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DNA PROFILING AND DIGITAL DNA EVIDENCE: AN INNOVATIVE FORENSIC APPROACH IN THE INDIAN LEGAL SYSTEM

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Abstract: In recent years, DNA profiling has become an integral part of the investigative and trial processes as a vital forensic tool and technique. In a court of law, the method and the DNA data provide supporting evidence to establish guilt or innocence beyond a reasonable doubt. With an eye toward improving justice delivery and introducing new forensic methods, this research investigates how the Indian legal system may include DNA profiling and digital DNA evidence. The growing importance of forensic science in criminal investigations and the demand to fill the loopholes in the current DNA evidence legal framework in India motivate this study. The study recognizes the profound influence that DNA technology has had on the field of justice. The study's overarching goals are to assess DNA forensics in India as it stands right now, catalog the obstacles to its widespread use, and recommend solutions for better integration with judicial processes.
In order to gain a thorough understanding of the topic, this study uses a mixed-method approach. Doctrinal method involves reviewing literature and analyzing legal and case law. Empirical method involves collecting data in the context of technological assessment and the efficacy of this innovation. For evaluating the value of DNA evidence in Indian courts, it examines pertinent statutes, rationes decidendi, court rulings, and scientific literature. Furthermore, it delves into the utilization of digital platforms and tools for DNA data management and analysis, showcasing their ability to enhance precision and efficacy. Despite DNA profiling's substantial contribution to solving complicated criminal cases, as per the finding a number of obstacles, such as inadequate infrastructure, a lack of qualified staff, and worries about data privacy and security, remain. To guarantee the ethical use of DNA technology in India's justice delivery system, the study finds that the legislative framework needs to be strengthened, worldwide best practices should be adopted, and ethical norms should be promoted. Additionally, for effective incorporation of DNA evidence into the Indian legal system, the research highlights the significance of forensic scientists, legal professionals, and legislators working together.

Keywords: Digital Evidence, DNA Data, DNA Profiling, Indian Judiciary, Forensic Science, Justice Innovation.

1 Introduction

Forensic science, a multidisciplinary use of scientific knowledge to the process of civil and criminal justice, plays an indispensable role in modern legal systems. The Indian legal system, rooted in both colonial legacy and indigenous jurisprudence, has undergone considerable transformation to embrace scientific advancements, especially in criminal justice delivery. An integral part of this shift is the field of forensic science, offering objective insights into cases involving murder, sexual assault, cybercrime, fraud, drug trafficking, and even terrorism. Derived from the Latin word '*forensis'*, meaning 'before the forum', collecting, preserving, and analyzing physical evidence from crime scenes is the essence of forensic science, which is grounded in scientific principles and procedures. Over the years, its relevance has grown immensely, owing to the increasing complexity of criminal activities and the need for objective, evidence-based adjudication. Within the framework of Indian law, forensic science serves as a bridge between science and law, aiding investigators, prosecutors, defense lawyers, and judges in the pursuit of truth and justice.

Forensics plays a crucial role in the Indian legal system as it helps ensure justice is based on scientific evidence rather than solely on eyewitness testimony or circumstantial

evidence. Forensic science provides objective and accurate information, helping to identify suspects, establish guilt or innocence, and reconstruct crime scenes. Techniques like DNA analysis, fingerprint comparison, ballistics, and toxicology are pivotal in solving complex cases. Judges often rely on forensic experts to interpret scientific evidence that is beyond the common knowledge of legal professionals. By providing concrete evidence, forensics helps prevent miscarriages of justice caused by unreliable eyewitnesses, false confessions, or biased investigations. In addition to criminal law, forensic science aids in civil matters such as document authentication, cybercrime, insurance fraud, and disputed paternity cases. With the rise in digital crimes, cyber forensics has become essential in tracking electronic evidence, decoding data breaches, and identifying online fraud. Reliable forensic evidence can help accelerate investigations and trials, reducing case backlogs in the overburdened Indian judiciary.

The landmark use of DNA fingerprinting in the 1989 Rajiv Gandhi assassination case marked a turning point, after which forensic science began to gain institutional and procedural importance in Indian law enforcement. India's criminal justice framework, comprising the Bharatiya Nyaya Sanhita (BNS), the BharatiyaNagarika Suraksha Sanhita (BNSS), and the BharatiyaSakshyaAdhiniyam (BSA), has gradually incorporated forensic procedures to strengthen investigation and trial outcomes. Sections such as 39 and 40 of the BharatiyaSakshyaAdhiniyam explicitly permit expert opinions, including those of forensic experts, to be admitted in court. These expert testimonies often become pivotal in cases where circumstantial evidence alone is insufficient.

Among all the possible forensic techniques, this research is keenly based on two phenomenal areas, one is DNA profiling and the other is Digital DNA Evidence. Though both are different on their own, but many cases, either criminal or civil, are solved by a collaboration of both. DNA profiling is a biological forensic technique to analyze the physical substances in a human being or animal, whereas Digital DNA evidence is a computer forensic technique that refers to a unique pattern of behaviour or activity in the digital world. In this research, the authors have penetrated into the theoretical aspect concerning the use, significance, as well as issues and challenges of both the emerging techniques, and through empirical analysis, data have been collected to satisfy the objectives and research questions regarding such innovative techniques.

2 Objectives of Research

1. Assess the current state of forensic DNA profiling and digital DNA evidence analysis within the Indian legal system.
2. Identify the issues and challenges in integrating DNA profiling and digital DNA evidence with the Indian legal system.
3. Enhance the integration of DNA profiling and digital DNA evidence inside the Indian legal system by proposing innovative solutions and changes.
4. Evaluate the potential impact of integrating advanced forensic techniques on the efficiency and effectiveness of the Indian justice system.
5. Establish a framework to address the ethical, legal, and societal ramifications of utilizing DNA profiling and digital DNA evidence within the Indian context.

3 Methodology

Research has been made by a mixed approach of Doctrinal and Empirical. Doctrinal method has been applied to collect data from literature review, accessing secondary data from different journals, books, as well as government reports. Empirical analysis has been made by

collecting data through the Questionnaire technique. Structured questions have been put by selecting the target area by a blend of convenience and purposive sampling technique. The responses received have been analyzed by MS Word.

4 Research Questions

1. How can the DNA profiling technique and digital DNA evidence be effectively integrated with the Indian legal system to ensure justice in criminal cases?
2. What are the current limitations of DNA profiling in India, and how can these be addressed through technological advancements and policy reforms?
3. How can digital DNA evidence be authenticated and validated for admissibility in Indian courts?
4. What ethical considerations arise from the use of digital DNA evidence in the Indian legal context, and how can these be mitigated?
5. What are the potential challenges in establishing a comprehensive national DNA database in India, and how can these be overcome?
6. How can forensic DNA technologies be leveraged to address specific types of crimes prevalent in India, such as sexual assault and homicide?
7. What are the international best practices in forensic DNA analysis, and how can these be adapted and implemented in the Indian context?
8. How can public awareness and understanding of forensic DNA technologies be enhanced to promote greater acceptance and trust in the Indian legal system?

5 Forensics as an Innovating Justice

Innovation in justice implies modern tools. The evolution of justice is driven by forensics, which brings impartiality, efficiency, and transparency to legal proceedings. With DNA analysis, digital forensics, and biometrics, law enforcement and courts can find the truth, reduce human error, and prevent miscarriages of justice. Modern forensic procedures have exonerated innocent people after years or decades of incarceration, making this breakthrough extremely important. It shows the global trend toward standardizing forensic techniques and enhancing forensic training and certification. These initiatives assure fair and credible justice. Forensic innovation builds public trust and a more equitable society by improving investigation and court outcomes. [1] Forensic Technologies help in different areas such as criminal investigation, civil dispute adjudication, national security, fraud detection, military services, medical fields, disaster victim identification, archaeology, historical investigation, and wildlife and environmental protection.

6 Types of Forensics

Forensic techniques have evolved a lot. It has different areas to look into. In every crime scene or civil disputes judiciary and investigative agencies are looking towards concrete scientific analysis for strong evidence. Whether it is biological or digital technology, forensic science has gone a long way. Here, the authors have mentioned some key areas of forensic sciences that are doing excellent work towards the implementation of legal principles on different sectors throughout the Indian territory.

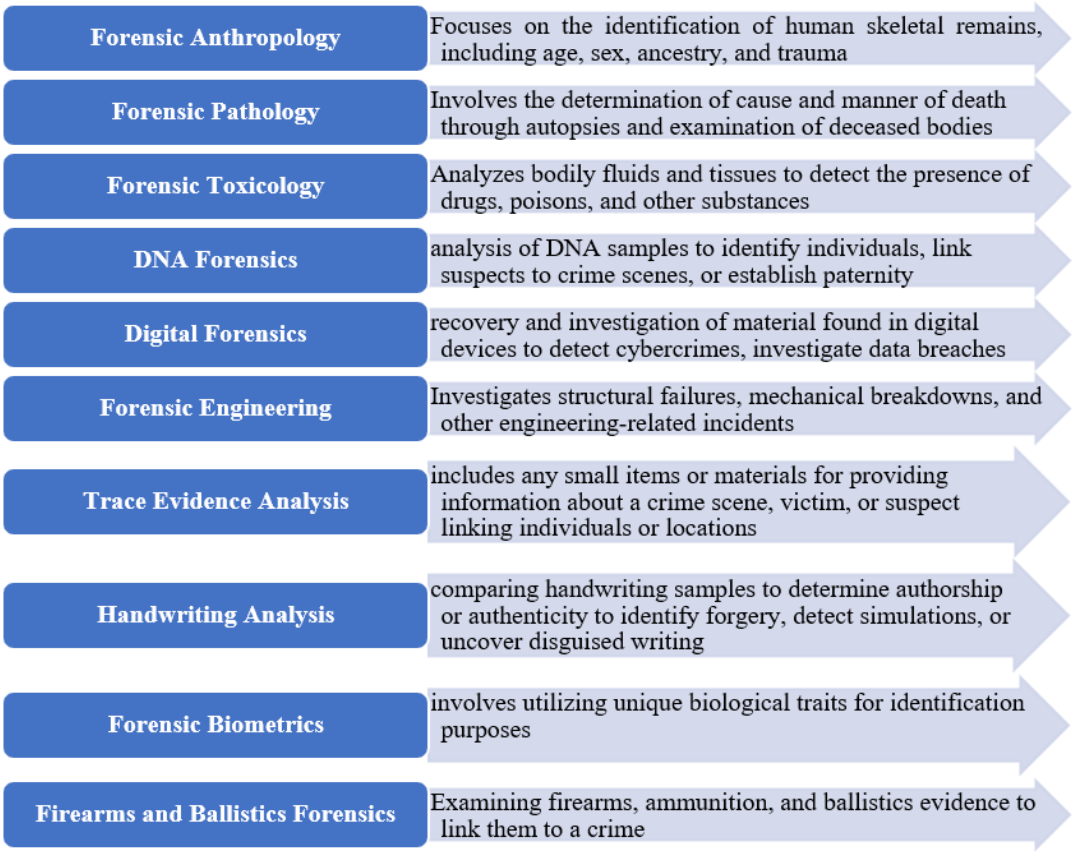


Fig. 1: Different fields of Forensics

7 DNA Profiling

DNA profiling is used in forensics to identify people by their genetics. A person's DNA sequence can distinguish them from others (excluding identical twins). This method examines Short Tandem Repeats (STRs), which vary substantially among individuals. [2] DNA profiling involves obtaining a biological sample (such as blood, saliva, hair, or skin), extracting DNA, amplifying it using PCR, and examining the STR patterns with electrophoresis or sequencing. The DNA profile is compared to known samples or forensic databases. Since 1985, forensic DNA profiling has advanced rapidly. PCR (polymerase chain reaction) allows forensic investigators to evaluate tiny DNA samples. Instead of a 2-centimeter-wide bloodstain, DNA from a cigarette butt or postage stamp can identify a person.

Numerous fields can benefit greatly from DNA profiling, including law enforcement, disaster relief, paternity determination, and cases involving missing persons. Its usefulness in establishing guilt or innocence based on biological evidence is most apparent when it connects criminals to specific locations. In the legal system, DNA profiling is recognized as a reliable form of scientific evidence due to its high accuracy. Overall, DNA profiling enhances the administration of justice by offering a powerful tool for evidence-based investigations and plays a crucial role in modern forensic science and legal procedures.

8 Digital DNA Evidence

Digital DNA evidence refers to the digital behavioral footprint left by an individual during interaction with technology. Unlike biological DNA, which is derived from physical samples like blood or hair, digital DNA consists of unique patterns of digital behavior; such

as keystrokes, browsing history, device usage, geolocation data, app interactions, and online communication patterns, that can be systematically collected and analyzed to identify or profile an individual. [3]

This concept is rooted in the idea that each person's digital interactions form a distinctive signature, just as physical DNA does. It has gained prominence with the rise of big data, artificial intelligence, and cybercrime investigation tools, offering law enforcement a non-invasive yet effective method for tracking digital activities and verifying identity.

8.1 Types of Digital DNA Evidence

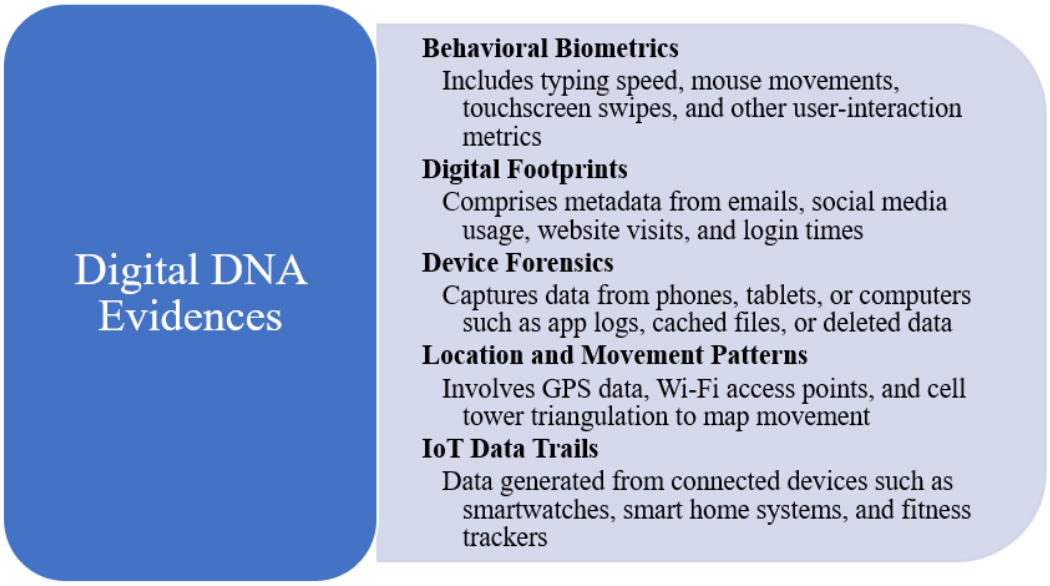


Fig. 2: Different types of Digital DNA Evidence

Criminal investigations, digital fraud, cyberstalking, identity theft, and insider threats increasingly use digital DNA evidence. It helps law enforcement trace suspect activity, authenticate identity, distinguish between multiple users of a device, reconstruct timelines, map events and digital interactions, match digital behavior patterns across platforms or incidents, support physical evidence in courtrooms, etc. Computer, mobile, network, digital picture, and video, and social media data can be used to extract these. Its accuracy and individualization, non-intrusive collection, real-time suspect or system monitoring, cybersecurity enhancement, and data-driven justice nature make it important and useful to the judicial system. In conclusion, digital DNA evidence is a forensic frontier that addresses digital crime. It improves legal responsibility, precision, and efficiency, strengthening cyberlaw.

Digital DNA evidence has become an indispensable part of the legal system. Its ability to provide detailed, accurate, and accessible information enhances the pursuit of justice and helps to ensure that legal outcomes are based on sound evidence. As technology continues to evolve, the importance of digital forensics and the proper handling of digital evidence will only continue to grow.

9 Increasing role of DNA Profiling and Digital DNA Evidence in modern forensics

DNA profiling and digital DNA evidence have revolutionized forensic science and improved investigation and judicial processes. Traditional DNA profiling uses unique genetic markers to identify people with near-perfect accuracy. Since its invention in the 1980s, the approach has been essential in forensic science for disaster victim identification, missing

person inquiries, paternity difficulties, and criminal investigations. Growing dependability, precision, and legal acceptance of DNA profiling have pushed its application beyond conventional limitations. Molecular biology allows forensic experts to evaluate tiny, degraded biological materials like hair strands, skin cells, saliva, and bloodstains from crime scenes. These innovations have helped law enforcement solve cold cases, exonerate innocents, and improve criminal prosecutions. DNA evidence has become the 'gold standard' for tying suspects to crimes in courtrooms.

Additionally, digital DNA evidence is becoming more popular in forensic investigations. Digital DNA—data-driven behavioral patterns and metadata from smartphones, laptops, and smart wearables—identifies an individual's identity, activities, locations, and conversations. This digital imprint, like biological DNA, is unique to each person and is increasingly utilized to augment or replace physical evidence in cybercrime, fraud, stalking, and organized crime investigations. Digital DNA includes IP addresses, login timestamps, GPS positions, social media activities, biometric unlock data, and cloud storage access logs. This digital trail lets investigators recreate timelines, validate alibis, and find hidden networks or online conduct, increasing cyber-forensics.

Fusion of DNA profiling with digital DNA evidence is potent forensics. DNA can be used in both physical and cybercrime. The capacity to mine and cross-reference massive DNA and digital datasets is also changing predictive policing and criminal profiling as law enforcement adopts AI and big data analytics. The rise of DNA profiling and digital DNA evidence has transformed forensic science. It improves criminal investigations and forces judicial systems to adapt to new evidence. Although beneficial, this dual advancement raises privacy, data protection, ethical, and legal issues. Concerns about data collecting, consent, retention, and misuse require immediate regulatory action. Worldwide, nations must balance investigative utility with fundamental rights.

9.1 Emerging Technologies for DNA Analysis

Forensic analysts have long relied on hand extraction systems as the gold standard for DNA testing. It is Affordable, widely accessible, and suitable for small labs. Having said that, it's More time to process, more room for human mistake, and unpredictable results. Gradually, Automated Extraction Systems came into light, which are fully automated systems that handle the entire DNA extraction process. It increases throughput, reduces human error, and improves consistency. As a basic need, it requires an Initial cost, maintenance, and training requirements. Streamlining processes and reducing room for mistakes is ideal for forensic labs that process a large number of cases daily. Certain emerging and modified technologies are explained below.

9.1.1 Massively Parallel Sequencing (MPS)/Next-Generation Sequencing (NGS)

NGS, also known as MPS, is revolutionizing forensic DNA analysis by making it possible to sequence millions of DNA fragments all at once. New genomic sequencing (NGS) technology can examine a wider range of genetic markers, such as mitochondrial DNA (mtDNA), short tandem repeats (STRs), and single-nucleotide polymorphisms (SNPs). This technology allows for a higher rate of identification and the availability of clues about a suspect's physical traits and biogeographical ancestry (Phenotypic and ancestry prediction). [4]

9.1.2 Rapid DNA Analysis

With Rapid DNA technology, you can get your results in less than two hours by automating the whole DNA extraction, amplification, and analysis procedure. These portable systems are increasingly used in police stations, border controls, and disaster victim identification, enabling On-site DNA profiling, speeding up investigations. However, rapid

DNA systems must meet strict quality and reliability standards before widespread adoption in court proceedings. [5]

9.1.3 Artificial Intelligence (AI) and Machine Learning

AI-driven forensic workflows are being integrated to interpret complex DNA mixtures, automate data analysis, and enhance pattern recognition. Machine learning algorithms can accurately separate DNA profiles from multiple contributors, analyze genetic data to infer eye color, hair color, and other features, improve mixture deconvolution, predict phenotypic traits, and enhance quality control. [6]

9.1.4 Single-Cell Sequencing

Forensic experts may now create DNA profiles from single cells using this new method and technology. which is particularly valuable when evidence is limited or highly degraded. Single-cell sequencing pushes the boundaries of sensitivity and specificity, enabling Precise profiling from minimal samples. [7]

9.1.5 Epigenetics and DNA Methylation Analysis

Epigenetic markers, especially DNA methylation patterns, are being explored to provide additional forensic information, such as determining the biological source (e.g., blood, saliva) of a DNA sample, and age estimation. [8]

9.1.6 Forensic Genetic Genealogy

By leveraging public genealogy databases and advanced SNP analysis, forensic genetic genealogy has gained significant traction as a potent method for introducing previously unknown individuals into the criminal justice system, solving cold cases. [9]

9.1.7 Mobile and Field-Deployable DNA Platforms

Portable DNA analysis devices are being developed for real-time, on-site investigations. These platforms offer Immediate results at crime scenes that reduce the time between evidence collection and actionable intelligence, and also enhance disaster response, which is Useful in mass casualty events for rapid victim identification. [10]

9.1.8 Forensic DNA Phenotyping and Predictive Analysis

One of the most groundbreaking areas of development is forensic DNA phenotyping, which predicts physical characteristics—such as eye, hair, and skin color—from DNA. Tools like Parabon Snapshot and HIrisPlex-S help investigators develop facial composites of unknown suspects from genetic clues.Another significant application is biogeographical ancestry inference, which uses ancestry-informative markers (AIMs) to estimate a person's genetic origins. This has been useful in narrowing down leads when no suspect is available.Researchers are also exploring age estimation from DNA using epigenetic markers, such as DNA methylation levels, which change predictably over time. This technology could assist in constructing biological profiles from unknown samples. [11]

9.1.9 Epigenetic and Gene Expression Technologies

Epigenetic forensics uses patterns like DNA methylation to infer various attributes, including age, tissue type, and even the time since deposition (TSD) of biological material. This could allow investigators to determine not just who left the sample, but also when it was left—a significant development in time-sensitive investigations.mRNA-based tissue identification is another emerging technique that detects body fluids based on the expression of specific genes. This approach can confirm whether DNA originated from blood, saliva, semen, or other tissues, enhancing the contextual understanding of crime scene evidence. [12]

9.1.10 Touch DNA and Low-Copy Number DNA

The ability to detect and profile DNA from incredibly tiny biological samples has greatly broadened the field of forensic research, because to techniques like Low-Copy

Number (LCN) DNA analysis and Touch or trace DNA (tDNA). Microtraces of a person's DNA are known as "touch DNA" and are transferred from one surface to another via physical contact. Also, these tiny amounts—typically less than 100 picograms—are the main emphasis of LCN DNA analysis.[13] These methods are lifesavers when standard DNA analysis fails to connect suspects to evidence such as crime sites, firearms, or other critical items.

10 Integrating advanced DNA profiling techniques and Digital DNA evidence within the Indian Legal system

Advanced DNA profiling and digital DNA evidence can alter the Indian legal system scientifically and technologically. It assures precise, timely, and fair justice—the foundation of any modern democratic judiciary. Such integration into the Indian legal system could transform criminal justice accuracy, efficiency, and fairness. Traditional evidential methods typically fail to resolve crimes quickly and accurately due to their complexity and cyber-physical nature. DNA profiling is a reliable and scientifically sound forensic method that can precisely identify persons. This partnership can be unchallenged with Digital DNA evidence.

DNA evidence collected from crime scenes, when analyzed with cutting-edge techniques, can link suspects to crimes with near-certainty or exclude innocent individuals. False arrests and wrongful convictions can be avoided. Moreover, integrating Digital DNA provides corroborative digital traces that can validate or challenge physical DNA evidence. Secondly, efficiency in case resolution is significantly enhanced. Indian courts face staggering delays due to a lack of concrete, timely evidence. DNA profiling, if conducted in certified forensic labs under a streamlined procedural framework, can hasten the investigative process. When coupled with digital tools and AI-assisted DNA matching databases, the legal process becomes less dependent on circumstantial testimony and more grounded in scientific precision. Furthermore, digital documentation and e-governance systems can facilitate faster evidence sharing among law enforcement, forensic labs, and courts, reducing bureaucratic delays. Thirdly, and most crucially, fairness and justice are strengthened through the use of objective scientific evidence. The Indian legal principle of ‘beyond a reasonable doubt’ is better supported when verdicts rely on indisputable biological and digital evidence. This protects both the rights of the accused and the victims, ensuring a more balanced adjudication process. It also aligns with the constitutional guarantees of a fair trial under Article 21.

10.1 Real-life cases based on DNA Profiling and DNA Evidence

The first criminal case to use DNA profiling was the Colin Pitchfork case in the United Kingdom, which marked the birth of forensic DNA technology in the justice system. British geneticist Alec Jeffreys, in 1984, developed DNA fingerprinting based on restriction fragment length polymorphisms (RFLP), exploiting the high variability in certain DNA regions among individuals to uniquely identify them. In 1986, two teenage girls were raped and murdered in a quiet English town. The police initially arrested a suspect who confessed, but DNA testing by Jeffreys showed his genetic profile did not match the crime scene evidence, exonerating him. This was the first time DNA evidence cleared a suspect. Afterwards, more than five thousand male residents were analyzed in what was the first-ever nationwide DNA screening. Colin Pitchfork, the true offender who attempted to avoid capture by having a friend's blood sample submitted in his stead, was eventually identified and convicted thanks to this genetic dragnet. This case demonstrated DNA profiling's power to both convict the guilty and exonerate the innocent, revolutionizing forensic science and criminal investigations globally.

In India, in *Kunhiraman v. Manoj* (1991, Kerala HC) [14] DNA technology in paternity testing was first recognized under Sections 45–51 of the Indian Evidence Act, 1872 (Sec. 39-

45 of the BharatiyaSakshya Adhiniyam), establishing expert DNA reports as admissible evidence for paternity disputes.

10.1.1 ***Tandoor Murder (Naina Sahni Murder, 1995)***

Husband Sushil Sharma fatally shot his wife Naina, then made an effort to scorch her. in a tandoor oven. Identification hinged on DNA evidence. Blood and tissue samples at the restaurant matched DNA from Naina's parents. Confirmatory DNA profiling (likely autosomal STR) conclusively proved the remains were hers. DNA evidence became the foundation for his conviction by the trial, High Court, and Supreme Court. [15]

10.1.2 ***Rajeev Gandhi Assassination (1991)***

After the attack on then-PM Rajiv Gandhi at Sriperumbudur, DNA profiling identified both victims and the suicide bomber. This was among India's first field deployments of DNA profiling for mass casualty identification, setting a precedent for forensic responses to terrorist incidents. [16]

10.1.3 ***Priyadarshini Mattoo Case (2006)***

Law student Priyadarshini Mattoo was raped and murdered in Delhi. The key forensic breakthrough was that DNA from semen on her undergarments matched the accused, Santosh Kumar Singh. Delhi High Court convicted Singh in 2006, basing the judgment heavily on DNA evidence. [17]

10.1.4 ***Delhi/Nirbhaya Gang-Rape (2012)***

The horrific gang rape of a young woman (later "Nirbhaya") sparked national outrage. Multiple DNA samples (vaginal swabs, clothes) were matched against suspects. The Supreme Court, in *Mukesh &Anr v. State of NCT of Delhi*, explicitly accepted DNA evidence as "virtually positive identification" and "almost a hundred per cent precise". [18]

10.1.5 ***Shiney Ahuja Rape Case (2009)***

Bollywood actor Shiney Ahuja was convicted of raping his domestic worker. DNA analysis of ten samples from the victim matched the accused. DNA found to be "absolute identification", leading to conviction. [19]

10.1.6 ***Bilkis Bano Post-Gujarat Riots Case (2002)***

In the course of the riots in Gujarat, Bilkis Bano was the victim of gang rape and the murder of her family. DNA tests contributed indirectly to evidence collection. Conviction and reinstated rulings were secured, reaffirming the prosecution's case. [20]

10.1.7 ***Nithari/Noida Serial Murders (2006)***

At Nithari (Noida), human remains were discovered with bones scattered and partially chopped. AIIMS, CFSL, and CDFD were involved. Post-mortem and skeletal fragments (viscera, bones, skulls) underwent DNA profiling to identify multiple victims. The usage of DNA from bone and tissue enabled the identification of children, a critical factor in moving forward. [21]

10.2 Real-life cases based on Digital DNA Evidence

A more advanced usage of digital DNA was seen in the ***Elgar Parishad-Maoist links case (2018)***. [22] The Pune Police and NIA analyzed laptops and hard drives of arrested activists and alleged Maoist sympathizers, retrieving metadata, file access patterns, document authorship details, and encrypted email chains. The digital devices were subjected to forensic analysis, and experts tracked keystroke patterns and login signatures. Though contested by defense lawyers claiming fabrication, courts accepted this evidence during the initial bail and charge-framing stages, setting a precedent for considering digital behavioral data as part of prosecutorial strategy.

Another critical case was the ***INX Media Case*** **[23]**, involving former finance minister P. Chidambaram. The Enforcement Directorate and CBI used digital trails—email headers,

transaction records, and server logs—to demonstrate alleged bribery and money laundering. In this instance, the consistency in digital behavior and location tagging from devices was pivotal in linking key persons to questionable financial decisions.

In **cyber fraud cases**, such as the ***Yes Bank phishing scam (2020)*** and the ***Cosmos Bank cyberattack (2018)*** **[24]**, investigators relied heavily on analyzing the digital DNA of attackers, including unique keystroke dynamics, repeat command-line syntax used across attacks, and pattern recognition in money transfer behavior. These insights helped to link disparate attacks to single cybercriminal groups, with evidence being admissible in court under Section 65B of the Indian Evidence Act.

Moreover, in matrimonial and civil disputes, digital DNA has supported judgments involving stalking, online harassment, and hidden communications on social platforms, such as in ***Shreya Singhal v. Union of India (2015)*** **[25]**, where digital expression and tracking were central to the constitutional validity debate of Section 66A of the IT Act.

Despite regular use of these forensic techniques, to fully realize the benefits, India must strengthen regulatory frameworks like the DNA Technology (Use and Application) Regulation Bill, ensure data privacy under robust digital evidence laws, and invest in forensic infrastructure and training. Concerns about misuse, data breaches, and digital impersonation must be mitigated through legal safeguards, technological encryption, and ethical oversight.

11 Current state of DNA profiling technique and Digital DNA evidence

DNA profiling has revolutionized forensic science, becoming an indispensable tool for recognizing suspects and connecting them to locations of criminal incidents.

In recent years, the integration of digital technologies into traditional DNA profiling has given rise to the concept of Digital DNA evidence—a confluence of biotechnology, data science, and digital forensics. Techniques such as Polymerase Chain Reaction (PCR), capillary array electrophoresis, and next-generation sequencing (NGS) (otherwise known as Massively Parallel Sequencing which allows for the simultaneous sequencing of numerous DNA fragments, providing a more comprehensive analysis of genetic markers), Rapid DNA Analysis (that enables the automated processing of DNA samples, significantly reducing the time required to obtain a DNA profile), Mini-STRs (particularly useful for analyzing degraded DNA samples), microchip capillary electrophoresis, and mass spectrometry have significantly improved the sensitivity, speed, and accuracy of DNA profiling. These advancements have enabled forensic experts to derive reliable profiles from degraded samples, trace evidence, and even mixed DNA sources at crime scenes. Simultaneously, the evolution of Digital DNA evidence has expanded the forensic domain beyond traditional biological analysis. Digital DNA refers to digitized genomic data that is stored, processed, and interpreted using computational platforms. The digital transformation facilitates remote analysis, real-time collaboration among forensic labs, and integration with national and international DNA databases such as CODIS (Combined DNA Index System).

11.1 Necessary steps taken by the Indian Govt. towards successful integration and result result-oriented approach of Forensic techniques

At present, seven CFSLs can be found in the following cities: Chandigarh, Delhi, Kamrup, Kolkata, Bhopal, Pune, and Hyderabad. A further eight CFSL has been authorized in Jammu (Samba), and seven more CFSLs are planned to be established under the National Forensic Infrastructure Enhancement Scheme, which has a budget of ₹860.3 crore. [26] In order to probe significant instances of cyber forensics and digital fraud, the Central Forensic Sciences Laboratory in Hyderabad has set up a National Cyber Forensic Laboratory (NCFL). In addition, a total of 126.84 crore rupees would be spent by the Indian government to establish six more NCFLs at the CFSLs in Chandigarh, Delhi, Kolkata, Kamroop, Bhopal,

and Pune. The total of thirty projects, totalling ₹245.29 crore, that were submitted by states and union territories have been authorized with the aim of enhancing the DNA analysis and cyber forensic capabilities at state forensic science laboratories. Up to this point, ₹185.28 crore has been disbursed. [27]

A state-of-the-art DNA Analysis and Research & Development facility has been established at the CFSL Chandigarh, equipped with four independent units specializing in sexual assault & homicide, paternity, human identification, and mitochondrial DNA analysis. This lab handles complex cases including rape, murder, child abuse, and challenging DNA samples such as charred bones and exhumed skeletal remains. [28] The Ministry of Home Affairs (MHA) has launched an e-Forensics IT platform connecting 117 forensic laboratories across India to facilitate data sharing and coordination. [29] The government has developed Quality Manuals and Working Procedure Manuals for forensic labs adhering to NABL accreditation standards (ISO 17025), ensuring quality and reliability in forensic processes. [30]

As part of its efforts to meet the demand for more qualified forensic science workers, the MHA is providing training to investigating officers, prosecutors, and medical officers from various states and territories on how to properly collect, store, and handle DNA evidence, as well as how to use specialized kits for collecting evidence of sexual assault. Training for medical officers, prosecutor's assistants, and investigating officers has reached 32,524 people. The training also includes the distribution of 18020 Sexual Assault Evidence Collection Kits to the states and territories by the Ministry of Home Affairs. [31]

To ensure that the whole nation has access to qualified forensic professionals, an Act of Parliament established the National Forensic Sciences University (NFSU) in 2020. Goa, Agartala, Bhopal, Dharwad, and Guwahati are the five additional off-campus locations of the NFSU that have been granted in principle approval, in addition to the original campuses in Gandhinagar (Gujarat) and Delhi. Imphal (Manipur) and Pune (Maharashtra) are two more locations where the NFSU has established training and skill academies. Additionally, the "National Forensic Infrastructure Enhancement Scheme" was authorized by the Cabinet on 19.06.2024. This scheme includes, among other things, funding for the establishment of nine more NFSU campuses across the nation. [32]

However, these innovations are accompanied by new challenges that revolves around privacy, data security, consent, and potential misuse of sensitive genetic data. As digital DNA records can be stored indefinitely and accessed across borders, they raise serious questions about surveillance, data protection laws, and ethical considerations. In India, for example, the DNA Technology (Use and Application) Regulation Bill, 2019, attempts to establish safeguards, yet lacks clarity on digital data governance, access controls, and audit mechanisms.

12 Comparative analysis between India and other countries

The integration of forensic science, particularly DNA profiling and digital DNA evidence, into criminal justice systems has revolutionized law enforcement globally. However, the extent of its implementation and effectiveness varies widely across countries. India has made notable strides in incorporating DNA profiling into its investigative procedures. The enactment of the Criminal Law (Amendment) Act, 2013 and the proposed DNA Technology (Use and Application) Regulation Bill, 2019 aim to institutionalize and regulate DNA evidence in criminal investigations. However, despite such legislative advancements, India's forensic infrastructure remains underdeveloped. A shortage of accredited DNA laboratories, limited trained personnel, backlog in forensic analysis, and inadequate chain-of-custody protocols severely hamper case resolution speed and accuracy.

Furthermore, digital forensics—key to investigating cybercrime, financial fraud, and digital identity theft—is not yet fully integrated with traditional law enforcement or court processes, reducing the effectiveness of digital DNA evidence.

In contrast, countries such as the United States, United Kingdom, and Australia have established more robust frameworks. For instance, the United States' Combined DNA Index System (CODIS), regulated under stringent federal and state laws, provides a highly effective model for criminal identification and exoneration of the innocent. The UK operates under the Forensic Science Regulator Act 2021, ensuring strict quality control of forensic processes. Their National DNA Database (NDNAD) is among the world's most comprehensive, with DNA evidence admissible and regularly decisive in courts. Australia, too, integrates digital DNA (metadata, device traces, and cyber footprints) with biometric profiling to track, convict, and monitor offenders efficiently.

One of the key challenges in India is the absence of a national DNA database and privacy safeguards comparable to GDPR standards in Europe. This raises concerns about data misuse, wrongful convictions, and the protection of individual rights. Additionally, Indian courts have shown hesitancy in consistently admitting digital DNA evidence due to ambiguities in the Information Technology Act, 2000 and lack of judicial training on emerging forensic techniques.

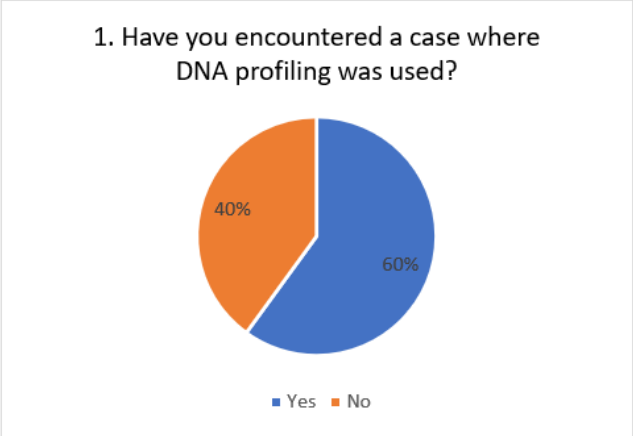
The comparative analysis reveals that while India is making progress in policy formulation, it significantly lags in practical implementation and technological modernization compared to developed legal systems. Issues such as lack of uniform standards, poor inter-agency coordination, and low public trust in forensic institutions further dilute the potential of DNA-based justice delivery.

To bridge this gap, India must invest in forensic capacity building, create standardized operational procedures, and establish a national DNA database governed by a data protection regime. The legal system should be reformed to make room for expert testimony, streamline the admissibility of electronic and DNA evidence, and sensitize judicial officers and investigators to technological nuances.

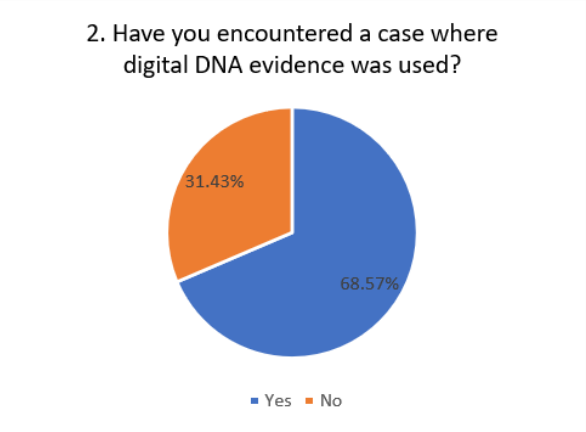
13 Empirical Analysis

In the context of the use of the DNA profiling technique and digital DNA evidence, the authors have made empirical analysis by collecting data through questionnaire method. Structured questionnaire has been prepared and circulated for collection of data. The total targeted sample size is 100, of which 70 responses have been received. The targeted samples are Judges, Advocates, Police Officers, and Forensic Experts. Among 70 responses,15 responses have been given by Judges, 30 responses have been provided by Advocates, and 18 and 7 responses have been received from Police Officers and Forensic Experts, respectively.

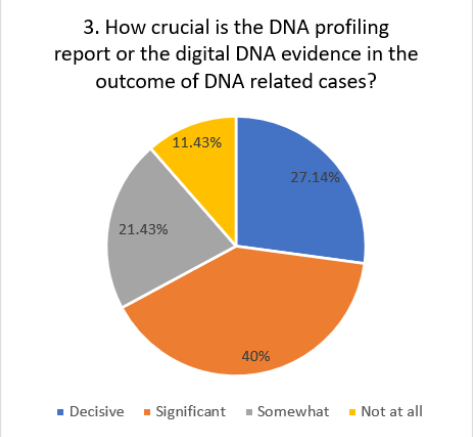
The responses to all the relevant questions have been presented through pie charts and have been analyzed below.



The first question that was asked of the targeted sample was whether they had encountered a case involving DNA profiling in their lifetime. Among all the persons, 42 (60%) have said 'yes', whereas 28 (40%) have said 'no'.

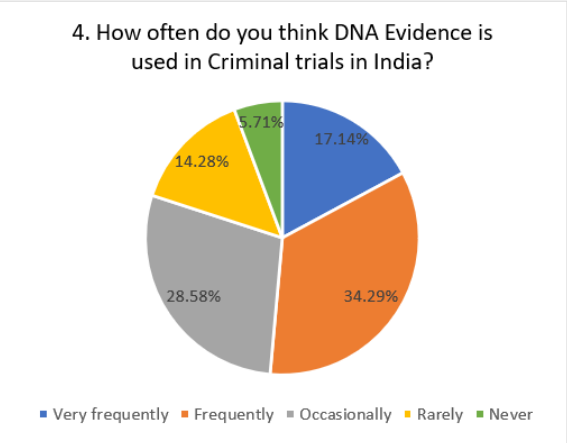


The second question put was whether in their lifetime they have come across a case involving digital DNA evidence or not. 48 (68.57%) responses have come in affirmative, and 22 (31.43%) responses were negative.

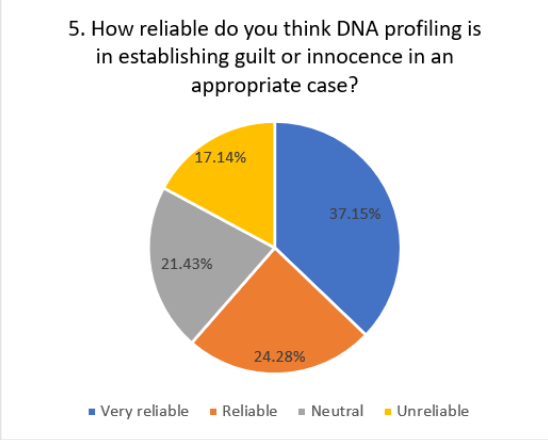


The third question was only related to those cases that involve either a DNA profiling technique or digital DNA evidence. The answer must be how far the result of those cases was dependent on the DNA profiling report or the digital DNA evidence. Out of all the responses received, 19 (27.14%) persons said that such evidence is the best evidence towards the adjudication of the proceedings. 28 (40%) and 15 (21.43%) persons say that the evidence is

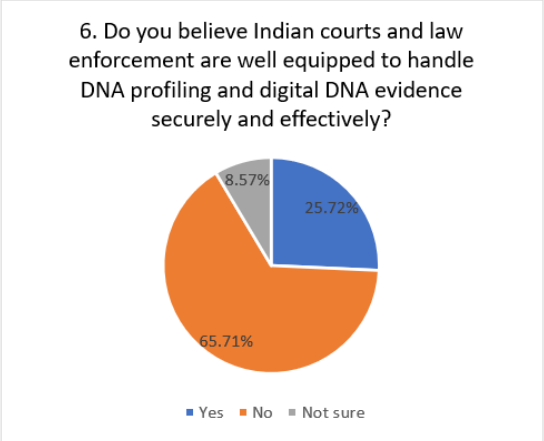
either strongly or partly corroborative towards the finalisation of the dispute. The remaining 8 (11.43%) persons said that such forensic evidence was not a crucial point in the proceedings.



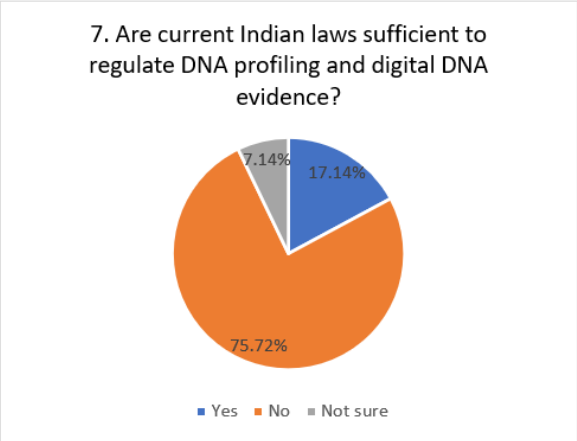
The fourth question was about their opinion about the frequency with which DNA evidence is being used in criminal cases in India. Out of all the responses received, 12 (17.14%) and 24 (34.29%) responses are saying about 'very frequently' and 'frequently' respectively, whereas 20 (28.58%) and 10 (14.28%) persons are saying about occasional or rare use, as the case may be.



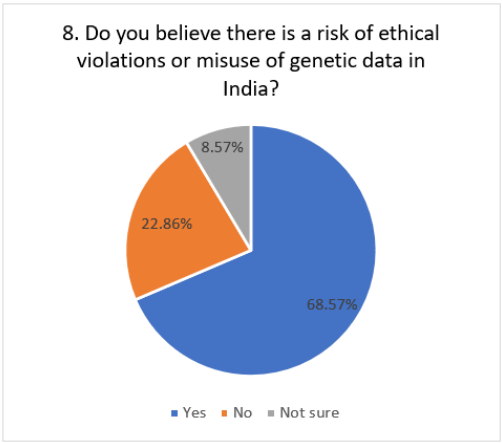
This question was about whether DNA profiling is an important tool to establish the guilt or innocence of an accused in a case. Out of the total responses received, 26 (37.15%) and 17 (24.28%) persons gave their opinion in affirmative, whereas 15 (21.43%) persons stood neutral, and 12 (17.14%) persons were against the reliability of this forensic technique.



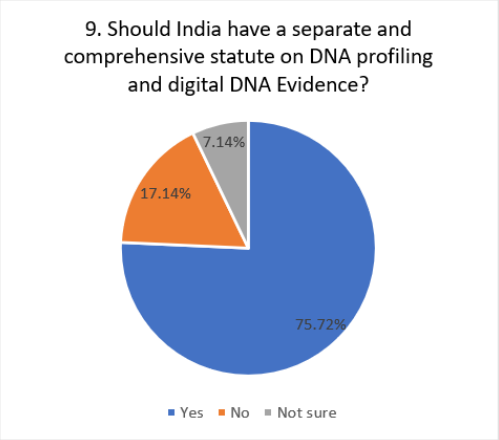
A question has been asked about the availability of legal and institutional infrastructure to handle these forensic techniques in a secure and effective manner. Maximum persons, i.e., 46 (65.71%), are saying that such infrastructures are not properly available, and minimum persons, i.e., 18 (25.72%), are affirming availability.



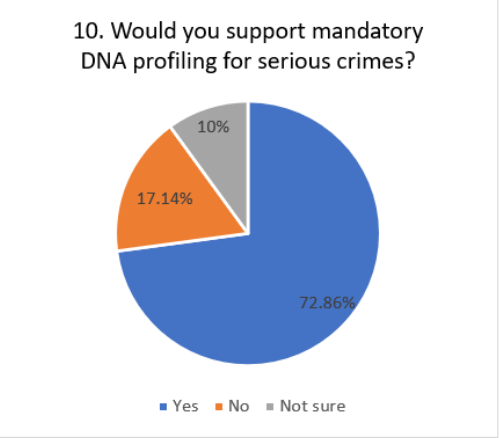
When the question was asked whether Indian statutes have concrete provisions for the successful regulation of DNA profiling and digital DNA evidence, more than half, i.e., 53 (75.72%) persons, said that the laws in force are not sufficient. And the remaining 12 (17.14%) are saying that present laws are sufficient, whereas 5 (7.14%) are not sure about the present scenario.



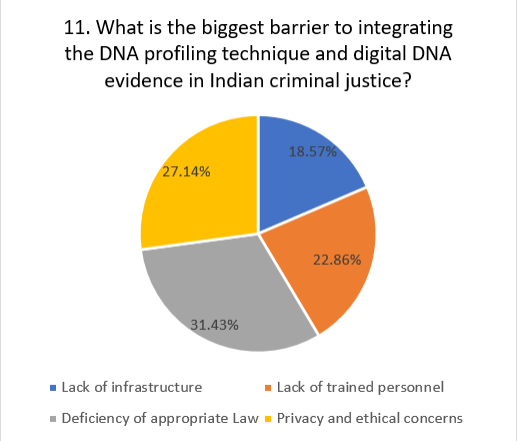
People have been asked about the ethical and safety challenges of the DNA data stored. Among the responses received, 48 (68.57%) are concerned about the possibility of such ethical and safety issues, whereas 16 (22.86%) are concerned about the capability of the technology and safety personnel to protect these rights.



On the recent debate on the enforcement of a separate statute regarding the DNA forensic techniques, their use, regulations, and procedures, more than half, i.e., 53 (75.72%) responses are in favour of such enforcement. 12 (17.14%) persons are saying that the laws present to date are sufficient to cover all matters in regard to these techniques.

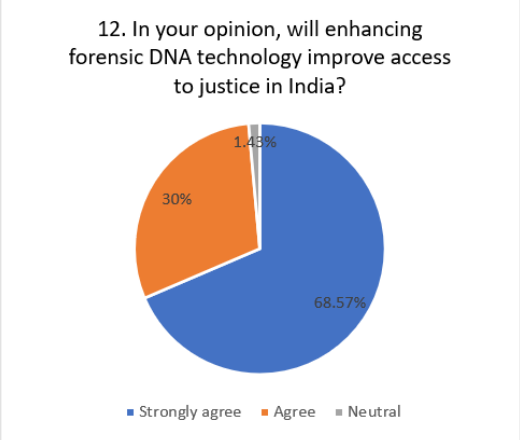


On the question of whether DNA profiling should be mandatory for certain crimes of a serious nature, 51 (72.86%) responses are in favour of such a thought, and 12 (17.14%) are against it. 7 (10%) are in a double mind whether it should be made mandatory or should be left as optional.



Among different types of obstacles in the process of successful integration of DNA profiling technique and digital DNA evidence in the Indian criminal justice system, responses

are divided in quite similar number, as 13 (18.57%) are saying lack of infrastructure is the biggest barrier, 16 (22.86%) are of the opinion that lack of trained personnel is the biggest obstacle, whereas 22 (31.43%) have opined that lack of appropriate legislation is the most adequate obstacle, and 19 (27.14%) are saying that ethical and safety concerns are the biggest barrier towards the integration.



On the question of whether these forensic techniques will enhance the accessibility to justice in India, most people are in favour of this thought. More than 90% say that justice can be enhanced by the use of such forensic techniques.

13.1 Discussion and Findings

From the responses received, it is quite evident that the maximum number of persons are in favour of the use of DNA profiling and Digital DNA evidence in the Indian legal system, but there are some concerns, such as ethical and safety concerns that can't be overlooked. DNA technology is emerging as an effective tool for adjudication of critical, complicated, and cold cases, and it can also be involved in civil as well as paternity proceedings. Hence, it is the duty of the state to take it as a challenge and build adequate infrastructure and recruit sufficient amounts of skilled personnel for successful and appropriate performance. It is conclusive that comprehensive legislation in relation to the DNA technique is absent in India, but is present and is operative in certain foreign states. So specific law must be enforced.

14 Recommendations

1. Enact Comprehensive Legislation for DNA and Digital Evidence

A separate, specific, and stringent statute must be made containing all the uses, procedures to use, and other necessary rules and regulations regarding DNA technology and evidence.

2. Strengthen Chain of Custody Protocols

As per the guidelines prescribed by the apex court of India and some High Courts, the chain of custody of DNA evidence must be secured. There should be proper guidelines and SOPs in this context.

3. Invest in Forensic Infrastructure and Capacity Building

Though the central government is investing nowadays in this capacity-building programme, still, more investment is required to lessen the burden on the forensic laborers and trained professionals.

4. Enhance Judicial Sensitization and Training

Training and awareness of the judicial members about these forensic techniques is the need of the hour. Periodic training programmes must be organized.

5. Safeguard Privacy and Fundamental Rights

Technology must be developed for the protection of data stored. It is the duty of the state to protect the fundamental rights of every citizen, which includes the right to privacy.

6. Develop Guidelines for Digital DNA Evidence

Though digital DNA evidence is used in every odd case, there is no strict law on this, and appropriate guidelines are also absent. Due to this, there remains a fear of mismanagement or misuse of the data. So, guidelines must be issued on the use and storage of the digital DNA evidence.

7. Promote Interdisciplinary Collaboration

Forensic experts, relevant personnel, technological experts, and other necessary areas must collaborate to form a proper and error-free procedure for the collection, storage, analysis, and use of this DNA data.

8. Encourage Public Awareness and Transparency

People must know about these techniques. They must be aware of their rights to claim these techniques and also to protect their information. So, the state and all academic institutions must encourage awareness on this topic.

9. Recommend Database for DNA Cases

DNA databases must be made for the storage and matching of samples. Different databases, such as those for accused persons, for convicts, for different types of cases, for civil disputes, for victims of disasters, and for lost persons, must be made, protected, and regulated.

10. Advocate for International Collaboration

Collaboration of National databases with foreign databases of other countries, and foreign investigative agencies shall enhance the adjudication procedure.

15 Conclusion

The integration of DNA profiling and digital DNA evidence into the Indian legal system marks a transformative step toward achieving justice through scientific innovation. DNA technology provides an unparalleled level of accuracy in identifying perpetrators and exonerating the innocent, thereby strengthening the integrity of criminal investigations and judicial outcomes. Its application has already led to the resolution of complex cases and the prevention of wrongful convictions, demonstrating its immense potential within the Indian context. However, the effective use of these advanced forensic tools is currently constrained by several challenges, including an underdeveloped legal framework, privacy concerns, and infrastructural limitations. While the DNA Technology (Use and Application) Regulation Bill, 2019 represents progress, further legislative reforms are crucial to ensure robust safeguards for individual rights and the ethical use of genetic data. Learning from international best practices can help India strike a balance between effective law enforcement and the protection of civil liberties. To conclude, innovating forensics by integrating DNA profiling and digital evidence holds the promise of a more just, reliable, and efficient legal system in India.

16 Conflict of Interest

There is no conflict of interest in relation to this work.

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