national laboratories, universities and specialized scientific institutions created a foundation for systematic research in chemical sciences. Over subsequent decades, Indian researchers established strong research programmes in organic chemistry, inorganic chemistry, physical chemistry, analytical chemistry, electrochemistry, polymer science, catalysis, natural products and chemical biology. The growth of Indian chemistry research has been documented through several scientometric investigations. Varaprasad *et al*. (2011) analyzed indian chemical research during 1987-2007 and reported sustained development across chemical-science subfields. Their analysis demonstrated that Indian chemical research had developed identifiable areas of relative strength and had become an important contributor to global chemical research. A later analysis by Arunachalam *et al*. (2017), covering 1991-2015, showed that the number of chemistry papers originating from India increased steadily, particularly after 2007. Importantly, the growth was not restricted to publication quantity; the researchers also observed increasing representation in leading chemistry journals. These findings indicate that Indian chemistry has gradually moved toward greater international visibility. However, publication growth alone does not completely represent scientific strength. Research quality, citation impact, originality, international collaboration, technological translation and societal relevance are equally important. Madhan *et al*. (2020) reported that although India had a large share of global chemistry publications during 2011-2015, its representation among highly cited papers and high-impact journals remained comparatively modest. This observation highlights a central challenge for the future: India needs to transform its substantial research volume into greater

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scientific influence and technological impact.

Historical Evolution of Chemistry Research in India:

The evolution of chemistry research in India can broadly be divided into several interconnected phases. Early modern chemical research concentrated on fundamental areas such as organic synthesis, inorganic compounds, physical chemistry, natural products and analytical methods. University departments played an important role in developing research capacity and training postgraduate students. The establishment and expansion of national research laboratories provided another major stimulus. Institutions associated with CSIR, the Department of Atomic Energy and other government scientific organizations developed specialized research capabilities. These institutions enabled Indian researchers to work on industrially relevant problems including pharmaceuticals, catalysts, polymers, specialty chemicals, electrochemistry and materials.

The later expansion of IITs, IISc, IISERs and other research-intensive institutions further diversified the chemistry research landscape. Modern chemical research became increasingly interdisciplinary, incorporating physics, biology, materials science, computational science and engineering. Scientometric evidence supports this long-term expansion. Karki *et al*. (2000), in an analysis of Indian organic chemistry research from 1971 to 1989, documented the historical development of the field and examined India's contribution relative to worldwide organic chemistry. Their study illustrates that the foundations of India's current organic chemistry strength were established several decades ago. By the twenty-first century, the research environment had become increasingly international. Improved access to scientific literature, advanced instrumentation, international collaborations and computational resources enabled Indian researchers to participate more extensively in global chemical research.

Present Landscape of Indian Chemistry Research:

Chemistry is among India's most productive scientific fields. Studies examining Indian chemical-science publications have identified substantial output across organic, physical, inorganic, analytical, medicinal and materials-related areas. Arunachalam *et al.* (2017) observed that India's chemistry publication output increased substantially between 1991 and 2015. Their analysis also suggested that the growth in publication numbers was accompanied by increased representation in leading journals. However, the study identified a continuing gap between India's overall research output and its contribution to some of the world's most influential chemistry journals. Madhan *et al.* (2020) provided a broader international comparison. Their analysis of chemistry publications during 2011–2015 found that India accounted for approximately 6.9% of world chemistry publications. Nevertheless, the

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proportion of Indian papers appearing among the world's most highly cited chemistry papers was substantially lower than the corresponding proportions for several scientifically advanced countries. This indicates that the next stage of development should emphasize research quality and scientific impact rather than publication volume alone. The Indian chemistry ecosystem is also characterized by extensive collaboration. Hosamani and Bagalkoti (2016) found that Indian chemistry research showed considerable collaborative activity during 1999-2013. Collaborative research is especially important for chemistry because modern experiments often require specialized instrumentation, interdisciplinary expertise and substantial financial resources.

Organic Chemistry: A Major Strength:

Organic chemistry remains one of the most prominent areas of Indian chemical research. It encompasses synthetic methodology, heterocyclic chemistry, natural products, reaction mechanisms, organometallic chemistry, stereochemistry, photochemistry and medicinal chemistry. Dwivedi *et al*. (2015) analysed more than 17,000 Indian publications in organic chemistry and related sub-disciplines during 2004-2013. Their findings showed significant growth in Indian organic chemistry research, with academic institutions and CSIR laboratories accounting for major portions of the national output. The study also demonstrated that several productive Indian institutions achieved citation impacts above the national average. Salini *et al*. (2014) similarly evaluated Indian organic chemistry research during 2004-2013 and reported positive growth and substantial research activity. Their analysis demonstrated that Indian organic chemistry had developed considerable breadth, with contributions from numerous institutions and researchers. The future of Indian organic chemistry is likely to be strongly influenced by sustainable synthetic methods. Photoredox chemistry, electrochemical synthesis, organocatalysis, C-H functionalization, mechanochemistry and biocatalysis can potentially reduce waste, energy consumption and dependence on hazardous reagents. India's pharmaceutical and chemical industries provide an additional opportunity. Academic discoveries in synthetic chemistry can potentially be translated into active pharmaceutical ingredients, agrochemicals, specialty chemicals and advanced materials. Strengthening the connection between fundamental synthetic research and industrial process development will therefore be important.

Medicinal Chemistry and Drug Discovery:

Medicinal chemistry has particular strategic importance for India because of the country's pharmaceutical manufacturing capacity. The field connects organic chemistry with pharmacology, molecular biology, computational science and drug development. Vishwakarma *et al*. (2017)

described the substantial expansion of medicinal chemistry research in India following changes to the country's product-patent environment. They highlighted the increasing contributions of both academic and industrial laboratories and noted the development of research programmes addressing infectious diseases, cancer, inflammation, neurological disorders, diabetes and neglected tropical diseases. More recently, Talukdar *et al*. (2023) reviewed more than a decade of medicinal chemistry research in India and described the breadth of contributions from academic and industrial researchers. The development of new synthetic methodologies, molecular targets, computational approaches and drug-discovery strategies has increased the scientific sophistication of this field. India's medicinal chemistry future should focus increasingly on translational research. Discovery of a biologically active molecule is only the initial stage of drug development. Lead optimization, pharmacokinetics, toxicity evaluation, formulation, intellectual-property protection and clinical development are essential for successful translation. Greater interaction among universities, pharmaceutical companies, hospitals, biotechnology enterprises and research institutes could help reduce the gap between academic discovery and commercial or clinical application.

Nano chemistry and Materials Research:

Nanoscience represents one of the clearest examples of interdisciplinary chemistry research in India. Nanomaterials combine chemical synthesis with physics, materials science, electronics, medicine and engineering. Karpagam *et al*. (2011) examined Indian nanoscience and nanotechnology research between 1990 and 2009 and demonstrated considerable growth in national research activity. Chemistry represented one of the major subject areas within India's nanotechnology research landscape, alongside materials science, physics and engineering.

Nanochemistry has enabled researchers to design materials with novel optical, electronic, catalytic, magnetic and biological properties. Indian laboratories have investigated nanoparticles, nanocomposites, two-dimensional materials, porous materials, semiconductor nanomaterials and functional surfaces.

Potential Applications:

- Energy storage and conversion
- Solar-energy technologies
- Chemical and biological sensors
- Water purification
- Photocatalysis
- Drug delivery
- Antimicrobial materials
- Environmental remediation
- Advanced electronic materials

The challenge is to move beyond proof-of-concept laboratory studies toward scalable, reproducible and economically viable technologies. Nanomaterial safety should also receive greater attention, particularly concerning environmental persistence, biological interactions and end-of-life disposal.

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Analytical Chemistry and Instrumentation:

Analytical chemistry provides the measurement foundation for virtually every branch of chemical science. Reliable chemical analysis is essential in pharmaceuticals, environmental monitoring, food safety, forensic science, clinical diagnostics, agriculture and industrial quality control. Verma (2017) argued that analytical chemistry in India had not progressed as rapidly as some other chemistry disciplines despite substantial development in teaching and research. The availability of sophisticated analytical instruments, access to modern facilities, appropriate training and development of specialized expertise remain important considerations. India needs strong analytical infrastructure because modern chemistry increasingly depends on high-resolution mass spectrometry, nuclear magnetic resonance spectroscopy, chromatography, advanced microscopy, electrochemical techniques and elemental analysis. A particularly promising opportunity is the development of portable analytical systems. Miniaturized sensors, microfluidic devices and smartphone-enabled analytical platforms could make chemical monitoring more accessible in rural and resource-limited settings. The integration of analytical chemistry with artificial intelligence could further improve the interpretation of complex spectra and the identification of chemical patterns in large datasets.

Physical, Inorganic and Electrochemical Chemistry:

Physical chemistry continues to provide the theoretical and experimental foundation for understanding molecular interactions, reaction kinetics, thermodynamics, spectroscopy and materials behaviour. Indian researchers have contributed significantly to spectroscopy, computational chemistry, electrochemistry, surface science and molecular modelling. Electrochemistry is particularly important because of its connections with batteries, fuel cells, corrosion, sensors, electrochemical synthesis and renewable-energy technologies. India's growing interest in energy storage and hydrogen technologies creates significant opportunities for electrochemical research. Inorganic chemistry also plays an important role in catalysis, coordination chemistry, functional materials, bioinorganic chemistry and energy-related materials. The combination of inorganic chemistry with materials science and computational modelling may generate important technologies in catalysis, sensing and energy conversion.

Green and Sustainable Chemistry:

Environmental sustainability is becoming an essential dimension of chemical research. Traditional chemical manufacturing can generate hazardous waste, consume large quantities of energy and depend on non-renewable feedstocks. Green chemistry seeks to address these problems through safer chemical design, waste prevention, catalysis, renewable resources, solvent reduction and energy efficiency. Indian chemistry research has increasingly incorporated sustainability concepts. Green chemistry can be particularly relevant to India's large pharmaceutical, chemical, agricultural and materials industries. Future Indian research should emphasize not only greener reactions but also complete process sustainability. Researchers should consider raw materials, reaction conditions, energy consumption, solvent recovery, waste treatment, product toxicity and end-of-life behaviour. Biomass-derived chemicals represent another promising opportunity. Agricultural residues and other renewable resources can potentially serve as feedstocks for valuable chemicals, polymers and fuels. Such approaches could simultaneously contribute to waste management and rural economic development.

Computational Chemistry, Data Science and Artificial Intelligence:

The digital transformation of chemistry is creating new research opportunities. Computational chemistry can predict molecular structures, reaction energies, material properties and interactions before experimental validation. Artificial intelligence and machine learning can extend these capabilities by identifying patterns in large chemical datasets. For India, the combination of chemical expertise and a strong information-technology sector presents a major strategic advantage. AI-assisted drug discovery, reaction prediction, catalyst design, materials screening and analytical-data interpretation are potential areas of rapid development. However, successful AI-based chemistry depends on reliable data. Experimental datasets need standardized formats, accurate metadata, reproducible procedures and appropriate validation. Researchers should therefore receive training in data science alongside traditional chemical methods. AI should complement rather than replace experimental chemistry. Computational predictions require experimental validation, while experimental results can continuously improve computational models.

Industry-Academia Collaboration:

One of the major future priorities for Indian chemistry is strengthening interaction between academic researchers and industry. India has substantial pharmaceutical, chemical, petrochemical, polymer, fertilizer, agrochemical and specialty-chemical industries. Yet many academic discoveries remain at laboratory scale. Stronger industry academia collaboration could help identify practical research problems and accelerate technology development. Collaborative research centers, industrial PhD programmes, sponsored laboratories, shared instrumentation facilities, technology incubators and joint intellectual-property arrangements could create stronger connections. The pharmaceutical sector offers an especially important model because medicinal chemistry research already involves substantial interaction between academic and industrial groups. Similar structures could be developed in sustainable materials, energy chemistry, catalysts, sensors and environmental technologies.

Major Challenges:

Despite substantial progress, Indian chemistry research faces several persistent challenges:

Unequal Research Infrastructure: Advanced instrumentation and specialized facilities remain concentrated in major institutions. Researchers at smaller universities may experience difficulties accessing high-end analytical equipment. Publication volume should not become the primary indicator of scientific success. Greater emphasis is needed on originality, reproducibility, rigorous experimental design and internationally significant research questions.

International Visibility: Madhan *et al.* (2020) demonstrated that India's publication share was substantial, but its representation among highly cited papers and high-impact journals was comparatively lower than that of several leading research countries. Improving scientific visibility therefore requires greater emphasis on research quality and international collaboration.

Technology Translation: A promising laboratory result does not automatically become a commercial technology. Scale-up, process engineering, intellectual-property protection, regulatory requirements and market assessment must be integrated into the research pipeline.

Skilled Human Resources: Future chemistry research requires scientists who can operate across traditional disciplinary boundaries. Training should therefore combine chemistry with computation, data science, materials science, biology and engineering.

Future Perspective:

The future of chemistry research in India will increasingly depend on interdisciplinary convergence. Chemistry is expected to become more closely integrated with artificial intelligence, biotechnology, medicine, materials science, agriculture and environmental science. Several research directions deserve particular attention.

- Sustainable chemical manufacturing can reduce environmental impact and improve resource efficiency.
- Energy chemistry can contribute to batteries, hydrogen production, fuel cells, carbon utilization and renewable-energy technologies.
- Medicinal chemistry can support the discovery of new therapies for infectious diseases, cancer, metabolic disorders and neglected diseases.
- Advanced materials chemistry can generate functional materials for electronics, sensors, energy storage and environmental remediation.
- Analytical chemistry can enable low-cost monitoring of pollutants, food contaminants, pharmaceutical compounds and biological markers.
- Agricultural chemistry can support safer pesticides, controlled-release fertilizers, plant-growth regulators,

soil amendments and chemical sensors.

- Computational and AI-driven chemistry can accelerate molecular and materials discovery while reducing experimental cost and time.
- India also needs to build stronger national and international research networks. Large-scale collaborative projects involving multiple universities, national laboratories and industrial partners can address problems that are beyond the capabilities of individual laboratories.

Conclusion:

Chemistry research in India has developed from a predominantly discipline-based academic activity into a broad and increasingly interdisciplinary scientific enterprise. Organic chemistry, physical chemistry, inorganic chemistry, analytical chemistry and electrochemistry remain important foundations, while medicinal chemistry, nanotechnology, materials chemistry, green chemistry and computational chemistry are creating new opportunities. The next stage should therefore move beyond publication expansion toward scientific excellence, technological translation, sustainability and societal impact. Greater investment in advanced infrastructure, high-quality research training, international collaboration, industry partnerships and interdisciplinary science will be essential. India possesses the human resources and institutional foundation required to become a major global center of chemical innovation. If research excellence is combined with sustainable technologies, advanced instrumentation, digital chemistry and effective commercialization, chemistry can contribute substantially to India's future in healthcare, agriculture, energy, environmental protection and advanced manufacturing.

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