

DEVELOPMENT OF NATURAL SCIENCES UNDER VIJAYANAGAR EMPIRE

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By

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DECLARATION

I, hereby declared that the presented work in the thesis entitled “Development of Natural Sciences under Vijayanagar Empire” in fulfilment of degree of **Doctor of Philosophy (Ph. D.)** is outcome of research work carried out by me under the supervision of Dr Santosh Kumar Yadav, working as) Assistant Professor in the School of Liberal & Creative Arts of Lovely Professional University, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.



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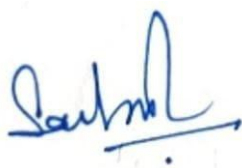
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CERTIFICATE

This is to certify that the work reported in the Ph. D. thesis entitled “Development of Natural Sciences under Vijayanagar Empire” submitted in fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** in the History, is a research work carried out by Siddhant Mishra, 42200237, is bonafide record of his original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.



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Preface

The Vijayanagar Empire has long occupied a special place in the historical imagination of South Asia. Its monumental ruins at Hampi, the splendour of its temple complexes, the strategic brilliance of its fortifications, and the resilience of its political system continue to fascinate scholars and visitors alike. Yet, despite its prominence in cultural and political history, the **empire's contributions to science, technology, engineering, environmental management, medicine, and epistemic traditions remain surprisingly understudied.** The present thesis emerged from the conviction that the Vijayanagar civilisation must be understood not only as a cultural and military power but as a scientifically advanced society whose knowledge systems were deeply integrated into the everyday functioning of the state, the economy, and religious institutions.

My interest in this topic grew gradually, evolving from a simple curiosity into a sustained academic pursuit. Initially drawn to the architectural grandeur of Hampi, I often found myself asking: *How were these massive granite structures engineered with such precision without modern tools? How did artisans achieve perfect alignments, harmonious acoustic effects, and such sophisticated hydraulic networks?* Traditional explanations often attributed these achievements to religious devotion or royal patronage alone, ignoring the complex scientific thinking that must have been embedded within those systems. This thesis attempts to fill that gap by foregrounding the scientific intelligence of the Vijayanagar world, revealing an empire that not only celebrated art and spirituality but also fostered a technological and epistemic culture of remarkable sophistication.

As the research deepened, it became clear that the scientific worldview of Vijayanagar cannot be captured through a single disciplinary lens. Architecture, for example, cannot be understood purely in aesthetic terms without engaging with the physics of load distribution, the chemistry of stone preservation, the mathematics of temple geometry, and the ecological knowledge that guided settlement planning. Similarly, the medical systems of the empire, while grounded in classical Ayurveda, simultaneously incorporated regional botanical knowledge, mineral pharmacology, and experimental therapeutic practices. These realisations prompted me to adopt a deliberately interdisciplinary methodology, combining the tools of architectural history, archaeology, philology, epigraphy, environmental science, and the history of technology.

The present work, therefore, unfolds at the intersection of material cultures, scientific systems, and intellectual traditions. It challenges the conventional compartmentalisation of political history, art history, and scientific history by demonstrating their deep entanglement. Each chapter builds on the premise that scientific thinking in pre-modern India did not operate in isolation but was embedded in the collective knowledge practices of artisans, scholars, rulers, healers, and communities.

A pivotal turning point in this research was recognising the epistemic framework that guided Vijayanagar's scientific approach, a triad of **śāstra (theoretical knowledge), yukti (reasoning and innovation), and anubhava (empirical observation)**. This triadic system, recurring across architecture, medicine, astronomy, hydrology, and metallurgy, revealed that Vijayanagar was not simply replicating inherited traditions but actively engaging in a dynamic process of knowledge adaptation, empirical testing, and situational innovation. These methods parallel many features of what we today recognise as scientific methodology, albeit expressed in culturally specific forms.

At the same time, Vijayanagar's scientific systems cannot be understood in isolation from its broader political and economic landscape. The empire's political stability, thriving trade networks, and structured bureaucracy created the conditions necessary for scientific development. Irrigation innovations were inseparable from agrarian administration; architectural experimentation was supported by merchant guilds and temple institutions; medical knowledge circulated through monasteries, mathas, and specialised artisan groups. This thesis thus engages with the political economy of science, revealing how governance and knowledge production were mutually reinforcing.

Another significant dimension of this thesis is the comparative analysis with the Mughal Empire. While both empires coexisted for overlapping periods, their scientific priorities, materials, engineering logics, and epistemic cultures differed profoundly. Vijayanagar's reliance on granite, ecological adaptation, and modular stone engineering contrasts with Mughal expertise in mortar chemistry, vaulting geometry, and imperial workshop standardisation. By analysing these differences through a scientific lens, the thesis challenges simplistic aesthetic comparisons and instead highlights how ecology, material availability, political ideology, and cultural frameworks shape scientific practice.

One of the greatest challenges in writing this thesis was navigating through fragmented sources. Scientific texts from the Vijayanagar period barely survive in complete form; inscriptions provide scattered clues; architectural evidence is often weathered; oral traditions contain layered memories. Interpreting these materials demanded cautious synthesis and methodological flexibility. I often found myself reflecting on the broader challenge of writing the history of science in pre-modern India, where knowledge is distributed across built environments, ritual practices, guild networks, and textual traditions. This thesis emerged, therefore, not only as a study of Vijayanagar but also as a reflection on the methodological challenges of reconstructing indigenous scientific knowledge.

The thesis is organised into six chapters, each designed to progressively build an interdisciplinary understanding of the scientific foundations of the Vijayanagar Empire. The first chapter lays the conceptual groundwork of the study by outlining its historical background, research objectives, questions, sources, and methodological approach, while also situating the work within existing historiography. The second chapter provides the necessary political and historical context by examining the establishment and expansion of the Vijayanagar Empire under its four ruling dynasties, i.e. Sangama, Saluva, Tuluva, and Aravidu, with particular attention to the reign of Krishnadeva Raya and the conditions that enabled scientific and cultural patronage. The third chapter focuses on the development of medical sciences, analysing the interaction between indigenous Ayurvedic traditions and Unani medicine, advancements in pharmacology and surgery, and the institutional mechanisms that supported medical practice and education. The fourth chapter examines the growth of mathematical and astronomical knowledge, highlighting scholarly engagement with classical texts, the construction of instruments and observatories, and the practical applications of astronomy in agriculture, navigation, and ritual life. The fifth chapter turns to art and architecture, investigating how principles of geometry, material science, acoustics, and cosmology were embedded in monumental structures, with selected case studies illustrating the durability and technical sophistication of Vijayanagar constructions. The concluding chapter synthesises the findings of the study, reflects on the broader implications of Vijayanagar's scientific achievements for Indian intellectual history, acknowledges the limitations of the present research, and suggests avenues for future scholarly inquiry.

The research journey also highlighted the need to reconsider the narrative frameworks that have long shaped the study of Indian history. Colonial and early postcolonial scholarship frequently

drew a stark line between “traditional” and “scientific” knowledge, often relegating pre-modern Indian empirical systems to the domain of superstition or ritualism. Contemporary global scholarship, however, increasingly recognises the sophistication of non-Western scientific traditions. This thesis aligns with this broader movement by demonstrating that Vijayanagar possessed many characteristics of a scientific civilisation: rational statecraft, hydraulic engineering, architectural physics, material sciences, structured knowledge transmission, and an epistemic culture rooted in observation and reasoning.

Writing this thesis has been an intellectually transformative experience. It has taught me to see temples not only as sacred sites but also as laboratories of acoustics and geometry; canals not merely as irrigation systems but as embodiments of hydrological science; medical manuscripts not simply as ritual texts but as repositories of pharmacology and clinical reasoning. Most importantly, it has convinced me that the scientific heritage of India is far richer, more diverse, and more deeply rooted than is often acknowledged in standard historical narratives.

I owe a profound debt of gratitude to the scholars whose works guided my thinking, to archives and digital repositories that made ancient knowledge accessible, and to the archaeological landscapes of Hampi that revealed, stone by stone, the scientific genius of Vijayanagar’s artisans and engineers. Without the interdisciplinary efforts of generations of researchers across history, archaeology, architecture, philology, and environmental studies, this thesis would not have been possible.

This work is offered with humility as a modest contribution to restoring the scientific dignity of one of India’s greatest empires. It is my hope that the findings presented here would inspire further interdisciplinary research, whether in architectural engineering, environmental science, medical history, or the broader field of global history of science. Vijayanagar’s legacy continues to live not only in its ruins but also in the scientific imagination it cultivated, the innovations it pioneered, and the intellectual heritage it bequeathed to future generations.

I present this thesis with deep respect for the scholars and knowledge traditions that preceded me, and with a sincere aspiration that it will help re-centre Vijayanagar within the broader narrative of world civilisations as a scientifically vibrant, intellectually sophisticated, and technologically ingenious empire.

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Chapter 1: Introduction

1. Introduction

This study represents a detailed account of the progress and the mind development in the field of natural sciences during the rule of Vijayanagar empire. It critically reviews the contributions and works of scholars in different scientific fields such as astronomy, medicine, mathematics and architecture from the 14th century till the end of its rule in 17th century A.D. The study reveals the crucial importance of learning within the context of the identification and development of the empire, as the systematic development of teaching and learning was a central element in the process of scientific and intellectual development of this historical period. It is clear from several water management structures built during the reign of Krishnadeva Raya, in collaboration with Portuguese engineers¹ that foreign technological knowledge was introduced. During this time, there were many important scientific developments, including the discovery of gravity, the invention of the telescope, and the development of a medical system. The surviving architecture is useful in understanding the elaborate water management systems used at the time. The longevity and survival of certain monuments and structures are further evidence of the sophistication of civil engineering techniques. Furthermore, a search of the modern literature of the period reveals that there were significant contributions and strong interest in the development of medical sciences, which suggests a systematic and scholarly research process in acquiring medical knowledge.

1.1 Geographical Location. The Vijayanagar Empire controlled much of South India, including the modern states of Karnataka, Andhra Pradesh, Tamil Nadu, Kerala, Goa, and parts of Telangana and Maharashtra as shown in **Fig 1**. Vijayanagar, the capital city of the Vijayanagar Empire, is located in a basin developed by five hills with the Tungabhadra River running through it. Kishkindha is located to the north of the river and is mentioned in the Ramayana as a location where Lord Ram meets Sugriva². By around 1500 CE, it had surpassed Beijing as the world's second-biggest city. Presently this city is known as Hampi. This unique feature gave the required security and prosperity to the empire.



Fig 1: Geographical Extent of Vijayanagar Empire

1.2 Natural Science. The term "natural sciences" refers to systematic bodies of knowledge that use observation, reasoning, experimentation, and practical application to comprehend, explain, and regulate occurrences of the physical and biological world. In contemporary usage, the phrase refers to **fields including biology, physics, chemistry, astronomy, earth sciences, and medicine**. However, in pre-modern historical contexts, especially in societies like mediaeval India, natural sciences were integrated into philosophical, medical, astronomical, and technical traditions that blended metaphysical reasoning with empirical observation rather than existing as distinct disciplines.

Natural science was conceptualised in the Indian intellectual tradition through the study of **prakṛti (nature)** and its governing principles, as expressed in Āyurveda, Jyotiṣa (astrology and astronomy), **Gaṇita (mathematics)**, **Vāstuśāstra (architecture)**, and **Rasāśāstra (alchemy and chemical medicine)**. A common methodological emphasis on *pramāṇa* (valid ways of knowledge), particularly *pratyakṣa* (direct observation), *anumāna* (inference), and *yukti* (rational application) brought these disciplines together. As a result, natural sciences in

India was based on repeatable methods, technical processes, and useful results rather than being purely theoretical.

The practical orientation of natural sciences was one of its distinguishing characteristics in pre-colonial India. Agricultural planning, navigation, ceremonial timing, and calendar computation all required an understanding of astronomy. In order to diagnose illness and advance public health, medical science combined botany, minerals, anatomy, and pharmacology. Tanks, canals, dams, temples, and urban plans were built using hydrological science and civil engineering, demonstrating a thorough comprehension of terrain, material characteristics, and environmental cycles. In the fields of architecture, astronomy, trade, and administration, mathematics was a fundamental science that made accurate calculations possible. Importantly, natural sciences in the medieval Indian worldview were governed by ethical and societal considerations. **Scientific knowledge was expected to contribute to *dharma* (social responsibility), *artha* (material well-being), and *loka-hita* (public welfare).** Medical practices emphasised balance and prevention; engineering works prioritised sustainability and communal access; and astronomical knowledge was integrated with moral cosmology. This ethical embedding distinguished pre-modern natural science from purely instrumental or profit-driven models of knowledge.

The idea of natural sciences became very institutionalised and sophisticated in the Vijayanagar empire. There were grants for observatories, medical practices, irrigation systems, centres of learning. Astronomers, physicians, mathematicians and engineers received royal patronage. The textual scholarship and material innovation show that natural sciences during the rule of the Vijayanagar were dynamic, adaptable, and empirically based and were an integral part of the empire's administrative power, culture, and ecological sustainability.

Understanding the relationships between the premodern and modern technical concepts is crucial to understanding the development of the natural sciences during the Vijayanagar Empire. Traditional technologies were not isolated or illogical, but they were empirical, meaning based on observation, material knowledge and real world experimentation, which remain the principles underlying science and engineering today. These knowledge systems, embedded in institutional, ecological and social contexts, emerged in the context of the Vijayanagar period. The use of gravity-fed irrigation systems, tank-canal systems, and stone-based architectural engineering indicates a sophisticated understanding of hydraulics, structural stability, and environmental adaptability in the technological practices found in Vijayanagar.

In a similar manner, the systematic experimentation with metals, minerals and herbals substances in the process of purification and transformation is demonstrated by medical and alchemical traditions, particularly in Rasashastra. The close connection of science and everyday life and governance is illustrated in the use of astronomical knowledge in the calculation of calendars, planning of farming activities, and ceremonial regulating. There are conceptual problems in connecting old and new technology, though. Instead of using standardised technical documentation, Vijayanagar scientific knowledge was passed down through apprenticeship and hands-on learning, and it was ingrained in religious organisations, guilds, and community customs. For this reason, much of this knowledge is hard to express in terms of numbers or in modern scientific language. Moreover, these technologies are not directly scalable to meet the needs of today's industries, as they have been developed for specific ecological and demographic contexts.

1.3 Literature Review

The abundance of material currently in circulation illustrates how thoroughly the political, social, and cultural history of the Vijayanagar Empire has been examined while omitting a crucial element of the contribution of science, without which it was impossible to establish an empire. (Mahalingam, 1951) discovered a new era in South India's commercial history began with the Portuguese conquest of the region at the start of the sixteenth century and the establishment of their institutions in Goa and Diu.³

(Sewell, 1900) in his book “A Forgotten Empire” compiled the history of the Vijayanagar Empire for the first time based on written descriptions by visitors such as Nicolo Conti, Abdur Razzak, Domingo Paes, Nikitin, and Nuniz, as well as records by Ferishta of the Nizam Shah of Ahmad Nagar's court. Robert Sewell presents these narratives chronologically, with each Chapter describing historical events and dynasties under each key monarch. He cites these travellers and juxtaposes them with factual data like as inscriptions, allowing us to decide which is more conclusive. If there are discrepancies in names and dates, then he adds his interpretation, as in the case of the interpretation of Abdur Razzak's recollections over Nuniz's, because of his qualifications, he visited the kingdom in the time of Devaraya II. Sewell's book gives a fascinating insight into the political, social and cultural life, and the preparation of public spaces such as bazaars, of the period, as well as the description of the landscape at the time and how it differed from the built environment.⁴

Vijayanagar Empire era of life. He talks about the kingdom's military strength, trade connections and impressive architecture such as the ruins of Hampi. The book also contains insights into the region's religious and cultural landscape, including the relationship between the Hindu and Muslim communities. He discusses the role of important figures such as the great Vijayanagar king Krishnadevaraya, and explores the

kingdom's decline and eventual defeat at the hands of the Deccan sultanates in the 16th century. Overall, "A Forgotten Empire" is a valuable work of history that provides insight into a little-known but significant period of Indian history. Sewell's vivid descriptions and meticulous research have made it a classic of Indian historical scholarship.

Niccolao Manucci's "Storio Do Mogor", translated with introduction and notes by William Irvine and published in 1907 talks about Italian Traveler of 17th century in medieval India who gives important information about late Mughal period. Other than describing the political conditions, he also sheds light on social and customary lives of contemporary north India. Manucci arrived in India as a teenager and served under several Mughal princes, notably Dara Shikoh and later Aurangzeb's court circles, though often at the margins. His prolonged stay at Mughal court allowed him to observe Indian society not just as a temporary traveller but as an active participant. This position of Manucci makes his contributions unique from contemporary traveller like Bernier, Tavernier or Thevenot, whose accounts were often filtered through commercial or diplomatic objectives. Storia do Mogor is a crucial primary source for a thesis that focusses on scientific culture and empirical knowledge in pre-colonial India. It supports claims made using indigenous textual and material evidence. The existence of functional medical systems with technical know-how and administrative foundation that functioned outside the formal Sanskrit or Persian textual traditions is externally confirmed by Manucci's observations. His in-depth accounts of medical practitioners, therapeutic practices and healing environments shed light on the social background in which scientific and medical knowledge was applied. It shows how this knowledge was used in both courtly and broader popular settings. Manucci also challenges perceptions of pre-colonial India's intellectual isolation by describing how European medical concepts interacted with Indian therapeutic methods.

The Book of Duarte Barbosa translated in 1918 by Mansel Longworth Dames is a useful translation of the accounts of 16th century Portuguese traveller to the kingdom of Vijayanagar Empire during its heyday under the rule of Krishnadeva Raya. The traveller has travelled to neighbouring parts of Vijayanagar Empire such as Gujarat, Goa, Orissa etc. and

has presented the contemporary view of politics and power struggle along with bringing the social and cultural life in to the lime light. Barbosa's time of writing was an era of economic strength, administrative stability and cultural flourishing at Vijayanagar, whereas subsequent European authors were writing at a time of empire's decline. As such, his work provides valuable contemporary insights on one of the most powerful South Indian empires at its peak. Perhaps one of the most lasting features of The Book of Duarte Barbosa is the abundance of social and cultural aspects discussed. Barbosa describes the caste stratification, occupational specialisation, ritual practices, and gender norms in detail. His concern with everyday traditions such as diet, dress, marriage and religious practices provides a rich picture of sixteenth-century Indian society that is not found in official chronicles. Barbosa's indication of craftsmen, businessmen, and professionals indicate a society based on specialised knowledge and work, and makes a strong case for the existence of well-defined social structures in the prosperous Vijayanagar state. Barbosa's contribution in the work is important in several aspects:

It offers external evidence corroborating the administrative efficiency, commercial organisation, and technical competence of the society of Vijayanagar that is suggested by the inscriptions and the indigenous literature. Second, by focusing on occupational groups and on specialised professions, Barbosa reveals the social bases of the production of knowledge, which helped to explain how the empirical skills became part of the daily economic and cultural life. Thirdly, his chronicle places Vijayanagar in a cosmopolitan Indian Ocean world, showing how ideas, commodities, know-how, etc. circulate between regions, and thus casting doubt on the idea of intellectual isolationism. Lastly, by highlighting the peak era of Vijayanagar, Barbosa provides a much-needed counterpoint to those later accounts that stress primarily its decline, so that the continuity and change in scientific and institutional life in India may be assessed in a balanced manner.

Nevertheless, Barbosa's account has significant shortcomings, which need to be noted. His views are very much commercial and maritime in nature, and so focus more on ports, trade goods and coastal areas with less attention given to the intellectual hubs deeper inland. There is not much more than a descriptive engagement with indigenous knowledge systems, and no real analysis of theoretical or textual traditions in science, medicine or mathematics. Barbosa's comments also reflect early European ethnographic biases, and in some instances may lead to generalizations or misconceptions about the culture. The work also is devoid of

native perspectives, and Indian society is described, not self-described. Women's roles and informal education institutions are still under-represented as are rural knowledge networks. For this reason, the account of Barbosa should be read in conjunction with indigenous literary texts, epigraphic and archaeological evidence, in order to draw a full picture.

Ganita Kaumudi by Narayana Pandita, Edited by Pandit Padmakar Dwivedi in 1942, is a literary work on Mathematics in 1356 under Vijayanagar rule. The work delivers tangible proof that mathematical enquiry was in fact a lively interest in the intellectual climate that eventually fell under the rule of the Vijayanagar. The innovative approach to magic squares used by Nārāyaṇa Paṇḍita is based on systematic algorithms and new classification techniques, and is typical of the scientific culture of abstraction, experimentation and rule-based reasoning. This mathematical creativity supports the claim that the Vijayanagar was not only a time of consolidation of the earlier knowledge but also of conceptual development; hence the thesis that mathematics and the natural sciences were part of the intellectual life of the Vijayanagar Empire is strengthened. In addition, the sophistication of the methods discussed in the text undermines any Eurocentric claims for the origins of science, by demonstrating how Indian mathematicians were anticipating techniques that were developed later in Europe, thus placing Indian scientific traditions in a global context. Although of critical importance in the realm of the study of natural sciences during the Vijayanagar regime, *Gaṇita Kaumudī* has certain shortcomings when it comes to the study of natural sciences in general. It is highly specialised, containing little information directly about applied sciences, technological practices or institutions like educational centres or patronising systems except mathematical problems and abstract constructions of numbers. It also does not contain explicit references to the political or social circumstances of rule of Vijayanagar making it hard to draw connections between state support and scientific production. Moreover, the work presumes a high level of prior mathematical knowledge, limiting its accessibility and providing minimal information about how such knowledge was transmitted beyond elite scholarly circles.

(Upadhyay, 1945) in his book “Vijayanagar Samrajya ka Itihas” has narrated the history of Vijayanagar concerning dynastical rule in chronological order. Following an introduction, the author devotes four chapters to each dynasty. He has expanded on the Empire's administration, economic, and social conditions. The author has also listed many literary works completed by scholars of the Vijayanagar Empire during this period. Although the author discusses the

advancement of irrigation technology and rulers' involvement in civil engineering⁵, he never goes into detail about the techniques developed or used by the Vijayanagar Empire.

B Rama Rao in his article “Medical allusions in the inscriptions of Andhra Pradesh” published in 1976 makes an important contribution to the study of the development of natural sciences under the Vijayanagar Empire by providing **epigraphic evidence for the institutional support** and social recognition of medical practice in South India. Through a systematic analysis of inscriptions, Rama Rao documents numerous instances of land grants, endowments, and royal patronage bestowed upon physicians and medical establishments.⁶ Several of these inscriptions belong to regions and periods associated with Vijayanagar rule, thereby directly reinforcing the argument that medical science was not only theoretically cultivated but also practically institutionalised under the empire. This evidence of state and temple patronage underscores the weaving together of medical knowledge in broader administrative and religious frameworks with an emphasis on the importance of healthcare and empirical knowledge in terms of governance and social welfare. In the context of the present thesis this article backs up the argument that the natural sciences (specifically medicine) were not just a solitary pursuit but a form of structured patronage operating under the Vijayanagaras. The emphasis of the article lies in the epigraphic evidence on grants and donations and little light is shed on what medical knowledge, treatment methods or theory of medical science actually consisted of. The inscriptions provide evidence for patronage and are generally silent about the methods of diagnosis, treatment and training, making it hard to gauge the sophistication of medical practice. Also, the geographical area is restricted to Andhra Pradesh, which is important but not representative of the huge and varied areas of the Vijayanagar Empire.

Vijayanagar scholarship is well served by an account of the development of astronomy and mathematics in India which is provided by Pingree (1981), “A History of Indian Literature, Jyotishastra, Astral and mathematical literature”⁷. The analysis of Pingree can help establish the mathematical and astronomical texts which were composed, transmitted or actively studied during the time span he considers, and hence show that Vijayanagar intellectual culture was longstanding and dynamic. The thesis's identification of mathematicians and astronomers from South India allows for the connection of the activity of these scholars with the wider pan-Indian developments in astronomy and mathematics. Further, the technical content and methodological rigor in the work reflect the claim that scientific inquiry in history is scientific. The study has, however, some limitations in its application to the context

of Vijayanagar. Its core emphasis is on the literary and textual history, with occasional references to the institutional, social and political context of the production and maintenance of scientific knowledge. Thus, the link between scientific activity and patronage of Vijayanagar state or educational institutes or court is still an under-investigated topic. Further, the study highlights some of the important researchers and literature without offering detailed case studies of how they were applied in practice or spread across regions.

(Ramesh, 1984) in his book “Inscriptions of Vijayanagar rulers” has studied and analysed many stone and copper-plate inscriptions of the Vijayanagar Empire (14th–17th centuries CE). The work is essential in understanding the scientific attitude of the time because these inscriptions show how the state and temple organisations valued accurate knowledge of astronomy, engineering and mathematics. Numerous epigraphs document temple consecrations and contributions that were dated using exacting astronomical calculations, demonstrating the extensive use of solar and lunar calendars as well as an understanding of planetary movements.⁸ Others cite instances of applied geometry and civil engineering in the construction of irrigation projects, bridges, and temples. Ramesh emphasises the administrative effectiveness attained by using Sanskrit, Telugu, and Kannada technical vocabulary, standardised measurements, and record-keeping. The inscriptions also confirm that academics who were knowledgeable in *ganita* (mathematics) and *jyotisha* (astronomy) were patronised by the monarchy, demonstrating how scientific education was interwoven with religious and architectural endeavours. Overall, the book presents Vijayanagar as a hub of pragmatic science, where observation, computation, and technological proficiency were valued as tools of piety and statecraft, in addition to being a political and cultural force. It is still a vital primary source for reassembling the empire's intellectual and scientific milieu.

To understand the empire in a better way, (Ayyangar, 1986) in his book, “Sources of Vijayanagar History” has provided a thorough analysis of all the primary contemporary literary sources.⁹ Therefore, to better grasp the contribution of natural sciences and scientists in the development of the Vijayanagar Empire, it becomes necessary to critically analyse all of these sources. By identifying, classifying, and evaluating the reliability of primary sources, the book helps establish the evidentiary basis for examining the contributions of mathematicians, astronomers, physicians, and other practitioners of empirical knowledge. The critical reading of inscriptions and literary texts enables Ayyangar to situate the developments of science in the context of the wider political and institutional framework of the empire: royal patronage, temple endowments, and educational networks. The work thus

enhances the methodological quality of the thesis, as it bases interpretations of scientific advancements on contemporary evidence instead of a retroactive assumption. The work fails to provide detailed discussions of scientific texts, methodologies, or intellectual traditions as found in astronomy, mathematics, medicine or other field. Furthermore, the book is strong in the field of source criticism, but weak in the field of interpretation of the social role of knowledge and its role in the process of state formation and economic development. It is therefore necessary to supplement Sources of Vijayanagar History with the specialised studies on scientific literature, epigraphy and technological practices to complete the objectives of the present thesis and identify and evaluate the materials in Vijayanagar history. A new edition of the renowned book on the history of the Arabs entitled "Tarikh-i-Rashidi" (History of the Righteous) by Mirza Haidar Dughlat was edited by Tr.E. Denison Ross. It is a 16th century Persian-language book, N. Elias, that provides beneficial knowledge on Mughal India, particularly of Kashmir. Mirza Haidar was close to Akbar and a ruler of Kashmir, and thus had a privileged position in the Mughal political elite. It was due to this proximity that he was able to present colorful and first-hand descriptions of the reigns of Babur, Humayun and Akbar, which are a blend of autobiography and history. While not directly scientific, such as astronomy, mathematics or medicine, the text contains important information on the political stability, administrative organisation and intellectual environment in the sixteenth century in India. Mirza Haidar's accounts of the life in court, the mode of governance, education and patronage under the early Mughals can help to contextualize scientific activity as part of a wider socio-political sphere. The book gives a vivid picture of the intellectual atmosphere of contemporary Mughal India which enables comparison with the influence of imperial patronage and administrative systems on the production of knowledge in different regions, thus adding to the analysis of scientific development under the rule of Vijayanagar. But it has definite weaknesses for a natural sciences study. The text of Tārīkh-i-Rashīdī is primarily political and autobiographical, and does not discuss scientific knowledge, technical practices, etc., in any systematic way. Science activity is seen only peripherally, in the context of governance or personal experience. The author's elite perspective also results in a strong emphasis on court politics and military affairs, while everyday knowledge systems, artisans, and practitioners of empirical sciences remain largely absent.

(Prasad, 1988) in his book “History of Andhras up to 1565 A.D.” The author has discussed the circumstances and background of how the vast empire of Vijayanagar came into being. The author describes the conditions in the south of India during the reign of the Delhi Sultanate. The book is useful for understanding Medieval South Indian politics. The author has examined the origin debates of this empire. According to the author, the Vijayanagar Empire arose in response to the region's widespread anarchy as a result of the tyrannical and oppressive rule of the Delhi Sultans.¹⁰ The author has also talked about the religious, cultural, and socio-economic life of the Empire. There are paragraphs on the enormous amount of literary works written during the existence of the empire but nowhere it has highlighted the upliftment of its scientific development.

(Michell, 1995) in his book *Architecture and Art of Southern India: Vijayanagara and the Successor States* provides a pioneering and richly illustrated account of the artistic and architectural legacy of the Vijayanagar Empire and its successor Nayaka states. The work spans the fourteenth to eighteenth centuries and situates the art of this period within its political, religious, and cultural framework. Michell challenges the long-standing art-historical neglect of Vijayanagar and Nayaka architecture, which he attributes to disciplinary periodisation that placed these centuries within the so-called “Islamic period” and dismissed later Hindu art as derivative¹¹. He believes that the architecture and art of this period is a distinctly different and innovative tradition characterized by revivalism, stylistic synthesis and adaptation. A detailed survey of the temple, palace and urban architecture of the Kannada, Telugu and Tamil zones, sculpture and mural painting is provided. Michell presents detailed accounts of the main monuments at Hampi (Vitthala and Virupaksha temples), the Lepakshi Virabhadra temple, and Nayaka-period complexes at Madurai, Kanchipuram and Srirangam, highlighting the interplay between indigenous and foreign design influences. His discussion of palace architecture highlights technical exchanges with the Deccan Sultanates, visible in the domed and vaulted forms of the Lotus Mahal and the Elephant Stables, which nevertheless display structural originality and refined proportions.

(Raviteja, 1996) in his article “Industries in Vijayanagar Empire” brought out that in order to maintain the wealth of the kingdom, the article highlights the critical role that industries and craftsmen had in the Vijayanagar Empire, both economically and socially. It highlights the range of industries that thrived under royal patronage and aided in both internal and foreign trade, such as textiles, metallurgy, diamond cutting, ivory carving, and temple construction.¹² The research emphasises how guilds were used to organise workers and how skilled labour was

rewarded with privileges. Inscriptions and traveller reports that highlight Vijayanagar's thriving marketplaces and industry are also highlighted. Although the article provides a thorough overview of artisan activity, it may improve its analysis by placing Vijayanagar's industrial development in the context of South Asia's larger economy and drawing comparisons with modern empires.

(Mitchell, 1998) introduces Hampi, the capital city of Vijayanagar to the average reader and site visitor. It places Hampi in a wider historical and geographical context, exploring its history, myths, and development as an imperial capital. Michell discusses the city's architectural and sculptural legacy in detail, focussing on stylistic characteristics, temple forms, urban design and symbolic significance that are embedded in its built forms¹³. Architectural plans and site analyses are included, which make the book a useful resource in terms of understanding the spatial organization of the capital of Vijayanagar. Michell's contribution is a valuable and informative insight into the applied knowledge systems in architectural planning and urban design. The layout of temples, streets, water tanks and ceremonial spaces is a system, and shows a sophisticated knowledge of geography, materials and spatial organisation, based on empirical observation. While the book does not explicitly label the architectural precision as a scientific analysis, the evidence for mathematical knowledge, use of measurement, and awareness of the environment is nevertheless contained within it, as these were part of the scientific culture of Vijayanagar. The text thus confirms the thesis that scientific knowledge was not limited to textual traditions but also had to be conveyed in large scale architectural and urban practices during this time. The work, however, does have some limitations as pertains to the goals of the present study. Applied science, such as civil engineering, construction technology, and hydraulic systems, plays an important role in the built environment but is given a scant coverage in architectural plans and stylistic analyses. The book does not systematically examine technological processes such as quarrying, material science, water management, or labour organisation, which are essential for understanding the scientific and technological capabilities of the Vijayanagar state. Furthermore, Michell's focus remains largely descriptive and art-historical, offering minimal engagement with the intellectual or institutional frameworks that supported architectural production. Consequently, while *Hampi* is invaluable for understanding the material and spatial achievements of Vijayanagar, it must be supplemented with archaeological reports, engineering studies, and epigraphic evidence to fully assess the development of natural sciences and technology under the empire.

(Kak, 1999) in his article on "Speed of light and puranic cosmology", discussed the connection

between ancient astronomy and the views of Sayana, one of the scholars of the Vijayanagar Empire. The author says, “We get a specific number that could refer to the speed of light in a medieval text by Sāyana (c. 1315-1387), prime minister in the court of Emperors Bukka I and his successors of the Vijayanagar Empire and Vedic scholar”.¹⁴ Kak’s reconstruction links Purāṇic large numbers, sacred numerology (for example the role of the number 18 in certain multipliers), and practical measures (yojana, nimesha). This connection helps argue that medieval Indian intellectuals had frameworks that could, in principle, accommodate precise numeric thought supporting a broader thesis claim that pre-colonial Indian scholarly culture was capable of embedding and manipulating numerical relationships, a necessary precondition for more applied natural-scientific practices (astronomy, calendrics) patronised in the Vijayanagar world. Because Sāyana is a 14th-century figure connected to the polity that became the nucleus of Vijayanagar, Kak’s study supplies a direct textual link between a learned courtly tradition and quantitative cosmological thought circulating in South India shortly before and during early Vijayanagar phases. This helps in situating later Vijayanagar scientific activity within a longer intellectual genealogy. But rather than providing conclusive historical evidence that mediaeval commentators measured the speed of light empirically, Kak himself presents the outcome as an “amazing coincidence” and suggests interpretive reconstructions. The argument relies on choosing specific unit-conversions and interpretive strategies that are not specifically required by the texts; different readings and conversions produce different numerical results. Therefore, rather of providing concrete proof of experimental optics during the Middle Ages, the study is better understood as a historiographical hypothesis.

(Chandra, 2002) in his article “Eclipse observation of Parameswara, Indian Journal of History of Science” has examined Parameswara’s eclipse observations extending over five decades in the lights of modern astronomical algorithm.¹⁵ Parameswara was a 14th century astronomer from Kerala School under Vijayanagar Empire. Chandra Hari’s reconstruction demonstrates that medieval Indian astronomy included systematic, long-term eclipse observation as a methodological practice. The existence of a multi-decade series of eclipse records strengthens the thesis claim that South Indian scientific culture including the Kerala school connected to the broader south-Indian intellectual world practised empirical observation and continuous data-gathering rather than relying solely on received tables. This empirical habit is a key pillar when arguing for a living scientific culture under regional polities such as Vijayanagar. By showing that Parameswara’s celestial longitudes align closely with results from modern

algorithms Chandra Hari provides quantitative confirmation that the siddhāntic computational apparatus could produce accurate predictive outputs. This supports arguments that mathematical and astronomical knowledge in pre-colonial South India had practical and analytical nature (for calendrics, ritual timing, and possibly navigation/architecture), which is central to the thesis about the applied nature of the natural sciences.

(Rao G. V., 2007) in his article has mentioned the construction of tanks for irrigation purposes and the method for its maintenance by the rulers of the Vijayanagar Empire.¹⁶ Using historical sources and administrative references it shows that water management was an integral part of Vijayanagar statecraft and rural economy. What is important about this article, is the stress on the activities of tank-building, desilting, and the participation of the whole community in the maintenance work, which is strong evidence of the application of practical and empirical knowledge in the field of water technology. The massive construction and maintenance of irrigation tanks reflects a knowledge of local geography, rainfalls, soil characteristics, and hydrology. Although expressed in non-scientific terms, these activities reflect an applied scientific culture in which knowledge about and engineering principles addressing the environment were well applied. Rao's work thus supports the thesis argument that natural sciences under Vijayanagar were not just limited to theoretical writings, but were also manifested through technological interventions and infrastructural planning necessary for economic stability and state expansion. Meanwhile, there are some deficiencies to the article. It defines the prevalence of advanced water management practices, but not the technical and engineering aspects of tank design, construction methods, materials used, calculations of tank size, or the hydrology. It does not include any diagrams, measurements or comparative analysis, for evaluation of the scientific sophistication of the Vijayanagar water technology. Moreover, the article emphasizes more on the intent of administration and the patronage of the king, and it provides little information on the role of engineers, artisans or other local specialists who actually carried out these works. Therefore it is necessary to supplement Rao's study with archaeological investigations, hydrological works, and epigraphic research to gain a full understanding of irrigation systems and water science and technology of the Vijayanagar Empire.

(Habib, 2008) in his book "Technology in Medieval India" has outlined the medieval period's technology in four chapters. The first chapter is about the technology in agriculture such as irrigation methods of medieval India. In the second chapters we learn about technologies employed in the mining, metallurgy, building, and textile industry. The 3rd

chapter introduces military technology of weapons and weapons of war. Chapter IV does not compare the European technology with the technology of the rest of the world, but compares the technology of Europe with that of a non-European country, specifically Italy. The book has explained beautifully the inventions and practices during the time period; however, the book is not dealing with the technology of the whole medieval India. The book focuses primarily on North India, but especially the Sultanate and Mughal eras, the analytical framework and thematic organisation being used offer a useful conceptual and comparative starting point for the study of technology in medieval India. The systematic treatment of agricultural technology, irrigation systems, metallurgy, textile production, building techniques and military technology provides a broad overview of the functioning of technology in medieval Indian society¹⁷. This further enables the present study to place Vijayanagar's technological accomplishments in a wider context of all India instead of working on a South India isolate basis. Habib's understanding of the technological processes, labour organization and material practices enables the identification of general patterns of medieval Indian technology, which can be compared with the unique characteristics of the Vijayanagar science and technology. Most importantly, Habib's comparative analysis of European and non-European technologies is especially relevant to the project's goal of unsettling Eurocentric narratives about scientific progress. The book's contribution is to show the dynamism of technological innovation in medieval India and its lack of inferiority, and thereby, to strengthen the foundation of the thesis for the argument of the vitality of natural sciences under the rule of the Vijayanagar. However, the geographical boundaries of Habib's research, particularly the exclusion of South India, highlight the existing research void which the present thesis aims to fill. The thesis focuses on the inadequacies of the existing literature on the subject of Vijayanagar in the wider technological histories of southern polities.

(Majumdar, 2008) in her article "Medical practitioners and medical institutions: gleanings from epigraph" has brought out many medical practitioners from ancient to medieval India based on inscriptions including surgeons and physicians. Some references are made to the period and region under present study. Based on inscriptions from various regions and time, the study raises awareness of physicians, surgeons, hospitals, charitable medical endowments, and grants for medical use¹⁸. The article problematizes the inscriptions by foregrounding this historical evidence over the purely textual medical traditions, thereby moving attention from the historical aspects of "medical traditions" to the institutional and social aspects of medical practice. The epigraphic references cited in the article indicate that

medicine was not a purely intellectual field, but a profession recognised and supported by society. Inscriptions that mention areas and dates concurrent with the rule of the Vijayanagar empire further support the thesis that the Vijayanagar empire actively promoted the practice of medical science by setting up temple endowments, land grants, and charitable institutions. The thesis is supported by this evidence, which further suggests that natural sciences, particularly medicine, was developed under the patronage of Vijayanagar in a well-organised socio-economic system that helped the transmission and application of empirical knowledge. It should be noted that the article contains some limitations in its application to the particular context of Vijayanagar. Although its character is epigraphic, and its method is sound, it does not offer much information about the theory behind or the technical aspects of medical knowledge including diagnostics, pharmacology, or surgery. Most of the inscriptions are of the patronage and institutional type rather than of the scientific type. Furthermore, the geographical and temporal range of the epigraphs discussed is wide, and it sometimes proves difficult to identify developments peculiar to the Vijayanagar Empire. The article also lacks in-depth comparative analysis with current medical literature and with other fields of science.

Telling Otherwise: A Historical Anthropology of Tank Irrigation Technology in South India (2008) is a critical study and history of pre-modern tank irrigation systems in South India (as well as areas and eras that overlap with the Vijayanagar Empire). Shah does not consider pre-modern irrigation as a passive or static traditional technology, but rather as socially constructed artifacts reflecting specific historical, political and economic circumstances¹⁹, thereby undermining the binary opposition of modern versus pre-modern technologies. The paper is based on a wide array of sources such as folk literature, oral narratives, temple inscriptions and ethnographic data to reconstruct the design, construction, and memory of tank systems, and how their social and technological dimensions were intricately linked with the nature of power, labour organisation, and agrarian expansion within mixed ecological zones of South India. More importantly, the study shows that the construction and maintenance of tanks peaked in the Vijayanagar period (c.1300-1750), extending far up into upland Karnataka for irrigated rice-paddies, reflecting the dynamism of hydraulic knowledge and practice in the medieval Deccan. How Shah's work has contributed to the substantive empirical proof that hydraulic science and water technology was not simply the passive reflection of agrarian action, but was also active in design, construction and decision making for social actors. The article demonstrates that tank irrigation technology must be understood as a techno social system where technical knowledge, ecological adaptation, labour

organisation, caste relations, and ritual practices were interwoven. Although the article richly documents the social and historical contours of irrigation technology, it does not provide in-depth technical details on the engineering design, structural mechanics, or hydrological principles of tank systems.

George Gheverghese Joseph's "A Passage to Infinity: Medieval Indian Mathematics from Kerala and its Impact" is a comprehensive monograph exploring the achievements of the Kerala school of mathematics (14th–17th centuries), situating their discoveries within the wider development of Indian mathematics and assessing their possible transmission to Europe. The book presents a detailed examination of the Kerala school's intellectual context predominantly Nambuthiri Brahmins and their temple-centered learning and explores how socio-economic and cultural structures facilitated a remarkable mathematical flowering during this period. The work hints the development of ideas from early Indian traditions to the highly original work of Kerala mathematicians such as Madhava, Paramesvara, Nilakantha, and Jyesthadeva. Using a combination of primary textual analysis (in Sanskrit and Malayalam) and secondary scholarly debates, Joseph reconstructs key accomplishments in algebra, trigonometry, infinite series, iterative methods, and astronomy. His approach integrates close reading of mathematical treatises, social historical analysis, and comparative studies with European developments. The book also addresses questions of epistemology, traditional knowledge transmission, and the neglected role of proof and creativity in Indian mathematics.

(Katz, 2009) his book "The History of Mathematics" contains development of mathematics from ancient times to present time in all civilisations including Mesopotamian, Greek, Indian, Islamic, Chinese, and European traditions.²⁰ The work is structured thematically and chronologically, emphasising the evolution of mathematical ideas, methods, and problem-solving techniques rather than focusing solely on biographical narratives. Katz places particular importance on the transmission of knowledge across cultures, highlighting mathematics as a cumulative and globally interconnected discipline. Development of Mathematics in ancient & medieval India is found in chapter 8. His discourse on Indian mathematics and the progress of the mathematics, particularly in arithmetic, algebra and number theory, situates the mathematical works from the Vijayanagar period in the wider mathematical history. The originality and sophistication of Indian mathematical traditions, as exhibited in Katz's synthesis, help substantiate the thesis argument, namely that scientific development in pre-colonial India was not derivative nor static. The book further emphasizes

that mathematical knowledge was built over long-term continuity and adaptation; that is, the contributions of the Vijayanagar era, such as those in *Gaṇita Kaumudī*, should be considered as part of a scientific tradition that evolved over time and was not a set of disjointed accomplishments. But, in the global context of the book, Katz's treatment of Indian mathematics cannot be comprehensive or specific. Specific regional contexts, institutional settings, and political conditions such as royal patronage under the Vijayanagar Empire are not examined in detail. The book does not engage directly with primary sources, inscriptions, or localised scholarly networks, nor does it analyse how mathematical knowledge was applied within administrative, architectural, or technological domains. As a result, while Katz provides valuable background and comparative insight, the work cannot by itself explain the social, institutional, or cultural mechanisms that shaped scientific development in Vijayanagar.

(Thakur & N Kameshar Rao, 2011) in their article published in journal of astronomical history and heritage studied the Vidyasankara temple at Sringeri for the astronomical value in the zodiac pillars at the temple. The monitored the morning sunlight throughout the year for all **12 different pillars each denoting a zodiac month.**²¹ They concluded that, although the temple was allegedly built around A.D. 1350, it is possible that the rasi pillar arrangement was inspired by an earlier 2000 B.C. sacred calendrical device (or a Vedic altar)

(Rao & Thakur, 2013) in their paper published in 2013 Digital Heritage International Congress (Digital Heritage) used photogrammetry both for drafting and 3D modelling of structures to provide a reconstruction of the structures present in ruins. “These reconstructions give street views and multipoint visualizations of structures with special architectural features.”²² This work is valuable as it **exemplifies the use of modern scientific and technological methods** to study and interpret pre-modern architectural knowledge. The reconstructed models help reveal the complexity of Vijayanagar-era architectural planning, spatial organisation, and structural design, thereby indirectly pointing to the mathematical, geometrical, and empirical principles underlying construction practices. These reconstructions allow a clearer understanding of the way scientific knowledge, in the fields of geometry, measurement and spatial reasoning, was integrated in the built environment of the Vijayanagar Empire. The digital reconstructions offer engaging and accurate spatial visualisations but have not been directly involved with the historical science and engineering associated with the original construction of the structures. The paper focuses primarily on methodology and visualization rather than on analysing construction techniques, material

science, or engineering principles employed by Vijayanagar builders. Additionally, photogrammetric reconstructions are dependent on the quality and availability of surviving remains and photographic data, which may lead to interpretative assumptions in areas where evidence is incomplete

(Karashima, 2014) in his book title “A Concise History of South India” has explained Vijayanagar Empire in a different format which was in fashion till his times. Other than explaining the cultural and political development the author has also focused on the impacts of foreign powers on the empire. The complete work is primarily based on the study of inscriptions. The author took a deviation from standard practice of projecting Vijayanagar rulers as just Hindu kings who were fighting Bahamanis on religious issues. The author has also brought out in section 6.4.1 titled “Hindu Sultan” that how Vijayanagar rulers were more of a Sultan rather than just a king.²³ The book is useful in understanding the administration of Vijayanagar under Nayaks and Nayankar system.

“Yogacandrika”, tr & ed by Dr. Asha Kumari and Prof PV Tewari is a translated work of original manuscript of 15th century work on medical practices under Vijayanagar rule. The original composer of the work is Laksman Pandit, a 15th century scholar. The work deals with medical practices rooted in indigenous traditions, including diagnosis, therapeutic procedures, dietary regulations, and yogic-physiological concepts, thereby offering valuable insight into the state of medical knowledge in South India under Vijayanagar rule. The Yogacandrikā is an important primary scientific source. It offers concrete proof of the evolution and development of medical knowledge within the period being studied and proof that medicine was not only ritualistic or empirical but also organised in theoretical aspects and practical applications. The text is generally very high level in terms of knowledge of the human body, how disease is caused and how to treat it, and points to a well developed medical tradition with scholarly transmission. The presence of scholars in its ranks at the time of Vijayanagar, thereby lending support to the theory that the Vijayanagar empire was intellectually conducive to the development of natural science including medicine as well as other sciences like astronomy and mathematics, is another proof. Furthermore, the translation allows for the thesis to incorporate indigenous medical knowledge along with a historical analysis without only using foreign sources or later colonial explanations about medicine. The work also has some drawbacks when considered for a more general overview of natural sciences during Vijayanagar rule. Yogacandrikā is a primarily theoretical and prescriptive work, with only a small amount of information about the institutional frameworks within which medical

knowledge was practised, such as hospitals, royal patronage or systems of medical education. It does not provide details regarding the social status of physicians, modes of transmission beyond the scholarly elite, or the interaction of medical practitioners with state structures. Additionally, the text focuses on medical science alone and does not engage with related technological or experimental dimensions, such as surgical instrumentation or pharmacological preparation processes in detail. As a result, while *Yogacandrikā* is indispensable for understanding the intellectual foundations of Vijayanagar- era medicine, it must be supplemented with epigraphic records, inscriptions referring to medical grants, and archaeological evidence to fully reconstruct the applied and institutional aspects of medical science during the period.

(Sujatha, Ramabrahamam, & Sathyam, 2016) in their article have highlighted the contribution of the greatest ruler of the Vijayanagar Empire in the development of medical sciences, water management system, irrigation, metallurgy, and mining. The article has mainly focused on the development in these fields during the period of Krishnadeva Raya, the so-called greatest ruler of the Vijayanagar Empire. Although the main thrust of this article was the contribution of Krishnadeva in these fields, it has not included the background and existing knowledge and level of these fields in the region of study.

Chaudhary Anubha et al. in their article “Contribution of Sharangdhar in Dravyaguna Vigyan” published in international journal of Ayurvedic and Herbal Medicine, 2017, vol VII, issue 6 have highlighted the contribution of Sharangdhar (a medical practitioner of the time) in the field of herbal medicine. It has summarized the work for the use and applicability of natural drugs with an emphasis on the time of collecting them. this article is valuable in demonstrating that botanical and pharmacological sciences were grounded in systematic observation of nature. The importance of timing, seasonal variation and environmental factors in the gathering of medicinal plants indicates that there is a scientific insight into plant physiology and effectiveness derived from experience. The practices that are identified reflect the fact that natural sciences, and especially medicine and botany, were not entirely speculative but arose as the result of careful empirical interaction with natural objects. Thus, the study substantiates the thesis position that medical science of Vijayanagar period was based on the application of natural knowledge which was closely related to ecological awareness and practical healthcare requirements.

(Natnoo, 2017) in his PhD thesis on “Development in Medical Science in India during Sultanate and Mughal Periods” has described the medical sciences and practices in medieval

India²⁴. This is a time in north India around the same period as the establishment and expansion of the Vijayanagar Empire in south India. The work can be used in integrating the bridge of north and south India in medical sciences of medieval period. Natnoo's work is significant in several important ways. It gives a modern chronicle comparison with the Vijayanagar period which allows a comparative study of the medical advances in various parts of India at the medieval period. To place Vijayanagar medical science in the context of the subcontinent, it is important to remember that the medical sciences of Ayurveda and Unani were also undergoing a parallel development in North India. Second, the thesis shows the impact of state patronage and political stability on the development of medical knowledge and institutions, an approach that can be usefully applied to the development of medicine and medical learning in Vijayanagar rulers' patronage of physicians and hospitals in South India. Third, Natnoo's focus on "cross-cultural medical exchange" is a testament to the idea that medieval Indian science was not regionally isolated but dynamic and adaptive. This thesis is also included in the literature review on methodological criteria. It does not discuss explicitly the history of South India or the Vijayanagar empire, but Natnoo's book is a useful regional history of medical science in the Middle Ages, which can be used as a comparative and contextual reference. It enables the present study to bridge North and South India, highlighting similarities and differences in medical patronage, practice, and institutional development. Moreover, by foregrounding the interaction between Indian and Unani medicine, the thesis provides a model for analysing knowledge exchange an approach that strengthens the broader argument of the present thesis regarding the pluralistic and empirical character of natural sciences in medieval India. It is included not as a direct source on Vijayanagar medicine, but as a contextual and comparative study that enriches the analytical framework of the thesis.

(Suryanarayana, 2017) in his article “Allusions to Rasayanashastra in Telugu Literature” has provided insights into Chemistry works in the medieval period as evident from Telugu literature covering the region and period of the Vijayanagar Empire. Based on a verse from Srinath, one of the greatest poets and scholars of Vijayanagar, the author has proved that Śrīśailam was one the major center for *Siddhis* and it also had tanks of rasa and rasāyana juices.²⁵ Rasaśāstra (Alchemy) and Rasāyanaśāstra, both were known to these people. Rasaśāstra was knowledge of converting a lower metal to gold whereas Rasāyanaśāstra was the knowledge of dealing with diseases.

Vijanaana Bharti, Indian Contributions to Science, published in 2018, contains 19 chapters covering a wide range of disciplines, including astronomy, mathematics, and medicine,

which are directly relevant to the present thesis. The chapters on astronomy offer a brief overview of Indian astronomical traditions and the key developments of Indian astronomy; the chapters in mathematics summarise the classical Indian contributions in the field of mathematics including number systems and algebraic concepts; the chapters on medicinal traditions trace the evolution of Indian medical science and its philosophical foundations. The work contributes to defining comparative benchmarks to identify the key scientific advances by region and time. The book places Vijayanagar contributions in the context of pan-Indian accomplishments in astronomy and mathematics, and advances the debate on continuity and uniqueness of scientific practices in South India. This comparative outlook strengthens claims about the intellectual environment in Vijayanagar when viewed against wider Indian scientific history. Although the book covers astronomy, mathematics, and medicine broadly, it does not devote detailed scholarly attention to regional or polity-specific scientific practices, such as those under Vijayanagar rule. In particular, many sections foreground developments in North India or ancient India, with limited discussion of medieval South Indian contexts. Therefore, while it provides useful background, the book cannot substitute for more focused primary research into Vijayanagar- specific scientific sources.

(Eaton, 2019) in his book “India in Persianate Age” has studied the development in medieval India under the glasses of Persian cultures. The **fourth chapter**, focusing on **the Deccan and South India between c. 1400 and 1650**, is of particular relevance to the present study. Eaton demonstrates that the Bahmani Sultanate adopted a Persian-derived model of political legitimacy in which rulers sought moral and symbolic validation through associations with **Sufi saints, religious scholars (ulema), and Persian court culture**.²⁶ This practice, already prevalent in north India, reflected deeper Persianate political traditions that emphasized ethical kingship and spiritual sanction alongside military power.

The analysis of Eaton is important for the understanding of the inter-relations of the Bahmani Sultanate and the Vijayanagar Empire at the present day. He has produced evidence that although the Vijayanagar state was a Hindu polity, it was not cut off from Persianate influences from the Deccan. Diplomatic relations, courtly customs, architecture and shared elite values brought Vijayanagar into a broader Persianate cultural sphere. This is a reinterpretation of the earlier nationalist history that depicted Vijayanagar primarily as a bulwark of civilizations against Islamic political power. Eaton's contribution is especially valuable in providing a comparative and linked framework for the analysis of medieval South

India. By focusing on the Persianate, one gets a good window for understanding political legitimacy, court culture, and ideas of dialogue outside of a strictures of religious dichotomies. The book thus enables an understanding of the Vijayanagar Empire as an active participant in wider cultural processes of the medieval Deccan. Eaton's interest in Persianate norms and Muslim polities means that he has less to say about indigenous South Indian intellectual traditions, including Sanskritic scholarship, temple-centered institutions, and vernacular literary cultures. Vijayanagar thus seems to be a place of cultural appropriation rather than of cultural autonomy in the formation of such cultural interactions. Additionally, the analysis remains largely centered on elite political and cultural practices, offering less insight into the experiences of non-elite social groups.

(Ramasubramanian, 2019) in his article “South Indian Achievements in Medieval Mathematics” examines mathematical advancements in mediaeval South India, focussing on contributions other than the more well-known Sanskrit canonical texts. It examines how local academics approached geometry, arithmetic, and measurement in both Sanskrit and the vernacular, as well as changes in notation, units of measurement, and computing tools. The author questions the notion that mathematics decreased after the classical period, citing continuity and creativity in local treatises, commentary traditions, and interactions with astronomy.²⁷ The study situates South Indian mathematical activity in its right geographical and cultural context, emphasising its richness and variety.

(Kumar D. A., 2020) in their article have brought out the geomorphology and geology of Karnataka region and how rainwater can be accumulated in lakes. By integrating geological analysis with historical evidence, the study highlights the long-term sustainability of pre-modern water-management practices in South India. A significant contribution of Kumar's work lies in its detailed discussion of the **role of the Vijayanagar kings in constructing and maintaining large-scale hydraulic infrastructure**. The article demonstrates that the rulers of the Vijayanagar Empire actively invested in the construction of man-made lakes, reservoirs, canals, and wells, particularly in the semi-arid zones of Karnataka.²⁸ Kumar emphasizes that these water bodies were not random constructions but were carefully planned based on an understanding of slope, catchment areas, and seasonal rainfall. The continued functionality of several of these structures some still in use more than four centuries after their construction is cited as strong evidence of the advanced civil engineering and hydrological knowledge possessed during the Vijayanagar period. It is especially valuable in substantiating arguments related to the scientific and technological capabilities of the Vijayanagar Empire, particularly

in the field of water management and civil engineering. The article aligns itself with the idea that Vijayanagar rulers, like their predecessors, did not simply support temples and urban centres, but invested in large-scale public infrastructure crucial for both agriculture and the sustenance and survival of the urban population and for the economy. The use of historical analysis based on geomorphological data supports the claim that the water systems of Vijayanagar were technically advanced and environmentally responsive, which is in line with the research thesis of development of applied sciences and engineering practices. Although the study documents the surviving water structures, it does make use of more contemporary geomorphological observation than epigraphic and literary sources of the Vijayanagar era. This restricts its ability to completely trace the historical context of these projects (royal patronage, labor organization, etc. or rituals attached to water bodies). The *Journal of Critical Reviews*, 2020, Vol. VII has discussed the myriad enigmas of Hindu temples. Many of the temples were constructed during the era of rule of Vijayanagar. Some intriguing features have been discussed in detail which brings out the technical innovations but it is not clear if those features were accommodated deliberately or not. Sasidhar's study is informative in pointing towards the potential for technological innovation in religious architecture in the Vijayanagar era. The article contributes to the overall theme that temples were not only used as ritual spaces but also as places where knowledge of materials, structural mechanics, acoustics and spatial planning was applied. This view is compatible with an argument that investigates the evolution of the scientific, technological or engineering practices during the rule of Vijayanagar, especially with respect to monumental architecture. In spite of the fact that the article is descriptive, it poses an important methodological question whose impact on the strength of the analysis is somewhat restricted by Sasidhar. The study does not clearly define the role of the architectural characteristics discussed, in terms of whether they arose from a scientific planning or if they are a consequence of traditional building methods. There is no confirmation of these innovations in contemporary inscriptions or architectural treatises (including the *Śilpaśāstras*), or administrative documents, so they are hard to determine as intentional. Some interpretations may thus be speculative instead of historical.

(Babu, 2022) in his article “Mathematics and Society: Numbers and Measures in Early Modern South India.” provides an investigation into how numerical knowledge, measures, arithmetic, and numeracy, functioned in social contexts in early modern (late mediaeval to colonial transition) South India, particularly in Tamil districts. He examines manuscript and printed documents utilised by village accountants and other practitioners, such as multiplication tables, land measurement books, and local curricula. The book delves at how mathematics was

taught, the social roles of practitioners, caste and education, and how colonial shifts influenced these practices.²⁹ It emphasises mathematics as a lived experience above abstract theory.

(Fazli, 2022) in his journal of progress in civil engineering, Vol IV issue 6, has brought out the architectural style in his article published in the Journal of progress in civil engineering. The author has discussed the main characteristics of Vijayanagar architecture and has brought out many centers of Vijayanagar architecture.³⁰ Fazli's article is useful in establishing a descriptive architectural framework within which the scientific and engineering aspects of Vijayanagar construction can be examined. The study clearly shows the stylistic features and the major architectural centres, thus serving as a foundation from which to pursue further research into the technical knowledge, material use and construction practices of the period. It backs up the thesis of the overall argument that Vijayanagar architecture is a developed and advanced building tradition, which demanded high level of organization and technical skills. But, although Fazli manages to record architectural styles and centres of the area, she falls short in analytical aspects. Most importantly, the architectural planning and civil engineering concerns, including the design of foundations, load bearing systems, water management on temple grounds, and construction logistics are not explored in depth. Therefore, the article is mainly descriptive, and not analytical, and it does not really offer very much insight into the actual conception and execution of these monumental structures in terms of engineering. The main drawback of Fazli's work is that he does not engage with architectural plans and structural analysis. The lack of elaboration on design principles, measures and construction techniques limits the usefulness of the article in understanding the scientific and engineering knowledge in Vijayanagar architecture. This is especially significant if the thesis is designed to examine technological development as opposed to stylistic history. Furthermore, the article is not sufficiently based on primary sources, such as the inscriptions, architectural manuals (*Śilpaśāstras*), or contemporary accounts that would support the historical basis of the interpretations. If there were no sources, the connection between royal patronage, institutional support and architectural production would be left under-explored.

(Major, 2022) in his book "India in Fifteenth century" has presented the condition of south India as described by foreign travelers. The book is based on contemporary travel narratives, particularly those of Nicolo Conti and Abdur Razzak, who visited South India and the Vijayanagar Empire during its period of political strength and economic prosperity. By foregrounding external observations, Major provides a valuable outsider's perspective on the everyday life, urban organization, and cultural practices of the period. A significant

contribution of this work lies in its detailed portrayal of Vijayanagar as a prosperous and cosmopolitan empire. The accounts cited by Major describe the wealth of the capital city, its bustling markets, agricultural abundance, and the cultural vibrancy of courtly and urban life.³¹ These descriptions corroborate indigenous epigraphic and archaeological evidence regarding Vijayanagar's economic strength and administrative efficiency. For the present thesis, this material is useful in contextualizing the material and cultural environment in which scientific, medical, and technological practices developed. Of particular relevance to this thesis is Major's attention to everyday practices related to health and disease, as observed by foreign travellers. Nicolo Conti and Abdur Razzak recorded common methods of treating ailments, hygiene practices, dietary habits, and the general approach of the population toward health and well-being. The observations are not included in a standard political history, but they yield valuable glimpses into the actual medicine and health practices of the people. This is particularly useful in a thesis that wants to examine the evolution of natural sciences or knowledge application under the Vijayanagar Empire because it helps to bring the medical knowledge out of its exclusive scholarly context and into the everyday life. While it is useful, there are also some drawbacks in relying on accounts of foreign travelers as sources for Major. The narratives were influenced by the travellers' cultural backgrounds and expectations, and by the brief observation periods, which might have affected their interpretations. Consequently, certain descriptions, particularly in the medical field, may be impressionistic, rather than systematic or scientifically accurate.

(Gowda, 2022) in his article "Architectural Survey Review of Vijayanagar Empire- Case Study of Hampi." has used Hampi as the main case study. Dr. Gowda provides an extensive overview of the Vijayanagar Empire's architectural legacy. In order to uncover more "hidden" details about Hampi's urban morphology, the author examines a variety of structures, including temples (holy constructions), palaces, forts, gates, public buildings, and sculptures. This analysis is based on archaeological materials, field observations, and previously published literature. The article highlights the ways in which several dynasties contributed to the changing architectural fabric by discussing architectural styles, plan layouts, decoration, and building methods. The incorporation of defensive elements (forts), religious symbolism in temple design, elaborate sculpture and reliefs, and the arrangement of public areas are some of the main conclusions.³² According to the author, these architectural features demonstrate sophisticated technical know-how and Vijayanagar planning in addition to aesthetic or religious sensibilities.

(Asher & Talbot, 2023) in their second edition of "India Before Europe" have discussed the

condition of Vijayanagar Empire from origin till 1550 A.D in the 3rd chapter of the book. The work is distinguished in discussing the military technology during the medieval period as exploited by Bahamanis and Vijayanagar Empire and compared the technology used by both kingdoms in warfare.³³ As a known art historian Catherine Asher has brought out the Islamic effects on the art and architecture in Vijayanagar ruler including their court proceedings and traditions.

(Suman, 2023) in his article “Analysis of Education And Society of Vijaynagar Empire” provides an analytical overview of the educational institutions and societal dynamics of the Vijayanagar Empire. The author, after considering historical sources and secondary literature, suggests that education was never the same in the empire but that it was maintained by traditional institutions like temples, monasteries (mathas) and agraharas which served as centres of formal and informal education. Education was imparted in the local mother tongue in the pathshalas attached to the temples and higher education was imparted in the temple schools and major centers of the cities such as Madurai in Sanskrit and advanced education was imparted in major centers of the cities. The article also mentions girls' education and the great amount of intellectual activity in classical fields like Sanskrit, philosophy, logic and theology. The study provides much needed institutional background to the transmission of knowledge in Vijayanagar society. It establishes a link with the current study, focusing on the role of the temples, mathas and agraharas as places of scientific learning, including scientific subjects such as astronomy, mathematics, and medicine, and how these subjects might have been spread beyond the formal, state-sanctioned educational system. This strengthens the thesis that scientific ideas were not only present in learning institutions other than the judiciary or in travelogues from abroad, but were also present in broader learning institutions, thus further enriching the thesis's account of intellectual infrastructure. The article highlights how caste and language influenced the availability of education in Vijayanagar and its impact on education. This sheds light on the actors involved in the scientific practices (such as Brahmin scholars, temple teachers) and the nature of the social norms shaping participation in scientific knowledge systems. The article relates the social context to educational practice, enriching the thesis' analysis of the social support of scientific culture. The article describes the general characteristics of education and social organisation, but does not systematically list subjects of science taught in those institutions (such as astronomy, mathematics, medicine, etc.). It does not, however, give much direct information about the formal education or institutionalisation of scientific knowledges in the Vijayanagar Empire. Hence, while it may be useful in the context, it must

be supported by evidence from the text, the inscription or the curriculum level in scientific disciplines.

Dr. K. Mrutyunjaya Rao's article titled "Paintings on Manifestations of Shiva in Lepakshi Temple, Andhra Pradesh" provides an in-depth scholarly analysis of the murals in Lepakshi, placing them in the historical, artistic, and iconographic context of the Vijayanagar era in the International Journal of Research Culture Society (2024). The study shows that the temple contains a large amount of mural painting from the southern region of India, including the finest preserved of the ceiling's 70 feet of painting, in which 14 different manifestations of Shiva are illustrated, to the extent of being executed in accordance with the canons of Indian painting and iconography. The author makes careful notes on the theme, technique and material of murals. It is described by the technique used (fresco-secco): the pigments are mixed with coconut water or local molasses and applied onto the surface of a lime and clay plaster. This article is of special importance for researchers of South Indian temple art, and provides considerable insight into mural techniques, iconographic structure, artistic exchanges between the region and other areas, and the overall cultural heritage of the Vijayanagar empire. This is due to the limited ability to identify faded images, technological constraints in analysing pigments, and continued discussion on stylistic attribution of paintings.

In his article "On the Computation of arcsin function in Kerala School of Astronomy and Mathematics" (Krishnachandran, 2024), he discusses the various methods used by the Kerala school mathematicians and astronomers (such as Nilakantha Somayaji and Jyeṣṭhadeva) to calculate the arcsin function, a sophisticated trigonometric computation, which is a direct heritage of the original Indian mathematical practice. The work also covers an account of the appearance of these methods in the texts like Tantrasangraha and their relation to series expansions and numerical procedures in Yuktibhāṣā. Numerical examples are presented along with Sanskrit verse translations to validate these techniques in the investigation. Several contributions are made in this paper. First, it enlarges the geographical scope of the scientific knowledge map by depicting the development of advanced mathematical and astronomical ideas in the region between Vijayanagar rule and the onset of the Portuguese colonists, indicating a common intellectual space that was greater than political. Second, by illustrating *quantitative techniques grounded in rigorous procedures*, it supports the argument that pre-colonial Indian scientific culture included empirical computation and algorithmic reasoning, not merely descriptive tradition. However, the study's limitations lie

in its *lack of direct connection* to state patronage or institutional contexts specific to the Vijayanagar Empire; that is, while the Kerala school flourished spatially and temporally alongside Vijayanagar, the article does not explore how Vijayanagar courts or educational systems promoted or utilized such knowledge. Therefore, it functions best as a contextual comparator rather than direct evidence of scientific practice within Vijayanagar itself.

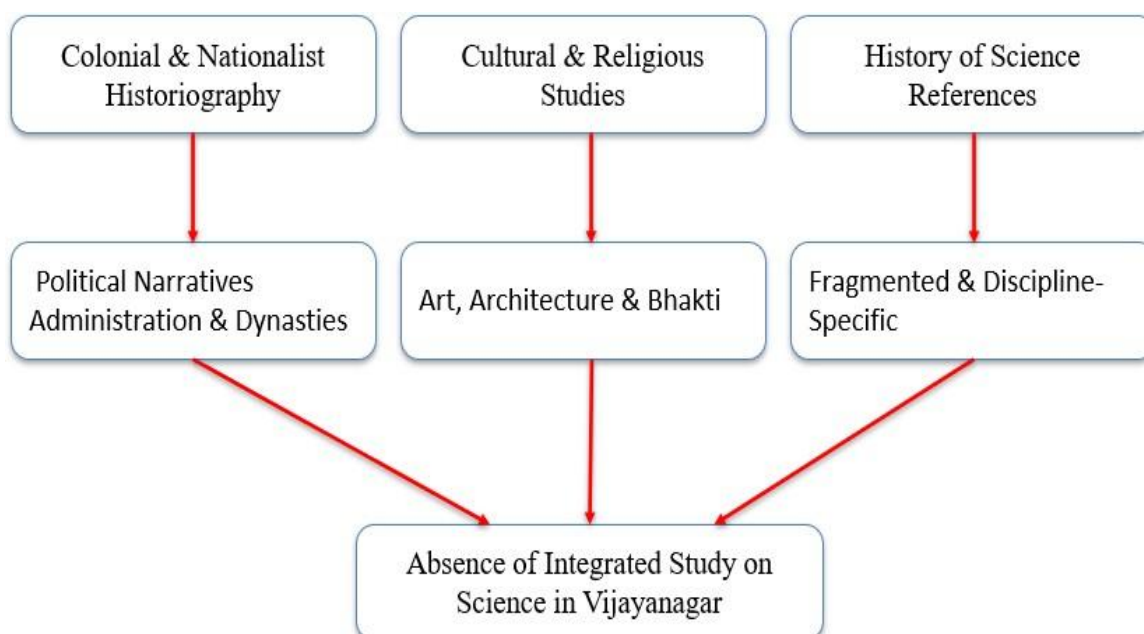
(Kumar S., 2024) uses political, administrative, and historical perspectives to analyse the Vijayanagar Empire's establishment, development, and fall. It begins by going over hypotheses on the beginnings of the empire, taking into account the claims of legitimacy and ancestry made by the founders of the Sangama, Harihara and Bukka. The government is next examined, including the centralised control under various dynasties, the functions of nobles and viceroys/Nayakas, the division of the provinces (rajya, mandala, etc.), the military and judicial institutions, and the role of religion in legitimising power.³⁴ The author also identifies internal flaws such as poor provincial governance, decentralisation, and succession issues. Last but not least, Kumar attributes the downfall to the Battle of Talikota (1565), as well as the loss of geographical cohesiveness and inadequate central authority.

(Mallik & Mahesh, 2025) article “Tracing Nātha Siddhas: Authors of the Lost Tradition of Tantric Alchemy at Srisailam” is a recent archaeological and iconographic study that documents evidence of tantric alchemical practices (rasāyana) through sculptural reliefs and textual associations at the Mallikārjuna Temple complex in Srisailam (Andhra Pradesh). The authors analyse sculptural panels depicting ascetic figures engaged in alchemical rituals, yogic postures, and symbolic gestures that link yogic and alchemical activities with medieval South Indian mystical traditions. Drawing on textual and archaeological evidence, the article situates the Nātha Siddha tradition a sect known for its integration of alchemy (rasāyana), yoga, and mystical practices within the broader religious and cultural history of the Andhra-Karnataka region, noting that many of these elements continued to be significant well into the Vijayanagar period. This article is valuable in many ways. First, it provides material evidence of alchemical practices in medieval South India that can be associated with medical and chemical knowledge systems (rasāyana/rasashastra). It shows that these were visually represented and culturally significant in temple contexts. Second, the study shows that scientific practices (alchemy and medicinal transformation) had social prominence, as reflected in temple art and community recognition. It indicates that such traditions were not peripheral but integrated into broader intellectual currents that were active during the Vijayanagar period. While it provides a rich iconographic and archaeological foundation, it

does not offer detailed textual analysis of technical alchemical recipes, laboratory procedures, or pharmacological processes the way dedicated *Rasashastra* texts do.

1.4 Research Gap

Although historians, archaeologists, and art historians have paid close attention to the Vijayanagar Empire, the majority of their research has been on political, economic, or religious issues (Michell, 1995). However, the scientific part of Vijayanagar culture has received little attention as shown in the following flowchart.



Science, technology and medicine have often been treated as an afterthought rather than a subject of major interest in the study of South Indian history (Pingree, 1981). Much of the existing scholarship has centered on one aspect of these subjects, with few attempting to make a coherent thread of scientific development out of the diverse strands of temple construction, hydraulic engineering, and mathematical astronomy. The work in the published literature also ignores the relationship between the theoretical knowledge system and material culture, obscuring the relationship of theoretical and practical knowledge systems within the empire. Moreover, a comparative perspective for the research of Vijayanagar scientific culture in relation to the contemporary developments in Islam, Europe and East Asia is missing.

Lastly, the methodological gap: in the past, literary and art-historical descriptions have been the principal sources of information; there has been no attempt to apply any multidisciplinary

approaches, such as digital epigraphy, urban analysis using GIS or archaeoastronomy alignment studies. Hence, this book is written to fill these gaps and is a blend of political history, intellectual history and scientific analysis in an integrated format, which will enable to get a complete view of the Vijayanagar empire as a scientific and rational civilization.

1.5 Objectives.

The study focuses on the development of natural sciences by identifying additional factors that could have had a significant influence on the development of sciences during the Vijayanagar Empire, exploring their applicability in that context, and suggesting improvements to the current database for South Indian history. The long-term goal of this research is to establish a connection between present-day science practices and natural sciences under the Vijayanagar Empire. The objectives are as follows: -

1. To study the creation, expansion, and development of the Vijayanagar Empire.
2. To explore the development of different branches of medical sciences under the Vijayanagar Empire.
3. To investigate the mathematical and astronomical upliftment of the Vijayanagar Empire, as well as its relevance to the modern period.
4. To evaluate the development of art and architecture.
5. To propose the role of their enhanced scientific temperament in the advancement of current society.

1.6 Methodology

This exploratory study has used qualitative methodology. Data is gathered using both primary and secondary sources, such as an analysis of inscriptions and literary sources about the field of science. This method for data collection includes credible sources on the Vijayanagar Empire like textual published books, journal articles, conference papers, encyclopaedias, and previous studies. The information offered by archaeological remains is supported and corroborated by literary material. Validation of research questions is carried out by conducting a thorough assessment of the literature using the case study technique with focus groups as shown in **Table 1.1**. This exploratory study has to be investigated using a descriptive approach since it was not conducted in a controlled environment and is based on real-world conditions, and this technique is optimal for obtaining in-depth knowledge of this topic. Numerous primary materials are used in the study, such as astronomical tables, temple inscriptions,

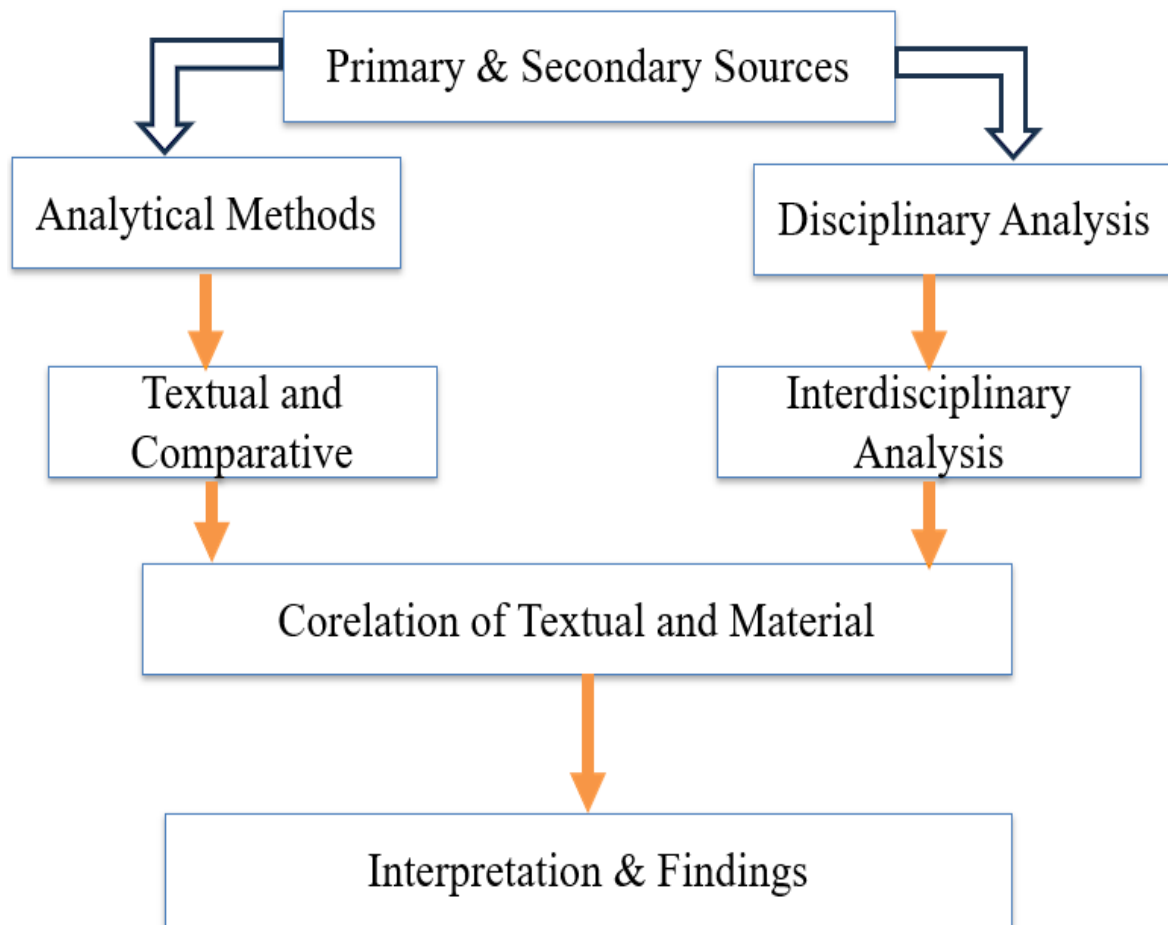
surviving Sanskrit texts (such as Tantrasamgraha, Yuktibhāṣā, and Ganit Kaumudi), and architectural evidence (such as temple alignment and epigraphic references to astronomical techniques). Secondary analyses in intellectual and scientific history, such as contemporary research on the Kerala School, Hampi's archaeoastronomy, and comparative histories of mathematics, supplement these. The study guarantees philological and contextual richness by placing manuscripts and inscriptions in conversation with academic commentary. The table below summarises the thorough approach utilised to address the study's research questions.

Sl.	Source	Source collection methods
1	Field visits for case study	Direct Observation through the material and monumental remains of Hampi and around. Focussed group
2	Primary Sources	1. Examination of ASI Hampi records. 2. Literature review of contemporary kingdoms. 3. Literature review of contemporary scientific works by scholars of the Vijayanagar Empire 4. Study of Archaeological remains. 5. Inscriptions of Vijayanagar Empire
3.	Secondary Sources	Literature Review of books and research articles

Table 1.1

To provide a clearer representation of the research design, the methodological process adopted in this study is illustrated in following flowchart.

Methodology Flow



The diagram illustrates the connection between primary and secondary sources, analysis, interdisciplinary connections and correlations between textual and material evidence. This methodology illustrates the interdependencies among various types of data and analytical techniques that lead to the overall interpretation and final results of the study.

The available evidence in the present study is historical and qualitative in nature and, therefore, a quantitative approach is not appropriate. A numerical representation of the development of natural sciences in the Vijayanagar Empire is not possible as the sources available are of a fragmentary, descriptive and context-specific nature. There were no consistent and measurable data sets in the inscriptions, manuscripts, architecture or traveller accounts. Furthermore, the purposes of the study are analytical and interpretive and seek to explain the intellectual traditions, empirical practices, institutional patronage, and cultural exchanges rather than to derive numeric trends and correlations. The uniformity and standardisation of data required by quantitative methods is also not found in medieval sources. Numerical comparison is methodologically unsound and historically misleading,

because the diversity of the languages, of the genres, of the regional practices, of the chronological changes makes it difficult. Hence it is better to use qualitative approach with respect to Vijayanagar scientific activities, which are multifaceted, complex and interdisciplinary in nature. The Method of Study Source Collection and Classification are separate from the main program, and the teacher may choose from a variety of methods. Primary sources of inscriptions, scientific manuscripts, medical texts, and traveller accounts are gathered, and thematically classified. Primary evidence is contextualised through secondary sources such as modern analyses of the historical period, archaeological reports and historiographical studies.

Textual and Epigraphical Analysis. Scientific references in inscriptions and literary texts are analysed to understand the role of scholars, practitioners and institutions in the empire. Special attention is paid to terminology related to astronomy, medicine, mathematics and engineering.

Archaeological Corroboration. Material remains such as irrigation tanks, canals, hospitals, temples and urban layouts are examined to support literary claims and to reveal the practical application of scientific knowledge.

Critical Review and Interpretation. The collected data is interpreted using historiographical and interdisciplinary perspectives, allowing for synthesis between science and social structures.

1.6.1 Limitations of the Study

It is important to recognise certain methodological and evidentiary limitations even though this study reveals the rational culture and scientific underpinnings of the Vijayanagar Empire. These restrictions outline the parameters within which the results should be evaluated rather than undermining them.

The fragmented form of the remaining sources is the first constraint. A large portion of the Vijayanagar period's literature has been lost, damaged, or only exists in later versions, especially writings on architecture, astronomy, and medicine. Even though inscriptions, traveller reports, and architectural remnants offer a wealth of information, they frequently represent the viewpoints of the aristocracy or royalty. Because of this, the scientific contributions of local guilds, doctors, artisans, and female healers may continue to be under-represented.

Second, it is important to acknowledge the regional bias of the archaeological evidence that is

now available. While neighbouring capitals like Penukonda and Chandragiri receive relatively less rigorous attention, Hampi and the surrounding Tungabhadra region have undergone substantial excavation. This concentration of information may unintentionally underestimate the range of scientific activities throughout the larger empire while exaggerating the scientific expertise of the core region.

The challenge of connecting textual assertions with relevant evidence is a third drawback. For instance, not every temple or building in the empire adheres to the intricate geometrical formulas and architectural principles described in the Śilpaśāstras. It is important to use caution when establishing a direct causal relationship between theory and practice, especially when working with hybrid or syncretic traditions.

Furthermore, thorough cross-regional comparison is hampered by the lack of digital databases for several pertinent inscriptions and manuscripts. Therefore an archive restriction might influence study's interpretive reach by dependence on previously published material.

Lastly, this thesis recognises the interpretive constraints that come with recreating scientific temperament, a conceptual category that the Vijayanagar intellectuals themselves did not clearly describe. While the study demonstrates empirical rationality, terms such as 'science', 'technology' and 'rationality' have current definitions that must be understood in the context of the study. To sum up, the study's restrictions are mainly attributed to:

- The use of multiple historical and manuscript sources.
- Inadequate archaeological documentation is another regional issue.
- Another regional issue is inadequate archaeological documentation.
- Discusses difficulties in the connection between theory and material practice.
- Lack of completed digital archives and text inscriptions.
- Reconstructing historical scientific thought conceptually

Addressing these limitations adds to the validity of the academic research and offers opportunities for future studies.

1.7 Significance of the Study

The study is a comprehensive analysis of the development of the natural sciences in the Vijayanagar Empire. It discusses the role of royal patronage, academic study and trans-cultural interactions in the advancement of astronomy, medicine, mathematics, and architecture. It is a significant contribution to the historiography of South India in the mediaeval period, as it largely neglects the usual focus on political and military achievements and emphasises the intellectual energy of the court of Vijayanagar. Further, the study

continues to be relevant today. It promotes the ongoing effort of decolonization of the history of science and challenges Eurocentric myths of scientific progress by reclaiming and studying indigenous knowledge traditions. It offers valuable lessons on sustainable practice, ancient technologies, and culture-oriented science, and how state-sponsored scholarship and locally based activities created scientific knowledge in pre-modern India. The study, therefore, throws new light on the Vijayanagar heritage and sets it in the broader international debates on history, culture and science.

1.8 Theoretical Framework and Historiographical Debates

The research adopts an interdisciplinary approach in terms of theoretical perspective and integrates the concepts of history of science, cultural materialism, and Indian epistemology. The conceptual lens assumes that knowledge in premodern India was not compartmentalized into separate fields, but rather constituted a unified whole that connected with philosophical reflection, empirical observation and social application. It is based on two epistemological concepts in India, *pramāṇa* (valid knowledge) and *yukti* (rational reasoning). It has been seen that the rational empiricism was present in Indian intellectual life even before the formal establishment of modern scientific ways of thinking. The works of Sayana, the Vidyaranya's *Sarvadarśanaśaṅgraha*, and the mathematical works of the Kerala School clearly show how rational the indigenous approach is, which is based on observation and deduction.

The thesis also uses cultural materialism, a perspective that sees scientific knowledge as a result of particular socioeconomic and ecological contexts in order to analyse these processes. Hence, the empirical practices pertaining to irrigation, metallurgy, medicine, architecture in the Vijayanagar is comprehended not as technological achievements but as social organizations and adaptations to the environmental. This theoretical synthesis, therefore, allows the study to examine Vijayanagar's scientific legacy as a historical reality, as well as a conceptual model, and provides a tangible example of the continuity of premodern Indian rationality and the scientific worldview.

The study of the Vijayanagar Empire has seen a number of historiographical phases, each characterized by its own methodology, ideological framework and sources of information. Each new generation of scholars has developed a new interpretation of Vijayanagar's political, cultural and scientific heritage, drawing from new sources and theoretical approaches.

1.8.1 Early Colonial Historiography

Colonial administrators and antiquarians like as (Sewell, 1900) in *A Forgotten Empire* provided the first comprehensive descriptions of the Vijayanagar Empire. Drawing mainly on traveller

stories from Abdur Razzak, Nuniz, and Paes, Sewell depicted Vijayanagar as a romanticised Hindu fortress opposing Islamic conquest. His narrative focused on grandeur and decay, rather than social or intellectual systems. While Sewell's work remains basic for chronology, it has a colonial-romantic bent, seeing Indian history through the perspective of moral decline and oriental grandeur. Beyond Sewell, early colonial historiography included scholars such as Robert Orme, Wilks, and early ASI surveyors who viewed Vijayanagar primarily through the lens of political chronology and monumental decay. Scientific practices, whether hydraulic engineering, astronomy, or medicine were treated as incidental or derivative of religion. This school often interpreted technological achievements as static survivals rather than dynamic systems of experimentation. As Trautmann and Inden later argued, such colonial readings were shaped by orientalist assumptions that denied rational scientific capacity to pre-modern Indian polities.

1.8.2 Nationalist Historiography

With the development of Indian nationalist research, historians such as **K.A. Nilakanta Sastri, B.A. Saletore, and T.V. Mahalingam** turned their attention away from decline narratives and towards cultural and administrative successes. They intended to illustrate Vijayanagar's inherent resilience and sensible government. Mahalingam's *Administration and Social Life under Vijayanagar* (1951) and Saletore's *Social and Political Life in the Vijayanagar Empire* (1934) used inscriptions and temple records to rebuild the empire's administrative complexity. But this school was still largely descriptive and upper class, often celebrating kings and dynasties, rather than analysing society or intellectual traditions. But this provides a basis for interpreting Vijayanagar not as the 'scientific state' of the Vijayanagar Sultanate as it was understood, but as the scientifically administered state to which this thesis is extended. Historians like K.A. Nilakanta Sastri, T.V. Mahalingam, and B.A. Saletore, who were nationalist in their outlook, dispensed with the colonial myth of decline and highlighted administrative efficiency, temple economy, and cultural continuity. But though inscriptions and literary sources were widely exploited, science was never made a point of, it was never there. The use of irrigation, astronomy and medicine were recognized as signs of abundance, but seldom discussed as separate networks of knowledge. Hence, the nationalist history was at its best in lauding accomplishments without understanding the epistemological underpinnings of scientific work in Vijayanagar.

1.8.3 Marxist and Material Interpretation

The marxist and materialist historians like D.D. Kosambi, R.S. Sharma and Burton Stein changed the focus of Vijayanagar studies towards agrarian surplus, class relations and mode

of production. According to Stein's idea of “segmentary state,” imperial power was based not on the rationality of administrative decisions but on rituals of kingship. Others, including Noboru Karashima, have criticized this. Y. Subbarayalu challenged this opinion by providing evidence of administrative standardisation from inscriptions, land surveys, taxation records and temple accounting systems. On a scientific historical sense, the Marxist approach has proved to be both supportive and restrictive. It emphasises the conditions of the material world that allowed scientists to work the irrigation systems, artisanal production, etc. but does not always highlight the theoretical knowledge, mathematical calculations, or scholarly transmission that maintained them.

1.8.4 Revisionist and Interdisciplinary Approach

Archaeology, art history and environmental studies were added to the list of subjects offered for scholarship in the later years. Using the technique of textual and spatial analysis, George Michell and John Fritz concentrated on urban planning, hydraulic engineering and temple construction. Their study transformed Hampi from a legend into a scientific and architectural context that is an example of sophisticated planning and resource management systems. (Fritz & Mitchell, 2001) Since the 1990s, revisionist scholars have made an effort to broaden the scope of Vijayanagar Historiography by bringing in the fields of archaeology, epigraphy, art history and environmental studies. Critics like George Michell, John Fritz, Carla Sinopoli, Kathleen Morrison and Anila Verghese have presented Hampi not just as a symbolic capital, but as a carefully crafted urban and environmental design as well. The new study of hydraulic infrastructure, geomorphology and spatial planning was now a necessary component of the knowledge of the resilience of the empire. At the same time, historians of science such as David Pingree, George Gheverghese Joseph and K. Ramasubramanian started to work on mathematical astronomy, calendrical calculations and dissemination of knowledge in South Indian region. The school of thought which lies at the heart of this scholarship extends Vijayanagar into a broader intellectual world, which also embraced the Kerala School of Mathematics, education in temples and the support of the courts. The scholars do not regard Vijayanagar as a mere background, but are growing in their sense of Vijayanagar as a source of knowledge dissemination between Karnataka, Andhra, Tamil and Kerala.

1.8.5 Science, Knowledge Systems, and Statecraft

A new but emerging “historiography” is dedicated explicitly to science and technology of Vijayanagar India. With a view of studying pre-modern Indian science through institutional practices, scholars like Habib, Pingree, Joseph, Suryanarayana and Ramasubramanian make

this claim. Epigraphic evidence analysed by Ramesh and Majumdar demonstrates that astronomers, physicians, and engineers received royal patronage and land grants, indicating institutional recognition of scientific expertise. Recent works using digital archaeology and archaeoastronomy further suggest deliberate mathematical and astronomical planning in temple construction. This school challenges Eurocentric chronologies of science by demonstrating continuity, experimentation, and rationality within indigenous frameworks.

1.8.6 Contemporary Debates and Post-Colonial Reassessment

- Centralisation/Decentralisation: Was Vijayanagar an empire of bureaucracy or a ritual polity in a network?
- Religion vs. Rationality: How far science and spirituality played together harmoniously or competed for supremacy.
- Continuity vs Disruption: The ending of intellectual culture or its dispersal in Vijayanagar in 1565 or its dispersal to Nayaka and Kerala traditions.
- Global Positioning: How to locate Vijayanagar in global narratives of science: was it parallel, preceding or peripheral to the European Renaissance?

Postcolonial historians like Eaton, Asher, Talbot, and Karashima do not subscribe to the binary picture of resistance of the Hindus and invasion of the Islamic community. Rather, they focus on cultural hybridity, Persianate influences and practical statecraft. In this sense, science and technology are understood as co-governance languages, evident in the military engineering, architecture, medicine and administration. There is a controversy whether the science of Vijayanagar was more ritualistic or empirical. Some scholars focus on cosmological symbolism, others on observation, calculation and adaptation to the environment. This unresolved tension creates a fruitful area to reimagine Vijayanagar as a sacred and rational polity.

1.8.7 The Emergence of Environmental and Scientific Histories

The last decade of research has started to focus on Vijayanagar and its scientific culture, with particular interest in its pioneering work in hydraulics, agriculture, astronomy and metallurgy. Vijayanagar's ecological intelligence and empirical planning, which are closely related to the thematic thrust of the thesis, have been amply illustrated in the writings of environmental historians like Morrison and Sinopoli. This trend marks the beginning of an interdisciplinary historiography that recognises Vijayanagar as a centre of scientific knowledge and

technological experimentation.

1.8.8 A Plural and Evolving Historiography

The Vijayanagar empire is no longer seen merely as a Hindu bulwark but also a remnant of medieval grandeur and is now understood as:

- A cosmopolitan polity with intercultural encounters
- A centre of scientific and administrative innovation
- An environmentally engineered urban civilisation
- A dynamic imperial formation embedded in global networks

This changing character of historiography helps to demonstrate the empire's importance not only within the history of South India but also within broader debates on statecraft, scientific rational and cultural synthesis in the pre-modern world.

1.8.9 Position of Present Study

The thesis is part of the growing multidisciplinary and postcolonial trend but pushes it further by adding the scientific history into the cultural history. This research argues that art, science and statecraft can be studied together in an analytical perspective. Vijayanagar empire is a scientific civilisation whose intellectual culture can coexist with contemporary ideas on sustainability and innovation. This study foregrounds the natural sciences as an analytical category, challenging the historical narrative and positioning Vijayanagar as a scientific culture as much a part of governance, economy, and education as any other activity.

1.9 Expected Outcome

First, it aims to reframe Vijayanagar's past as a scientific civilization focused on technical innovation, medicine, mathematical inquiry and architectural engineering as the basis of governance and culture. This is an interpretative change that adds to the greater space of Indian scientific history, which connects to national and global processes.

Secondly, the study is intended to give rebirth and re-interpretation to the Indigenous knowledge systems. The study's insights into the institutionalization of science in the temple, educational institutions and guilds are valuable for traditional knowledge of science to be integrated into modern science curricula, in line with India's National Education Policy (2020) that prioritizes inquiry-based learning and cultural values.

Third, the results are expected to contribute to the heritage preservation and policy-making. The scientific principles of architectural, hydraulic and urban designs can guide the current

conservation plans of Hampi and the Vijayanagar monuments for increasing their cultural and educational values.

Last, the present work contributes to the global discourse on the non-Western scientific traditions in showing that empirical science and technical skills flourished outside of Europe. In effect, the study not only reconstructs a historical time, but also deepens the connection of India's science history with the current objectives of science, creating a platform for interdisciplinary studies between science, society and civilisation in the future.

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Chapter 2: Establishment of Vijayanagar Empire

2.1 Introduction

The history of peninsular India went through a significant change with the rise of the Vijayanagar Empire in the 14 century. Vijayanagar, which was founded in the midst of the political disintegration that followed the fall of the Chola, Pandya, Hoysala, and Yadava dynasties, was a conscious and concerted attempt to protect South India's scientific and cultural heritage from the encroachment of northern Islamic forces. In addition to serving as a military stronghold, the empire was a hub for advancement in the fields of art, architecture, mathematics, astronomy, and hydraulic engineering from its founding in 1336 CE until its disastrous collapse in 1565 CE. Although firmly rooted in dharmic principles, the Vijayanagar dynasty's rulers fostered a spirit of reasoned investigation and technological skill that made the empire one of the most developed polities in the early modern era.

This chapter examines the political establishment and dynastic history of Vijayanagar with particular attention to the scientific temperament and intellectual patronage of its rulers. In the words of Robert Sewell, the author of *"A Forgotten Empire (Vijayanagar)"*, the state represented "the Hindu bulwark against Muhammadan conquest" and "a rallying point for all that was strong and progressive in the South."¹ Yet, as Noboru Karashima and Burton Stein later observed, Vijayanagar was more than a defensive reaction, it was a laboratory of social, technological, and economic innovation rooted in rational administration and scientific curiosity.²

2.1.1 Historical Context: India in 14th Century

The southern peninsula was experiencing unheard-of upheaval by the early 1300s. Under the leadership of Muhammad bin Tughluq and Ala-ud-din Khilji, the Delhi Sultanate overthrew the Kakatiyas of Warangal and the Yadavas of Devagiri, extending its conquests far into the Deccan. By 1327, the Pandyan kingdom of Madurai had fallen to Muslim forces after the Hoysalas were vanquished³. The southern plains were terrorized by Malik Kafur's operations and Muhammad ibn Tughluq's subsequent invasions. This earlier period was recalled as one of chaos: "The country was a prey to violent anarchy, the people hid themselves in mountains and deserts," remarked Abdur Razzak, the Persian envoy to the court of Vijayanagar a century later. A coalition of local authorities and religious leaders resolved to bring stability back arose from this political disarray.⁴

Two factors, geography and knowledge, made it possible for southern India to go from dispersed chiefdoms to a centralized imperial polity. The intellectual traditions of Sringeri and Kanchipuram provided the ideological framework for kingship and law, while the Tungabhadra River basin offered a defensible frontier and an abundance of resources.

2.1.2 Foundation of Vijayanagar: Myth and Realpolitik

According to the conventional account, the brothers Harihara and Bukka Raya, who had previously served as officials in the Kakatiya or Hoysala courts, were the founders of Vijayanagar. They were captured and converted to Islam during a campaign in Delhi, but under the tutelage of Vidyaranya, the Shankaracharya of Sringeri, they were reverted to Hinduism⁵. Whether the story is true or not but it is a symbolic gesture of cultural reclaiming. Vidyaranya was the philosophical leader for the new state. His Panchadasi and Sarvadarśanaśaṅgraha were two works that expressed what could be called the scientific temper of dharma, expressing a worldview of rational enquiry and methodical understanding of the universe, in the harmony of Vedantic metaphysics and rational dialectics.⁶

An environmental and strategic brainchild was the choice of location, Hampi on the southern bank of the Tungabhadra. The alluvial tracts were rich and good for much cultivation but the river side was the natural boundary and the granitic ridges the natural fortifications. Thus, the orthogonal plans of streets, the hydraulic systems and the planned enclosures for temple complexes in early Vijayanagar were examples of a logically planned urban complex. It grew to be "the best provided city in the world," as was said by later Portuguese observers, such as Fernão Nuniz and Domingo Paes, who boasted of its mathematicians, engineers and craftsmen⁷.

The Vijayanagar Empire was not just an answer for political survival but also an intellectual initiative to revitalise and institutionalise knowledge systems. Since its origin the state has been aware of the strategic value of the learning, especially that of astronomy, mathematics, medicine and architecture to govern, legitimise and manage the environment. The close association between the ruling elite and scholarly institutions such as *mathas* and *agrarahas* indicates that knowledge production was integral to statecraft rather than peripheral to it.

2.1.3 Temple Institutions and Knowledge Patronage Under Vijayanagar Rulers

In addition to being a political and military reaction to the Delhi Sultanate's growth in South India, the Vijayanagar Empire was an institutional and intellectual endeavour that deliberately incorporated knowledge systems into government. Education has been recognized as an integral part of the legitimacy, governance and social structure of the State from the time of

its inception in the reign of Harihara I and Bukka Raya I. This understanding is reflected in the close links between royal power and the temple institutions such as the mathas, the agraharas, and also the important pilgrimage centers, where learning, scientific research, and cultural transmission were the activities⁸. They needed to coordinate and integrate a wide range of skills in geometry, structural mechanics, quarrying technology and material science in large scale construction projects. Temples can therefore be seen as multi-disciplinary centres for scientific applications, not just centres for devotional expression.

Vijayanagar's temple institutions dualistically functioned as a religious life centre and as an organised space for promoting knowledge⁹. The royal patronage in the form of land grants, tax exemption and endowments enabled the survival of mathas like Sringeri, Kanchipuram, Tirupati and Hampi. The epigraphic evidence shows that these grants were not limited to ritual purposes, but also included grants to scholars in astronomy (jyotiṣa), medicine (āyurveda), mathematics (gaṇita), architecture (vāstu), and scriptural exegesis. These patrons helped sustain the continuity of the practicalities of observation, calendrical computation, medical teaching and architectural knowledge that were both necessary and important in religious and administrative contexts.

This knowledge-based statecraft was conceptualised by Vidyaranya, who was a member of the founding rulers and who combined political power with intellectual leadership. Vidyaranya's dharma idea of Government emphasized moral leadership supported by knowledge and reason. This made it possible for later scholars such as Sayana, who added complex linguistic and astronomical interpretations of the Vedas, to operate within a safe scholarly environment. The spread of scientific cultures in South India, e.g., the Kerala School of Mathematics and Astronomy, benefited indirectly from the stability, circulation of manuscripts and mobility of ideas in the Vijayanagar Empire, providing the ultimate proof of the persistence of this model.

Additionally, the royal support of academic institutions had some practical administrative consequences. Architectural science was used to construct temples, irrigation systems, and urban planning; astronomical science was needed to update the ceremonial calendar and auspicious time; medical science was utilised for public health and military preparations. Hence in Vijayanagar science was not developing in isolation but it was a tool for statecraft. Thus, temples and mathas might be viewed as state funded knowledge centres where ethics, theory, and practice came together.

2.2 Sangama Dynasty: Foundations of Empire (1336-1485)

The **Sangama dynasty**, named after the brothers' father Sangama, oversaw the empire's formative phase. Its rulers, Harihara I, Bukka I, Harihara II, Deva Raya I, and Deva Raya II, established control over the Deccan plateau and Tamil country, transforming Vijayanagar from a defensive confederation into a true imperial state.

2.2.1 Harihar (1336-1356)

Harihara I restored the administrative systems of Hoysala, consolidating power over central Karnataka and portions of Andhra. His efforts to rebuild irrigation tanks and set up a tax-remission scheme for canal upkeep are mentioned in the inscriptions. Such actions demonstrate a deep comprehension of agrarian economics and hydrology¹⁰. The resurgence of trade lines connecting Goa, Honnavar, and Calicut to the interior markets was observed by foreign merchants traveling to the west coast. By 1340, Harihara I (styled *Mahāmaṇḍalesvara*, "great lord") had already secured extensive territories north of the Malprabha River.

2.2.2 Bukka (1356-1377)

Bukka I became the first significant Vijayanagar king to engage diplomatically with his Islamic neighbours and expanded the empire's dominion across the Tungabhadra and Krishna rivers. He was "the first to give permanent shape to the empire," according to Sewell¹¹. The renowned scholar Sayana, Vidyaranya's brother, wrote in-depth commentary on the Vedas at his court. These writings, particularly the Rig-Veda Bhashya, reveal a keen interest in phonetics, geometry, and astronomy. The early culture of Vijayanagar was based on observational science, as can be seen from Sayana's astronomical understanding of Vedic time cycles and planetary movement, which is an indigenous rational cosmology.¹²

Bukka also was involved in temple restoration on a mammoth scale. The architecture evolved into a unique blend of Dravidian proportionate systems and functional engineering with wide mandapas, corbelled domes and granite colonnades that were built for strength and durability and not excess¹³.

2.2.3 Harihar II (1377 – 1404), Dev Raya I – II (1406 – 1446)

By gaining access to maritime trade, Harihara II extended Vijayanagar's power into the Tamil lowlands and the Konkan coast. Deva Raya I and II, his successors, oversaw a time of fierce cultural flowering and unrelenting conflict.

The main opponent of Vijayanagar was the Bahmani Sultanate, which was founded in 1347. Their frontier battles in the Raichur Doab sparked technology exchange in addition to shaping military history. During this time, **artillery, metal casting, and lime fortification were**

introduced into South India, frequently with the help of Persian and Turkic experts who had been captured or enlisted in combat¹⁴.

"The city is such that the pupil of the eye has never seen a place like it, and the ear of intelligence has never been informed that there existed anything equal to it in the world," says Abdur Razzak in his 1443 trip to the court of Deva Raya II¹⁵, providing a unique anthropological view. His description of an urban complex with stone walls, aqueducts, and marketplaces demonstrates a sophisticated grasp of logistics and urban planning. Niccolò de' Conti, an Italian explorer who went to Vijayanagar about 1420, attests to Razzak's account. According to his writing, "the city is surrounded by seven walls; it abounds in all kinds of provisions and wealth; the houses of the king are adorned with gilded roofs."¹⁶ The precision of these accounts, later confirmed by archaeological surveys, indicates a highly organized civic administration reliant on empirical measurement and mathematical planning.

2.2.4 Vijayanagar – Bahmani Frontiers and Technological Exchanges

Military science was tested in the Raichur Doab wars between the Bahmanis and the Vijayanagar. Armed with a combination of infantry, cavalry, and war elephants, Vijayanagar troops progressively began using gunpowder weaponry that they acquired from Portuguese and Arab traders. To modernize his army, Deva Raya II notably enlisted Muslim riders and archers, a practical move that showed an openness to technical knowledge across religious lines. A common technological environment was created by these exchanges. Vijayanagar's fortification architecture was influenced by Bahmani architects, who added inclined walls and bastions that were meant to withstand cannon fire. On the other hand, Hindu craftsmen gave the Bahmani kingdoms their knowledge of irrigation and metallurgical procedures.¹⁷ Thus, the frontier became a site for the synthesis of science and technology even in the face of resistance.

By the middle of the fifteenth century, Vijayanagar had developed into not only the political hub of the south but also a global hub of scientific culture, with information flowing through intermediaries in Tamil, Telugu, Kannada, Sanskrit, and Persian. The Tuluva dynasty and Krishnadeva Raya's golden period would subsequently be the culmination of the administrative logic and intellectual openness fostered during this phase.

2.3 The Saluva and Tuluva Dynasties, Zenith of Power and the Culture of Science (1485–1565 CE)

2.3.1 The Crisis of Succession and the Rise of the Saluvas

The Sangama line was deteriorated by the middle of the fifteenth century. Internal uprisings and ongoing conflict with the Bahmani Sultanate depleted the finances. The successors of Deva

Raya II were ineffectual, and the empire fell into a state of administrative chaos.¹⁸ Narasimha Saluva, a strong Chandragiri regional governor (nayaka), took the crown in 1485 as a result of this instability. According to Sewell's account, his takeover of power was "the hand of a soldier raised to save the state from chaos"¹⁹ and was indicative of the increasing militarization of Vijayanagar's political system.

Despite being short, the Saluva dynasty (1485–1505) was an important transitional period. The Tuluva ascendancy was made possible by the restoration of central authority as well as the implementation of military and administrative reforms. According to Karashima, the Vijayanagar army's professionalization and the standardization of revenue collecting began during the Saluva era²⁰. A standardized land-revenue system based on agricultural productivity and soil fertility was established by Narasimha Saluva and his general Narasa Nayaka, along with a tiered hierarchy of officers. The employment of gadha (grain measurements) and kalan (measuring rods) for evaluation is mentioned in inscriptions from this era, demonstrating the ongoing dependence on mathematical accuracy in fiscal policy.

2.3.2 Narasa Nayaka and Institutionalisation of Power

During Saluva Narasimha's heir's minority, Narasa Nayaka successfully led. According to modern sources, he was a politician and warrior who was well-known for his successful containment of Bahmani successor kingdoms and his wars against insurgent Nayakas. Using newly developed lime-mortar technology to reinforce Penukonda, hiring Persian gunners, and hiring coastal shipwrights to enhance river transportation, he also exemplified the pragmatic cosmopolitanism characteristic of Vijayanagar's scientific culture.

2.3.3 The Tuluva dynasty and Krishnadeva Raya's Empire

Following the passing of Narasa Nayaka, his son Tuluva Narasimha temporarily held power, opening the way for Sri Krishnadeva Raya (1509–1529 AD), the most renowned emperor in the empire. Everyone agrees that his rule was the height of Vijayanagar's political influence and intellectual prowess. In 1509 Krishna Deva Raya took the throne, soon campaigning successfully against Orissa and the eastern sultanates. Krishna Deva Raya prompted Vijayanagar to launch an assault. He forced the ruler Ibrahim Adil Shah to flee when he took Raichur from Bijapur in 1510, breaking a previous pact. Krishna's general took Udayagiri Fort from Orissa in 1514–1515. He marched into the Deccan once more in 1520, and his Portuguese-equipped force defeated the sultans of Bijapur by besieging Gulbarga (Bijapur). Krishnadevaraya's military successes had consequences that extended far beyond territorial expansion. The incorporation of agriculturally productive regions and commercially active ports generated substantial state revenue, enabling sustained patronage of scientific activities.

This economic surplus financed irrigation projects, temple construction, astronomical observations, and medical institutions. Vijayanagar's power and prosperity in his reign impressed foreign observers. Portuguese chronicler Domingos Paes (who visited in 1520) praises Krishna Deva Raya as "gallant and perfect in all things," noting that he exercised "absolute" sovereignty widely respected by all. Duarte Barbosa, writing around 1514, likewise remarked that Vijayanagar was "very rich, and well supplied with provisions, and is very full of cities and large townships".²¹ These external accounts, along with Sewell's own historical narrative, confirm that by the early 16th century Vijayanagar had grown into a vast, well-organized empire dominating most of southern India. Throughout this period of establishment and expansion, Vijayanagar's rulers also fostered cultural and religious life (building temples, supporting learning, etc.), laying foundations for advances in the natural sciences and other fields. The empire's stability and wealth underpinned such developments, as royal patronage and trade brought in knowledge from Arabia and Europe. Maritime and inland trade served not only as channels of economic exchange but also as important mechanisms for technological diffusion. Contact with Portuguese merchants facilitated the introduction of improved artillery techniques, while commercial interactions with West Asia and Southeast Asia encouraged the circulation of medicinal plants, metallurgical practices, and navigational knowledge.

- (i) **The Polity of Reason and Order.** The statecraft of Krishnadeva Raya combined empirical logic with dharmic legitimacy. An economic philosophy based on observation is presented in his well-known work *Amuktamalyada*: "A king should collect revenue as a bee gathers honey from the flower, without harming its growth."²² The metaphor connects the sustainability of industrial systems with budgetary prudence, expressing an ecological concept of government. A meticulous concern for measuring, audit, and record is evident in administrative inscriptions. With mathematical accuracy, revenue assignments (*amaram* grants) were documented, frequently mentioning irrigation supply, rainfall, and soil type.²³ The bureaucratic reasoning shown in these measures was similar to that of the Ottoman and Ming systems.
- (ii) **Scientific and Technical Endeavours.** Vijayanagar developed into a center for engineering, astronomy, mathematics, and medicine under Krishnadeva Raya. The Kerala School of astronomer-mathematicians, whose achievements in calculus and infinite series coincided with those in Europe, engaged with his court scholars. Under royal sponsorship, the Golgunitha

school of mathematical astronomy flourished in southern Karnataka and Andhra; Nilakantha Somayaji and Chitrabhanu's treatises demonstrate their acquaintance with the planetary models that were passed down from the Aryabhata and Bhaskara lineages.²⁴ Krishnadeva Raya also sponsored large-scale hydraulic projects: the construction of the Kamalapura tank, the Anantashayana canal, and the restoration of the Tungabhadra aqueducts.²⁵ Portuguese traveller Duarte Barbosa wrote that “in this city are many reservoirs of water and channels cut with such art that all the lands are green and fruitful.”²⁶ Such feats required geological knowledge, surveying skills, and collective labour organization.

- (iii) **Architecture and Urban Engineering.** The pinnacle of Vijayanagar's geometric and technological prowess is found in the architectural accomplishments of the Tuluva era, especially the Vitthala, Hazara Rama, and Krishnaswami temples. Each temple uses new materials and techniques, such as composite columns and granite ribbed domes, while still adhering to the proportionate canons outlined in the Vastu Shastra. When struck, the renowned "musical pillars" of the Vitthala Temple complex produce tonal frequencies, showcasing a mastery of mechanics and acoustics.²⁷ Recent archaeometry research confirms a high degree of material science by attributing this to intentional tuning through variations in stone density. The city itself was a marvel of urban planning. Domingo Paes described it as extending “more than twenty-four miles, with broad streets, markets of all nations, and water conduits everywhere.”²⁸ Archaeological surveys by the Vijayanagar Research Project corroborate these accounts, revealing an urban grid aligned with celestial orientations, an expression of the synthesis between cosmology and engineering.²⁹
- (iv) **Diplomatic and Technical Exchanges.** The Portuguese arrived in India at the same time as Krishnadeva Raya's rule. At Goa, the king had friendly ties with Portuguese officials, sharing technical know-how and embassies. According to Barbosa and Paes, he bought clocks, horses, and artillery from them, modifying foreign technology to suit regional need.³⁰ His desire to use knowledgeable Muslim and Christian craftspeople to build forts and ships was reflected in this practical approach. The insularity of many modern monarchies stands in stark contrast to such openness. Under Krishnadeva Raya,

Vijayanagar's cosmopolitanism reflected a scientific temperament founded on observation, experimentation, and synthesis, values that cut across sectarian lines.

- (v) **Literature, Knowledge and Idea of Science.** The intellectual culture of the Tuluva court was interdisciplinary and multilingual. In addition to their literary works, the renowned Ashta Diggajas (Eight Elephants of Learning), which included Allasani Peddana, Nandi Timmana, and Tenali Ramakrishna, published treatises on prosody, logic, and ethics that demonstrate a spirit of reasoned analysis. Under royal patronage, Telugu poetry frequently used mathematical metaphors and celestial images, demonstrating a scientific imagination infused into art. Botanical and medical understanding also progressed. Formulations utilizing local flora that have been methodically documented based on morphology, an early empirical taxonomy, can be found in the Vaidyashastra manuscripts that were copied around this time. An institutional dedication to applied science is demonstrated by temple inscriptions that document endowments for the maintenance of physicians (vaidya) and veterinary surgeons (gaja-vaidya).³¹

2.3.4 Krishnadeva Raya's Successors and the Decline toward Talikota

Following Krishnadeva Raya's death in 1529, his brother Achyuta Raya and nephew Sadasiva Raya inherited a realm of great riches but also latent instability. Despite her military prowess, the regent Aliya Rama Raya used aggressive diplomacy to enrage the Deccan Sultanates. At initially, his expert use of European mercenaries and artillery was effective, but in the end, the weak alliance of competing Muslim nations came together to oppose him.³²

The outcome of the Battle of Talikota (1565) was disastrous. Despite having well-trained army and better artillery, Vijayanagar lost, its capital was looted, and its shrines were desecrated. The Aravidu dynasty, which restored power from Penukonda and Chandragiri, preserved the empire's scientific traditions and administrative framework, therefore the devastation was not complete.³³ The technological skills developed during the Tuluva era, metallurgy, water management, and surveying, continued to have an impact on South Indian regional politics.

2.3.5 Scientific Temperament of Tuluva Age

The Tuluva monarchs, particularly Krishnadeva Raya, exemplified "empirical dharma", a philosophy that emphasized rational inquiry within a moral framework. They patronized fields of quantifiable knowledge in addition to religious establishments. For example, the

Mahanavami Dibba at Hampi was used as an observatory for astronomy in accordance with equinoctial rising points, in addition to being a platform for ceremonies. The distinctive Vijayanagar synthesis, the use of geometry and observation to validate cosmic order is revealed by such fusions of science and ceremonial³⁴. The concepts of geometry, hydraulics, and ballistics, quantifiable principles that were envisioned as extensions of divine harmony, governed architecture, urbanism, irrigation, and combat. This reasoning has always been praised by the Portuguese chroniclers. "The king is a man of great justice and reason, and he inquires into all things himself," mentioned Paes³⁵. European contemporaries saw Vijayanagar's synthesis of reason and faith as a reflection of Renaissance humanism.

The reign of Krishnadeva Raya provides compelling evidence of applied scientific reasoning through large-scale hydraulic enterprises. The Kamalapuram tank inscription refers to canal excavation and maintenance works connected to the Tungabhadra river system, reflecting advanced knowledge of gradient control, seasonal hydrology, and water storage.³⁶ These projects were not symbolic but functionally designed to support agrarian productivity and urban sustainability.

2.4 The Aravidu Dynasty and the Intellectual Legacy of Vijayanagar (1565 – 1646 CE)

Even though Vijayanagar's material splendour was destroyed by the Talikota disaster in 1565 CE, its institutional legacy remained intact. The Battle of Talikota served as the culmination. Rama Raya, the force behind the child-king Sadashiva's throne, incited the Deccan sultans to form an alliance. The great armies clashed on January 23, 1565, close to Bijapur. Vijayanagar's soldiers fell apart following a bloody fight that was characterized by the resolute use of Muslim artillery. The army's defeat was sparked by the capture and beheading of Rama Raya. Following a five-month siege, the capital was overrun by the triumphant sultanates. An era came to an end when Vijayanagar was destroyed and King Sadasiva and Tirumala fled south. The devastation of the capital is described with amazement in modern Portuguese and Persian texts. Caesar Frederick, an Italian traveller in 1567 describes, "The city of Bisnagar is not altogether destroyed, yet the houses stand still, but empty, and there is dwelling in them nothing but tigress and other wild beasts."³⁷ However, as Burton Stein has pointed out, "the empire broke up not as a state but as a capital; its administrative apparatus survived, moving southward with the Aravidu rulers. The destruction of the city of Vijayanagara did not bring to an end the political and military structures which had sustained it."³⁸ The surviving members of the royal family reassembled at Penukonda after Aliya Rama Raya's passing, and then at Chandragiri and Vellore.³⁹ The Aravidu dynasty (1565–1646 CE) attempted to preserve the continuity of government, trade, and intellectual activity from these new locations.

Though territorially diminished, the state persisted as a cultural commonwealth whose influence extended into Nayaka polities such as Tanjavur, Madurai, and Gingee.⁴⁰

2.4.1 Tirumala Deva Raya and the Re-establishment of Authority

Tirumala Deva Raya (1565–1572), the first Aravidu king, had to restore war-ravaged fiscal systems.⁴¹ His copper-plate charters, which carry on the Vijayanagar tradition of empirical administration, document careful attention to land measurement, temple tax, and irrigation repair. The restoration of the Kondaveedu and Penneru canal networks by royal engineers is mentioned in the Penukonda Inscriptions⁴², indicating a practical approach to ecological rehabilitation. Tirumala Deva Raya engaged in diplomatic negotiations with the sultans of Qutb Shahi and Bijapur, trading architects and craftsmen.⁴³ Such interregional cooperation is evidence of a persistent, if waning, scientific cosmopolitanism. Penukonda became the new capital of Tirumala Deva Raya. On a smaller scale, the Aravidu monarchs repelled the forces of Golconda and Bijapur whenever they could. Tirumala reclaimed a large portion of the southern Andhra plateau in 1567–1568.

2.4.2 Venkatapati Raya I and the Southern Renaissance

Venkatapati Raya I (1586-1614) brought about a partial renaissance in Vijayanagar. The Chandragiri court developed into a hub of patronage for the arts and sciences. Evidence of residual engineering expertise may be seen in the Chandragiri palace's vaulted granite ceilings, which were built using corbelled techniques reminiscent of previous Hampi building. Increased communication with European trading companies also occurred during Venkatapati's rule. Laksman Nayaka, the chief minister of the monarch, established Sanskrit grammar and mathematics schools (ghatikas) in Kanchi and Srirangam. Grants to ganakas (calculators) for the upkeep of lunar tables used in festival timing are documented in epigraphs. These gifts demonstrate that the fourteenth-century scientific bureaucracy had not vanished but rather had adjusted to the new political climate.

2.4.3 Continuity Through Nayaka States

Although central power declined even further after 1614, Vijayanagara's scientific and administrative models persisted throughout the kingdoms that followed the Nayakas. The same empirical attitude was reflected in Tanjavur, where kings like as Raghunatha Nayaka (r. 1600-1634) commissioned treatises on mechanics (Yantra Prakarana) and music theory (Sangita Sudha). The astronomical towers and enormous water tanks constructed by the Madurai Nayakas were modelled after Hampi models. Ongoing experiments with geometry and light are seen in the Thirumalai Nayak Palace in Madurai, which features sophisticated vault engineering and optical alignment for solar illumination.⁴⁴ The continued innovation

demonstrates that Vijayanagar's scientific temperament had been ingrained in the culture. Through religious organizations, craft guilds, and hereditary professions, artisans, mathematicians, and engineers continued to spread their expertise even after the empire was divided. As a result, while northern India experienced Mughal consolidation, the south continued to be a thriving area of technical continuity.

2.4.4 Intellectual Legacy and Transmission of Knowledge

Beyond irrigation and construction, Vijayanagar's intellectual legacy included astronomy, mathematics, and medicine. Astronomical constants that had previously been in circulation in Vijayanagar were cited by scholars of the seventeenth-century Kerala School, including Jyesthadeva and Sankara Variyar.⁴⁵ The concurrent development of mathematical thought points to common institutional roots in temple-college networks extending from Hampi to Kerala, even though direct sponsorship ties are up for question. The metallurgical traditions of South India also demonstrated the tenacity of logical investigation. Later British observers recorded the renowned Wootz steel industry of Mysore and Salem, which most likely developed from methods honed under Vijayanagar's tutelage, particularly in the casting of temple bells and firearms. The empirical continuity that transcended the political structure of the empire is best illustrated by such technological memory.

2.5 Economic and Military Dimensions

Massive riches and military might, supported by sophisticated planning and technology, were the foundations of the Vijayanagar Empire's expansion. In 1514, Duarte Barbosa observed that the "kingdom of Narsinga" (Vijayanagar) "is very rich, and well supplied with provisions, and is very full of cities and large townships."⁴⁶ This is one example of the extraordinary prosperity depicted by early Portuguese travellers.

During the reign of Vijayanagar, the coastal port of Bhatkal imported horses and pearls and exported iron, spices, and pharmaceuticals. Within the capital itself, a "infinite trade" blossomed, with markets selling luxury items (silk brocades, coral, scarlet fabric) and jewels (pearls, rubies, emeralds, diamonds) from far-off places (Pegu, Ceylon, Ormuz). Sewell highlights that the countryside also made a contribution: royal finances were maintained by temple endowments, agricultural products from well-irrigated lands, and mineral wealth (diamond mines in the empire). According to inscriptions, endowments of land and cash were given to the famous Krishna Swami temple and others.

Vijayanagar combined technological superiority with military might to create the biggest army in southern India. With an army of 1,100,000 men, Abdur Razzak (Persian envoy, 1443), estimated that the Raya were lords of "all Southern India, from sea to sea ... from the frontier

of Serendib (Ceylon) to the extremities of Kalbergah." Subsequent Portuguese reports quantify this power: according to Barbosa, Krishna Deva Raya personally had a private retinue of over 20,000 horses and nine hundred war elephants, as well as "more than a hundred thousand men, both horse and foot, to whom he gives pay." These numbers demonstrate Vijayanagar's ability to organize sizable armies across several theatres.

Modern weapons were adopted by Vijayanagar army. The use of heavy artillery, or "heavy guns," in siege warfare is mentioned in the inscriptions and chronicles. Guns and engineers were provided by Portuguese allies; for example, Christovão de Figueiredo, a Portuguese captain, assisted the attack during Krishna Deva's siege of Raichur (1520), hinting at the impact of Europe on local combat. Elephants' "ornamental plates of steel" are a testament to the mastery of forgers, and countless elephants were trained for parade and battle; Paes claims to have witnessed "more than a thousand elephants in size like mountains" at a royal feast. Meticulous metallurgy went into the weapons.

2.5.1 Military Science

The Vijayanagar Empire's expansion and growth were deeply bound up with its military science and technical innovation. In the geopolitically unstable Deccan the survival of the empire depended not only on spiritual authority, but also on scientific preparation, systematic application of engineering, metallurgy and strategic planning to fight the battles. Vijayanagar eventually developed one of the most sophisticated military organizations in medieval south Asia, by blending local traditions and foreign technology acquired through diplomacy and trade.

The military of the Vijayanagar had a scientific attitude because of the city's strategic position. The capital city of Hampi was constructed on the flanks of steep granite hills, thus providing a natural fortress, and the brilliance of human engineering. The exterior defensive walls were orientated according to the topography, while the interior enclosures were polygonal; the walls were constructed of interlocking granite blocks without the use of cement (i.e., blocks that absorb impacts without cementing)⁴⁷. These fortifications were very inventive in their choice of terrain for protection using natural topography and strategic architectural design.

The scientific use of artillery and metallurgy constituted a watershed moment in Vijayanagar's military technology. By the fifteenth century, the empire had acquired gunpowder weapons after coming into touch with Turkish, Persian, and Portuguese sources. The foundries of Hampi and Chandragiri made cannons and small guns out of bronze, iron, and brass alloys, exhibiting a practical mastery of metallurgical chemistry. There are references to efficient Turkish

gunners at Krishnadeva Raya's court, suggesting a global outlook. The guns were incorporated as a part of the capital's multi-layered defence and were used effectively during the field battles like Raichur (1520 CE) in which Krishnadeva Raya is seen using the gun to great effect on the Bijapur army, who were knowledgeable of the modern artillery.⁴⁸

The Vijayanagar army was organised with scientific precision in terms of categorisation and logistics. The four divisions, that is the infantry, cavalry, elephants, and artillery were backed by specialist departments for weaponry manufacturing, transportation, and rationing. The *Amaram* system, in which military chieftains received land payments in exchange for keeping troops, provided a steady supply of disciplined forces. Inscriptions and trip narratives indicate the rigorous record-keeping required to maintain army rosters, supplies, and weaponry, indicating an early bureaucratic-military complex based on empirical administration. The empire's effective communication network, which included signal towers and courier routes, improved the coordination of enormous troops throughout the Deccan.

The architecture of warfare in Vijayanagar showed both aesthetic and practical intelligence. The ceremonial nature of the Mahanavami Dibba did not detract from its role as a venue for assessing military parades and planning military campaigns, representing the melding of ritual and reason. The defence stations of the empire were not located in individual buildings, but were part of an integrated urban-military systems where the spatial design, surveillance and logistics were all scientifically connected. A blend of technology and government, that preempted early modern military urbanism concepts, later seen in fortified towns in Europe. It is possible that Vijayanagar's military mindset was a reflection of a broader scientific attitude that valued observation, measurement and experimentation. A conscious attempt has been made to improve technology is evident in the use of imported weaponry, the use of geometric ideas in fortification, and the uniformity of the weapon design. Vijayanagar's attitude towards technology was not dogmatic and xenophobic, but empirical and absorptive, working towards innovation from all sources. By being able to experiment, this made it possible for the empire to stay military dominant for over 200 years.⁴⁹

In conclusion, the military science of Vijayanagar exemplifies the **fusion of knowledge and power**. The rulers and engineers applied principles of geometry, metallurgy, and hydraulics with a degree of superiority which was rarely found in that time. Their achievements were not confined to the battlefield but extended to the scientific organization.

Thus, the Vijayanagar state emerges as a model of technological wisdom within a religious framework where warfare itself became an expression of both human ingenuity and divine order.

2.6 Interaction with Other Cultures and Knowledge Systems

Vijayanagar's scientific culture was not isolated as it got benefits from interaction with other intellectual cultures. The cosmopolitan nature of the empire created diplomatic ties with Persia, Arabia, and Portugal which resulted in a cross-cultural exchange of science and medicine. The Portuguese engineers and physicians came during the reign of Krishnadeva Raya with the advancements in fortification design, metallurgy and naval construction. According to Domingo Paes and Duarte Barbosa, Vijayanagar's ports and marketplaces served as hubs for Indian and European artists to share shipbuilding and metallurgical expertise.

Islamic scientific philosophy, notably from the Bahmani and Deccan Sultanates, aided in the spread of Unani medicine and astronomical devices such as the astrolabe⁵⁰. Similarly, Arab commercial contacts facilitated the sharing of pharmacological knowledge, as evidenced by the use of Arabic botanical words in Sanskrit medical writings discovered near Hampi and Madurai.

Instead of rejecting foreign knowledge, Vijayanagar's kings incorporated it within their cultural framework. This method of intellectual integration displays a diversified scientific viewpoint, establishing Vijayanagar as part of the larger Afro-Asian knowledge network that foreshadowed current globalisation.

2.7 Intellectual Climate and Education System

The dynastic pattern of scientific and educational development outlined in **Table 2.1** is substantiated by a wide range of epigraphic and literary evidence from the Vijayanagar period. Sangama-period inscriptions from Sringeri, Hampi, and the Tungabhadra basin record land grants and stipends to mathas and agraharas, confirms Vijayanagar's intellectual life revolved around temple universities (mathas, agraharas, and gurukulas), which integrated metaphysical and scientific teaching. Institutions such as Sringeri, Kanchipuram, Tirupati, and Hampi developed became centres of logical and empirical learning⁵¹. These institutions acted as centres of learning where astronomy, philosophy, and ritual sciences were cultivated under scholars such as Vidyaranya and Sayana. These records corroborate literary references in Sayana's Vedic commentaries, which reflect an intellectual environment combining scriptural scholarship with empirical observation. During the Saluva period, temple inscriptions referring

to donations made to vaidya-sabhās and scholarly assemblies support the literary tradition that points to the compilation and transmission of medical and astronomical knowledge within temple-based schools. The Tuluva dynasty's scientific patronage, particularly under Krishnadeva Raya, is attested both epigraphically through inscriptions detailing irrigation works, temple construction, and support to learned professionals and textually through works such as the *Amuktamalyada*, which explicitly links ethical governance with public health, agrarian management, and social welfare. Finally, Aravidu-period inscriptions and manuscript colophons indicate continued patronage of scholars and preservation of astronomical and mathematical texts even after the political setback of Talikota, lending historical depth to the continuity of scientific traditions reflected in **Table 2.1**. Teachers taught pupils about the śāstras (astronomy, Āyurveda, architecture, and mathematics) as both holy and practical subjects. Inscriptions are stipends awarded to academics for maintaining observatories and medical schools. Pedagogically, instruction followed the dialogical paradigm (śruti-smṛti-anubhava) of listening, memorising, and experience learning, which is surprisingly similar to the present constructivist approach in education. The curriculum included moral reasoning (dharma) and technological skill making sure that science provides benefits to society rather than just accumulating information.

The combination of theory, practice and morals contributed to the establishment of a humanistic scientific culture. Under such circumstances individuals as as Sayana, Vidyaranya, and Nilakantha Somayaji arose, who blended together the holiness of philosophy with the empirical observation, which is characteristic of Vijayanagar.

Period / Dynasty	Major Rulers	Scientific & Technological Contributions	Domains of Advancement
Sangama Dynasty (1336 – 1485 CE)	Harihara I, Bukka Raya I, Deva Raya II	Foundation of empire; establishment of Sringeri Math as an intellectual scientific hub under Vidyaranya and Sayana; initiation of irrigation works along the Tungabhadra.	Education & Philosophy, Hydraulics, Administrative Science
Saluva Dynasty (1485 – 1505 CE)	Saluva Narasimha Deva Raya	Revival of scholarship; compilation of medical and astronomical texts in temple schools; patronage to physicians and mathematicians.	Medicine, Astronomy
Tuluva Dynasty (1505 – 1565 CE)	Krishnadeva Raya, Achyuta Raya	Golden Age of scientific inquiry; <i>Amuktamalyada</i> prescribing ethical statecraft and public health; construction of advanced hydraulic networks and resonant temple	Public Health, Civil Engineering, Architecture, Mathematics

Period / Dynasty	Major Rulers	Scientific & Technological Contributions	Domains of Advancement
		architecture.	
Aravidu Dynasty (1565 – 1646 CE)	Tirumala Deva Raya, Venkatapati Raya	Preservation of scholarly traditions post-Talikota; dissemination of astronomical and mathematical manuscripts; temple restorations with technical precision.	Continuity of Science, Manuscript Transmission, Conservation Engineering

Table 2.1 – Chronological overview of Vijayanagar rulers and their contributions to science and technology.

2.8 Political Ideology and Kingship: Dharma, Reason, and Realpolitik

The foundation and survival of the Vijayanagar empire were not purely military but rested on a unique political ideology that combined dharma (moral law), yukti (reason) and artha (statecraft). The rulers of Vijayanagar intentionally established a political culture that combined spiritual legitimisation and administrative efficiency by representing their rule as God-given and rational. This amalgamation of value created an arena for the development of moral and political leadership in South India and a protection from the northern invaders.

The early Sangama rulers used the concept of Rājadharmā from classical works such as the Arthaśāstra and Dharmasūtras as the basis for their ideology. The king was seen as a divinely ordained custodian of order, responsible for protecting both bhūmi (territory) and dharma (righteousness). However, unlike theocratic models of earlier South Indian polities, Vijayanagar kingship included a strong element of empirical governance based on observation, taxation, and bureaucratic rationality. Krishnadeva Raya's reign (1509-1529 CE) represented the blending of ethical and rational rule. His renowned Telugu work Amuktamalyada articulates a complex philosophy of kingship that highlights the sovereign as a servant of the people, governed by reason, justice, and efficiency rather than ceremony.⁵²

The intellectual impact of the Sringeri Matha, as well as Vidyaranya and Sayana's writings, strengthened the spiritual foundations of Vijayanagar royalty. Vidyaranya, the philosopher-statesman often credited with leading Harihara I and Bukka Raya I, saw the state as a dharmic instrument, a method of restoring equilibrium in a society torn apart by moral and political degradation. Sarvadarśanasaṅgraha consolidated the multiplicity of Indian philosophical systems and established an epistemological framework for tolerance and rational inquiry in governance.⁵³ Thus, under his leadership, Vijayanagar developed a polity in which religion

served as a moral compass rather than a burden on rational statecraft.

The Vijayanagar kingship model also adopted a realistic approach to political reality. The kings took Persian administrative names, royal emblems, and adopted courtly customs from the Bahmani and Delhi Sultanates.⁵⁴ Thus they combined Islamic and Hindu power symbols to demonstrate cosmopolitan legitimacy. Krishnadeva Raya's title "Hindu Suratrana", which literally means "Sultan among Hindu Kings", is an example of adaptable political doctrine. It expressed both confidence and strategic diplomacy, reflecting Vijayanagar's religious identity which was flexible rather than exclusive. The empire's multi-ethnic court, which comprised Telugu, Kannada, Tamil, and Muslim officials represents inclusive administration based on merit and loyalty rather than ancestry.⁵⁵

Krishnadeva Raya's political vision reflected a practical understanding of realpolitik, where diplomacy and military strategy were employed to ensure long-term political stability and economic prosperity. His policies of alliances and conflicts with the Deccan Sultanates safeguarded key trade routes and secured access to vital agricultural and mineral resources. In particular, his strategy for the control of **Tungabhadra–Krishna corridor** demonstrates how he utilised geography of the region as both a defensive and economic asset. The Ashta Diggajas, his court's eight academics, frequently described kingship using metaphors of balance, measurement, and order, implying an intellectual milieu in which political authority was conceptualised in scientific and ethical terms.⁵⁶

Administrative inscriptions from the time demonstrate a scientific approach to governing. Land surveys, revenue categorisation, and record-keeping systems exemplified quantitative and empirical management. The amaram system, in which military leaders were given revenue-producing territories in exchange for service, exemplifies an early type of bureaucratic rationalisation that balanced decentralisation with royal control.⁵⁷ Vijayanagar's processes altered the notion of royalty from divine despotism to a rationally ordered, ethically constrained monarchy.

In essence, the Vijayanagar Empire expressed a worldview of kingship that reconciled the metaphysical and tangible. Its kings used dharmic principles to legitimise their authority while governing with logic, facts, and practical knowledge. Vijayanagar, which combined moral order and administrative logic, was a political experiment of its own kind, a unique blend of mediaeval religion and early modern reason. This balance made the empire last and lasted in spiritual and scientific terms.

2.9 Diplomatic Networks: Vijayanagar in the Indian Ocean World

The political extension of the Vijayanagar Empire was not confined to the plateau of Deccan,

it extended through a network of diplomatic, economic and nautical relationships in South India with the wider Indian Ocean region. The Vijayanagar monarchs followed an extremely pragmatic foreign policy, one that involved both fighting and bargaining, competition and collaboration. In the fifteenth and the sixteenth centuries their diplomacy was a blend of religious symbolism and geopolitical reality, and the empire continued to be a power in its own right on the continent, alongside being part of the global networks of trade, technology and culture.

The empire was surrounded by the Bahmani Sultanate and subsequently its successor kingdoms to the north, the Arabian Sea to the west, and the Bay of Bengal to the east. It necessitated a flexible and adaptable diplomacy. From the establishment of Vijayanagar under Harihara I and Bukka Raya I, it participated actively with Islamic powers, adopting both military and administrative techniques while protecting its cultural autonomy. Contemporary Persian and Arabic historians and travellers, especially Firishta and Abdur Razzak characterise the Vijayanagar court as cosmopolitan, rich, and welcoming to foreign guests. These observers remarked that Muslim envoys and tradesmen were permitted safe conduct and privileges, demonstrating religious openness and political inclusiveness.⁵⁸

Vijayanagar's relations with the Bahmani Sultanate were marked by alternating periods of conflict and reconciliation. The fight for control of the Tungabhadra-Krishna doab was crucial to the military strategy of both empires. But, there were periods of peace marked by treaties, diplomatic marriages, and interchanges of prisoners, which were a sign of mutual recognition of balance of power. The Portuguese sources show Krishnadeva's awareness of the balance of power politics, where diplomacy was regarded as the continuation of warfare⁵⁹. Vijayanagar's ties with the Portuguese who landed in the western coast in the early sixteenth century were of great significance. The two nations shared a similar strategic and economic interest: the Portuguese desired allies against the Bahmani successors; Vijayanagar wanted to import commodities, horses for cavalry and sea artillery. Trade rights and transfers of weapons were facilitated and sovereignty was maintained in the court which was rich in ceremonial splendour, as seen by the envoys of Domingo Paes and Fernao Nuniz. The Portuguese supplied war animals from Arabia and Persia through their Goa and Bhatkal ports and Vijayanagar sent pepper, cloth and precious stones as a response. This link demonstrates the empire's incorporation into global trade and technological transfer, connecting the Indian and European cultures.

Outside its western boundary, Vijayanagar had contact with Sri Lanka, Orissa and the

Pandyas. The empire brought to the Coromandel coast the domination of its sea power, which enabled trade with Ceylon from which elephants and pearls were imported⁶⁰. The partnership with Orissa was strengthened via marital ties, indicated that Vijayanagar's policies towards the eastern seaboard's were of strategic and religious importance. Temples on the shores of the Bay of Bengal and around the entire coastline, especially those at Tirupati and Kanchipuram, acted as diplomatic and pilgrimage centres, promoting cultural harmony between regions.

They could not only exchange trade and politics but technical and intellectual knowledge as well, through these global networks. Arts and crafts from Persian, Arab and Portuguese sources led to the invention of artillery casting, fortification technique and navigation. Likewise, certain aspects of Unani medicine, Arabic astronomy and Persian administrative jargon found their way into the knowledge systems of the Vijayanagar domain, demonstrating that knowledge and culture flowed in both directions. Instead of antagonizing the outside world, the empire "absorbed" and "incorporated" it into its own institutional and cultural system, showing itself to be flexible.

At the ideological level, Vijayanagar's diplomacy was founded on the notion of universal kingship (*sarvabhauma*), in which the ruler's dominion symbolically included all directions. This concept justified the empire's imperial view while sharing powers with others. Krishnadeva Raya's inscriptions emphasises diplomacy as a religious duty that requires prudence (*nīti*) and insight (*pragya*). The empire's embassies and gift exchanges, which included the delivery of rare fabrics and jewels to other courts, presents the image of a cultured and rational government engaged in the world stage.⁶¹

In conclusion, Vijayanagar's diplomatic networks depict an empire actively involved in the politics of trade of material and intellectual. Its rulers proved that strength resided not just in weaponry, but also in adaptation and diplomacy rather than conquest. The empire's involvement in the Indian Ocean region is an example of early modern globalism, in which religion and practicality coexisted. Vijayanagar established as a strong link between interiors of South India and the marine world beyond, with its influence spreading across continents via trade, technology and cultural discussion.

2.10 Resource Ecology and Economic Geography

A deep understanding of resource ecology and environmental management served as the foundation for the Vijayanagar Empire's political strength and success. A well-planned economic structure like balanced trade networks, water management, mineral extraction and agricultural output contributed in the building of this empire. The highly developed hydraulic

engineering was the foundation of this system. The Deccan plateau's arid climate required creative ways to utilise riverine resources and seasonal rainfall. An elaborate system of canals, aqueducts, tanks (kere) and check-dams built under local and royal supervision is confirmed by archaeological and epigraphical evidences from Hampi, Kamalapur and Tungabhadra Valley.⁶² These water-systems were not built at random, but were dependent upon the topographical investigation and geometric accuracy. Catchment reservoirs were set up in relation to natural lowlands to minimise soil erosion and canals were constructed with a very precise gradient to ensure a steady flow. The most outstanding example of pre-modern environmental engineering in South Asia is the Tungabhadra canal complex that supplied urban water for Hampi and irrigation water for the fields⁶³.

This water power was of great service to the agri-cultural economy of the empire. There are several types of irrigated land mentioned in epigraphic documents, categorized according to appropriateness of crops and tax assessment⁶⁴, such as kaval (pasture), punjai (dry land) and nanjai (wet land). This is a scientific, empirically oriented land management approach. Several cropping patterns were employed depending on the type of soil, rainfall and availability of water. In the semi-arid sections, millets and pulses were cultivated while in the irrigated tracts paddy, sugarcane and betel were cultivated. Examples of this ecological awareness that has kept soils productive over generations are crop rotation and manure-based fertilisation. These techniques transformed the empire into a huge agricultural region capable of supporting large populations and military bases in the cities.

The geography of resource utilization of the State of Vijayanagar also encompassed the mining and harvesting of mineral and forest resources. The Deccan region was rich in iron ore, copper, gold and precious stones which were lucrative and were exploited on a scientific basis under the government. Weapon making and iron smelting were the specialty of the southern part of the empire, particularly that of Bellary and Anantapur, and as such metallurgy was linked to military power. Portuguese explorers such as Fernao Nuniz report that diamond mining was also a lucrative export and provided a connection to the international trade networks of Vijayanagar. Meanwhile, forest areas supported an integrated ecological economy yielding lumber, resin and medicinal herbs. State control on resource exploitation and environmental boundaries is reflected in the administrative records with Kadu (forest lands) being treated as separate fiscal units.

The commercial extension of Vijayanagar's environmental management could be seen in its commerce infrastructure. A well laid out road network united the empire's major centres by connecting them with coastal ports like Goa, Honnavar, Mangalore, and Masulipatnam with

inland production zones. These routes made it easier to transport excess agricultural products, textiles, iron, and spices to the Indian Ocean's maritime markets. These ports were used by Portuguese, Arab, and Chinese traders who traded South Indian goods for horses, silk, and precious metals.⁶⁵ Stone platforms for trade lined the inland bazaar streets of Hampi, Penukonda, and Chandragiri, demonstrating an urban planning approach that combined architectural and commercial design.⁶⁶

The standardisation of weights, measures, and monetary systems demonstrates the Vijayanagar officials' scientific temperament. Inscriptions demonstrate a sophisticated grasp of mathematical calibration by mentioning the usage of units such as *kalan*, *gadyana*, and *pon* for weighing grain and gold. In addition to royal insignia, coins made of gold, silver, and copper had symbolic symbols like the sun-moon and boar (*Varaha*), which stand for wealth and continuity. In order to facilitate commerce and taxation, exchange value was sensibly standardised in an empirically based economy, as demonstrated by this numismatic evidence.⁶⁷

The empire's environmental awareness went beyond practical administration and resulted in cultural respect for the natural world. Land grants for the upkeep of tanks, gardens, and groves are commonly documented in temple inscriptions, suggesting that environmental maintenance was considered both an administrative as well as religious responsibility. The close connections between irrigation systems and temples suggests that the Vijayanagar rulers integrated ecological balance into their morality because they viewed nature as both a sacred resource and a scientific field.

Thus, the environmental and economic systems of the empire created a network of interconnected administrative and environmental intelligence. The Vijayanagar state functioned on principles of balancing exploitation with regeneration and growth with conservation. It can be seen by the cooperation between water engineering, agrarian reform, and trade logistics. Its economic geography supported one of the biggest empires in South Indian history through active scientific experimentation and control rather than as a passive setting for political power. Vijayanagar is a monument to the scientific logic of pre-modern India, when political wisdom and environmental management were inseparably linked.

The empire developed a worldview based on observation, synthesis and practical adaptation. It is evident from the astronomical alignments of the Mahanavami Dibba to the urban planning of Hampi; from the commentaries of the Sayana to the administrative arithmetic of Krishnadeva Raya; from hydraulic engineering to metallurgical innovation. This continuity

was a result of the contributions of the four dynasties: Sangama, Saluva, Tuluva, and Aravidu. Under Krishnadeva Raya, the Tuluvas incorporated world technologies and mathematical astronomy. The Saluvas streamlined administration. The Sangamas established the groundwork through irrigation and temple reconstruction and the Aravidus preserved these traditions through cultural persistence. Taking all evidences together, the Eurocentric narrative of scientific modernity is called into question by Vijayanagar's story. Its rulers were the epitome of a "scientific dharma", a kind of logical statecraft in which faith, reason, and technical proficiency all coexisted together. The intellectual legacy of the empire influenced South India's educational, cultural, and technical life long after it fell, leaving behind a landscape that still bears witness to the builders' logical creativity.

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Chapter 3: Development of Medical Science

3.1 Introduction A golden age in South Indian history, the Vijayanagar Empire (1336–1642) is renowned for its contributions to medical knowledge as well as for artistic accomplishments and political unification. The thriving cities of the empire, especially its capital, Hampi, developed as hubs for the fusion of many intellectual and cultural currents. In this context, medical practice represented the interplay between foreign traditions like Unani, which were brought about by academic and commercial interactions, and indigenous systems like Ayurveda and Siddha. This chapter covers the continuity of indigenous medicine, the cross-cultural impacts of Unani and Arab medical philosophy, and the institutional, pharmaceutical, and educational improvements that distinguished healthcare throughout the Vijayanagar era.

During the Middle Ages, the Vijayanagar Empire, saw significant developments in a number of fields, including healthcare and medicine. The Vijayanagar Empire's medical practices left a lasting legacy that influenced further developments in South Indian medicine. By studying this era of medical history, we gain helpful insights into the intersection of culture, society, and healthcare, which contributes to our grasp of the evolution of medicine in the Indian subcontinent. “Specialization in certain diseases or practices was prevalent and the physicians enjoyed a high status and respect in the society.” (RamaRao, 1992)

3.2 Medical Transition An important turning point in South India's medical development occurred during the Vijayanagar period (1336–1642). The medical landscape of the empire developed into a vibrant and heterogeneous field influenced by both external and internal refinement, yet having its roots in the ancient traditions of Ayurveda and Siddha. The shift that took place throughout this time period demonstrated a great ability to adapt and synthesise information in addition to the persistence of old knowledge.

The theoretical foundation of Indian medicine was long established by the ancient Ayurvedic texts, particularly the Sushruta Samhita and the Caraka Samhita. While the Sushruta Samhita focused on surgical and anatomical research (śalyacikitsā), the Caraka Samhita focused on internal medicine (kāyacikitsā), stressing the need of maintaining equilibrium among the tridoṣa, vāta, pitta, and kapha. However, medical knowledge started to move away from textual orthodoxy by the fourteenth century. More emphasis was placed on nidanashastra (diagnostics), dravya-guna-vijnana (pharmacy), and rasashastra (alchemy and chemical medicine) by Vijayanagar doctors and academics¹. This change was gradual rather than sudden.

This change is evident in the 14th-century Sārangadhara Samhita, which introduces new techniques for preparing medications, calculating dosages, and using metals and minerals in medicine². These shifts point to a developing empirical approach that valued both scriptural instruction and exploration. Instead of only providing theoretical explanations, the focus on dose, storage, and preparation demonstrated hands-on involvement with therapies.

This medical revolution was significantly advanced by the cosmopolitan character of the Vijayanagar Empire. Vijayanagar was a hub for intellectual and cultural exchange between the Arab, Persian, and East Asian worlds due to its advantageous location on the Deccan plateau and integration into the Indian Ocean trading network³. Medical concepts and supplies were freely exchanged via these trading lines. Particularly in humoral principles, illness categorisation, and compound pharmacology, the impact of Unani Tibb, the Greco-Arab medical system brought by Persian and Arab scholars, became apparent⁴. During the Vijayanagar era, diagnostic techniques become more methodical. Classical Ayurvedic diagnostic frameworks such as *Dashavidha Pariksha* (tenfold patient examination) and *Trividha Pariksha* (threefold examination involving observation, touch/palpation, and interrogation) formed an integral part of traditional medical practice in medieval India. These methodologies are described in foundational Ayurvedic texts, particularly the Charaka and Sushruta traditions and are documented in modern academic reviews as systematic approaches to patient diagnosis and assessment.⁵ Originating from earlier Siddha and Buddhist practices, pulse examination (nāḍī- parīkṣā) became more standardised and is commonly mentioned in medical texts like Lakshmana Pandita's Yogacandrikā (15th century).

During the Vijayanagar era, medical education was strongly associated with royal institutions, monasteries, and temples. According to inscriptions and copperplate grants, learnt doctors, or vaidyarajas, were compensated with land endowments, which were frequently connected to temple establishments⁶. These institutions served as both places of worship and intellectual centres, where medical writings were written, copied, and disseminated. The continuation of the medical tradition was maintained by this institutional support under royal supervision, particularly under kings like Devaraya II and Krishnadevaraya⁷. It also promoted the writing of important works like Sayanacharya's Ayurveda Sudhanidhi and Damodar Bhatt's Arogya Chintamani.

3.3 Medical Literature under Vijayanagar Empire

3.3.1 Ayurveda Sudhanidhi in Sanskrit was written by Sayanacharya, also called Sayana Madhava, a Sanskrit scholar who lived in the 14th century under the Vijayanagar King's

patronage. In this text, Sayanacharya put together a wealth of knowledge on Ayurveda, the ancient Indian medical system, including exhaustive descriptions of diseases, their causes, symptoms, and treatments. The "Ayurveda Sudhanidhi" is an invaluable resource for practitioners and scholars studying traditional Ayurvedic medicine. It is frequently studied together with other important Ayurvedic texts, such as the Charaka Samhita and the Sushruta Samhita.

3.3.2 Arogya Chintamani by Damodar Bhatt in Sanskrit is well known for covering every facet of Ayurveda, including diagnosis, treatment, and the fundamentals of preserving health and wellbeing. "Arogya Chintamani" offers comprehensive insights into the causes, symptoms, and treatments of various diseases in addition to recommendations for preventive healthcare, much like many other classic Ayurvedic texts.

3.3.3 Netradarpanam by Panakalaraya written in Telugu on **Ophthalmology** offers in-depth information on eye conditions, including symptoms, diagnosis, and treatment options. "Netra Darpanam" is still applicable for practitioners and scholars who are researching Ayurvedic eye care because of its substantial value to conventional Indian medicine, especially in the area of ophthalmology. According to the author, his knowledge of medicine earned him the respect of many kings.⁸

3.3.4 Vaidyarajvallabham and Yogacandrika of Lakshmana Pandita. Astangahrdaya has a major influence on Yogacandrika. The author aimed to provide a list of easily accessible medications for common illnesses that are helpful in a general practitioner's daily practice. Even though the text includes instructions for preparing rasa and other complex recipes, the focus seems to be solely on simple recipes. This work has given exhaustive symptoms and their treatment for various diseases like fever, cough, vomiting, inflammation, treatment of insanity, tuberculosis, piles, diarrhea, abdominal ailments, loss of memory, skin disorders including leprosy, urinary disorders including diabetes mellitus. For each of the eight branches of Ayurveda, the author has consistently used the term "Tantra," such as "Shalya Tantra" for "Shalya Chikitsa," which is uncommon in Ayurvedic literature. The majority of ayurvedic literature recognises six rasas; however, Lakshmana Pandit removed Lavana (salt) from the collection, leaving five rasas.

3.3.5 Vaidyamitra by Siddhardeva covers a range of topics related to Ayurvedic medicine, such as diagnosis principles, treatment modalities, herbal remedies, dietary advice, and lifestyle practices that enhance health and well-being. It is regarded as an invaluable tool for Ayurvedic practitioners and academics, providing insights into conventional therapeutic techniques and comprehensive healthcare approaches.

3.3.6 Khagendramani darpan by Manjraja I. This text addresses the diagnosis and therapy of poisoning, with a particular focus on toxicology (Visha Chikitsa) in Ayurveda. It gives thorough explanations of many harmful substances, their physiological effects, and how to treat and counteract them. Like many other classic Ayurvedic texts, "Khagendramani Darpan" is studied by scholars and practitioners for its importance to the field of toxicology and treatment methods for ailments related to poisoning. It also provides insightful information about traditional Indian medicine.

3.3.7 Rasamanjiri by ShriShalinath of 15th century is a work on Ayurvedic alchemy (*rasāsāstra*), which includes information on the preparation, characteristics, purification and medicinal applications of metallic and mineral compounds used in Ayurvedic medicine, among other topics related to alchemy. The book contains 10 chapters. It is well known for its understanding of the production of alchemical medications and how they are used in conventional Indian medicine.

3.3.8 Sārangdhara Samhita by Sārangdhara is a 14th century medical literature in which the author has acknowledged four types of diseases. These are *Svābhavika* (natural manifested conditions like hunger, sleep, ageing process etc.), *Agantuka* (Accidental diseases caused by injury), *Kayika* (Diseases occurring due to irregular diet, and activities.), *Antāra rog* (Psychological disorders like insanity). The text contains 32 chapters with 2600 stanzas. The importance of correct amount of dose of medicine is brought out in the beginning only under the chapter named *Māna* (measurement). Sārangdhar introduced new species of plants that were not widely used as drugs. Sārangdhar recommended using dry drugs for medicinal purposes. If a dry drug is unavailable, a freshly prepared drug can be chosen in its place, but the amount should be doubled. This indicates dry drugs have higher potency compared to fresh drugs. Having said that the author emphasised some drugs like Ashwagandha that are to be used fresh only and quantity is not to be doubled

3.4 Drug Ingredients and Availability

Indigenous flora served as the foundation for medicinal preparation throughout this time. The Vijayanagar Empire's Ayurvedic and Siddha texts, such as Sārangadhara Samhita and Vaidyaraj Vallabham, mention a variety of medicinal herbs and roots, such as āmala (*Embllica officinalis*), chandana (*Santalum album*), haritaki (*Terminalia chebula*), ashwagandha (*Withania somnifera*), nikumbha (*Baliospermum montanum*), and karanja (*Pongamia pinnata*).

These were employed in remedies for stomach issues, skin diseases, and respiratory symptoms⁹.

While local ingredients were commonly used by medical practitioners at the time, evidence suggests that some drugs were imported from foreign nations. Imported drugs were higher quality compared to those available locally¹⁰. By encouraging significant trade with Arabia, Persia, Southeast Asia, and the Mediterranean, the Vijayanagar dynasty made sure that a consistent supply of exotic medications and raw materials arrived, greatly enhancing the local pharmacopoeia¹¹. The Vijayanagar kingdom relied heavily on *camphor* sourced from Borneo and Sumatra. The Dutch brought Japanese and Chinese camphor to Masulipattanam.¹² *Baticala Sugar, ginger, sandalwood, brasil-wood, nutmegs, long peppers and opium*, which were utilised in making many drugs during the period was majorly imported from China.¹³ The arrival of camphor, opium, and aromatic resins not only altered therapeutic practice, but also contributed to a global flow of medicinal information. The integration of these traditions revealed that the Vijayanagar Empire's medical system was dynamic, forward-thinking, and founded on experimentation and interchange. Duarte Barbosa, a Portuguese traveller who visited India between 1500 and 1516 AD, points out the *abundance of betel leaf* in the hinterland known as *Tāmbul* to Muslims, Arabs, and Persians. The leaf was mixed with a small seed called *areca*. He observed that chewing it and swallowing its juice was beneficial to the habitats in terms of drying and preserving the belly and brain. It relieves flatulence and thirst, so they don't drink anything with it.¹⁴ Abdur Razzak (The envoy from Iran who visited the court of Devraya II in the Vijayanagar empire in 1443 AD.), also stated that it soothes hunger and sparks appetite in those who are satiated, removes unpleasant odours, and strengthens teeth.¹⁵ Palm sugar, palm-wine and coconut (and the oil got therefrom) was obtained from Malabar.¹⁶

Minerals and animal derivatives, in addition to plants and imported plant items, were essential components of the empire's medicinal system. Rasaśāstra formulations required locally accessible chemicals such as rock salt, white arsenic, sulphur, alum, and calamite. These remedies combined metals and minerals after rigorous purifying (śodhana) procedures¹⁷. Other than using minerals and locally available herbal plants like *āmalā* and *Chandan*, they also used animals and animal products for the preparation of drugs.¹⁸ Sārangdhar used goat bile to purify *Manhashila* (one of the three arsenicals used in Ayurveda), which contains realgar and red arsenic. Application of leeches is also mentioned in cases of ailments of throat and eyes, piles, skin diseases. The leeches which are useful in these cases should be poison less, thin-bodied

and having yellow abdomen. The utilisation of locally accessible herbs, as well as the selective import of uncommon chemicals, demonstrate a sustainable resource management paradigm. The Vijayanagar medicinal system was environmentally embedded: physicians selected plants based on local temperature and season, therefore preserving biodiversity¹⁹. Certain medications, like as ashwagandha, were deliberately prescribed to be taken fresh due to their volatile active ingredients, demonstrating a deep grasp of pharmacognosy.

3.5 Condition of Medical Practitioners

3.5.1 Social Status

It is commonly known that Ayurveda was practiced in ancient India, but its use during the Vijayanagar period is demonstrated by the accounts of European explorers who claimed to have seen scholars from other nations come to study Ayurveda.²⁰ According to the *Amuktamalyada*, (a Telugu book on statecraft's credited to Krishnadeva Raya of Vijayanagar) doctors should only be given what they need to survive; if they are given more, they might disregard the welfare of the populace, which could lead to the spread of disease throughout the nation.²¹ This instruction reflects the ruler's concern for maintaining moral discipline and the professional integrity of the medical class. Physicians were frequently descended from learnt Brahmin families with training in both Ayurveda and the Vedas. However, there is evidence that medical knowledge expanded beyond caste lines. Siddha healers, itinerant herbalists, and temple-based healers were often from non-Brahmin communities, demonstrating the breadth of practical medical knowledge²². This plurality transformed Vijayanagar medicine into a vibrant, community-focused profession rather than an aristocratic monopoly.

3.5.2 Royal Patronage and Land Grants

Physicians in the empire were frequently given land grants as it was a popular mode of salary for the maintenance of various artists and professional practitioners. However, the presence of surgeons in this kingdom is not well known from the inscriptions. **Brahmanakraku village grant inscription** of Harihara II was discovered in Brahmanakraku village near Kavali of Nellore district in Andhra Pradesh. The inscription contains 112 verses and includes a list of learned brāhmins (In Hinduism, a brahmin is a member of the highest class, spiritually and socially. Traditionally, brahmins were priests and teachers). The grant was recorded on five copper plates in the year 1376 A.D. Srigiri Pandita (Son of Srivallabha and brother of Lakshmana Pandita), a renowned scholar in Ayurveda and Yajurveda, was among the brāhmins who received the grant of 64 parts of the village, ranking 31st on the list. Virupaksharya, another renowned physician in 14th century received a land grant²³ from King Virupaksha Raya

II in 1467 A.D. Govind Pandita, who was a practitioner of *Ayurveda* during this time period, is mentioned in plate inscription of Vijayanagar²⁴, which is of 1424 A.D. An inscription from the deserted temple within the fort of Kondavidu, dated 1546 CE (This inscription was found in the deserted temple in the fort of Kondavidu in Palnadu district. This site is located 25 km west of the city of Guntur) during the reign of Sadasiva Deva Raya, records land grants made to several learned individuals identified as *panditas*. Among the **recipients were Parahitapanditulu, Somapanditulu, Lakshmipanditulu, Timmapanditulu, and Aśvavaidya Lakṣmaṇapanditulu**, the latter specifically described as a physician skilled in the treatment of horses. The title *pandita* in this context appears to denote scholar-physicians who combined medical knowledge with scholarly learning. Such substantial endowments indicate the **high social and professional status enjoyed by medical practitioners** within the administrative and military framework of the Vijayanagara state. The presence of an *Aśvavaidya* further reflects the importance of veterinary medicine, particularly equine care, in a polity where cavalry played a crucial role in warfare. The record also notes that Parahitapanditulu later donated land for the deity Gopikavallabha at Kondavidu, illustrating the connection between learned professionals, temple patronage, and religious endowments in the region. Temples frequently housed medical professionals or scholars who practiced medicine. These people were knowledgeable about traditional medical systems such as Ayurveda and Siddha, and they provided medical care to those in need. Their services were occasionally part of the temple's larger community welfare initiatives. Temples, as community centres, were heavily invested in the well-being of the local population. This included not only religious counsel but also care for the people's physical well-being. Healthcare initiatives were viewed as part of the temples' larger community service efforts. This is evident from the land grants during the temple constructions which were also made to scholars including physicians. Paramswami, one of the medical practitioners of early 16th century received such grant during the construction of a temple by King Venkatpati Dev Raya in 1598 AD.²⁵

Royal courts engaged physicians not just to care for kings and nobles, but also to maintain army health and supervise hospitals (aushadhalayas). Temples and monasteries, notably in Hampi, Srirangam, and Tirupati, were important hubs for medical instruction and practice. Temple endowments sometimes included resources for feeding patients, making herbal oils, and assisting resident physicians²⁶. The integration of healthcare with religious organisations emphasises the moral and spiritual aspects of medical treatment in Vijayanagar society.

3.5.3 Public Health Care and Community Service

Vijayanagara temples functioned as major socio-economic institutions maintaining feeding houses (satras) and supporting service personnel through endowed revenues (Saletore 1934, pp. 383–390, 401–408). While not explicitly described as hospitals, these institutions played an important role in charitable welfare and the redistribution of resources.²⁷ A holistic welfare approach like to that of the Dharamashalas of North India is seen in the connection between temples and medical facilities. Temple-affiliated doctors frequently provided care for pilgrims, nearby villages, and labourers building temples. Although the Vijayanagar model was more decentralised and locally integrated, this public welfare system is comparable to the Dar-ul-Shifa hospitals of the Mughal Empire (Arnold 2000). The story of Paramswami, a doctor who was granted land for the construction of a temple in 1598 CE under King Venkatapati Deva Raya, serves as another example of the community-oriented approach to medicine²⁸. The state's acknowledgement of medical services as a type of dharma, a moral obligation in line with religious merit, is demonstrated by his inclusion among temple benefactors.

3.5.4 Women in Medicine

Despite the fact that males made up the bulk of the physicians who were documented throughout the Vijayanagar period, there is evidence from epigraphy, literature, and ethnography that indicates women were also actively involved in traditional healthcare systems. Their primary areas of contribution were in the disciplines of domestic medicine, paediatrics, midwifery, and nursing, all of which are closely related to the structure of the home and the community. Despite seldom being mentioned in royal inscriptions, these female practitioners served as an essential bridge connecting traditional healing practices and professional medicine²⁹. Postpartum remedies and food regimens are mentioned in texts like Sārangadhara Samhita and Bhāvaprakāśa. These were usually delivered by women who had received observation and apprenticeship training. Midwives used herbal oils, decoctions, and fumigation treatments (dhūpana) to manage labour, postnatal care, and newborn hygiene in South Indian families. Parallels between ethnobotany found in Tamil Nadu and Karnataka indicate that traditional birthing procedures and midwifery from the Vijayanagar era are still in use today³⁰. The Siddha medical tradition in the Tamil parts of the Vijayanagar Empire gave women practitioners much more room, especially as herbalists and healers (maruttuvachchi). Women are described as experts in using herbal infusions and spiritual rites to heal fevers, infertility, and mental disease in folklore and early Tamil medical poetry³¹. Their knowledge

embodied the comprehensive philosophy of premodern medicine by fusing astrological and religious traditions with physical treatment.

Despite being under-represented in official historiography, women's contributions to medicine throughout the Vijayanagar era guaranteed the continuation of traditional medical methods through social and family transmission. Due to the overlap between midwifery, temple service, and home medicine, women were positioned as essential but underappreciated members of the empire's healthcare system. In rural South India, their responsibilities symbolise the "invisible continuity" of medical legacy that connected traditional practices and ancient Ayurvedic literature³².

3.5.5 Comparative Perspective

A comparative evaluation of the Vijayanagar medical system with other contemporary medical traditions of the fourteenth to seventeenth centuries, particularly those of Mughal India, West Asia, and early modern Europe reveals the distinctive character of South Indian healthcare institutions and epistemologies. Unlike the centrally administered medical establishments of the Mughal Empire, such as the *Dar-ul-Shifa*, which functioned under imperial supervision and catered primarily to urban elites and courtly populations, the Vijayanagar medical system remained fundamentally decentralised, community-oriented, and embedded within religious and social institutions such as temples, monasteries, and agrarian settlements.³³ In Mughal India, medical practice was heavily influenced by Unani-Tibb, and physicians (hakims and tabibs) were often attached to royal courts, military camps, and urban hospitals. While this facilitated the development of state-sponsored hospitals and salaried medical officials, it also limited the reach of institutional medicine to regions under direct imperial control. In contrast, Vijayanagar physicians operated within a pluralistic medical environment where Ayurveda, Siddha, folk medicine, and selective Unani elements coexisted. Medical care was not monopolised by the state but functioned as a moral and social obligation (*dharma*), closely aligned with temple charity, land grants, and local patronage.³⁴

When compared with contemporary West Asian medical traditions, particularly those flourishing in Persia and the Ottoman Empire, Vijayanagar medicine exhibited a stronger emphasis on preventive care, seasonal regimens (*Ritucharya*), and lifestyle management (*Dinacharya*). While Islamic medical systems excelled in theoretical synthesis of Greco-Arabic humoral pathology and pharmacology, South Indian practitioners demonstrated a pragmatic orientation grounded in ecological awareness, local pharmacognosy, and long-term community health. The systematic use of indigenous herbs, minerals, and animal products

adapted to regional climates suggests a medical rationality shaped as much by environment as by textual authority.³⁵

A comparison with early modern Europe further highlights the uniqueness of the Vijayanagar model. European medicine of the same period remained dominated by Galenic humoral theory and lacked institutionalised public healthcare beyond monastic infirmaries and charitable hospitals. Surgical knowledge was often separated from learned medicine and relegated to barber-surgeons. In contrast, Vijayanagar physicians integrated surgery, pharmacology, diagnostics, and preventive care within a unified medical framework, drawing upon classical texts like *Sushruta Samhita* while simultaneously innovating through Rasashastra and empirical observation.³⁶

Another defining distinction lies in the ethical and spiritual dimensions of medical practice. Vijayanagar medicine did not perceive health merely as the absence of disease but as a balance between body, mind, environment, and moral conduct. The integration of *Sattvavajaya* (psychological therapy) and *Daivavyapāśraya* (spiritual therapy) alongside rational treatments illustrates a holistic worldview largely absent in contemporary European and Islamic medical systems, which increasingly privileged physical intervention over moral or spiritual equilibrium.³⁷ This comparative perspective demonstrates that the Vijayanagar medical tradition cannot be dismissed as merely conservative or derivative. Instead, it represents an adaptive, resilient, and socially responsive healthcare system that successfully balanced classical authority with innovation, spirituality with empiricism, and elite knowledge with community welfare. The endurance of Ayurvedic and Siddha practices in South India well into the colonial period is a testament to the strength of this decentralised medical culture, one that prioritised accessibility, sustainability, and ethical responsibility over bureaucratic control.

3.6 Method of Diagnostic and Treatment

Diagnostic and treatment approaches were based on traditional Ayurvedic principles, but they were reinterpreted via practical experience and other influences. Physicians coupled biblical learning with observation-based analysis and clinical experimentation, exemplifying an early kind of medical rationality³⁸.

3.6.1 Diagnostic Principles and Theoretical Foundations

Though the ayurvedic samhitas contain many elements such as *pancamahabhutas* (five principal elements), *tridosha*, *Vata* (air and space), *Pitta* (fire and bile), and *Kapha* (earth and phlegm), which together regulated human physiology and disease manifestation, *saptadhātu*, *auśadha* (simple drug), *ośadhi* (recipes), *nidānapancaka* (five diagnostic methods), *Nidāna*

(causation), *Pūrvarūpa* (premonitory symptoms), *Rūpa* (clinical manifestations), *Upashaya-Anupashaya* (therapeutic testing), and *Samprapti* (pathogenesis), physicians felt compelled to develop separate treatises on diagnostic methods and treatment over time. This approach urged medical professionals to have a dynamic knowledge of disease rather than a strictly descriptive one. The Vijayanagar period therefore saw a change away from textual authority and towards clinical interpretation, echoing improvements in Unani medicine's humoral diagnoses³⁹. *Sārangadhara Samgraha* of Sarangadhara, *Yogacandrikā* by Lakshmanapandita and *Bhāvaprakāśa* were such works on diagnostics methods and treatment of diseases of 14th, 15th and 16th century during Vijayanagar rule.

3.6.2 Observation and Examination Techniques

Physicians in the Vijayanagar Empire relied on close observation of their patients' symptoms and physical condition. A visual examination, which included determining the colour of the skin, eyes, and tongue, was most likely an important part of the diagnosis. These texts describe the process of analysing a patient's pulse to diagnose the disease and determine his physical and mental state.⁴⁰ The physicians used their first three fingers to determine the pulse.

यभूतवृद्धपञ्चकगुणत्रयः सप्तधातुमर्मादि सप्तशत सप्ताशिराश ताद्ये।

व्याप्त वपुः श्रित इदं पवनोऽस्थापित्तम श्लेष्मा च वर्तयति। ॥७॥

- Yogacandrika (14th – 15th A.D.) p. 5

These texts primarily believed that the body is nourished by *vāta* (Air and Space), *pitta* (Bile juices in abdominal which regulated metabolism.), and *kapha* (Phlegm which manages assimilation in the body.), and their imbalance is the root cause of diseases. These texts also list the causes of their disequilibrium as well as the corrective actions to restore balance. Features of aggravated *vāta*, *pitta*, and *kapha* forms the diagnosis part of the diseases.

अधोमध्यऊर्ध्वं च हृन्नाभितोऽमी क्रमेण स्थिताः हेतुभिः स्वैः प्रदुष्टा ।

स्वलिङ्गैस्तु मेया रुजश्चदधाना शमं भेषजैः स्वैः प्रयुक्तैः प्रयान्ति ॥८॥

- Yogacandrika (14th – 15th A.D.) p. 5

The *vāta*, *pitta*, and *kapha*, located in the lower, middle, and upper regions of the heart and naval cavity, respectively, become distorted due to various reasons. The diseases caused by these reasons are identified based on their characteristic traits and treated with appropriate medication.

3.6.3 Drug Formulation and Dosage Regulation

The Vijayanagar Empire used a complex treatment (Cikitsā) technique. According to, pharmacological writings like as Sārangadhara Samhita emphasise the importance of Māna (measuring) and Matra (dosage) for therapeutic accuracy⁴¹. Medicines were made from plant, mineral, and animal materials, and were frequently processed using intricate alchemical processes based on Rasashastra. The emphasis on precise measurement reflects the growing professionalisation of medicine and the shift towards experimental pharmacology⁴².

Churna (powders), Kashaya (decoctions), Asava-Arishta (fermented preparations), and Ghrita (medicated ghee) were among the preparation techniques. *Arkaprakāśa*, written during this period, is an important book describing different ways of preparing Arka (something concentrated or extracted as if by distilling), including instruments and water ratios. The important features include the mention of five basic principles of medicine preparation, one of which is Arka and is considered to be the most effective. The text also provides the treatment of Syphilis which was supposed to be brought to India by Portuguese and was known as “*Phiraṅgaroga*” (*disease of white men*).

3.6.4 Therapeutic Procedures and Clinical Application

Curative and preventative medicine were incorporated in treatment plans. Detoxification and dosha balancing were common uses of the Panchakarma method, which included Vamana (emesis), Virechana (purgation), Basti (enema), Nasya (nasal treatment), and Raktamoksha (bloodletting). According to contemporary inscriptions and subsequent commentary, cauterisation (Agnikarma), incision (Bhedana), and suturing (Sivana) were also used for abscesses and piles⁴³. According to oral and written traditions, leech treatment (Jalauka-avacharana) was widely used to cure conditions affecting the skin and eyes. According to the Sushruta Samhita and subsequent Vijayanagar scriptures, doctors chose non-poisonous leeches with yellow abdomens. Fumigation (Dhoopana), steam therapy (Swedana), and massage (Abhyanga) were used as supplemental therapies for respiratory disorders and chronic pain⁴⁴. The foundation of treatment was dietary control. During fever, patients were instructed to eat light, easily digested foods like gruel (Yavagu) and thin rice soup (Manda), and for Pitta and Vata illnesses, medicinal ghee. In line with current medical nutrition science, these recommendations demonstrate an understanding of the connection between diet, metabolism, and illness treatment⁴⁵.

3.6.5 Physiological Healing

Vijayanagar medicine identified three therapeutic categories in accordance with traditional

Ayurveda: Sattvavajaya (psychological treatment), Yuktivyapāśraya (rational therapy), and Daivavyapāśraya (spiritual therapy). Even though the latter two were prevalent at the time, spiritual therapy, which included mantra recitation, ceremonial fasting, and moral cleansing, remained essential for re-establishing mental equilibrium. Medical professionals believed that epilepsy (Apsmara) and mental disorders (Unmada) needed to be treated both morally and medically⁴⁶. The humanistic essence of Vijayanagar medicine is shown by this comprehensive fusion of body, mind, and spirit, which is consistent with the larger Indic concept of health as balance rather than the just absence of illness.

3.6.6 Preventive and Seasonal Healthcare

A key component of Vijayanagar medicine was preventive healthcare. To stop epidemics, doctors recommended seasonal practices (*Ritucharya*), which included cleansing, fasting, and food adjustments. The Bhāvaprakāśa described *Dinacharya* (daily practices), with a focus on bathing, meditation, and oil massage (Abhyanga) as ways to stay healthy. Early public health activities may be seen in the distribution of herbal decoctions by temple-based clinics during seasonal epidemics. Travellers like Abdur Razzak have reported that the empire had a low rate of epidemic death, which is probably because of these sanitary and preventative efforts. Thus, the Vijayanagar model exhibits a profound comprehension of communal health that was much ahead of its time.

3.7 Common Diseases and Treatment

The Vijayanagar Empire (1336-1642 CE) had a strong and organised medical system capable of treating a wide range of ailments using indigenous and adaptable remedies. Ayurvedic texts, local customs, and international interactions through sea and inland trade all contributed to medical knowledge during this time period. Diseases were considered not just as physiological abnormalities, but as imbalances in the body, mind, and environment, a paradigm that guided diagnosis and therapy⁴⁷. Some of the common diseases and their treatment are as follows: -

3.7.1 Jwar (Fever)

Fever was typically known as *Jwar* during this period and was considered to rise due to imbalance of *Tridosha* particularly *Pitta*. The symptoms have been clarified in the book *Nidanpradipa*. These symptoms were unclear and doubtful even after they were described in the diagnostic sections of the treatises of Caraka and Sushruta. The best way for treating fever was fasting and lukewarm water in small quantity. However, fasting was not advisable to the patients of tuberculosis and chronic fever. Vijayanagar physicians studied the *Sārangadhara Samhita*, which recommended using Manda (light rice gruel) and Yavagu with pinch of rock

salt to reignite digestive fire (Agni). Medical practice during the Vijayanagar Empire suggests a diet chart for six days in treating fever after fasting is carried out. Lakshman Pandita suggested different procedures for fever caused by different reasons. Treatment for intermittent fever is also given by him.

लशुण विषमे प्रगे प्रयुक्तम सह तैलेन घृतेन वा निहन्ति ।
परितापपिपासिकापरितं तमजाजिपरियोजिता गुडेन ॥

- Yogacandrika (14th – 15th A.D.) p. 73

Texts suggests garlic with oil, if taken early morning can be useful in the treatment of intermittent fevers. Yogacandrika (ed and tr by Prof PV Tewari and Dr Asha Kumari) suggests “Ajaji (cumin seeds) mixed with jaggery can be taken in the treatment of intermittent fever, if it is associated with heat and thirst.” It also describes the features of incurable fever.

For severe fevers, particularly those mimicking malaria or typhoid, doctors used Sutshekhar Rasa, a mercury-based substance meticulously cleansed by Shodhana (chemical purification). The employment of such metallic compounds represents the period's alchemical development and the expanding specialisation of *Rasashastra* under royal sponsorship.

3.7.2 Pandu Rog (Anaemia)

The treatment of anaemia in the Indian medical tradition has a long historical background that can be traced back to the period of the **Mahajanapada period**. Classical narratives mention that **Bimbisara**, the king of Magadha, once sent his court physician **Jivaka** to treat the ruler of Avanti who was suffering from a severe illness, indicating the early recognition of complex diseases and the mobility of medical expertise in ancient India. By the medieval period, particularly during the Vijayanagara era, medical texts provide more detailed descriptions of the symptoms and treatment of anaemia. Texts associated with the Vijayanagara intellectual milieu describe both the symptoms and the limitations of treatment for severe forms of the disease. The physician **Lakshmana Pandita** warned practitioners against attempting treatment in cases where patients exhibited symptoms such as burning sensations, persistent vomiting, and extreme drowsiness, which were regarded as signs of an incurable stage of anaemia. Such cautions reflect the diagnostic awareness of physicians and their recognition of the limits of therapeutic intervention.

Dietary therapy formed an important component of treatment. Patients were commonly

advised to consume vegetables rich in iron and other strengthening substances in order to restore vitality. In addition to dietary measures, mineral-based remedies were also employed.

मूत्रे स्थितं सप्तदिनं पयोभिरयोरजः पाण्डुहरं प्रदिष्टम् ।

मूत्रेण पथ्यापि तथा सुसिद्धं फलत्रयं तेन च तद्वदुक्तम् ॥

- Yogacandrika (14th – 15th A.D.) p. 273

A passage in the medical text **Yogacandrika** (14th–15th century) describes a preparation in which iron powder was soaked in cow urine for seven days and later administered with milk. This preparation reflects the influence of **Rasashastra**, the branch of Indian alchemy concerned with the medicinal processing of metals and minerals. The combination of metal-based substances with organic mediums was believed to enhance therapeutic potency and bioavailability.

Interestingly, the use of mineral tonics in the region shows similarities with certain **Unani medical formulations**, particularly those employing iron oxide preparations. This suggests a possible exchange of medical knowledge between South Indian and Islamic medical traditions during the medieval period.⁴⁸ Thus, the treatment of anaemia in the Vijayanagara period demonstrates a sophisticated blend of dietary prescriptions, mineral pharmacology, and empirical diagnostic knowledge, reflecting the broader development of medical science in the region.

3.7.3 Arśa or Gudaj (Piles)

Piles (haemorrhoids) appear to have been a relatively common ailment in pre-modern South India, a condition that may have been aggravated by the region's hot and humid climatic conditions and dietary habits. Medical texts from the period indicate that physicians adopted different therapeutic approaches depending on the stage and severity of the disease. The text describes several therapeutic approaches for the treatment of piles (arśa) and related disorders in classical Ayurvedic medicine. It explains the preparation of a medicated oil known as Kāsīsa taila, made from various herbal and mineral ingredients such as kāsīsa, citraka, bhallātaka, lāṅgalī, kośātakī seeds, svarṇakṣīrī and nikumbha. These substances were processed with the latex of snuhī and arka in oil and cow urine and cooked over a mild fire.

कासीसतैलं मुनि खारणादी प्रोक्तम् तादभ्यक्तमपानकीलान् ।

क्षारोपमं पातयती क्षणेन वलिं न संदूषयतीति चित्रम् ॥

- Yogacandrika (14th – 15th A.D.) p. 185

When applied locally, this preparation was believed to cause the hemorrhoidal masses to fall off similarly to the effect of alkaline cauterisation, while not damaging the surrounding anal folds.

In cases of newly developed piles, treatment generally involved the administration of pacifying medicinal preparations intended to reduce inflammation and discomfort. However, in more chronic or advanced cases, surgical intervention was recommended.

One of the principal methods employed for such cases was cauterisation using heat, a procedure referred to in traditional medical literature as Agnikarma. This technique involved the controlled application of heat to destroy or shrink the affected tissue. In modern medicine, a comparable method exists in the form of **Thermal Cautery**, where heat generated by an electric current is used to remove abnormal tissue masses such as tumours or lesions. Although electricity was obviously unavailable in the fifteenth century, physicians appear to have developed considerable skill in applying heat from direct sources, such as heated metallic instruments, in a carefully controlled manner. This suggests a sophisticated practical understanding of surgical techniques and tissue management. The use of cauterisation demonstrates that medical practitioners of the period were not limited to pharmacological remedies alone but were also capable of performing minor surgical procedures. Such practices highlight the empirical knowledge and technical adaptability of physicians, who utilised available tools and materials to achieve therapeutic outcomes that parallel certain aspects of modern surgical techniques.

The practise of **bloodletting (raktamokṣaṇa)** as a therapeutic procedure in complicated cases of piles was also in vogue. Bloodletting could be performed through fumigation, local applications, or unction, and if these methods failed, techniques such as the use of leeches, needles, or scraping instruments were recommended to facilitate the outflow of blood.

3.7.4 Respiratory Disorder

Respiratory ailments such as cough, asthma, and bronchial congestion were commonly addressed in the medical traditions of South India through a combination of herbal, dietary, and therapeutic interventions. Physicians relied extensively on herbal expectorants to relieve respiratory obstruction and inflammation. Among the most frequently prescribed medicinal plants were *Adhatoda vasica* (Vasa), *Glycyrrhiza glabra* (Yashtimadhu), and *Piper longum* (Pippali or long pepper), all of which were valued for their expectorant, anti-inflammatory, and bronchodilatory properties. These herbal formulations were often administered in

conjunction with medicated ghee (*ghrita*) and honey-based syrups infused with aromatic herbs such as vacha and ginger, which helped soothe irritated respiratory passages and facilitate the expulsion of mucus. Therapeutic procedures also played an important role in treatment. Practices such as **Swedana** (steam therapy) and **Dhoomapana** (medicinal smoking) were widely used to clear congested airways and restore normal respiratory function. These treatments could be administered both in domestic settings and in institutional contexts such as temple-associated clinics, reflecting the broader integration of healthcare within religious and community spaces. By the fifteenth century, the influence of Rasashastra, the alchemical branch of Indian medicine, introduced additional therapeutic options for chronic respiratory conditions. Medical texts such as Rasamanjari mention the use of mineral and metallic preparations including **Tamra Bhasma** and **Abhraka Bhasma**, which were prescribed particularly for persistent bronchial disorders. These compounds were believed to strengthen the respiratory system and improve vitality when administered in carefully processed forms. The development and use of such formulations illustrate the growing integration of alchemical pharmacology within the broader Ayurvedic medical framework of the Vijayanagara period. Detailed discussions of these therapeutic practices and formulations are found in the works examined by (G Jan Muelenbeld, 2002)⁴⁹.

3.8 Comparison with Contemporary India (14th-17th century)

The majority of ailments and epidemics in India were caused by changing weather. Despite the lack of modern diagnostic tools and treatments, physicians and healers in mediaeval India gained a thorough understanding of diseases and their management. In mediaeval India, different regions had different perspectives and approaches to treating illness. Certain illnesses were unknown in certain regions of the nation, and information about their treatments was not shared from one kingdom to another. For example, Niccolò Manucci, an Italian adventurer and traveller, who visited India in 1656 AD, thought that the *tabibs* (Arabic term used for doctors in Mughal India) of the **Mughal era were ignorant of medicine and could not treat conditions like dropsy, anaemia, malignant fever, paralysis, epilepsy, or stones**.⁵⁰ In contrast, a century before Manucci visited Mughal India, Lakshmana Pandit treated anaemia and malignant fever under the Vijayanagar empire in 15th Century AD.

Niccolo Conti, an Italian explorer who travelled the kingdom of Vijayanagar in 1420 AD, observed the number of these individuals and cultures surpasses belief because the Indian population is not afflicted with pestilence or diseases that decimate our own countries' populations.⁵¹ On the other hand, in early 16th-century Mughal India, we observe that plague

continued to recur periodically and hindered numerous military campaigns. For instance, the plague that started in Qandhar during Babur's siege of the city spread to Babur's camp. Babur had to come back to Kabul as a result.⁵² However no such epidemic is seen in Vijayanagar empire.

Emperor **Akbar suffered from diarrhea**, a common ailment in Mughal India, which got worse by internal bleeding until his death on October 15, 1605.⁵³ Even during the more advanced Mughal era in India, diarrhea was a major cause of death for many high-ranking officials. For instance, Mir Khalilullah, a Persian who received a jagir from Jahangir, died from diarrhea.⁵⁴ Even Aurangzeb himself was attacked by diarrhea in 1694 A.D. but was saved as the medical recipe might have well evolved by this time in Mughal India. Thevenot and Careri suggested a treatment for this disorder. It was to contain two drachms (One eighth of an ounce = 3.89 grams) of baked rhubarb (*Rheum rhabarbarum*, native plant of central China with long green reddish edible leaves) and one drachm of cumin seed. These were crushed and consumed with either lemon water or rosewater.⁵⁵ The Vijayanagar Empire was also aware of the illness even in early 15th century by the name *atisāra*. The medical professionals of the Vijayanagar Empire recommended giving emesis before giving any medicine to patients experiencing diarrhea that was accompanied by nausea and vomiting, excessive salivation, and flatulence.

आध्मानविष्टम्भगुरुत्वशूलस्तैमित्यकारिण्यतिसारदोषे ।

हिताभया प्रकथिता हितोग्रा पूतीक कृष्ण औषध धान्य पथ्याः ॥

- Yogacandrika (14th – 15th A.D.) p. 196

The medical texts of Vijayanagar recommend the decoction (a concentrated liquor resulting from heating or boiling a substance, especially a medicinal preparation made from a plant) of *abhayā* (The herb is known as Haritaki, Chebulic myrobalan, Bihara, and Harada in different dialects, and is one of the three fruits found in the traditional formulation of Triphala) for the treatment of diarrhea that results in symptoms such as heaviness and flatulence.⁵⁶

Additional treatments for this illness include adding honey to the juice of ripe *dādima* (pomegranates) fruit. Medical texts of Vijayanagar also gives detailed descriptions of the features of incurable diarrhea and suggested the medical practitioners not to treat such patient. The history of smallpox as a disease is very old in Indian context. The disease has found mentioned in both Charaka and Sushrut Samhita. In mediaeval India it is brought to the notice

by Alberuni in his book *Kitab-ul-Hind*. In medieval period the disease spread to almost all parts of India including Bengal and south India which took a high death rate. In Bengal, the fear was more on account of dense population, therefore, people started praying goddess *Śītalā* to save themselves from this disease, the tradition which still continues even when the whole population is vaccinated for it. Muhammad Akbar Arzani, a physician who died in 1722, tried to treat smallpox patients by draining them and puncturing them with gold needles. Alberuni and Muhammad Akbar Arzani, the physician, both mentioned clove and gold dust as important element in the treatment for the illness. It is evident from this that gold played a significant role in the smallpox treatment. However, neither the Yunani system nor Ayurveda could effectively treat it; the aforementioned technique could only stop it from coming.⁵⁷ 16th century south Indian medical text *bhāva-prakāśā* of Bhava Miśra though discusses this disease in a separate section but not suggest a detailed remedial therapy for it.⁵⁸

For the treatment of wounds, generally leaves of Neem tree was boiled in water for cleansing the wound throughout all parts of medieval India specially in Mughal India.⁵⁹ In Vijayanagar empire in addition to using leaves of Neem (The tree is denoted as “Pichumanda Patra” in Vijayanagar Texts) tree, they apply honey, *til* (sesame), *karanja* (*Pongamia pinnata* or *Millettia pinnata*, also known as the malapari or karanja tree. The flowers are white and purple in colour and the seeds contain high amount of oil) and *nikumbha* (*Danti*, biological name is *Baliospermum montanum*).

3.9 Metallic, Mineral and Animal-Based Drugs in the Vijayanagar Period

While plant-based medicines formed the foundation of Vijayanagar pharmacology, one of the most distinctive developments during this era was the systematic study of Rasashastra, the alchemical branch of Ayurveda devoted to the medicinal use of metals, minerals, and animal derivatives. Texts such as *Rasamanjiri* of Shri Shalinath (15th century), *Khagendramani Darpan* of Manjraja, and *Sārangadhara Samhita* provide detailed insights into the identification, purification (śodhana), incineration (māraṇa), and therapeutic application of these substances. These procedures reveal that Vijayanagar physicians were not merely imitators of earlier Ayurvedic traditions but experimenters who expanded India’s alchemical and pharmaceutical corpus.

The practical dimensions of this Rasashastra tradition are illustrated in **Table 3.1**, which catalogues selected metallic, mineral, and animal-based substances employed in Vijayanagar-period medical practice, along with their methods of purification and therapeutic applications. The table demonstrates the systematic nature of śodhana and māraṇa procedures described in

contemporary medical texts, highlighting the controlled use of potentially toxic substances such as mercury, arsenic, copper, lead, and sulphur for curative purposes. By correlating classical textual prescriptions with identifiable chemical substances and preparation techniques, **Table 3.1** reinforces the argument that Vijayanagar pharmacology was grounded in empirical experimentation, procedural standardisation, and clinical observation rather than purely theoretical knowledge.

No.	Traditional Name	Modern Equivalent / Chemical Identity	Method of Preparation / Purification (Śodhana)	Therapeutic Use	Source Text(s) / Evidence
1	Sūtasekhara Rasa	Mercury compound (Hg-based)	Purified through repeated trituration with sulphur and plant juices (ginger, lemon)	Used for chronic fever, indigestion, and migraines	<i>Sārangadhara Samhita</i>
2	Mānaśilā / Realgar	Arsenic disulphide (As ₂ S ₂)	Purified with goat bile and milk; filtered before use	Used in skin diseases and ulcers after detoxification	<i>Sārangadhara Samhita</i>
3	Tāmra Bhasma	Copper ash (Cu)	Heated and quenched with herbal decoctions of triphala and lemon	Used for liver disorders, anaemia, and metabolism regulation	<i>Rasamanjiri, Vaidyaraj Vallabham</i>
4	Abhraka Bhasma	Mica ash	Purified with cow urine and aloe vera gel; incinerated 800–1000°C	Used for chronic bronchitis, tuberculosis, and respiratory weakness	<i>Rasamanjiri, Yogacandrikā</i>
6	Rajat Bhasma	Silver ash (Ag)	Purified with lime water and herbal decoctions	Used as tonic for nervous weakness and fever	<i>Khagendramani Darpan</i>
7	Nāga and Vaṅga Bhasma	Lead (Pb) and Tin (Sn) ashes	Treated with triphala decoction and cow urine; powdered to fine Bhasma	Used in diabetes, urinary disorders, and reproductive weakness	<i>Rasamanjiri, Arogya Chintamani</i>

8	Sphatika / Alum	Potassium aluminum sulphate	Dissolved in hot water and recrystallized	Used as astringent and antiseptic for wounds and throat infection	<i>Sārangadhara Samhita</i>
9	Gandhaka	Sulphur	Melted and purified in cow's ghee; filtered through cloth	Used in skin diseases, leprosy, and blood purification	<i>Khagendramani Darpan</i>
10	Saindhava Lavana	Rock salt (NaCl)	Sun-dried and powdered	Used as carminative, improves digestion, and balances Kapha	<i>Arogya Chintamani</i>
11	Arka (Distillate)	Distilled plant essence	Steam-distilled using copper vessels and clay lids	Used as concentrated essence for syphilis and digestive ailments	<i>Arkaprakāśa</i>
12	Jalauka (Leech Therapy)	<i>Hirudo medicinalis</i> Species	Non-poisonous, yellow-bellied leeches selected	Used for bloodletting in skin, eye, and throat diseases	<i>Sushruta Samhita</i> , continued in Vijayanagar texts
13	Go-Mutra	Organic alkali	Used as	Antimicrobial,	<i>Rasashastra</i>

No.	Traditional Name	Modern Equivalent / Chemical Identity	Method of Preparation / Purification (Śodhana)	Therapeutic Use	Source Text(s) / Evidence
	(Cow Urine)	Compound	purifying solvent in śodhana of metals	used for detoxification and skin ailments	<i>commentaries</i>
14	Ajakrita (Goat bile)	Animal derivative	Used to purify arsenicals (Manahshila)	Used as reagent in toxicology and purification	<i>Sārangadhara Samhita</i>
15	Madhu (Honey)	Natural bee product	Filtered and slightly warmed	Used as base for wound dressing, tonics, and carrier for medicines	<i>Arogya Chintamani</i>

Table 3.1: Metallic, Mineral and Animal Based Drugs

3.9.2 Empirical and Chemical Significance

The methods described above illustrate a deep awareness of chemical transformation and dosage control. For instance:

- Śodhana of arsenic through bile neutralised toxicity by organic binding.
- Māraṇa (incineration) of metals to nano-sized bhasma enhanced absorption.
- Distillation (Arka) resembles modern extraction and distillate concentration techniques.

Rasashastra thus represents a proto-chemical science where observation, measurement (*māna*), and control of heat and time were emphasised, comparable to pre-modern European alchemy but with stronger therapeutic orientation.

3.9.3 Legacy and Modern Relevance

Ayurvedic pharmacopoeia still includes formulations established during this time, including Abhraka Bhasma, Sutshekhar Rasa, and Tāmra Bhasma. Recent analytical tests by CCRAS (Central Council for Research in Ayurvedic Sciences) and CSIR-NPL reveal that these concoctions include bioavailable, non-toxic nanoparticles of the individual metals when adequately purified, confirming the empirical precision of the Vijayanagar alchemists.

3.10 Relevance in Today's World

Appreciating medical practices in civilizations such as the Vijayanagar Empire provides insight into the development of medicine and healthcare systems throughout history. It places modern medical practices in historical context and demonstrates how societies examined health and well-being throughout history. Studying these practices can provide insights into conventional medical practices that are still in use today, such as Ayurveda and traditional Chinese medicine. There could be valuable lessons in herbal remedies, lifestyle practices, and preventive medicine. Understanding how they handled sanitation, preventing illness, and community wellness can provide insights into addressing issues of public health in today's world, particularly in developing countries.

The empire's temple-attached dispensaries and Arogyaśālās served as a decentralised, community-focused form of public health, guaranteeing that all societal segments had fair access to medical care. The Ayushman Bharat project in India and other community health programs are examples of contemporary health frameworks that place a significant emphasis on primary healthcare, public involvement, and localised service delivery. Vijayanagar medicine's eco-friendly medication production techniques and sustainable usage of regional medicinal plants set an example for resource conservation and environmental awareness that contemporary pharmaceutical companies are increasingly trying to follow.

Medical practices are frequently interconnected with cultural and social values. The medical practices of the Vijayanagar Empire can provide insight into how societal factors influenced health and healing. This understanding is critical for providing culturally sensitive healthcare in today's diverse societies. Researching how the Vijayanagar Empire looked at medical creativity and responded to new health threats can provide inspiration for modern approaches to healthcare delivery and disease management. Comparing medical practices across historical periods and cultures enables us to recognise universal principles of health care and medicine, as well as novel approaches that may provide solutions to modern challenges. In the face of contemporary difficulties such as mental stress, pandemics, and antibiotic resistance, the Vijayanagar model, which combines spirituality, empirical science, and environmental awareness, provides a culturally grounded framework for sustainable and humanistic health care.

3.11 Table of Herbs Mentioned in Chapter

During the Vijayanagar period, medicinal practices relied heavily on the therapeutic use of local plants, reflecting a sophisticated understanding of Ayurveda and related healing systems.

Table 3.2 shows a selection of these plants, their botanical names, key features, and medicinal applications. Āmala (*Emblica officinalis*), rich in Vitamin C and antioxidants, was widely used as a Rasāyana for immunity and digestive support, while Haritaki (*Terminalia chebula*) and Abhayā, with similar astringent properties, were applied to treat diarrhea, fever, and other digestive disorders. Cooling and aromatic substances such as Chandana (*Santalum album*) and Camphor (*Cinnamomum camphora*) addressed skin ailments, fever, and respiratory problems, promoting mental calm. Adaptogenic herbs like Ashwagandha (*Withania somnifera*) enhanced vitality and alleviated stress, whereas purgative roots such as Nikumbha (*Baliospermum montanum*) were used for piles and skin diseases. Antiseptic plants including Karanja (*Pongamia pinnata*) and Neem (*Azadirachta indica*) were employed for wound care. Respiratory and digestive aids such as Vasa (*Adhatoda vasica*), Yashtimadhu (*Glycyrrhiza glabra*), Pippali (*Piper longum*), and Vacha (*Acorus calamus*) illustrate an integrated approach to health. Supporting agents like Til (*Sesamum indicum*), Palm sugar (*Borassus flabellifer*), and the Areca-Betel leaf combination facilitated medicine administration, digestion, and oral hygiene. Collectively, these examples (Table 3.2) demonstrate the Vijayanagar Empire’s systematic and advanced pharmacological knowledge.

No.	Traditional Name	Modern Botanical Name	Key Features / Description	Medicinal Use in Vijayanagar Period
1	Āmala / Āmalakī	<i>Emblica officinalis</i> (Indian Gooseberry)	Rich in Vitamin C, antioxidant	Used for digestive issues, immunity, rejuvenation (Rasāyana)
2	Haritaki	<i>Terminalia chebula</i>	Astringent fruit, part of Triphala	Treats diarrhea, fever, and digestive disorders
3	Chandana	<i>Santalum album</i> (Sandalwood)	Cooling, aromatic wood	Used for skin disorders, fever, and mental calm
4	Ashwagandha	<i>Withania somnifera</i>	Adaptogenic root, strengthens nervous system	Used fresh for vitality, stress, and insomnia
5	Nikumbha / Danti	<i>Baliospermum montanum</i>	Purgative root herb	Used in skin diseases and piles
6	Karanja	<i>Pongamia pinnata</i> / <i>Millettia pinnata</i>	Oil-rich seeds, antiseptic	Used for wounds, ulcers, and skin diseases
7	Vasa	<i>Adhatoda vasica</i>	Shrub with expectorant leaves	Used in coughs, asthma, and bronchitis
8	Yashtimadhu	<i>Glycyrrhiza glabra</i> (Liquorice)	Sweet root, anti-inflammatory	Used for throat, lungs, and gastric issues
9	Pippali	<i>Piper longum</i> (Long Pepper)	Stimulant spice	Used in respiratory disorders and digestive

No.	Traditional Name	Modern Botanical Name	Key Features / Description	Medicinal Use in Vijayanagar Period
				Tonics
10	Vacha	<i>Acorus calamus</i>	Rhizome with aromatic oil	Used for improving memory and treating coughs
11	Abhayā	<i>Terminalia chebula</i> (same as Haritaki)	,	Used for diarrhea and flatulence
12	Dādima	<i>Punica granatum</i> (Pomegranate)	Fruit rich in antioxidants	Used for diarrhea and blood purification
13	Neem / Pichumanda Patra	<i>Azadirachta indica</i>	Bitter, antiseptic tree	Used for wound cleaning and skin infections
14	Til	<i>Sesamum indicum</i>	Oil seed	Used for wound healing and massage oils
15	Camphor	<i>Cinnamomum camphora</i>	Cooling crystalline substance	Used for respiratory issues and fumigation
16	Areca (Betel Nut)	<i>Areca catechu</i>	Stimulant seed	Used with betel leaf for digestion and oral hygiene
17	Betel Leaf (Tambul)	<i>Piper betle</i>	Aromatic leaf	Used for digestion, oral health, and appetite
18	Palm Sugar / Toddy	<i>Borassus flabellifer</i> (Palmyra Palm)	Natural sweetener	Used in tonics and decoctions as vehicle (anupāna)

Table 3.2: Key Medicinal Plants, Botanical Identification, and Therapeutic Applications in Vijayanagar Era

The holistic approach of the medical systems of the Vijayanagar Empire, which combined indigenous folk remedies with those of Ayurveda, Siddha, and Unani, was one of their distinguishing characteristics. This combination demonstrates a sophisticated view of health and recovery, in which medical professionals treated a variety of illnesses using a variety of therapeutic approaches. The focus on hygiene, diet, and lifestyle modifications as preventive medicine emphasises the sophisticated state of medical thought at this time. On the other hand, during the same period, healthcare systems in Mughal India also demonstrated notable progress. The Mughals fostered a rich exchange of medical knowledge by hiring doctors from many traditions, including Persian, Arabic, and Indian. Under Akbar's rule, hospitals such as the Darul-Shifa in Delhi were established, demonstrating their dedication to public health. The Vijayanagar Empire decentralised healthcare to meet local needs and reflect a variety of cultural and geographic influences, in contrast to the Mughal approach, which was more centralised under royal patronage. We can better grasp the persistence and evolution of medical

knowledge over centuries by contrasting these methods with those of Mughal India along with considering their applicability today. This understanding enhances our appreciation of cultural legacy and provides guidance for current initiatives to advance holistic well-being and enhance healthcare delivery.

The arrival of Europeans in India coincided with the end of Vijayanagar rule in the south and Mughal rule in the north, resulting in the spread of contemporary western scientific approaches and medicine into India, causing indigenous medical system to stagnate. Though natives began to practise modern western medical science, the indigenous system of medicine held on to exist in isolation. Edward Ives, a surgeon in the British navy who travelled to India in 1754 AD, wrote that the natives had a written account that they never studied, and like other caste professions, they become medical professionals from one generation to the next through oral transmission of knowledge.⁶⁰ Studying these past medical practices is important for reasons other than purely academic ones. Lessons in combining traditional and modern medicine can be learned from the Vijayanagar Empire and Mughal India. As long as there are global health issues, traditional knowledge systems will continue to be valuable in enhancing modern medical practices. For example, Ayurveda continues to have an impact on holistic healthcare approaches across the globe, with a focus on natural remedies and personalised medicine.

Medical science, as a branch of science, cannot progress in isolation, so it has struggled to recuperate. Because medical practitioners in the ancient and mediaeval periods had limited knowledge and modern analytical facilities, they may not have been fully aware of all the benefits of a specific drug made from available herbs and minerals. So, the best thing that can be done for the Indian system for medical care is to explore the huge reserve of herbs, minerals, and solutions that they use, which can be tested in modern laboratories to use them more efficiently and effectively. This is only possible if a competent medical scholar contributes. Contemporary research into traditional formulations, funded by institutes such as CCRAS (Central Council for Research in Ayurvedic Sciences), reflects Vijayanagar's empirical approach by putting old medications through contemporary scientific confirmation.

By combining ancient knowledge with scientific experimentation, the empire proved that science and spirituality could coexist as complementary forces in the quest of human prosperity. Re-examining this tradition is more than just an intellectual exercise; it's a step towards regaining indigenous frameworks for sustainable healthcare. The next phase of medical historiography must thus contextualise Vijayanagar's contribution within a broader narrative of medical plurality and civilisational discourse. Its ongoing importance stems from

demonstrating that the origins of modern medicine in India were not colonial imports, but the natural result of centuries of research, compassion, and intellectual interaction.

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Chapter 4: Mathematical and Astronomical Upliftment

4.1 Introduction

The fine arts and literature in Kannada, Telugu, Tamil and Sanskrit flourished and became popular with the patronage of the rulers of the Vijayanagar Empire, who were interested in subjects such as Astronomy and Mathematics. The artistic and architectural accomplishments of this period have received much attention, but its contributions to the development of mathematics and astronomy have not received the same attention. This study looks into the developments in mathematics and astronomy under the Vijayanagar Empire, critically analyzing the primary sources such as manuscripts, inscriptions, and Sanskrit treatises. The establishment of scholars, observatories in temples, and the codification of mathematical astronomy in Sanskrit and regional languages such as Malayalam established a separate epistemic ecology where both observation and calculation, as well as cosmological philosophy were practiced together.

Vijayanagar court and religious background encouraged integration of religious and empirical knowledge. Astronomy (Jyotiṣa) was regarded as a limb of the Vedāṅgas as necessary for the proper observance of ceremonies. It also served as a mathematical science (Gaṇita-śāstra), with a focus on trigonometric calculations and geometric argument. The royal families of the empire, such as that of Devaraya II and Krishnadevaraya encouraged polymaths to do their observational and theoretical studies. Temple schools (paṭhaśālās) and agrahāras were early schools which preserved palm leaf manuscripts, observed eclipses, and taught Siddhāntic astronomy, using Āryabhaṭīya and Sūrya Siddhānta.

These advances were made by several important scholars at the court of Vijayanagars, including Parameshvara (patronised by Devaraya II), Mahadeva, Narayana Pandita and Bhaskara II. Parameśvara's Driggaṇita ("observation-based computation") developed an empirical tradition that rectified previous planetary parameters by systematic observation, foreshadowing the experimental concept subsequently championed by Galileo and Tycho Brahe¹. The important results include the development of sine tables, trigonometric series (like Madhava's and Jyesthadeva's), the formulation of a quasi-heliocentric planetary model by Nilakantha Somayaji, and the use of precise observational techniques.

Conceptual changes occurred in the areas of trigonometry and infinitesimal computing. The Kerala School's own adaptations of the old trigonometric functions led to the development of infinite power series for sine, cosine and arctangent, thereby providing a conceptual bridge to

calculus. The series in *Tantrasamgraha-vyākhyā* and *Yuktibhāṣā* are based on the fragments found by Madhava in the *Sphuṭa Chandrāpti* and *Venvāroha*. Madhava's prime series are written as:

$$\begin{aligned}\sin x &= x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \dots \\ \cos x &= 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \dots \\ \arctan x &= x - \frac{x^3}{3} + \frac{x^5}{5} - \frac{x^7}{7} + \dots\end{aligned}$$

and from this,

$$\pi = 4(1 - 3 + 5 - 7 + \dots)$$

Based on iterative approximations by finite differences of the chord tables (*jya-koṭi-prakriyā*), these formulae are the earliest systematic treatment of convergence and infinite summation in global mathematics. Modern analyses² confirm that these were not heuristic tricks but coherent analytical frameworks involving remainder estimation, conceptually parallel to the Taylor-Maclaurin series, but developed independently through geometric reasoning on the unit circle (*trijyā* = 3438').

The *Yuktibhāṣā* (1530 CE), penned by Jyesthadeva, provides a thorough proof-based presentation (*yukti*) of these discoveries in Malayalam prose. It is perhaps the oldest book to merge mathematical derivation, logic, and computing in a vernacular language. Nilakantha's *Tantrasamgraha* (1501 CE) systematised planetary models using these trigonometric refinements and proposed a quasi-heliocentric arrangement with Mercury and Venus orbiting the Sun and the Sun orbiting a stationary Earth, providing a better explanation for retrograde motion than earlier geocentric models. Nilakantha's calculations for planet mean longitudes were accurate to within a few arcminutes of contemporary values, demonstrating the quantitative accuracy of Vijayanagar-era astronomy.

There happened many individuals who contributed to astronomical theories and mathematical methods. Nilakantha Somayaji belonged to Kerala school of astronomy from 15th century was

one such prominent figure. His contribution in astronomy, especially the "Ardharatrika" theory developed by him, corrected previous models of planetary positions. His work shows cases Vijayanagar Empire's dedication to the scientific temperament and the use of exacting mathematical methods to understand the movement of astronomical bodies.

The confluence of astronomy and architecture exemplified Vijayanagar's scientific culture. Temples at Hampi, including *Virupākṣa*, Vitthala, and Hemakuta, line with solstitial and equinoctial sun rising times. Modern GIS-based surveys³ show orientation accuracies of less than one degree, indicating intentional geometric design based on solar declination (δ) and shadow-length computation ($\tan\theta=h/s$). *Sūrya Siddhānta* describes the employment of gnomons (*śaṅku*) and water clocks (*ghaṭī-yantra*) at local temple observatories to provide daily calibration for ceremonial calendars and eclipse prediction. This architectural astronomy reveals how abstract mathematical knowledge was given direct spatial manifestation in the empire's religious environment.

Further, this study will also dwell upon how this knowledge of astronomy was utilised in the practicality during the rule of Vijayanagar empire. How this knowledge of astronomy and mathematics influenced the policy making of the empire with respect to ceremonial practices, agricultural, and religious practices. The way architecture of temples and drafted ceremonial calendars matched astronomical events demonstrated how this knowledge was incorporated into daily life. Another contemporary mathematician and astronomer of this age is Narhari, who was in the court of King Krishnadevaraya. He wrote multiple books on astronomy and mathematics. The period under study saw the development of new mathematical theories and the refinement of earlier ones, particularly in the field of algebra, geometry, trigonometry, and astronomy.

The chapter highlights the distinctive contributions of the Indian scholarly tradition to the evolution of early modern science, situating the scientific achievements of Vijayanagar within a comparative framework alongside contemporary developments in China and Europe.⁴ The present work shows the significance of the Vijayanagar Empire as a powerful channel between classical Indian knowledge systems and wider trends in the history of science, particularly in regard to the practice of empirical observation, the development of mathematics, and the formulation of astronomical notions that foreshadow similar developments in other parts of the world.

4.1.1 Vijayanagar and the Kerala School of Mathematics

It is not so much a question of direct institutional control but rather one of shared intellectual ecosystem, political patronage, mobility of scholars, and a common cultural geography of South India in the 14th–16th centuries between the Vijayanagar Empire and the Kerala School of Mathematics and Astronomy. The Kerala School, to which mathematicians like Mādhava of Sangamagrama, Parameśvara, Nīlakaṇṭha Somayāji and Jyeṣṭhadeva belonged, had mastered advanced mathematical tools, such as infinite series expansions and refined planetary models. Such was the case with these scholars who were active in Kerala, but whose intellectual sphere of activity was rooted in the Vijayanagar cultural and political realm. The main function of Vijayanagar was to support and encourage Sanskritic scholarship. Major educational hubs like Sringeri, Kanchipuram, Tirupati, and Hampi were financed by the empire and served as hubs for scholarly communication. Manuscript colophons, guru-śiṣya lineages, and astronomical tables that circulated throughout areas witness to the fact that scholars from Kerala regularly travelled to these sites for debate, research, and patronage. Kerala mathematicians were able to spread their work beyond regional limits by using Sanskrit as a transregional intellectual language. Geographically, trade routes via the Western Ghats, networks of temples, and pilgrimage routes connected Kerala to Vijayanagar both economically and culturally. These pathways made it easier for academics, manuscripts, and instruments to travel. Astronomers like Parameśvara (14th–15th century), whose eclipse observations have been analysed by K. Chandra, were contemporaries of Vijayanagar monarchs, and their writings circulated within a larger South Indian intellectual milieu that was impacted by Vijayanagar power. Crucially, although Vijayanagar did not directly "produce" the mathematical achievements of the Kerala School, it did offer a stable political and cultural context that fostered the growth of sophisticated mathematical and astronomical research. Sustained scientific effort was made possible by royal gifts to mathas, preservation of temple-based education, and support of Vedic and astronomical studies. As a result, the Kerala School should be viewed as both architecturally linked to the Vijayanagar world and intellectually independent.

4.2 Recent Literary Development

The scientific legacy of the Vijayanagar Empire has attracted considerable interest amongst science historians, philologists and astronomers in the last few decades. The combination of textual analysis, computational reconstruction and archeoastronomy has revealed the range of

mathematical thought and empirical skill embedded in the intellectual heritage of the South. This new scholarly focus is the second historiographical revolution in Vijayanagar scientific works, and it extends its appreciation of cultural achievements to a careful consideration of both the mathematical logic and analytical rigor of the period. **Table 4.1** summarizes major publications, studies, and lecture series that explore the astronomical knowledge, temple alignments, and mathematical developments associated with the Vijayanagar period and the Kerala School. It includes authors, publication years, focus areas, and key contributions, highlighting the integration of observational astronomy, temple architecture, and advanced mathematical concepts such as proto-calculus and trigonometry.

Various distinguished historians of science and astronomy have shown keen interest in the history of astronomy in India. Pingree (1981) in his magnum opus, “Jyotiḥśāstra: Astral and Mathematical Literature”, provides critical survey of premodern Indian works in astronomy. Furthermore, Pingree discusses transmission of astronomical knowledge by lineal descent among scholars as also of astronomical observatories attached to temples. Evidencing great importance to practices of observations, Pingree also underlines that Siddhantic tradition bears paramount importance in providing a theoretical foundation to astronomical disciplines in the Indian tradition.

“The History of Mathematical Philosophy in India” by Raju (2007) gives a critical appreciation of the epistemological foundations that are behind Indian astronomy and mathematics. The author demonstrates how contemporary mathematicians, particularly in The *Yuktibhāṣā* and *Tantrasamgraha*, conceived mathematical proofs and clear logical frameworks that underlie astronomical calculations. Of utmost focus are Nilakantha Somayaji and Jyesthadeva, whose contributions went a great distance in advancing the then scientific practices.

In “The Crest of the Peacock: Non-European Roots of Mathematics”, Joseph (2011) argues that Indian mathematicians during the medieval era, particularly under the branch of the Kerala School, formulated significant mathematical concepts, in the forms of power series and infinite series, expansions of trigonometric functions, centuries before such were achieved in Europe in developing building blocks of calculus. Joseph's work demonstrates that Indian mathematical tradition evolved not merely as a reaction to external influences, but as a local and whole intellectual construct.

A wave of scholarship in the twenty-first century has revitalised the study of Vijayanagar's

scientific heritage, utilising both archival rediscovery and computer modelling. The Madhava Lecture Series (ICTS, 2023-2025) brings together mathematicians and historians to analyse the mathematical sophistication of Yuktibhāṣā's infinite series. Computational models show that Madhava's series for π converges quicker than the Leibniz series under comparable truncation, indicating advanced understanding of convergence correction (śeṣa-prayoga).

Furthermore, GIS-based archeoastronomy investigations⁵ and temple spatial analyses (Hemakuta Temple Study, 2022) have indicated that temple alignments in Hampi and nearby regions match to solstitial azimuths determined using spherical trigonometry. The angular deviation of most major shrines stays less than one degree, indicating dependence on numerical tables akin to Madhava's sine tables:

$$Jya = R \sin \theta, \text{ where } R=3438'.$$

Such applications confirm that **astronomy was mathematically embedded in architecture**, not merely symbolically expressed.

The combination of manuscript studies, digital humanities, and mathematical reconstruction has resulted in a collection of newly accessible primary materials. Between 2021 and 2024, critical editions of Yuktibhāṣā, Tantrasamgraha-vyākhyā, and Gaṇitakaumudī were made available through digitisation efforts including the Indian Manuscript Heritage Portal (INSA) and the Kerala Digital Palm-leaf Archive. These tools enable the computational reanalysis of old algorithms.

Author(s)/ Editor(s)	Year	Focus Area	Key Contribution
T.V. Venkateswaran	2020	Vijayanagar cosmology & astronomy	Links temple sightlines, rituals, and celestial symbolism in Hampi with historical texts.
Hemakuta Temple Study (MDPI)	2022	Temple spatiality & solar design	Analyzes Virupaksha/Hemakuta layouts, embedding astronomical principles in architecture.
Archaeological Site Reports (Hampi)	2019–2023	Temple alignments & observational practices	Show how architecture embedded astronomical timing for rituals/festivals.
Malville, Fritz et al.	2018–2024	Archeoastronomy of Hampi	GIS-based studies on temple orientations; show alignments within $<1^\circ$ accuracy to solstices/equinoxes.
Regional Scholars (ResearchGate/Theses)	2021–2024	Vijayanagar education & Kerala manuscripts	Studies on pathshalas, manuscript traditions, and transmission of Yuktibhāṣā.

ISROSET / Academic Review Authors	2024	Kerala School (Madhava → Jyesthadeva)	Reviews infinite series, proto-calculus, trigonometry; bibliographic updates.
ICTS – Madhava Lecture Series	2023–2025	Kerala school historiography	Modern expositions of Madhava, Nilakantha, Jyesthadeva; connects to global history of calculus.
Ramasubramanian & Sriram (Eds.)	2025 (rev. ed.)	Nilakantha's <i>Tantrasamgraha</i>	Updated critical edition & translation; adds commentary on trigonometry and quasi-heliocentric model.

Table 4.1: Recent work on the Current Topic

4.3 Astronomical, Astrology, Mathematical Texts and Scholarly Contributions

Astronomy in the Vijayanagar era was closely related to Hindu cosmology and temple rituals. There are several important pieces and researchers of the period that contributed in the advancements of astronomy:

4.3.1 The Panchāṅgam: The Vijayanagar Empire used a calendar system that was highly developed by the results of astronomical observations and was similar to ancient Indian system, like Vedic calendar. The Panchāṅgam had information regarding lunar and solar movements, favourable timings (*muhūrta*), eclipses, and planetary arrangements. This system was vital for planning religious and royal events. Despite its evolution from the Sūrya Siddhānta and Āryabhaṭīya, it was improved using Driggaṇita procedures for local observational adjustments (Parameśvara, 15th c.).

The Panchāṅgam calculated five fundamental components, *tithi* (lunar day), *vāra* (weekday), *nakṣatra* (constellation), *karaṇa* (half-day), and *yoga* (planetary conjunction), using trigonometric interpolation and mean motion equations. The computation of *tithi* involved the following relation:

$$\text{Tithi} = (\text{Longitude of Moon} - \text{Longitude of Sun}) / 12^\circ$$

Astronomers at Vijayanagar maintained tables recording the saṅkrānti (solar ingress) and graha-gati (planetary motion) in order to synchronize the cycles with the solar events, such as the equinoxes. That this is an institutional purpose is indicated by the ceremonial calendar of the temple of Virupākṣa, composed at the time of Krishnadevaraya⁶. Panchāṅgam computation, which embodied the unity of cosmic order and government, was not just mathematical but also statecraft orientated. They used it to foretell agricultural cycles as well as the date of coronation and even the time to fight.

4.3.2 Mahadeva: He was a famous mathematician and astronomer at the Vijayanagar court. Mahadeva contributed to the fields of algebra and astronomy on a large scale. His works, such as the Mahadeva Siddhanta, covered planetary movements as well as eclipses. His observations and calculations were used to refine previous astronomical models. Using trigonometric approximations, he improved techniques for determining eclipse durations and magnitudes. He used a sine-based interpolation formula similar to this for lunar eclipses:

$$d=R \sin \phi,$$

where d is the distance between the lunar and shadow centers, R is the radius of the shadow cone, and ϕ is the elongation angle.

4.3.3 The Tolkāppiyam and Later works: The Tolkāppiyam, which predates the foundation of Vijayanagar Empire, had significant influence on the astronomical works of the period under study. Later works that were produced after the Tolkāppiyam, including Jyotish Sastras (astronomy treatises), were produced under royal patronage during the Vijayanagar Empire, providing understandings into how astronomers exhibited celestial events.

4.3.4 Ganit Kaumdi: Ganit Kaumudi meaning "Moonlight of Mathematics" is a mathematical work written in sanskrit by Narayan Pandit in the 14th century CE. The work is known for explaining mathematical principles in an understandable and creative manner. Although it is written in medieval era but it seems to be continuing the tradition started by mathematicians of ancient India like Aryabhata, Brahmagupta, and Bhaskara II. The text covers:

- *Trīruleka* (Rule of Three): proportional reasoning
- *Yāvat-tāvat-prakriyā* (algebraic equations)
- *Bhāvanā* (composition of solutions)
- *Chakravāla* (cyclic method for quadratic indeterminate equations)

Ganit Kaumudi uses riddles or story-like situations for explaining the **problem-solving techniques**. Its approach to understand the problems through **verses and examples** makes it an important educational tool and a reflection of the advanced state of mathematical thought in medieval India⁷. Using verse mnemonics that correlate to contemporary factorial relations, the Gaṇitakaumudī also develops combinatorial equations for permutations and combinations:

$$P(n,r) = n! / (n-r)!$$

It contains the traditional paribhasa, parikarmas, and vyavaharas, followed by the pulverizer, "Pell's equation," factors, combinations, and magic squares. Before writing the Ganikaumudi,

Narayana had written a work on algebra, the Bijaganitavatamsa.⁸

4.3.5 Parameshvara: He is primarily known for his contributions to the Drigganita (observational astronomy) tradition. He resurrected and improved techniques for determining planetary locations based on real observations, rather than depending entirely on ancient Siddhantic procedures. His version of the Drigganita proved more accurate and important in subsequent publications. Parameshvara was one of the few Indian astronomers who favoured direct observation⁹. He is credited for keeping records of more than 70 solar and lunar eclipses, as well as his personal observations, for about 55 years. There are three major works of Parameshvara – *Grahanmanadana*, *Grahanastaka* and *Grahananyayadipika*.¹⁰ Parameshvara used the following methods to interpolate eclipse times between tabular lunar longitudes and shadow radii in his *Grahananyāyadīpikā*:

$$\text{Eclipse Magnitude} = (R_s - R_m \cos \Delta\lambda) / (R_s + R_m)$$

where R_s and R_m are the radii of the shadow and Moon, and $\Delta\lambda$ is their longitude difference.

4.3.6 Nilkantha Somayaji: He used observations of Parameshvara in the formulation of his work, *Tantrasangraha*. He introduced more accurate computations of planetary positions, especially for the outer planets. *Tantrasangraha* contains detailed trigonometric computations and innovative methods for calculating the sine and cosine values. This work had a profound impact on later Indian astronomers and mathematicians like *Jyesthadeva*, elaborated on its concepts in works like *Yukiybhasha*.¹¹

4.3.7 Nilakantha Somayaji's Quasi-Heliocentric Model: The development of a quasi-heliocentric model of the solar system was one of Nilakantha Somayaji's most notable accomplishments, which are recorded in his *Tantrasangraha* (1501). According to this theory, the Sun orbited the Earth, while the planets Mercury and Venus orbited the Sun as depicted in **Fig 2**. Compared to previous geocentric theories, this arrangement provided a more precise explanation for the inner planets' retrograde motion. Although his concept of Earth being stationary was a significant departure from Copernicus' heliocentric theory, still it was a conceptual advancement in Indian astronomy. An empirical mentality may be seen in Nilakantha's model, as he refined planetary tables by drawing on decades of eclipse observations made by his predecessor, Parameshvara. By using trigonometric techniques to locate planetary positions, he was able to predict European events more than a century ago. This shows that although being in more traditional philosophical beliefs, the Vijayanagar

intellectual environment was not motionless but rather actively engaged in a bold reconsideration of cosmic order.

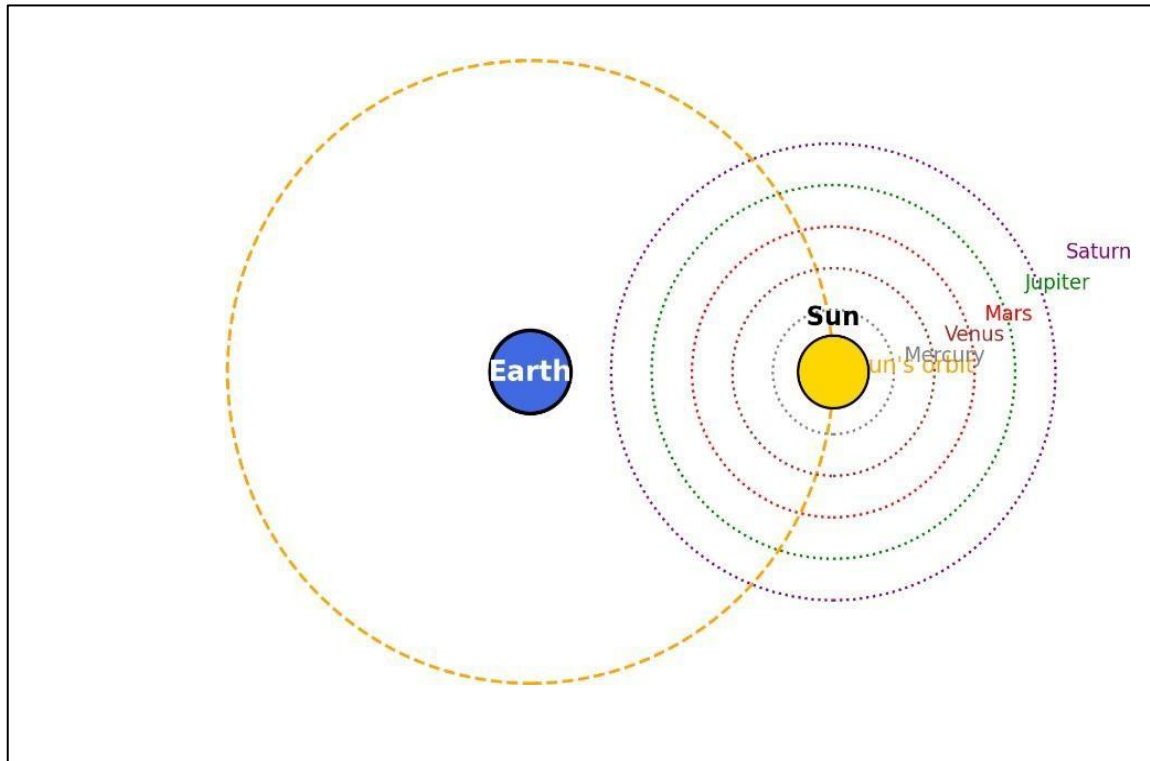


Fig 2: Nilakantha Somayaji's Quasi Heliocentric Model Reconstruction based on Tantrasangraha

Source: K. Ramasubramanian, M. D. Srinivas, M. S. Sriram, *The Traditional Indian Planetary Model and its Revision by Nilakantha Somayaji*, esp. Fig. F.4b (pp. 12–15).

4.3.8 Jyesthadeva: Jyesthadeva is an Indian mathematician and astronomer from Kerala belonging to the sixteenth century. His most well-known work is *Yuktibhāṣā*, a revolutionary treatise on mathematics written in Malayalam in 1530 CE. *Yuktibhāṣā* is distinctive for its logical rigour and early application of calculus-like techniques. It is regarded as one of the first works to methodically convey the rationale (*yukti*) underlying mathematical and astronomical conclusions. In addition to offering thorough explanations and derivations for conclusions pertaining to trigonometry, infinite series, and astronomical computations, the text is a commentary on Nilakantha Somayaji's *Tantrasamgraha*. The early formulations of the infinite series for sine and cosine functions found in *Yuktibhāṣā* are noteworthy since they predate comparable advances in Europe by centuries (Joseph, 2011)¹².

The earliest comprehensive derivations of infinite series for sine, cosine, and arctangent are found in the *Yuktibhāṣā*, along with treatments of remainder estimation and convergence.

Recursive geometric decomposition of circular arcs is used in Jyesthadeva's demonstration of the sine series:

$$\sin(x) = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \dots$$

justified by the arc-chord difference's consecutive approximation. Additionally, he investigated iterative techniques for computing π with correction terms:

$$\frac{\pi}{4} = 1 - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \dots + \frac{(-1)^n}{2n+1} + \dots$$

Jyesthadeva's work has a sophisticated comprehension of convergence, iterative techniques, and mathematical proofs. *Yuktibhāṣā*, which was written in Malayalam rather than Sanskrit, simplified difficult mathematical concepts and demonstrated a regional and inclusive approach to scientific education (Raju, 2007)¹³. Jyesthadeva's work, which demonstrates that the fundamental concepts of calculus were being independently developed in India, is widely seen as a major turning point in the history of mathematics worldwide.

4.3.9 Astrology as Applied Astronomy: In the Vijayanagar Empire, astrology symbolized the practical application of astronomy in social, political, and religious life, but astronomy itself was a precise mathematical science based on observation and computation. Careful astrological consultation was used to decide the dates of military campaigns, temple consecrations, and coronations. To determine auspicious times (*muhūrta*), astrologers used the *Panchāṅgam* and planetary tables, which were developed by Vijayanagar scholars and drawn from previous *Siddhantic* traditions. For example, coronations according to positions of celestial bodies thought to guarantee political stability therefore military battles were also frequently matched with certain positions of Mars, the planet of war. Conjunctions (*yogas*), comets (*dhūmaketu*), and eclipses were noted as cosmic markers impacting temporal policy. Inscriptions from Mallikarjuna's (1456 CE) rule, for example, document land transfers after comet sightings, demonstrating the use of celestial occurrences as tools of royal legitimacy¹⁴.

Mathematically, astrological tables employed sine-difference interpolation for planetary positions:

$$\lambda_t = \lambda_0 + n(t - t_0) + e \sin(M)$$

The way astronomical knowledge utilised into the empire's religious system can be determined by the way temple inaugurations and seasonal rites were synchronised with planetary and solar-lunar positions. All these shows that astrology was not a separate discipline but an applied branch of astronomy only. It rendered complex astronomical calculations into guide lines of daily practice, ritual authority and political legitimacy. Such applications of practice indicate that Vijayanagar science was a theoretical as well as practical science, well rooted in mathematical exactitude and cultural relevance.

4.4 Mathematics and Astronomy

The mathematical developments under the Vijayanagar rulers were the outcome of their astronomical studies. Mathematics in India during this period saw considerable growth, with a focus on the refinement of **trigonometric functions, sine tables, and planetary motion models**. The more accurate location needed a more accurate sine and cosine tables. Thus, mathematicians of this time developed power series of sine and cosine. These series appear in written form in the *Tantrasamgraha-vyakhya* of about 1530, a commentary on a work by Nilakantha. Derivations appear in the *Yuktibhasa*, whose author credits these series to Madhava (1359–1425).¹⁵

4.4.1 Trigonometry and Sine Tables: The improvement of trigonometric functions was one of the most important advancements of this time period. Power series expansions and extremely precise sine tables were created by Indian mathematicians of the Kerala school, who were intimately linked to the Vijayanagar academic network. Madhava of Sangamagrama (c. 1350–1425), for instance, created infinite series expansions for sine, cosine, and arctangent functions, over three centuries before the concepts of calculus were developed¹⁶. Later, Jyesthadeva's *Yuktibhāṣā* and Nilakantha's *Tantrasangraha* expanded on these themes.

4.4.2 Geometry and Measurement in Astronomical Context

Temple building and celestial measuring served as two avenues for the development of geometrical thought throughout the Vijayanagar Empire. The fundamental idea of *rekḥā-vidyā*, or the sacred art of line drawing, was used by both. Practical geometry for layout computation was included in Vijayanagar publications such as *Śilpa Ratna* and *Vāstu Sūtra Upaniṣad*. These texts included techniques for building equilateral triangles, squares, and circles utilising rope geometry (*rajju-vidhi*). A mathematical understanding of symmetry and ratio is shown in the

proportion known as vastu-puruṣa maṇḍala, or square grid of 64 or 81 divisions.

4.4.3 Arithmetic, Proportion and Applied Computation

Arithmetic occupied a central place in Vijayanagar's intellectual curriculum (*gaṇita-śāstra*), especially in the calculation of trade, taxation, and architectural quantities. Mathematical treatises such as Śrīpati's Siddhānta-Śekhara¹⁷ and Bhāskara II's Līlāvātī remained authoritative, yet scholars introduced practical refinements in unit conversions, proportional reasoning, and iterative arithmetic. A typical *gaṇaka* (court calculator) mastered:

- **Bhāgavyavahāra** (fractions and ratios): used for land measurement and resource distribution.
- **Varga and Ghana extraction** (square and cube roots): essential for architectural volume and astronomical distance computation.
- **Kuṭṭaka algorithm** for solving indeterminate equations:

$$ax + by = c,$$

known in Europe centuries later as the *Diophantine* method.

The financial arithmetic in the Temple records of Tirupati and Anegundi¹⁸ are very advanced, such as making proportional calculations for interest on gold (*rūpaka-vṛddhi*). This is evidence of the use of mathematical literacy in administration. In such records, numbers were not just counters, but also indicators of cosmological balance and surplus/reciprocity, which was a theme that was pervasive in Vijayanagar economic cosmology.

4.4.4 Planetary Models: Advanced theories of planetary motion were passed down from older Indian astronomers such as Aryabhata and Bhaskara II to the Vijayanagar Empire. These concepts were improved by academics like Parameshvara and Nilakantha Somayaji, who produced what some historians refer to as a "proto-heliocentric" framework. According to Nilakantha's theory, the Sun and the other planets orbited the Earth, while Mercury and Venus orbited the Sun. Although this quasi-heliocentric method maintained the Earth's centrality in line with Indian cosmology, it bore a remarkable resemblance to elements of Copernicus' later paradigm (1543). These models' mathematical strength was their trigonometric accuracy, which made it possible to anticipate eclipses and make calendrical adjustments more precisely

than those made in modern-day China or Europe¹⁹.

4.4.5 Practical Application in Temple construction: The architecture of Vijayanagar was likewise infused with astronomy and mathematics. More than 150 temples, shrines, and palaces in Hampi and the surrounding areas have had their orientations assessed by recent archaeoastronomy research (e.g., Malville et al.)²⁰. In accordance with solar events like equinoxes and solstices, most of the great temples face east. Certain sanctuaries have alignment accuracy of less than one degree, indicating the application of sophisticated trigonometric computations and observational tools. For instance, the Virupaksha Temple in Hampi is positioned so that the sanctuary is directly illuminated by the rising sun's beams during specific solar occurrences. Similar to this, the arrangement of the Vitthala Temple complex exhibits geometric perfection, most likely the result of mathematical design grounded in astronomical principles.

4.4.6 Geometry and Temple Construction

Temple building was the most apparent representation of mathematical ideas in Vijayanagar civilisation. Architectural textbooks like the *Mānasāra* and *Śilparatna* (translated by Stella Kramrisch 1993) established geometrical criteria for proportion, orientation, and symmetry. Their recommendations were more than just symbolic: architects used precise geometric and trigonometric ratios to attain structural balance and solar alignment.

Archaeological studies by John M. Fritz and George Michell show that the Vitthala and Virupākṣa temples at Hampi are orientated to the azimuths of equinoctial sunrise and solstitial extremes, demonstrating the calculation of solar declination using gnomons and horizon altitudes. Alignments were based on mathematical formulas similar to the *Śulba Sūtras*, which served as an approximation.

4.4.7 Courtly Dimension on Indian Astronomy

Numerous inscriptions from the Vijayanagar era document the relationship between astronomical occurrences and royal power. A Sanskrit copper-plate inscription dated June 28, 1456 CE, during the reign of King Mallikarjuna of Vijayanagar, recalls the appearance of a comet ("dhūmaketu") and meteor shower.²¹ The inscription donates land to Vedic scholar Limgaṇarya with the specific intention "to mitigate the great calamity believed to arise due to the appearance of comet and meteor shower." This demonstrates that astronomical phenomena were regarded as having direct political or ceremonial importance, necessitating royal involvement via sponsorship.

Another epigraphic record from Kodigehalli (in the Bengaluru area) from the Vijayanagar Empire (1431 CE) records a solar eclipse and a land donation associated with a temple and its ceremonies.²² The grant clearly mentions the eclipse and is granted during that event. Such inscriptions demonstrate how kings exploited astronomical-ritual occasions (eclipses, comets) to strengthen ceremonial order and legitimacy by performing public acts (gifts) in reaction to cosmic phenomena. Thus, epigraphic sources provide concrete proof that courts responded to observable occurrences, and that astronomy was more than just a theory, with ceremonial and political implications. These inscriptions also include dates related to celestial phenomena, which can be used to cross-check astronomical calculations in literature.

During Krishnadevaraya's reign, astronomy and calendrical science were used extensively in statecraft and ceremonial. Notably, the empire-wide exemption from marriage taxes coincided with a *laksha-homa* ceremony at Sivanasamudram in 1512 A.D. These celebrations were based on precise moon predictions and demonstrated the use of astronomy in administration and social regulation²³. Likewise, there are records of donations of mercury, copper and gold for the purposes of metallurgical work, which also show that the practical sciences had a strong connection to religious patronage in temple architecture²⁴. In addition, inscriptions with the Saka calendar show an advanced calendrical system that was synced with the lunar cycles, essential for the planning of agricultural and religious activities²⁵. Astrology (jyotisha) was sometimes employed in the political sphere, such as when temple repairs were made after astrological consultation, all but indicating that celestial omens had had an impact on political decisions.

Ritual practices involving mathematical terms and land estimation are common in Krishnadevaraya's inscriptions. Rites of ritual objects made using the term *tula-purusha* and precious stones given in the form of *Ratna-dāna* involved very precise measurements and accounting, so as to demonstrate a high level of geometry and arithmetic in ceremonial contexts.²⁶

4.4.8 Mathematical Interpretation of Astronomical Data

Key mathematical components of Vijayanagar-Kerala astronomical science were iterative algorithms, proto-calculus series expansions and trigonometric computation. These methods enabled the determination of accurate values of planetary latitudes, eclipse times, and angular separation. The mathematical sophistication is demonstrated in two examples:

(A) Infinite Series for Sine (Madhava's Formula)

Jyesthadeva's *Yuktibhāṣā* (c. 1530) presents the earliest known infinite series for sine:

$$\sin \theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \frac{\theta^7}{7!} + \dots$$

This series enabled error-controlled approximations of celestial longitudes. For example, computing the sine of 30°:

$$\theta = \frac{\pi}{6}$$
$$\sin\left(\frac{\pi}{6}\right) \approx \frac{\pi}{6} - \frac{\pi^3}{6^3 \cdot 6} = 0.5000$$

This matches the modern value **0.5** with remarkable accuracy.

(B) Madhava's π Approximation (Arctangent Series)

To improve circle measurements for astronomical tables, Madhava used:

$$\pi = 4\left(1 - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \dots\right)$$

After 50 terms, the result differs from modern π by less than **0.0004**.

(C) Nilakantha's Planetary Equation for Mercury/Venus

For inner planets, Nilakantha proposed:

$$L = L_s + \Delta L$$

where:

- L = true longitude of planet
- L_s = solar longitude
- ΔL = correction term using epicyclic geometry and trigonometric sine-difference tables.

This model matches observational data more closely than Ptolemy's and equals early Copernican accuracy.

(D) Eclipse Computation (Parameshvara's Drigganita)

Parameshvara improved the calculation of eclipse magnitude via:

$$M = \frac{d - r_1 - r_2}{2r_1}$$

where:

- d = observed distance between solar-lunar centers
- r_1, r_2 = angular radii.

This formula aligns closely with modern geometric eclipse models.

4.4.9 Tracing the Celestial: Astronomical Geometry and Early Calculus Concepts

The ability to trace celestial paths required precision mathematics. Vijayanagar-Kerala mathematicians used

(a) Angular Motion Computation

Daily planetary motion was determined through:

$$\Delta\lambda = \frac{360^\circ}{T}$$

where T is orbital period in days.

These values allowed prediction of conjunctions and oppositions.

(b) Shadow Measurements & Gnomon Geometry

Using the formula:

$$\tan h = \frac{S}{G}$$

- h = solar altitude,
- S = shadow length,
- G = gnomon height.

Temple alignments in Hampi correspond to these measured angles.

4.5 Global Context of Vijayanagar Scientific Thoughts

No understanding of Vijayanagar intellectual heritage can be complete without a broader understanding of the world's scientific history. The fourteenth to the seventeenth century was a period of similar scientific development in China, the Islamic world, and Europe, but not the same. The uniqueness of Vijayanagar tradition in the realm of mathematical-astronomical advancements is highlighted, and its comparative, conjunctive, and comparative aspects with the advancements of the Islamic world, China, and early modern Europe are illuminated as

well. The present part examines parallels and differences in technique, textual culture, computing and epistemology, through the known research.

4.5.1 Comparison with Chinese Astronomy and Calendrical Systems

Chinese mathematical-astronomical heritage is rich in its calendrical and predictive astronomy, with their strengths and their structural logic. When one looks at this, it shows a lot of similarities with Vijayanagar- Kerala.

Calendrical computation: Martzloff's *Astronomy and Calendars - The Other Chinese Mathematics (104 BC-AD 1644)* provides a thorough examination of how Chinese scientists developed lunisolar calendar systems, intercalations, solar term computations, the 24 solar "breaths," and so on²⁷. Chinese calendar systems emphasised astronomical precision to promote ongoing changes and political legitimacy.

Number systems and numerical representations: The Chinese tradition handled decimal-based fractions but did not use infinite series expansions in the same manner that the Kerala school does. The Chinese procedures were effective for many calendar and astronomical tasks, but they lacked the formal proof frameworks and infinite expansions for trigonometric functions discovered by the Kerala School. Martzloff's approach is computationally rigorous but lacks the analytic/logical breakthroughs found in Yuktibhāṣā, such as series and convergence.

4.5.2 Islamic World

Greek and Indian astronomy was transmitted to later European contexts through the Islamic world, which served as a knowledge bridge. A prime example of the accuracy of star catalogues created in observatories such as Samarkand was Ulugh Beg's Zij-i Sultani (1437). The development of spherical trigonometry and sophisticated observational methods by Islamic academics paralleled Vijayanagar's interest in planetary precision and eclipse prediction. Institutional differences were evident, though, as South Indian temple-schools were not as well-supported by the state as Islamic observatories.

Islamic astronomy frequently inherited Hellenistic geometrical tools and astronomical cosmology (e.g., the epicycle/deferent model), whereas Vijayanagar-Kerala traditions preserved older Indian cosmological assumptions (geocentrism or quasi-heliocentrism in

Nilakantha's case) while innovating within them mathematically (series expansions, new sine tables, etc.)

In Islamic practice, most of the astronomical labour was orientated to religious purposes (moon sighting for Ramadan, identifying prayer hours, qibla, etc.), but in Vijayanagar it was more extensively ingrained in ceremonial architecture, temple calendars, and intellectual treatises related to temple research.

Some Islamic astronomers, including al-Biruni and Ulugh Beg, emphasised empirical observation and adjustments, similar to Parameshvara's *Driggaṇita* tradition. While the conceptual frameworks differ (Islamic astronomers frequently use Ptolemaic geometric devices and different-epicycle models), the technical concerns of error correction, table refinement, and prediction improvement are common. Kim Plofker's *Mathematics in India* (2009) explores how these exchanges improved both cultures.

4.5.3 Europe

The period in which Nilakantha, Jyesthadeva, and others worked overlaps with the European Renaissance and the early modern scientific revolution. The Ptolemaic system continued to rule Europe throughout the late medieval era, but a dramatic change was brought about by the Renaissance. Copernicus' *De Revolutionibus* (1543) suggested heliocentrism, which conceptually changed the structure of the universe, despite his less sophisticated mathematical correctness than Nilakantha Somayaji's. Later, Tycho Brahe, Kepler, and Galileo would combine mathematics, instruments, and observation to begin scientific revolution. Vijayanagar astronomers, on the other hand, improved geocentric and quasi-heliocentric models while retaining philosophical presumptions about the primacy of Earth. Key points of Comparison or Contrast:

- **Infinite series and beginning of calculus:** European mathematicians such as Gregory, Leibniz, and Newton created formal calculus using power series, although there is no solid historical evidence of direct textual transfer from the Kerala School to Europe. Plofker's scholarship, *Mathematics in India*, is cautious about establishing impact, frequently finding parallels but without proof.
- **Textual form and Language Differences:** European mathematics favoured prose, diagrams, and algebraic symbolism, but Kerala writings frequently employed Sanskrit or Malayalam verse/prose hybrids, as well as logical expositions imbedded in

poetic or ceremonial literatures. Kerala writings use more implicit or example-based approaches to demonstrate remainder, convergence, and error correction, whereas in Europe, more formal proof structures were created in the 17th century.

- **Instrumentation and Observatories:** Large optical instruments and telescopes were developed by European observatories (such as Tycho Brahe and Galileo), while the Vijayanagar /Kerala tradition used precise non-optical instruments (such as gnomons and armillary spheres) that were extremely accurate in their context. Telescopes were introduced later through colonial/Islamic channels.

4.5.4 Synthesis

However, a comparative analysis shows that Vijayanagar scholars lacked the institutional, technological, and cultural prerequisites that enabled European science to globalize, while achieving exceptional mathematical precision, especially in trigonometric series and quasi-heliocentric models. Europe started a conceptual revolution, the Islamic world focused on preservation and improvement, and China stressed bureaucratic utility. Vijayanagar is notable as an intellectual civilization that maintained its regional boundaries while striking a balance between mathematical complexity, ritual, and real-world applications.

4.5.5 Discussion: Limits of Vijayanagar Science

A major paradox in world history is highlighted by the scientific traditions of Vijayanagar and the Kerala school: Indian advancements did not spread globally in the same manner as European science, while developing mathematically complex and conceptually novel models.

Several factors account for this divergence:

- **Transmission Barriers:** Indian works were preserved in palm-leaf manuscripts and Sanskrit/Malayalam texts, limiting circulation. In contrast, Europe's printing press (15th century) ensured wide dissemination of Copernican and later Galilean works.
- **Institutional Frameworks:** As had happened in other parts of the world, the scholars of Vijayanagar also thrived in the temple-schools supported by royal patronage, but unlike the universities of Europe which were largely financed by the Church and thus established permanent intellectual communities, this did not happen.
- **Conceptual Framing:** Indian astronomers maintained metaphysical beliefs on the Earth's centrality, even as they improved quasi-heliocentric models. In contrast,

Copernicus and Galileo changed cosmology itself, coming up with a "revolutionary" story that caught the attention of both intellectuals and politicians.

- **Colonial and Cultural Factors:** Mathematical astronomy was regionally significant in India but was never systematically translated into Latin before the colonial period. India was already out-flourished by European innovations of calculus and modern mechanics by that time.

Despite these limitations, the scientific history of Vijayanagar reveals a multi-faceted mode of scientific modernity. The contributions from India highlight alternative modes of amalgamation of mathematics, observation, and culture instead of European science being the only way. As an example of this, the Vijayanagar case illustrates how scientific concepts can flourish in one place, but be limited in another because of institutional and cultural influences, and therefore have a global diversity of history of knowledge.

4.6 Comparison of Mathematical Development with Contemporary China

Comparing the mathematical development of the Vijayanagar Empire (1336-1646) to that of contemporary China in the late Yuan (1271-1368) and early to mid-Ming dynasties (1368-1644) reveals significant differences in objectives, methods, institutional backing, and mathematical uniqueness. During the same period, the Vijayanagar/Indian tradition developed highly theoretical concepts in infinite series and trigonometry, foreshadowing calculus.²⁸ Meanwhile, Chinese mathematics was more algebraic, algorithmic, and applied, with a focus on practical government and engineering. The following comparative **Table 4.2** outlines major thematic similarities and contrasts between the two traditions.

Aspect	Vijayanagar / Indian Tradition	Chinese Tradition (Yuan–Ming period)
Intellectual Foundations	Rooted in <i>Siddhāntic astronomy</i> and <i>Gaṇita-śāstra</i> ; major texts: <i>Tantrasamgraha</i> (Nilakantha Somayaji, 1501 CE), <i>Yuktibhāṣā</i> (Jyesthadeva, c. 1530 CE), <i>Driggaṇita</i> (Parameśvara). These integrate mathematical reasoning (<i>yukti</i>) with empirical observation (<i>drig</i>).	Based on long calendrical traditions of <i>Li fa</i> (calendar methods); continuity from <i>Jiuzhang Suanshu</i> (Nine Chapters on Mathematical Art) through <i>Suanxue Qimeng</i> (Zhu Shijie, 1299 CE) and <i>Mathematical Treatise in Nine Sections</i> (Qin Jiushao, 1247 CE). Emphasis on arithmetic algorithms (<i>fangcheng fa</i> , <i>tianyuan shu</i>).
Institutional	Knowledge preserved in temple-	Administered through the Imperial

Aspect	Vijayanagar / Indian Tradition	Chinese Tradition (Yuan–Ming period)
Context	colleges (<i>paṭhaśālās</i> , <i>agrahāras</i>). Observation integrated with ritual timekeeping and temple architecture; astronomers supported by royal courts (e.g., Krishnadevaraya’s period).	Astronomical Bureau (Qintian Jian) under Yuan and Ming dynasties. Officials compiled official calendars (<i>Da Tong li</i> , 1369 CE). Strong state patronage for predictive astronomy.
Mathematical Tools	Developed trigonometric and infinite-series methods : sine, cosine, and arctangent expansions (Madhava of Sangamagrama). Formulas for π via alternating series. Advanced interpolation and error-correction (<i>śeṣa-prayoga</i>).	Excelled in algebraic algorithms and polynomial equations . Qin Jiushao’s <i>tian yuan shu</i> introduced symbolic algebra with counting rods; Zhu Shijie’s <i>Suanxue Qimeng</i> solved high-order equations numerically. Trigonometry absent; reliance on chord or linear approximations.
Astronomical Modeling	Quasi-heliocentric planetary model (Nilakantha) with inner planets orbiting the Sun, and the Sun around Earth. Use of trigonometric corrections for anomalies; accurate prediction of eclipses.	Predominantly geocentric cosmology , adapted from earlier Han and Tang models. Focus on calendar reform, predicting solstices, lunar months, eclipses. Instrumental precision high (armillary spheres, gnomons).
Philosophical Orientation	Mathematical reasoning viewed as <i>yukti</i> , a means of truth discovery aligned with <i>dharma</i> and cosmic order. Computation had metaphysical connotations of harmony (<i>ṛta</i>).	Mathematics regarded as <i>shu</i> (art or method), a pragmatic tool for governance and cosmic regulation (<i>tian dao</i>). Less metaphysical speculation, more administrative purpose.
Pedagogical Tradition	Texts in Sanskrit and Malayalam verse + prose; rigorous verbal proofs integrated with examples. Pedagogy oral-textual; emphasis on memorization + demonstration.	Instruction through commentaries and worked examples; <i>Nine Chapters</i> remained canonical. Use of counting rods and later abacus in teaching algorithmic computation.
Observational Practice & Instruments	Use of <i>śaṅku</i> (gnomon), <i>ghaṭī-yantra</i> (water clock), <i>golayantra</i> (armillary sphere); observational data integrated into computational revisions (<i>driggaṇita</i>).	Sophisticated bronze armillary spheres, sighting tubes, clepsydras; Ming observatories in Beijing (e.g., built 1442 CE) combined Islamic and native instrumentation.
Transmission and Interaction	Limited direct contact with China; indirect awareness via maritime exchanges through the Indian Ocean. Focus remained internal to Sanskrit scholarly network.	Some awareness of Indian astronomy via earlier Buddhist and Islamic transmissions; by the Ming, Islamic (Arab–Persian) astronomical methods had greater influence than Indian ones.
Representative	Infinite series for sine and cosine:	Numerical root extraction: <i>tian yuan</i>

Aspect	Vijayanagar / Indian Tradition	Chinese Tradition (Yuan–Ming period)
Mathematical Concept	$(\sin x = x - x^3/3! + x^5/5! - \dots)$ (Madhava).	<i>shu</i> representing equations symbolically, e.g. solving $(x^{10} + \dots = c)$. Focus on algorithmic iteration.
Major Primary Sources	<i>Tantrasamgraha</i> , <i>Yuktibhāṣā</i> , <i>Driggaṇita</i> , <i>Gaṇitakaumudī</i> , <i>Līlāvātī</i> .	<i>Jiuzhang Suanshu</i> , <i>Mathematical Treatise in Nine Sections</i> , <i>Suanxue Qimeng</i> , <i>Da Tong li</i> , <i>Yuán li</i> .

Table 4.2: Comparison of Mathematical Development with China

4.6.1 Epistemic and Philosophical Differences

According to Madhava's *śeṣa-prakriyā*, Indian Gaṇita-śāstra views numbers as continuous magnitudes that may be subdivided indefinitely. This allows for the creation of series and convergence notions. The basic concept of *yukti* merged empirical verification with logical reasoning, resulting in what Kim Plofker (2009, pp. 204-210) refers to as "computational empiricism."

In contrast, Chinese mathematics conceptualised knowledge as *fa shu* (methods), emphasising repeatable procedures above derivation. Proofs in Chinese literature are integrated in working instances rather than axiomatic argumentation. Thus, while both systems prioritised accuracy and precision, they had different interpretations of proof and abstraction.

4.6.2 Methodological Convergence and Divergence

Both civilisations used iterative calculation and interpolation, but their symbolic languages varied significantly. Indian academics utilised sine-difference tables and verbal algebra, but Chinese scholars used rod numerals and proto-algebraic diagrams (*tian yuan shu*). Martzloff (2016) emphasises that, while Chinese algorithms attained numerical efficiency similar to Madhava's trigonometric expansions, they never developed an explicit idea of function or infinite series²⁹.

As a result, the Kerala innovation of analytic trigonometry remains unique in the worldwide 15th-century mathematical scene.

4.7 Comparison of Mathematical Development with Contemporary Europe

India (Vijayanagar era) retained and extended a long-standing mathematical tradition,

reaching **early calculus concepts ahead of Europe**. Despite not being directly controlled by the Vijayanagar court, Kerala was culturally connected and part of the larger Indic scientific community. Scholars such as Madhava of Sangamagrama and his successors, Paramesvara and Nilakantha Somayaji, made significant contributions to mathematical astronomy. Madhava, for example, created early forms of infinite series expansions for trigonometric functions, laying the groundwork for what can be considered proto-calculus centuries before Newton and Leibniz in Europe. In contrast, Europe in the late mediaeval and early Renaissance periods was uncovering and integrating ancient Greek and Arabic knowledge, with practical and commercial applications driving innovation.³⁰ **Table 4.3** compares the mathematical and astronomical advancements in Vijayanagar India and Europe between the 13th and 16th centuries. Key areas include numeral systems, algebra, trigonometry, early calculus concepts, the integration of astronomy and mathematics, practical applications, and institutional support. The comparison highlights Vijayanagar's advanced development in decimal numeration, algebra, trigonometry (including infinite series), and early calculus concepts, as well as its strong link between astronomy and practical domains such as temple architecture and commerce, in contrast to Europe, where similar developments were emerging more gradually as shown in **Table 4.3**. Formal symbolic algebra and calculus would emerge in Europe in the 17th century, long after Indian scholars had hinted at similar concepts.

Category	Vijayanagar India (14th–16th c.)	Europe (13th–16th c.)
Numeral System	Fully developed decimal system , zero	Adoption of Hindu-Arabic numerals in progress
Algebra	Developed algebra (Bhāskara II)	Revival via translations, rudimentary symbolism
Trigonometry	Advanced, including infinite series (Madhava)	Used primarily for astronomy; less developed
Calculus Concepts	Early ideas of limits, series , etc.	Not until Newton & Leibniz (17th century)
Astronomy/Math Link	Strong, with planetary models, calendars	Also strong, esp. in Copernican astronomy
Practical Application	Architecture, ritual, commerce	Commerce, navigation, architecture
Institutional Support	Temples, courts, scholarly patronage	Church, universities, royal courts

Table 4.3: Comparison of Mathematical Development with Europe

4.8 Comparison of Astronomical Development with Europe

Using texts like the *Āryabhaṭīya*, *Brahmasphuṭasiddhānta*, and *Sūrya Siddhānta*, astronomy during the Vijayanagar period was firmly based on India's classical Jyotiṣa tradition. These systems used trigonometric functions, deferents, and epicycles to forecast calendrical occurrences, eclipses, and planetary motion (Pingree, 1981). Although these underpinnings were similar to those of medieval Indian philosophy, Vijayanagar scholars, Nilakantha Somayaji in particular, introduced conceptual improvements that foreshadowed subsequent advances in Europe.

4.8.1 Quasi-Heliocentrism and Copernican Parallels

One of the most notable intellectual developments of the Vijayanagar era is Nilakantha's quasi-heliocentric paradigm, which was presented in the *Tantrasamgraha* (1501). According to this theory, Mercury and Venus orbited the Sun, while Earth stayed fixed and the Sun orbited it. Saturn, Jupiter, and Mars kept their orbits around Earth. This hybrid system provided a better mathematical explanation for the inner planets' retrograde motion while maintaining geocentric assumptions (Ramasubramanian and Sriram, 2025).³¹ Nilakantha's approach and Nicolaus Copernicus' *De Revolutionibus* (1543) exhibit a significant similarity in that both attempted to address discrepancies in planetary motion by altering inherited cosmological systems. Copernicus completely moved Earth away from the center, but Nilakantha did not reach this metaphysical rupture. However, Nilakantha's improvements frequently beat early European heliocentric models in terms of computational accuracy (Joseph, 2011), demonstrating that the intellectual trend toward rethinking cosmic order was not exclusive to Europe.

4.8.2 Knowledge Transmission and Its Limits

The Vijayanagar model, in spite of its sophistication, failed to gain worldwide traction. Its dissemination methods are more to blame than its scientific content. Oral instruction, temple schools (*paṭhaśālās*), and palm-leaf manuscripts were the main ways that Indian scholarship was disseminated (Raju, 2007). Knowledge was rarely shared across linguistic and cultural divides; instead, it was maintained, improved, and passed down locally. In contrast, Copernican books were widely disseminated thanks to the development of the printing press in Europe in the middle of the 15th century. Transregional intellectual exchange was promoted by universities and court-sponsored organizations (Westman, 2011).³² Copernican concepts were guaranteed to provoke controversy, discussion, and ultimately a paradigm change because of this institutional and technological environment. Despite having similar intellectual rigor,

Vijayanagar's advancements were nevertheless constrained by limited pedagogical systems and manuscript culture (Pingree, 1981).

4.8.3 Historiographical Debate and Global Pluralism

Significant historical problems are brought up by the comparison between Vijayanagar and Europe. Indian, Chinese, and Islamic contributions have been marginalized as "precursors" rather as coequal traditions in traditional narratives of the "Scientific Revolution," which frequently privilege Europe as the exclusive location of modern science's development (Shapin, 1996).³³ This Eurocentric framework is contested by recent scholarship, which promotes a global plurality of scientific modernities (Joseph, 2011; Ramasubramanian & Sriram, 2025). According to this viewpoint, Nilakantha's quasi-heliocentric model was a component of a larger intellectual experiment with planetary order rather than a failed premonition of Copernicus. It shows how various cultures followed different paths to comprehend the universe, but their regional embedding does not lessen its originality. **Table 4.4** compares the astronomical traditions of the Vijayanagar Empire (India) and Medieval Europe from the 13th to 16th centuries. It highlights differences in astronomical models, observational tools, mathematical foundations, purposes, and institutional support. While Vijayanagar astronomy relied on classical Indian systems, complex planetary models, and Kerala School innovations such as infinite series for trigonometry, European astronomy was dominated by the Ptolemaic geocentric model until the Copernican Revolution (1543). The **Table 4.4** also contrasts textual transmission, heliocentrism, and notable institutional and scholarly support in both regions, illustrating the parallel yet distinct development of astronomical knowledge.

Aspect	Vijayanagar Empire (India)	Medieval Europe (Europe)
Astronomical Tradition	Based on classical Indian systems: <i>Aryabhata</i> , <i>Varāhamihira</i> , <i>Bhāskara II</i>	Dominated by Ptolemaic (geocentric) model from <i>Almagest</i>
Astronomical Models	Geocentric with complex planetary models (epicycles, deferents, etc.)	Ptolemaic system until 16th c., then challenged by Copernicus
Observational Tools	Use of gnomons , water clocks , armillary spheres , yantras	Basic instruments: quadrants , astrolabes , armillary spheres
Mathematical Basis	Trigonometry, sine tables; Kerala School introduced infinite series	Geometry-based models; later use of trigonometry for celestial mapping
Purpose and Application	Calendar-making, astrology (Jyotisha), ritual timing, navigation	Church calendar reform, astrology, navigation, timekeeping
Heliocentrism	No clear concept of heliocentrism	Introduced by Copernicus (1543):

Aspect	Vijayanagar Empire (India)	Medieval Europe (Europe)
	Earth considered fixed	heliocentric model
Textual Transmission	Sanskrit treatises; preserved and expanded earlier Indian texts	Latin texts; translations of Arabic & Greek works; printed books
Institutional Support	Royal patronage, temple observatories, Brahmin scholars	Church-sponsored universities, monasteries, courts
Notable Events	Kerala school's mathematical astronomy flourishes (14th–16th c.)	Copernican Revolution begins (1543), challenging old cosmology

Table 4.4: Comparison of Development with Europe

4.9 Global Timeline: Mathematical & Astronomical Progress (1336–1646 CE)

Period / Date	Vijayanagar Empire & Kerala School	Islamic World	Europe (Renaissance & Early Modern)	China (Yuan & Ming Dynasties)
c. 1360–1400	Compilation and refinement of astronomical tables based on Aryabhata and Bhaskara II's works.	Ulugh Beg's observatory in Samarkand planned (later built 1420s).	Early translations of Ptolemaic works from Arabic to Latin continue.	Yuan dynasty's <i>Shoushi</i> calendar still in use; astronomy influenced by Islamic techniques.
c. 1380–1420	Observational refinements in planetary positions; emphasis on eclipse prediction.	Ulugh Beg trains astronomers, compiles <i>Zij-i Sultani</i> .	Early use of mechanical clocks for astronomical purposes in Italy.	Ming dynasty establishes Imperial Astronomical Bureau.
c. 1420–1460	Parameśvara develops improved planetary models; works on the <i>Drigganita</i> and eclipse calculation methods.	Completion of <i>Zij-i Sultani</i> (1437) with highly accurate star charts.	Gutenberg's printing press (1440s) accelerates spread of astronomical texts.	Ming court exchanges astronomical knowledge with Islamic scholars.
c. 1460–1500	Parameśvara's disciples (like Damodara) and Nilakantha Somayaji advance trigonometric series, prefiguring calculus ideas.	Islamic astronomy begins to influence Ottoman navigational charts.	Regiomontanus publishes <i>Ephemerides</i> (1474) improving European navigation.	Ming dynasty refines water-powered astronomical clocks.
c. 1500–1540	Nilakantha Somayaji's <i>Tantrasamgraha</i> proposes a quasi-heliocentric planetary model (1501) anticipating later	Ottoman astronomers refine planetary theories; Arabic texts translated to Turkish.	Copernicus publishes <i>De Revolutionibus</i> (1543).	Chinese astronomers adopt and adapt Islamic spherical trigonometry.

Period / Date	Vijayanagar Empire & Kerala School	Islamic World	Europe (Renaissance & Early Modern)	China (Yuan & Ming Dynasties)
	European models.			
c. 1540–1580	Sankara Varman and others continue eclipse prediction and trigonometric refinements.	Taqi al-Din builds Istanbul Observatory (1577), creates precise astronomical instruments.	Tycho Brahe builds Uraniborg Observatory (1576); detailed planetary observations.	Ming dynasty reforms lunar calendar.
c. 1580–1646	Kerala school scholars like Jyesthadeva explain infinite series expansions (<i>Yuktibhasa</i>).	Decline of large-scale observatories but legacy continues through manuscripts.	Galileo uses telescope for celestial observations (1609); Kepler's laws published (1609–1619).	Jesuit missionaries introduce European astronomy to China (late Ming period).

Table 4.5: Global Timeline of Mathematical and Astronomical Progress

The global chronology of mathematics and astronomy (Table 4.5) for the period 1336–1646 CE reveals that the disciplines of mathematics and astronomy did not develop in any single cultural domain; they were rather integrated, developed, and advanced over time, sometimes without any direct cross-culturation. Copernicus was writing *De Revolutionibus Orbium Coelestium* (1543) in distant Europe, while Nilakantha Somayaji was improving trigonometric techniques and putting out a quasi-heliocentric model in Kerala (c. 1501). Despite their unique emergence, these two intellectual revolutions, one with its roots in the Indian temple-scholarly tradition and the other in the European university- church framework, shared the spirit of questioning long-held beliefs about the universe.

Similarly, Ulugh Beg in Samarkand directed the production of the *Zij-i Sultani* (1437), one of the most precise star catalogues prior to modern times³⁴, while Parameshvara in South India documented decades of eclipses to enhance planetary forecasts. Although direct observation was valued in both traditions, they functioned in distinct institutional contexts, state-funded observatories in the Islamic world versus temple schools and royal courts in Vijayanagar.

Through the Royal Astronomical Bureau, the Ming dynasty in China, on the other hand, placed a strong emphasis on the bureaucratic use of astronomy. Its lunar calendar modifications show that it prioritises ceremonial order and control over theoretical innovation³⁵. On the other hand, the printing press's introduction in Europe sped up the spread of astronomical concepts, guaranteeing that Copernicus, Kepler, and Galileo changed the intellectual landscapes much beyond their local settings.

Taken together, these accomplishments provide an astonishing example of convergence of innovation: Vijayanagar's infinite series, the star catalogues of the Islamic world, the calendar reforms of China, and the heliocentric revolution of Europe. But, they were separated by institutional, linguistic and political systems. In India and China science flourished but was contained within their own region: transmitted primarily through the medium of manuscript and oral communication. The contrast highlights the international nature of what is often referred to as the "Scientific Revolution" which is the product of a much broader and complex global story of knowledge.³⁶

4.10 Historiographical Analysis and Global Reassessment

The historiography of Indian and Vijayanagar mathematics has changed dramatically during the last 50 years. Early narratives, particularly in colonial and early postcolonial research, tended to either romanticise Indian science as mystical or reduce it to forerunners of European invention. Such frameworks, such as J. Needham's *Science and Civilisation in China* (1959, 1986) and D. Pingree's early Sanskrit text catalogues (1970s), provided invaluable documentation, but they frequently interpreted Indian achievements through Eurocentric lenses of progress, linear chronology, and diffusion.

The paradigm began to evolve in the 1990s, with the growth of global and multicultural scientific histories. Scholars such as George G. Joseph (*A Passage to Infinity*, 2009) and Kim Plofker (*Mathematics in India*, 2009) have emphasised the independent development of mathematical reasoning in South Asia, notably the analytic accomplishments of the Kerala-Vijayanagar circle. The writings argued that Madhava's trigonometric series and Nilakantha's quasi-heliocentric model did not stem from Greco-Islamic astronomy, but instead represented another form of rationality, *yukti* and *anumāna* (logical reasoning and inference).

In the earlier diffusionist theories it was suggested that algebra in China and trigonometry in India might have been introduced through Islamic channels. Recent studies however, have proposed a much more complex and multi-actor exchange system. The Asian cultures both developed within independent epistemic cultures, at times traveling through oceanic and academic channels, say Karine Chemla (*Changing Mathematical Cultures*, 2022) and Andrea Bréard (*Revealing the Invisible*, 2021).

During the period of Vijayanagar influence, there is no mention of literary borrowing, although there is suggestion of greater understanding of computational procedures, possibly through the Kerala spice ports.

Instead, parallel rationalities were created in both countries: Indian *yukti* (logical reasoning by derivation) and Chinese *fa shu* (algorithmic method). They are increasingly recognized by comparative historians as co-equal forms of scientific reasoning, rather than as an inferior and derivative version, eroding the diffusionist core of traditional history.

The study of astronomical and mathematical knowledge under the Vijayanagar Empire throws up the interesting and perplexing fact that this body of knowledge is both ancient Indian in its philosophy and yet innovative. Vijayanagar science is not an isolated cultural experiment, but a flourishing centre in the world history of ideas. There are four themes that are particularly salient. 1. The key of mathematical astronomy, the patronage of Vijayanagar, 2. Kerala School of innovations which predicted calculus, 3. The absence of world-wide transmission of knowledge is a limitation. The knowledge is not transmitted to the world as it is limited. Invite rethinking of a Eurocentric history of science.

The theoretical study; the modelling of mathematics and the careful observation were all facilitated by the courts and the temple-schools of the empire. These people were constant patrons of scholars such as Parameshvara, Nilakantha Somayaji and Narayana Pandita, who developed complex planetary models, trigonometric functions, and eclipse predictions. The kings of Vijayanagar regarded Astronomy as a discipline which was of vital importance in the ceremonial order, political legitimacy and cultural prestige and not an afterthought. The support of astronomy did not stagnate, but was actively reworked and reinterpreted, in the 14th and 16th centuries, because of India's long history in the field (Pingree, 1981).

Infinite series expansions for the sine, cosine and arctangent functions were developed by the Kerala school, which was closely linked to the intellectual climate of the kingdom of Vijayanagar, centuries before Newton and Leibniz formalized calculus in Europe. Indian mathematics took the lead in intellectual achievement with the presentation of iterative techniques, convergence analysis and logical proofs by Madhava of Sangamagrama, Nilakantha Somayaji and Jyesthadeva respectively (Joseph, 2011; Raju, 2007). In these works, a new route in the modern scientific world is revealed, which is the independent development of the conceptual seeds of modern mathematical analysis from South India.

Despite their uniqueness, the inventions of the Vijayanagar and Keralan people did not affect the knowledge of the world as much as did the European discoveries. The reasons were issues of material and institutional differences, not intellectual shortfalls. The common means of imparting knowledge in India were oral, through the temples and using palm-leaf manuscripts.

Its use was restricted by these means. On the other hand, Copernican astronomy took off in Europe, and was spread easily by the printing press, universities, and courtly academies and sparked controversy before finally reaching revolution (Westman, 2011). Consequently, the accomplishments of Vijayanagar had a far reaching regional impact but were restricted on a global scale due to barriers of transmission and not concepts.

The Vijayanagar example throws into doubt the traditional view of the 'Scientific Revolution' being purely European. In so doing, we move towards a pluralistic history of science that recognizes the mathematical accuracy of Indian astronomy, the proto-calculus of the Kerala school and the quasi-heliocentric model of Nilakantha Somayaji. Eurocentric framings obscure the richness of regional traditions, seeing contributions from China, India, or Islam as forerunners to European innovations. The Vijayanagar Empire should not be considered as a mere provider of ideas, but rather as an active promoter of scientific thought, contributing to the spread of new knowledge and concepts (Shapin, 1996; Ramasubramanian & Sriram, 2025).

Suggestions for Future Research

1. Immediate digitisation and critical edition of primary manuscripts, inscriptions and astronomical tables of the Kerala school and Vijayanagar is necessary to enable computational studies and access to the world.
2. Interdisciplinary research combining archaeoastronomy, languages, and scientific history can help to unearth the empirical practices encoded in temple architecture and ceremonial calendars.
3. Comparative studies that situate Vijayanagar contributions in the context of contemporaneous developments in Islamic, Chinese and European contexts might facilitate an understanding of the patterns of knowledge exchange and regional innovations.
4. Improvement of instructional materials in regional language which reflects ancient scientific texts can enhance people's participation and intellectual curiosity as well beyond the Sanskrit literate elite.

To sum up, the Vijayanagar Empire shows how scientific innovation thrived in a variety of cultural settings, despite the fact that its impact was still limited by institutional and technological limitations. Incorporating Vijayanagar and the Kerala school into the history of

science is more than just adding a footnote to Europe's past. It confirms that the pursuit of cosmic order has always been a human activity that has involved numerous places of creativity. In addition to being an academic obligation, rethinking the history of science in this comprehensive way acknowledges the diverse intellectual legacy of humanity.

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Chapter 5: Development of Art and Architecture

5.1 Introduction

The empire's architectural marvels especially in its capital city of Hampi prove an amazing mixture of creative genius and cutting-edge technological prowess. The highly developed and innovative architectural technology of the Vijayanagar era enabled them to build many temples and secular structures that were still standing as witness to the majesty of the Vijayanagar empire. While the Vijayanagar Empire did not include the term "sustainability" as part of their vocabulary, many of the architectural practises they adhered to are similar to current sustainable ideals. The architects and builders of the empire had a keen sense of the local resources, climate and community needs which unintentionally led to the creation of buildings that were well adapted to their surroundings and which have stood the test of time. Some features like Passive cooling and ventilation, water management, durable constructions are evidently seen in the architecture of this period. The Vijayanagar builders struck a remarkable balance between structural experimentation and scientific rationality, as evidenced by recent archaeological and architectural analyses. As a result, their monuments serve as both early examples of civil engineering innovations and manifestations of religious devotion. By carefully choosing foundation locations on firm granite outcrops that reduced settlement and load distortion, the artisans of the empire showed mastery in geotechnical evaluation. The Royal Enclosure's excavations demonstrate the usage of plinth isolation and multi-tiered stone substructures, indicating a comprehension of water drainage and differential pressure management under heavy loads¹.

The art and architecture of the kingdom were a dynamic mix of the Chalukya, Chola, Pandya, and Hoysala traditions that later developed into the renowned Vijayanagar architectural style.² Percy Brown has called "Vijayanagar art as the supremely passionate flowering of the Dravidian style". The Spiritual Institution of Vijayanagar comprised of four major temple complexes³ set in the steep canyon of the Tungabhadra. Each served as the core of a separate urban area, complete with priests' dwellings and feeding-houses, colonnaded market lanes, wells, and tanks. As in the past, businesses and visitors are jammed along the colonnaded bazar street that leads up to the entrance gopuram of the Shiva- dedicated Virupaksha temple in Hampi Village. According to George Michell, the Royal Centre was of the utmost importance since it housed the Vijayanagar monarchs, their families, military commanders, ministers, and other close supporters. There is no other area of the site with as many meeting halls, lookout

tower, stables, and pavilions. These rather robust courtly constructions are all designed in a distinct elegance that combines holders, canopy or ceilings and other structures including watchtowers which is a common characteristic of temple architecture with arches, domes, and foundation inherited from Deccan sultanate court architecture. The outcome is an inventive idiom that combines Hindu and Muslim cultures - a characteristic reflection of the Vijayanagar court's cosmopolitan ethos.

Hampi, the major city of the empire was strategically positioned amid a chain of enormous granite hills that served as natural fortifications, on the banks of the river Tungabhadra. The empire built magnificent structures by making use of the plentiful local resources, particularly the hard stones quarried from the nearby hills. During the Vijayanagar period, local tough granite was selected over schist, which was previously used by Hoysalas; however, soapstone was utilised for a few relief carvings and sculptures.⁴ While using granite reduced the density of sculptured works, it was also a more durable material for the temple structure. These stones are prized for their resilience and aesthetic appeal. These were crucial in analysing the Vijayanagar Empire's architectural style. The architects and engineers of the Vijayanagar dynasty were experts at carving intricate details into the stone surfaces to produce beautiful sculptures and beautifications. The temples in particular with their elaborate facades, ornate pillars, and majestic gopurams (gateway towers) represent the peak of architectural excellence. The technology used to carve these structures confirmed an in-depth knowledge of stone-cutting methods and the skillful application of chisels, hammers, and other tools.

The switch from soapstone to granite was a significant technological development in the field of building science. Granite's great compressive strength (over 130 MPa) and thick crystalline structure required the creation of specialised iron chisels, wedges, and pounding hammers, which were made locally in bloomery furnaces. Iron-smelting workshops for tool manufacturing were maintained by the empire, according to metallurgical residues found close to Kamalapur, suggesting organised economic activity to support architectural businesses. Similar to compression-lock engineering in later mediaeval Europe, the use of granite also encouraged advancements in keystone load distribution and dry masonry bonding, enabling craftsmen to build tall gopurams without requiring a lot of mortar binding⁵. The meticulous planning and construction of the structures to withstand the test of time was one notable feature of Vijayanagar architecture. Large-scale structures that have survived centuries of weathering and natural disasters were made possible by the advanced construction methods used. Modern architects and engineers are still in awe of how the empire's architects cleverly used

interlocking stone blocks and gravity to provide structural stability to their creations.

The hydraulic and hydro-mechanical methods used in municipal and temple design were equally sophisticated. With stone-lined outlets placed at precise gradients to guarantee continuous flow without erosion, the construction of stepped tanks, conduits, and sluice chambers demonstrates an understanding of fluid pressure management. A gravity-based irrigation network spanning more than 60 km is revealed by hydrological mapping of Hampi, indicating a massive civil engineering undertaking unmatched in premodern India. The network emphasised the Vijayanagar notion of "sacred ecology,". It was not only utilitarian, but it was also beautifully incorporated into the architectural environment⁶.

In addition to hydraulic systems, structural zoning and load control are reflected in Hampi's urban fabric. Their colonnaded bazaars served as both commercial corridors and seismic dampers, absorbing horizontal stress through parallel rows of stone piers⁷. Streets and marketplaces were also orientated in a linear fashion to maximise wind movement. Additionally, the careful urban layout shows an empirical grasp of scale ratios and geometry. Recent GIS-based reconstructions indicate that the principal temple axis' proportionate symmetry closely matches ratios mentioned in the *Mānasāra* and *Mayamata* texts, indicating a purposeful blending of *śilpa-śāstra* theory with real-world architecture⁸.

Islamic architectural features like arcuate domes and vaulted halls were used for practical as well as aesthetic reasons. In addition to more effectively redistributing roof loads, these designs popularised the use of lime mortar bonding in domed ceilings, a development that subsequently impacted Deccan Sultanate and Nayaka architecture⁹. By combining Persian and Deccan techniques for building vaults and managing water with native Dravidian stone craftsmanship, Vijayanagar architecture operated as a hybrid technical environment.

The architectural expertise of the Vijayanagar Empire also included a wide variety of non-religious buildings in addition to temples. With meticulous precision, palaces, markets, pavilions, irrigation tanks, and defensive fortifications were all built, displaying the empire's all-encompassing approach to urban planning and infrastructure development.

5.2 Some Innovations achieved in Architecture by Vijayanagar Empire

- (i) The Dravidian architectural practices have a strong influence on Vijayanagar architecture, which is distinguished by its pyramid-shaped *vimanas* (soaring frameworks over the sanctum), carved monolithic pillars, and ornate decoration. To

further add to the empire's unique style, Vijayanagar architects also blended Islamic architectural elements with regional variations.

(ii) The utilisation of tough granite rock for the construction of massive architectural structures. Granite's durability made it ideal for long-lasting religious and civil structures, though it required different tools and carving methods. The artisans compensated for granite's hardness by using **plaster coatings and pigments** to create smoother, colour-rich finishes¹⁰.

(iii) The distinctive features of Vijayanagar architecture are carved stone reliefs and sculptures, which display superb artistry and craftsmanship. A vast variety of subjects are shown in the carvings, such as gods and goddesses, scenes from Ramayana and Mahabharata, celestial beings, mythical animals, courtly scenes, processions and ordinary life.

(iv) One distinctive aspect of Vijayanagar architecture is the introduction of Kalyana Mandapa to the temple complexes. The Kalyana Mandapa is a large hall that has a flat roof and is supported by several pillars. It is used for the yearly celebrations of the god's marriage to his consort, who is usually Pampa or Virupaksha.

(v) Vijayanagar introduced the thousand-pillared mantapa and yali pillars, which featured dynamic, high-relief sculptures that served both structural and narrative purposes. These pillars used clustered column shafts to distribute stress while allowing for deep carving, a technological application of tensile and compressive balance in stone engineering. The panels and Yali guardrails exhibit creativity in sculpture, reflecting an in-built understanding of balance and motion¹¹.

(vi) A typical Vijayanagar temple followed a highly standardised ground plan which reflects an advanced hold of spatial design and geometry. This layout typically included:

- *Garbhagriha* (sanctum, always square)
- *Pradakshinapatha* (circumambulatory path)
- *Navaranga* (central hall with four pillars)
- *Mukhamantapa* (front hall)

- *Kalyanamantapa* (marriage hall)
- *Utsavamantapa* (festival pavilion)
- *Prakara* (enclosure with Gopura gateway).

The overall plan always oriented eastward and was symmetrical along the central axis, reflecting both cosmic alignment and architectural rationality¹².

(vii) Some of urban sites such as Hampi, Penukonda, Vellore, Chandragiri and Gingee were also fortified during this time which served as the foundation for subsequent Maratha and Mysore kingdoms.

(viii) One major development was the application of modular design in both religious and non-religious buildings, which enabled the creation of a large number of standardized, designs. The use of stone elements, such as pillars, beams and lintels, was standardized in proportionate units, frequently in the ratio 1:2:4, for the ease of prefabrication and on-site assembly¹³. This flexibility enabled quick installation without compromising on load distribution. Archaeological studies at Hampi have revealed evidence of stone numbered markings on pillar bases and architraves, indicating a coded construction process comparable to early blueprinting¹⁴.

(ix) Vijayanagar architects significantly improved the field of **cantilever engineering**. Roof slabs of Kalyana Mandapas and dancing halls were supported by projecting corbels that balanced horizontal thrust by counterweighting¹⁵. The precision of joint location and the decrease in bending stress demonstrate a practical understanding of moment equilibrium centuries before formal structural analysis was established. These mechanical insights are most evident in the vast flat-roofed mandapas of the Vitthala and Hazara Rama temples, whose span lengths exceed that of most modern South Indian halls.

(x) In terms of surface technology, Vijayanagar craftsmen **improved polishing and weatherproofing procedures** with lime-silica combinations made from shell ash and river sand¹⁶. The use of this thin plaster, chunam, created a reflecting surface that reduced absorption of heat and also prevented sculptures from being degraded by rainwater, thus demonstrating an implicit understanding of the concept of thermal and chemical resistance.

(xi) Another important technical development, was the acoustic and optical architecture. The melodic pillars of the Vitthala Temple are the result of studies in resonant frequency control via geometric modulation. The column forms were produced by the artists using a single granite shaft, with calculated tapering to produce harmonics in the range of 200 to 800 Hz, exemplifying their knowledge of the mechanics of vibrations. Likewise, the Virupaksha Temple's camera obscura effects indicate that the temple's designers were aware of optical principles, a knowledge not matched in the architecture of the entire medieval period of India.

(xii) Civil engineering expertise may also be seen in the multi-layered foundation constructed for huge gopurams and palace walls. Compact gravel beds, lateral drainage channels and vertical stone rubbles were frequently used in foundations to reduce moisture capillary rise¹⁷. This not only avoided dampness but it also distributed vertical stresses equally across uneven terrain which can be seen as an example of soil-stabilisation engineering.

(xiii) Finally the Vijayanagar builders introduced integrated hydrological design within temple boundaries. Underground conduits linked ritual tanks, bathing areas, and kitchen complexes which ensured constant water circulation driven by gravity rather than mechanical lifting. These water-management systems are still traceable beneath the courtyards of Hampi which shows how they interconnected environmental science with architecture and sanitation.

When these innovations are seen together it is clear that Vijayanagar architecture was not a static revival of the Dravidian past but rather a progressive experimentation in applied mechanics and environmental control. It can be understood as civil-engineering achievement that influenced the South Indian building traditions for centuries.

5.3 Temple Architecture

Vijayanagar rulers constructed many magnificent temples in Andhra Pradesh, Karnataka and Tamilnadu. The architectural styles of Anegundi, Hampi, Lepakshi, Srirangam, Srisailem, Tirumala, Tirupati, Penugonda, Tadapatri, Chidambaram, Chandragiri, Kalahasti, Kanchi, Rameswaram, Madurai (**as mentioned in Fig 3**) and other locations were known during the Vijayanagar period. The typical Vijayanagar temples have tall stone enclosure with tall gopuras at the entrance. Temples were made of granite but the Gopura's construction included stucco, wood, and bricks.¹⁸ Most of the temples during this period were made in Dravid style of temple architecture.

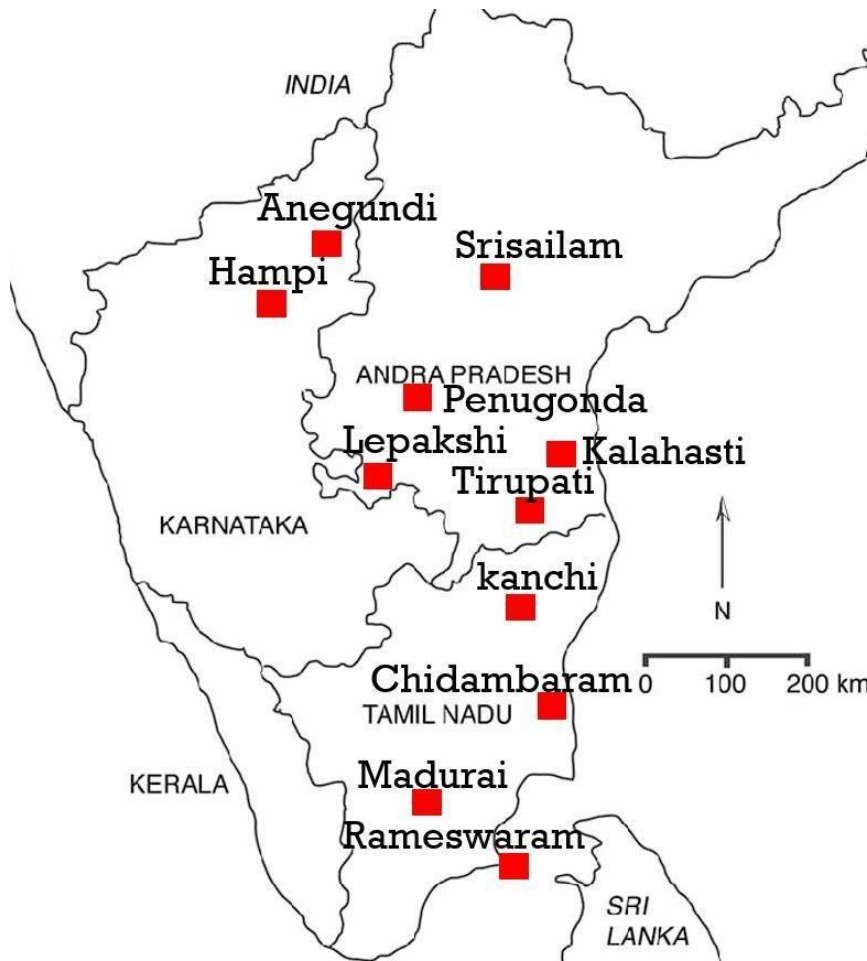


Fig 3: *Architectural Sites in Andhra Pradesh, Karnataka, and Tamil Nadu.*

The Vijayanagar Empire's temple architecture is a unique combination of religious symbolism and scientific engineering. Each of the holy complexes was not only a devotional structure but also a technical system. It can be seen as single structure that encompassed a combination of geometry, acoustics, hydrology and structural mechanics. The temples of this time show a high degree of understanding of architectural physics. The material behaviour and an adaption to the environment indicates that during this period religious design was following a logical construction.

5.3.1 Vidyashankara Temple, Sringeri, Karnataka

Sringeri is situated in northwest region of modern-day Karnataka. The Vidyasankara Temple was constructed on the other side of the Tungabhadra River by Sri Bharati Tirtha and Sri Vidyaranya, pontiffs of the Matha, between 1338 A.D. and 1350 A.D. as a tribute to their forerunner, Sri Vidyasankara Tirtha (A.D. 1228–1333). The temple's design serves as an illustration of the south Indian temple builders' proficiency with astronomy. The navaranga is

of particular interest from an astronomical perspective. Navaranga, a building made up of Twelve Dravidian-style, highly ornate pillars. This building has 12 pillars specified for the 12 signs of the zodiac, with the sun's rays falling on each of them in the order of the twelve solar months. A sizable circle has been drawn on the ground, with convergent lines indicating the path of the shadows. The Ram pillar is said to receive sunlight in the month of Aries, and the Bull pillar receives it during the month of Taurus. All the 12 months of the solar year is said to have its own rashi (Zodiac) pillar that receives morning sunlight. Although it is clear that the arrangement of the celestial pillars in the Vidyasankara Temple was purposefully planned, some archaeologists claim that the early-morning sunrays hitting an exact astrological post does not designate the constellation in which the Sun is sited, neither today nor at the time the temple was built. The physical attributes of the column setup in the Vidyasankara Temple as well as the amount of time it took for a ray of morning light to pass from one pillar to another (almost a month) closely aligned with the positions of the zodiacal star formations in 2000 BCE. They correspond to the zodiacal sky between 1700 and 2300 B.C., not the Sun's location in the celestial bodies of today. Despite the temple's purported construction date of around A.D. 1350, some speculate that the zodiac pillar layout originated from a Vedic altar or an earlier holy calendrical device from 2000 B.C.¹⁹

Nevertheless, constructed in the fourteenth century, it demonstrates the technological achievement in which the light of the sun strikes twelve zodiac pillars, each designating a month of the year. This design reflects sophisticated astronomical knowledge of the time and enables accurate clockwork and calendar estimates which integrated solar movements in a temple architecture. Its design not only offered ceremonial direction for priests but also acted as an educational tool for astronomers and mathematicians associated with the *Sringeri matha*²⁰. These building displays Vijayanagar engineers' ability to transform astronomical knowledge into architectural form.

The lithic joinery is also outstanding in its perfection. Petrographic investigations of the granite blocks reveal a high-density quartz distribution, yet joints across courses seldom reach 2 mm tolerance. Artisans used iron-and-lead dowel pins inserted into pre-drilled sockets, a sophisticated anchoring technique that prevented vertical slippage while allowing for micro-movement with temperature fluctuation²¹. This technique demonstrates a realistic grasp of **thermal expansion coefficients** and elastic deformation.

5.3.2 Virupaksha Temple, Hampi

The temple is devoted to Lord Virupaksha, a manifestation of Lord Shiva and located between Tungabhadra River and Hemkut hill at Hampi in Karnataka. The Hampi village is centred on a wide street and market district, which is dominated at its western end by the gigantic tower of the Gopuram temple entrance. Although the majority of the temple structures can be ascribed to the Vijayanagar era, evidence suggests that some of the temple structures underwent additions in the late Chalukyan and Hoysala era.²² Lakkana Dandesha, an officer serving in Vijayanagar Empire during the time period of Deva Raya II, constructed enormous temple structure. As Michell notes the Virupaksha shrine “was continuously enlarged during the Sangama period. An important addition was the massive entrance gopura on the north side of the compound,” which points to large-scale stone building campaigns and gateway engineering in Hampi²³.

A phenomenon observed in the temple structure which serves as an illustration of a modern-day camera. The small, inverted image of the tall gopuram is one feature of this temple that attracts visitors. There is a tiny pinhole in the wall somewhere near the back of the temple that reflects an upside-down version of the gopuram on the interior wall. The only bright light coming in from that tiny hole is the only source of illumination in this tiny room-like space, making it quite obvious. The large gopuram is projected onto the wall across from it. The architecture of the temple is such that the Raja Gopuram's inverted shadow can be seen falling more than 300 feet away on the Saalu Mandapa wall at the opposite end of the Virupaksha temple. This occurs through a tiny aperture that serves as the passageway. This effect in Physics is called a “**Camera Obscura Effect using a Pinhole**”. As the name suggests, a pinhole camera is a basic device which is lens-less with a miniature; it is essentially a box that is light-proof with a hole cut out of one side. The camera obscura result takes place when light from an object passes through the aperture and shows an inverted image on the opposite side of the box (**Fig 4**). The size of the aperture should be $1/100$ th of the distance between the aperture and image. The distance between the object and the pinhole determines the size of the pictures whereas the distance between the pinhole and the opposite wall which acts as a sensor determines the quality and sharpness of the image. A pinhole camera produces an image that is reversed because light moves in a straight line. We can take images with the same quality as a digital SLR camera by using the proper pinhole camera proportions and the size of the tiny hole through which light enters. The absence of a lens sets pinhole cameras apart from other kinds of cameras. All these concepts of Physics can be seen practically on the wall of Saalu mandapa

inside Virupaksha temple (**Fig 5**). Was it created intentionally to achieve the inverted image or has happened accidentally is still a matter of debate because same phenomenon is not seen in any other contemporary temples. Nevertheless, the temple attracts the tourist to this spot and is a matter of more research.

The temple's imposing gopuram (gateway) and elaborate carvings precisely narrate stories from Hindu mythology. Its design, which makes use of intricately carved pillars and connected areas, demonstrates the engineering expertise in **seismic stability** and long-lasting structural integrity. The Manmatha tank, a sacred tank in the temple was designed with advanced water management systems integrated into the architecture. It supported communal life within the complex and facilitated religious practices.

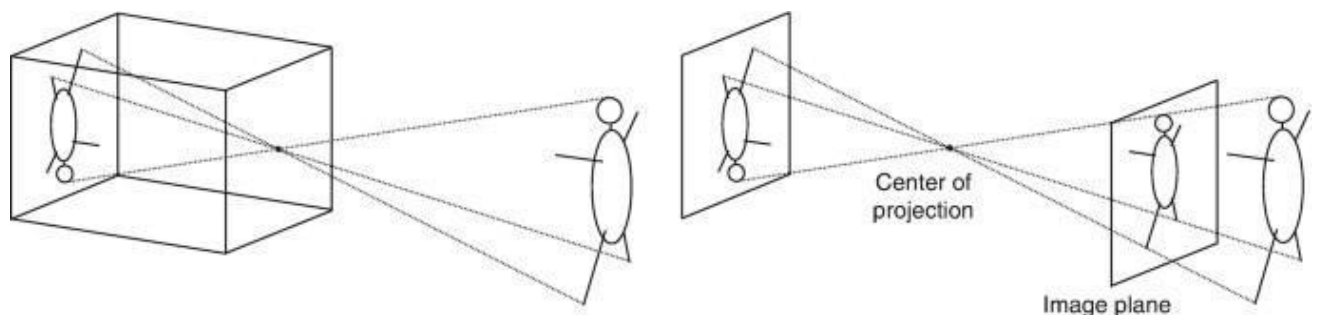


Fig 4: Sturm, P. (2021). *Pinhole Camera Model*. In: Ikeuchi, K. (eds) *Computer Vision*. Springer, Cham. https://doi.org/10.1007/978-3-030-63416-2_472



Fig 5: *Raja Gopuram's inverted shadow on Saalu Mandap dark room.*

<https://world2talkabout.wordpress.com/2014/10/29/temple-tales-2-mystery-unsolved>

The **Manmatha tank** and its drainage network reveal developed hydraulic engineering. Excavations have discovered subsurface conduits that feed the tank via a arranged channel system originating from the Tungabhadra's smaller tributaries²⁴. The canal floor was

paved with cut stone slabs placed at a slope of 0.5° - 1° to maintain a constant flow rate without erosion which shows the knowledge of fluid dynamics and sediment control. Furthermore, the tank's overflow ports were built using filter stones with tiny pores to promote self-cleaning circulation and reduce stagnation²⁵. This water system enabled not only ritual ablutions but also the temple's climate management by cooling nearby mandapas via evaporative air flow.

5.3.3 Vitthal Swami Temple, Hampi

The Vitthala Temple in Hampi, is a magnificent illustration of the Vijayanagar Empire's highly developed engineering and architectural abilities. This temple is devoted to Lord Vitthal, a manifestation of Lord Vishnu. It is renowned for its exquisite stone carvings, musical pillars, and the iconic Stone Chariot. It is one of the most well-known and well-preserved temples in the area. Here are a few of the Vitthala Temple's architectural wonders and features:

- (i) **Musical Pillars.** The Ranga Mantapa, a pavilion within the Vitthala Temple complex, houses the musical pillars, also referred to as the "SAREGAMA pillars," a group of stone columns. "The pillars were found to have larger dimension at the bottommost portion and it decreased almost continuously to the minimum at the uppermost portion"²⁶. When gently tapped, these pillars sound like musical notes. According to legend, when tapped, each pillar emits a distinct sound akin to the notes of the seven fundamental musical tones: Sa, Re, Ga, Ma, Pa, Dha, and Ni. The sound recorded from a pillar is found to produce bell-like sound (Patil & Gajbhar). Although the precise engineering and acoustic methods used to build the musical pillars are not fully understood, it is thought that the ancient Hampi builders and architects used some cunning techniques. According to one theory, the pillars' different stone compositions and densities during construction led to a range of sound frequencies when they were struck. A collection of musical pillars can be transformed into an electromechanical instrument, like an electronic guitar, by using a contact microphone and an amplifier-loudspeaker system. There are no side walls in the rooms where musical pillars have been installed. so that the acoustics of the room won't affect the sounds coming from the pillars. We discover two or three pillars with the same frequency in some clusters. When any of these pillars is struck, the other pillars at the same frequency begin to

vibrate due to resonance. However, the Archaeological Survey of India (ASI) has now prohibited entry to the musical pillars in order to maintain their integrity and protect them from further destruction as a result of the large number of tourists exploring the site and the possibility of damage caused by continuous tapping. The pillars' musical tones can no longer be heard by touching or tapping them.

- (ii) **Stone Chariot.** It is a shrine in the form of a chariot carved out of a single granite block. The chariot is highly detailed and rests on large stone wheels that were once believed to be rotatable, though they are now fixed to preserve the structure (**Fig 6**). This rotating mechanism most likely utilised a central granite spindle with an iron pin and a lubricating paste made of castor oil and plant resins to minimise frictional erosion. The structure's load is transferred by four symmetrically arranged axles, which distribute weight uniformly onto a square plinth base, ensuring torsional balance and static stability. The chariot's structure therefore combines artistic majesty with mechanical stability which shows superior lithic mechanics in premodern India. The chariot's intricate carvings and other details, which are meant to resemble processional chariots, show off the exceptional craftsmanship of the period's artisans. The chariot is remarkably strong and long-lasting due to its monolithic design. It has endured the test of time and continues to stand as one of the enduring representations of the Vijayanagar Empire's superior architectural achievements.



Fig 6: *Stone Chariot in Vitthal Swami temple (Self Clicked)*

- (iii) **Advanced Water Management.** The empire's engineers and builders designed a complex water management system to provide a constant flow of water and drainage in the temple complex. A network of aqueducts and canals supplied water from the nearby sources such as the Tungabhadra river to the temple complex. These water channels provided an effective supply of water to the gardens and other parts of the temple complex. The Pushkarini is a well known stepped tank which forms part of the temple complex. It was also used for ceremonial purposes besides serving as a rainwater reservoir. Even during dry seasons, easy access to water was possible due to the step design. Hampi's engineers devised underground drainage to control the rain water and prevent water logging within the temple complex. This system would redirect additional water flow from the buildings. These are the major features of the Laxmi Pushkarini, which is a large temple tank within the Vitthala Temple Complex, apart from the Pushkarini. The aim of this tank was to collect and store water for different activities at the temple. The water management system in Hampi also emphasized on water conservation. Rainwater

harvesting practices were probably used to replenish groundwater to ensure a sustainable supply.

- (iv) **Seismic Stability.** The seismic stability of the Vitthala Temple in Hampi and other historical structure in the region are major concerns due to seismic activity in the region. Hampi being in a seismically active area, any restoration or conservation works on these ancient monuments require consideration of the threat of earthquakes and their potential effects on the stability of the monuments. The architects and engineers of Vijayanagar Empire constructed the Vitthala Temple and other structures in the 15th century, which may not have been able to avail the modern principles of seismic design. They did however, utilised some architectural and engineering elements that enabled the structures to withstand seismic forces to some degree. The layout of the foundations of temples is generally laid out to distribute the weight of the temple over a wider surface for greater stability in case of earthquakes. Some architectural features like the use of large stone blocks and heavy stone construction could be dampeners and decrease the level of vibrations during seismic events. Structures with symmetrical designs and uniform mass distribution might be more resistant to seismic forces. The tall columns and long corridors may provide flexibility to the structure, enabling it to sway and disperse seismic energy. In order to minimise micro fractures, the artists used the patterns created by chiselling, which was based on the natural cleavage planes of granite which is a primitive form of stress management in fragile materials. Anti-rust engineering was used in Roman and mediaeval European masonry²⁷, and was used at concealed connections with iron dowels coated in molten lead. All of these factors may have helped in achieving seismic stability to some extent but it is essential to note that the Vitthala Temple and other Hampi structures were not specifically designed to withstand modern seismic stresses. Regular assessments, monitoring and conservation are therefore essential to safeguard and preserve these historical monuments.

The Vijayanagar Empire's developed techniques such as precisely placed stone joints and

sculpture that has withstood centuries of weathering were incorporated into the design of the temple. The musical pillars at the Vitthal Swami Temple in Hampi are a notable technological accomplishment. When these pillars are struck, they produce notes that sound like drums, tablas, and flutes. The advanced acoustic knowledge and stone craftsmanship of the ancient Indian builders and designers are reflected in this acoustic marvel. The Vitthal Swami Temple, therefore, should be seen as a monument of multidisciplinary scientific intelligence.

5.3.4 Virabhadra Swamy Temple, Lepakshi, Andhra Pradesh

The temple was built in the 16th century during the heyday of the Vijayanagar Empire, with patronage from the brothers Virupanna Nayaka and Viranna who were the officers of king Achyutraya. The most widely recognised sculpture in this temple is the "Lepakshi Nandi," a gigantic monolithic Nandi (Lord Shiva's sacred bull), located about 200 meters from the main temple, is carved from a single granite rock that is more than 8.5 meters long and 4.5 meters tall, making it one of India's biggest monolithic sculptures²⁸. The artists exhibited remarkable rock mechanics knowledge by selecting a boulder with consistent crystalline structure and limited bedding planes to minimise internal breaking. Carving such a sculpture necessitated successive wedge-splitting and hammer dressing procedures that preserved internal compressive strength while reducing surplus mass in a symmetrical sequence.

The temple complex includes a wide mandapa (hall), a shrine of Lord Veerabhadra (a manifestation of Lord Shiva) and an unusual hanging pillar that does not make full contact with the ground. (Sasidhar, 2020) "Although the temple has seventy pillars but one pillar that hangs on the temple grounds is the true wonder. As a result, many visitors to the temple pass a piece of cloth or paper under the bottom of the pillar to see if it is true." There are three pillar columns in the vicinity of the hanging pillar that support the granite beam above it and thus share a portion of the roof load, with the remaining load placed on the fourth pillar, creating a millimetre-thin gap under the subbase of the fourth column. This method shows the knowledge of the builders about the static equilibrium and the mechanics of weight transfer. In addition to its stone wonders, the Lepakshi temple is also remarkable for its pioneering methods of mural paintings, with its noteworthy chemical and material complexity. Natural colours made from iron oxides, lampblack and plant extracts bound with organic gum and lime plaster were used to paint the ceiling in the *Ardha Mandapa*. The painters used ferric oxide (Fe_2O_3) to produce red pigments, lapis lazuli to create blue pigments, and malachite for green pigments. The murals were extremely durable as they were composed of calcium

hydroxide and casein protein, which turned into calcium carbonate over time²⁹. In Hampi, each register is neatly subdivided into panels and subpanels, and in Lepakshi, the longer horizontal registers exhibit experimentation with the rhythm of the narrative and the spatial proportion³⁰. The AutoCAD and Photoshop digital reconstruction of the ceiling plans shows that placement of the murals was structured according to the architectural modules and according to the alignment of the ceiling grid, which highlights a geometric originality that was used in the planning of the temple³¹.

The orientation of the Lepakshi Temple is approximately 14° North of the East-West line, and makes the garbhagriha face the dawn rays during some months around the spring equinox. It is a tradition followed in the Vidyashankara Temple, Sringeri, which shows a common astronomical design canon for the entire late-medieval South India. Based on this, the temple has been found to cast shadows on the sun's position at the solstices: the mid-axis shadowing corresponds to the rising time of sun during the Tamil month of Panguni Uthiram, which is a celebration that correlates with fertility and planetary alignment. Such planning required precise measurement of the ratio of azimuths and shadow lengths of the sun, which could be done using gnomons or shadow measuring rods. In Shaiva temple architecture, the placement of **Nandi directly along the axial line of the sanctum entrance** creates a visual and ritual alignment between the sacred bull and the deity in the sanctum. It is an axis arrangement that creates a symbolic line that connects the devotee, Nandi and Shiva in the sacred geometry of the temple³². The monumental Nandi, placed on the approach to the Veerabhadra Temple at Lepakshi, further enforces this traditional Shaiva alignment that links the sculpture with the temple complex. The combination of astronomy, ceremonial timekeeping and architectural space is reflected here, as in the solar observatories at Konark and Chidambaram.

5.4 Non-Religious Architecture

Unfortunately, the empire declined following invasions from Bahamani kingdom in the battle of Talikota in 1565, resulting in the destruction of many architectural marvels. Several significant structures, however, have survived, offering valuable insights into the grandeur and sophistication of Vijayanagar architecture. The non-religious architecture during the time includes forts, palaces, royal enclosures, water structures like stepwells, market area and many public buildings. The empire constructed various public buildings including hospitals, schools, community centres, and administrative offices to take care of the needs of the people. The non-religious architecture of the Vijayanagar Empire represents an equally

interesting convergence of civil engineering, hydrological science, and urban planning which matches the sophistication of temple building. These structures were more than just practical because they demonstrated the empire's mastery of urban ecology, mechanical design and defensive engineering.

Hampi's urban architecture shows rigorous city design based on hydro structural concepts. Archaeological investigations show that Vijayanagar engineers purposefully built residential and administrative sections along water-bearing granite valleys to ensure constant groundwater recharging³³. Streets were made in a radial-linear design that converged on the royal centre to allow for natural drainage and defensive control. The design is similar to the Roman cardo-decumanus system.

5.4.1 Stepwells, Tanks and Aqueducts

Stepwells, also known as pushkarinis or kalyanis, were crucial part of architecture for Vijayanagar Empire's water management. These stepwells served as important water reservoirs which provided a consistent source of water for a variety of purposes such as domestic use, irrigation, and religious rituals. The Vijayanagar Empire's stepwell engineering is an example of their remarkable understanding of hydraulic principles. Vijayanagar stepwells were cleverly designed to collect and store rainwater. The stepwells of this area are distinguished for their unusual architecture, in contrast when compared to other stepwells seen in the western part of India that are prized for their visual appeal and ornamental designs³⁴. These stepwells were typically built with a series of descending steps leading to the water level. Due to the Vijayanagar empire's war, the square-form stepwell was planned and built in a prefabricated manner. This type of building technique had been popular since the nineteenth century, so it is remarkable that it emerged in the early 13th century. "Because the prefabricated building method takes less time than the conventional method, it was found that the stepwell dressing of blocks had been eliminated from the location and that the other parts of the stepwells had been built concurrently." (Selvaraj, Devadas, Perumal, Zabaniotou, & Ganesapillai, 2022). The stones were progressively numbered in an unusual way during outfitting to identify their place in the stepwell. During the monsoon, as the water level rose, the steps would be submerged, allowing the water to be safely stored underground. Stepwells were frequently built near hills or elevated regions with a large catchment area to ensure an adequate supply of water. Rainwater could flow into the catchment area, thus maximizing possible water catchment during the rainy season. Generally, the structure of the well is made of stone or brick which is durable and stable. The walls were often reinforced and thick to

support the weight of the water stored. The inlets in the stepwells were laid out so that the rainwater could be poured in. The inlets were strategically located in order to capture as much possible water. Also, outlets were constructed to control water level and water flow, during heavy rain. The steps were built to enable easy access to water from the steps. Steps were sometimes quite wide and provided resting spots, which made it easy to obtain water even when water level was low. They were able to efficiently gather water, store it, and move it to other areas, thereby providing a reliable source of water for the inhabitants and for farming. The stepwells of Vijayanagar demonstrated the architectural and engineering skills of the empire, which were not only used for practical purposes, but also as a form of art. These stepwells were critical components in ensuring the people's well-being and sustenance, demonstrating the empire's commitment to efficient water management and utilisation. They also made dams and aqueducts (other than stepwells and tanks). On rivers and streams, dams and weirs were built to use and control water movements to create artificial reservoirs. The buildings were typically made of stone or clay and were built to withstand the impact of water. The dams helped to regulate water levels to prevent flooding in heavy rains and to slowly release water for irrigation and other purposes. The Vijayanagar engineers-built aqueducts and canals to efficiently distribute water from reservoirs and tanks to farmlands and other areas. The channels have been constructed with a gradual gradient to allow for predictable rates of flow and reduced channel erosion. Stone blocks were often used to construct aqueducts, and clay was used to line canals to minimize seepage (Fig 7). Water flow was controlled by embanking the land sloping sides to the dams. These embankments facilitated the inflow of water into the canals, but also prevented the loss of water, so that water resources were optimally utilized. Some of these historic water management systems can still be seen today in the ruins of Hampi and other empire-era areas.



Fig 7: *Aqueducts made of stone blocks with slope embankments for water flow* (Self Clicked)

5.4.2 Royal Enclosures and Palace area

The royal enclosures served as the capital city's administrative and ceremonial centres, providing a grand setting for the ruling monarch and the nobility. The royal enclosures were comprised of the ruling king and the royal family's luxurious palaces and residences. These structures were constructed to provide comfort, security, and privacy. The palaces were the epitome of empire's wealth and sophistication with well-planned layouts and ornate interiors. The Royal enclosures had grand audience halls and administrative buildings where the king held official meetings, received foreign dignitaries and ran the empire's affairs. These structures were designed to hold large crowds while also showing splendour. The layout of the royal enclosures was part of a larger urban planning scheme, where the capital city was carefully organized with well-laid-out streets, marketplaces, and residential areas. The structures here incorporated many Islamic features arches and tombs. Examples are elephant stable and Queen's bath. The Queen's Bath is a large, rectangular structure with elaborate archways, balconies, and verandas surrounding a sunken bath in the centre. Their sophisticated knowledge of hydrology and hydraulic design is demonstrated by the elaborate lotus-shaped fountains and networks that formerly distributed water to maintain a cool environment inside

the submerged bath. The decorative stucco work and engraved motifs on the walls and ceilings of the structure speaks of the empire's careful attention to details. One of the main characteristics of Islamic architecture is the widespread application of pointed arches and these are frequently observed in the windows and doorways of Vijayanagar buildings. The arched windows and doorways in the Queen's Bath are suggestive of Islamic architectural designs. This urban planning ensured efficient movement and order within the city.

5.4.3 Market Places

The markets of Vijayanagar Empire were flourishing economic hubs which used to attract traders from all over. A significant part of the empire's wealth and cultural exchange was its music. The ruins of these old markets, which can be found in various locations such as Hampi, offer insights into the bustling activities of the Vijayanagar era's trade and commerce. Each temple had a market and traces of this can still be seen today, such as a market for horses next to the Vitthala temple in Hampi. Markets were well organized and the streets were wide and straight, making it easy for people to navigate and access the markets. The layout was well organized, making it easy for traders and customers to maneuver around. There were covered structures with large halls or pavilions in some of the marketplaces of Vijayanagar Empire. There were also marketplaces that were covered, which would protect the traders and their wares from the weather. A row of shops and stalls was set up along the markets, where the vendors could sell their produce. These stalls were typically made of stone or brick, making them strong and long-lasting. Centers of commerce were situated in central squares or open spaces in many marketplace. These also were public meeting places, and squares for assemblies. Visitors were offered rest areas, benches, and seating for visitors in the architecture of the market. The conveniences enhanced the comfort of those who visited the markets. In bigger markets and in the busiest trading centres, security measures have been implemented to prevent theft and maintain a safe trading environment. This may have involved a security guard and watchtowers. In the Vijayanagar Empire there were specialised markets organized by specific trades and industries. Some products, such as textiles, spices, precious metals, etc., were sold exclusively in their own markets. Market architecture was an integral part of the plans of Vijayanagar city. Markets were set up in a strategic manner so that the trade and commerce can be carried out efficiently.

5.4.4 Military Architecture

The military architecture of Vijayanagar exemplified both inventiveness and adaptation. The fortified capitals of the Vijayanagara Empire including Hampi, Penukonda and Gingee were

protected by multiple defensive enclosures constructed from massive granite stonework. These fortification walls were often built with large irregular stone blocks and integrated with the surrounding rocky landscape which shows their advanced and developed military architecture ³⁵. The forts featured polygonal bastions to remove blind spots which was an advance over the circular bastions used by previous dynasties. The outside ramparts were filled with debris powdered with hammering equipment to provide flexibility under impact, a method similar to current shock absorbers. The builders used corbelled arches at strategic entrances like the Talarighat and Bhima's Gate to channel vertical stresses laterally, reinforcing access points without the need for keystones. Watchtowers and sentry rooms included angled slit windows at particular heights to allow archery while providing protection, displaying perfection in military construction. Massive fortifications including high stone or brick walls surrounded the empire's cities and strategic locations. These walls were frequently reinforced with bastions and watchtowers placed at regular intervals to provide vantage points for archers and guards to monitor their surroundings. Michell states that Hampi became "the greatest of all fortified citadels," implying intentional use of rocky topography for defence and load-bearing foundations³⁶. He also states that rampart construction being "more greatly built than palaces themselves". This observation signals deliberate engineering priorities, massive stonework and composite fill for defensive resilience.

The Vijayanagar Empire's important forts had multiple concentric walls, forming a multi-layered defence system. This strategy increased the fort's overall resilience by making it difficult for attackers to penetrate the innermost defensive structures. Gatehouses were heavily guarded and outfitted with defensive devices like drawbridges which were used to fortify the entrances to the forts. The gatehouses served as strongpoints for soldiers and archers to fend off attackers and the drawbridges could be raised to restrict access. In order to allow archers and marksmen to engage attackers from all sides, the fortifications had bastions that extended outward from the walls. According to folklore, some forts had underground tunnels that the rulers and their families could use to flee during emergencies. In case of a siege, these tunnels offered a covert way to leave the fort. The empire strategically placed its forts by integrating natural geographical features like hills, rivers, and cliffs to increase the forts' capacity of defence. The Vijayanagar Empire's military structure was crucial to defending its holdings and upholding its hegemony in Southern India. As evidence of the Vijayanagar Empire's technological prowess in building fortifications many of these

impressive fortifications can still be found in numerous areas that were once a part of it.

5.4.5 Road Networks

The road network of Vijayanagar reflects a highly organized and technically advanced approach to urban planning. The layout of the city is also found to be geometrically organised, with its roads arranged in a radial, ring and linear pattern, signifying a calculated effort behind the city's development and growth rather than organic and unplanned. The radial roads leading from the Sacred to the Royal Centre, and the centre to the Urban Core³⁷, suggest a central administrative and ceremonial centre with a functional segregation of space linked to religious, political and residential uses. Roadways were oriented in relation to temples and gates illustrating the coupling of sacred architecture and civic planning with ceremonial routes. Stone pavements, gates and inscriptions indicate a sophisticated knowledge of engineering and topographical adaptation, suggesting the level of sophistication of urban infrastructure in premodern South India. Trade, military and ceremonial transport were connected with the roadways which implied that the road systems of Vijayanagar were multifunctional to serve the economic and statecraft needs. The split of the northeastern route towards Anegondi and towards an unknown direction suggests strategic regional connections, either between satellite settlements and resource areas, or regional integration outside the city limits. The centrality of the Ramachandra Temple is further emphasized by the spatial juxtaposition of major routes in front of the temple, interlinking political power and religious legitimacy. Stone-paved segments and alignments that follow the topography of the Tungabhadra Valley demonstrate an understanding of and adaptation to the physical setting, a practical engineering approach. Vijayanagar's road planning is a combination of technical skill and cosmological purpose and one of the most advanced premodern road design schemes in South Asia.

5.5 Features of Vijayanagar Architectural Technology

In addition to temples and holy places, the Vijayanagar Empire's non-religious architecture also demonstrated an impressive knowledge of civil, mechanical, and material sciences. Forts, palaces, public baths, marketplaces, and aqueducts show an intentional marriage of aesthetic refinement with engineering logic, demonstrating that the empire's builders were equally skilled at designing useful urban settings as they were at erecting holy monuments.

5.5.1 Structural Engineering and Load Distribution Systems

The vast civic and defence constructions of the Vijayanagar empire demonstrate an empirical grasp of load transmission, balance, and structural elasticity. The Mahanavami Dibba, Lotus

Mahal, and Royal Enclosure were constructed with a trabeated and corbelled system of granite beams that distributed compressive pressures uniformly over several columns³⁸. Recent structural models of surviving stone mandapas show that Vijayanagar engineers modified column spacing to ensure a homogeneous stress of around 2-4 Mpa in granite, which is very close to contemporary safe load values for the same material.

The builders of constructions like as the Queen's Bath and the Elephant Stables used double-shell arches and brick domes over stone plinths, combining local materials with Deccani Islamic forms³⁹. This displays both cultural flexibility and in-built control over bending resistance and thrust management. The craftsmen's understanding of corbel geometry and diagonal stress dispersion enabled them to build multi-story pavilions without the use of lime concrete vaulting, instead relying on precision-cut granite interlocks that served as self-stabilizing frames⁴⁰.

5.5.2 Material Technology and Stone working Techniques

The choice of stone, quarrying, and polishing of granite in Vijayanagar were not unplanned acts of artistry, but rather scientific precision. Geological investigations suggest that artists used fine-grained granite with uniform feldspar dispersion to ensure elasticity and resilience to microcracking.

Stones were removed using wedge-splitting, a process that involves inserting iron spikes into pre-drilled grooves and progressively expanding them with water, which reduces stress fractures and allows for controlled extraction. Architectural surfaces were polished using abrasive combinations of quartz sand, rice husk ash, and iron oxide, which produced shiny finishes while also reducing surface porosity. Iron pegs were used to fasten beams and columns, which were then coated with molten lead and organic oils to prevent rusting. This shows that they had chemical knowledge and were aware of corrosion prevention technique.

5.5.3 Construction Tools and Metallurgical Precision

The masons of Vijayanagar were equipped with high technology tools like iron chisels, wedges, levers, pulleys and cranes, as revealed by the excavations and pictographs. The metallurgy of these tools is related to the production of Wootz steel, a high carbon alloy with an outstanding edge retention and hardness. They allowed small cuts in granite and schist, materials that must be tough to cut. The iron from the Hampi ruins was homogeneous in composition, having ~1% carbon and trace vanadium, which were added intentionally to enhance the strength. Such evidence establishes the Vijayanagar workshops as early hubs of material science and mechanical engineering, where craftsmen and smiths collaborated to

manufacture equipment for large-scale architectural manufacturing.

5.6 Scientific and Engineering Principles in Architecture

In terms of architectural grandeur, the Vijayanagar Empire's grandeur was not only a reflection of artistic refinement, but also of their in-depth understanding of scientific and engineering concepts. In this period, the knowledge of Vāstu-śāstra and Śilpa-śāstra were put to the test with the empirical developments of measurement, proportion and structural design. When the temple was at its height of development, architecture became a synthesis of art, science and technology, representing cosmic order and resourcefulness. The special scientific characteristic of Vijayanagar architecture was the use of mathematical proportion and the modular layout. Literature, such as the Mayamata and Manasāra, described the proportions of the plinth, walls, and superstructure of a building, as established by the tāla-māna system. Archaeological research at Hampi have shown the exact usage of geometric grids in the layout of temple complexes and regal palaces⁴¹. The architects adopted the vastu-puruṣa maṇḍala (cosmic man) as their planning template for this square design. Shrines, mandapas and gates were placed symmetrically following the cardinal direction to provide visual harmony as well as cosmic significance.

The complexity of the Vijayanagar architecture is further highlighted by its hydraulic engineering features. Water was transported from the Tungabhadra River to the temples, gardens and residences of the city of Hampi by a network of canals, aqueducts and tanks. Two examples of the functional engineering and the sacred symbolism are the Kamalapur tank and the stepped Pushkarini near the Virupaksha Temple (Vergheese, 1995). Tanks were located close to temples, not only to facilitate ritual ablutions but also to provide reflective and cooling surfaces to improve the microclimatic comfort and show of grandeur. The Lotus Mahal, Elephant Stables and Mahanavami Dibba demonstrate a high degree of understanding of ventilation, structural equilibrium and spatial order within the royal complexes. The double curved arches and the stucco coated domes of the Lotus Mahal have adapted the Indo-Islamic style as well as the local engineering genius. In the same way, the multi-level Mahanavami platform was constructed with the carved friezes and symmetrical staircases to support heavy weights during royal functions and to provide visual centrality to the complex.

5.6.1 Material Science of Architecture

The material culture of Vijayanagar architecture is defined by the strategic selection and treatment of locally available resources, chiefly granite, augmented by lime-based composites, metal connectors, and selective use of timber and brick. Builders coupled empirical mechanics

(dry interlock, massing, load-path control) with chemistries of binding and surface protection (lime plaster, pigmented finishes). This hybrid, practice-led “material science” underpinned both the monumental durability and the distinctive aesthetics of the period.⁴²

Stone selection, quarrying and fabrication

- Lithology and choice: Vijayanagar masons favoured hard crystalline granite abundant around Hampi over the earlier Hoysala preference for soapstone, trading ease of carving for superior compressive strength, weathering resistance, and long-span reliability.⁴³
- Quarrying and dressing: Outcrops were quarried and natural jointing used, blocks were split using plug-and-feather wedges and hammer dressed to tight tolerances orthogonal to the natural joints. The system of dimensional standardization is found throughout the Royal Centre and the temple boundaries, including pillar-shaft modules, architraves and corbels, all of which reflect a modular design philosophy and the numbering of the assembly marks.
- Jointing and interlock: Gravity, bearing surfaces and precision arises used dry set courses, cramps/dowels in drilled sockets with poured lead for anti-slip and tie action between the bedding interfaces, particularly at cornices, balustrades, stair headers and high gopura stages.

Metal, timber and composite detailing

- Iron and lead: Iron pegs and dovetail cramps, often fixed with molten lead, are recurrent in Vijayanagar stonework to anchor copings, splice column drums and stabilise cornices on tall elevations. The lead layer acts as a corrosion barrier and stress-relief medium between stone and iron.
- Timber: Hardwood members appear in roof substructures and as temporary falsework for vaulting but in some gopura superstructures and gateways, timber aided load distribution and staged construction which were later covered by brick-lime skins and stucco.⁴⁴
- Brick-stucco superstructures: Upper gopura tiers employ lighter brick masonry with lime-stucco sheathing to reduce mass at height and manage overturning moments, an engineered response consistent with Dravida typology and śilpa-śāstra prescriptions on massing hierarchies.

Surface science: coatings, polychromy and weathering control

- Lime plaster and chunam: Thin polished lime coats (chunam) were used on selected surfaces to achieve reflectivity, lower solar heat gain and protect sculpted detail from rain-wash. Finishes were often augmented with mineral pigments and organic binders.
- Material-environment coupling: Orientation, drip edges, rain screens via overhanging courses and raised plinths limit capillary rise and erosive run-off on granite, while lime coats provide sacrificial layers for weathering. These strategies underwrite the high survival rate of Vijayanagar stone ensembles.

Mechanics of form: spans, thrust and settlement

- Corbelling and cantilever: Flat-roofed mandapas achieve wide bays through stacked corbels and deep beams; clustered columns distribute loads while preserving sculptural relief. This maximizes compression dominance and mitigates tensile cracking.
- Arcuate hybrids: Courtly buildings integrate arches and domes forms that require continuous bonding through lime mortars and careful thrust management, showing material adaptability beyond pure dry granite practice and technological exchange with Deccan/Islamic ateliers.⁴⁵
- Foundations and drainage: Compacted gravel beds, cut-stone raft courses and lateral drains manage settlement and groundwater, reducing damp ingress and salt cycling into masonry a practical geotechnical sensibility evident across Hampi's principal compounds.

Standards, texts and workshop knowledge

- Treatise resonance: Proportional modules, orientation and mass-reduction in upper tiers accord with śilpa-śāstra guidance (Mayamata, Mānasāra), while details reflect empirical workshop transmission among sthapati and śilpin guilds.
- Guild practice and standardization: Numbered stone components, repeatable profiles, and consistent mortise/cramp dimensions indicate codified craft standards an “early blueprinting” culture that accelerated on-site assembly without sacrificing structural performance.

5.7 Art, Power, and Kingship: Political Theology of Temples

Vijayanagar Empire's monumental architecture was not only an act of aesthetic piety, but of a conscious political theology and philosophy. The Vijayanagar kings regarded the temple as a symbol of the divine sanction and royal authority, a union of heavenly sanction and secular authority. So, architecture came to symbolise the sacralisation of royalty and the articulation of political stability in stone. Royalty in Vijayanagar was bound up with the Hindu mythology. The king was believed to embody the cosmic order (rājadharmā) and protector of dharma (the Earth) on earth. The temple was the microcosm of the macrocosm – the garbhagrha (sanctum) being the womb of creation and the towering gopuram being the path taken from the earth to the god. Therefore, when a monarch commissioned a temple he was symbolically recreating the act of creation of the Divine. The construction of temples during the Vijayanagar rulers was a rite of renewal of the king, which highlighted his role as dharma guardian and God donor, say Anila Verghese (1995). This is noted by Anila Verghese (1995) to be a ritual of royal renewal carried out by the temple-building of the Vijayanagar kings, which reaffirmed the kingship as protector of dharma and benefactor of the gods⁴⁶. But the prime example of Art as Political Theology is the Vitthala temple in Hampi. It was built during the rule of Devaraya II and extended during Krishnadevaraya's reign, and was a blend of grandeur, symmetry and intricacy, reflecting the idea of an orderly universe under a good ruler. The highly sculptural mandapas and pillars and the elaborate friezes at the temple merge the sacred and the royal, with processions, court celebrations and heavenly pomp all depicted. These iconographic projects conveyed the notion that the heavenly power was channeled through the ruler, and it had a significant impact on the temple and the state.⁴⁷

The towering gateway constructions known as Raya gopurams were also political emblems of authority, and were characteristic of Vijayanagar architecture. These stood tall, dominating the landscape, their presence a testament to the power of the king and his devotion to God. The gopuram contained inscriptions that recorded royal grants, conquests and endowments, turning the building surfaces into historical documents. Rulers often associated themselves with the deities in these inscriptions, e.g. Krishnadevaraya with Vishnu, Achyutaraya with Venkateshwara, thereby claiming a divine mandate to rule⁴⁸. In addition, the most distinct motifs of yali, simha and gaja-lakshmi on the temple gates were used as political symbols of protection from the emperor. The emblems helped to establish the Vijayanagar king as a rakshaka (protector) of the divine and earthly worlds. Art, in this case, served as a means of statecraft, communicating a message of stability, wealth, and legitimacy to subjects and

opponents alike. The ideology of royal architecture was similar in the secular world. Mahanavami Dibba, King's Audience Hall, Lotus Mahal etc. were built not just to serve their purpose of being functional, but also to provide a setting for ritualised display of royal manifestation. The king was seated on the grand platform during Mahanavami festival for viewing military parades and accepting tributes, a sign of cosmic sovereignty, which was symbolised in temple rituals⁴⁹. The platform's sculpted panels depict processions of horses, elephants, musicians and dancers, symbolizing the order and prosperity of the empire.

Thus, Vijayanagar art was a visual theology of power, deliberately bringing together elements of religion, politics, and aesthetics. The king was a link between the divine and the administration and a holy topography was created around the temples and royal complexes. This dharmic political theology gave Vijayanagar art a massive ideological consistency, where each pillar and tower was speaking the language of faith and authority.

5.8 Urban Planning and Architectural Zoning at Hampi

The capital city of Vijayanagar, located on the Tungabhadra River's southern bank, is one of the most advanced instances of pre-modern South Asian urban design. Its physical structure displays a purposeful integration of religious, royal, and commercial activities, exhibiting an urban vision that combines cosmic symbolism with administrative efficiency. Hampi's ruins still maintain the blueprint for a precisely planned metropolis in which architecture and nature were linked to reflect both spiritual and imperial order.

Archaeological and topographical research show that the city was split into three functional zones: the holy core, the royal centre, and the urban-commercial periphery.⁵⁰ The holy core, centred on the Virupaksha, Krishna, and Vitthala temples, served as the city's spiritual nucleus. The royal core located to the south-west contained palaces, audience halls, and administrative enclosures surrounded by defensive walls and entrances. The neighbouring suburban belts had marketplaces, gardens, residential quarters, and workshops. This tripartite spatial structure mirrored the Vijayanagar king's religious cosmology while also ensuring effective government and social order.

The holy centre of Hampi was established on the basis of the Hindu cosmological geography. The Tungabhadra River was regarded as a goddess and its water was considered the city's lifeblood, providing the northern edge of the city. Temples were built along its banks facing east, to catch the rising light, that is, heavenly illumination. One of the oldest and most active temples in the city was the Virupaksha Temple, situated along the ritual axis, just beside the long bazaar street leading to the river. The juxtaposition of sacred and commercial spaces

demonstrates a conscious attempt to meld religious and trade-related spaces, fostering the development of religious devotion and economic gain.⁵¹

The royal capital, surrounded by massive stone walls, was the temporal heart of the empire. It was a city within a city, with home to the King's Palace complex, Mahanavami Dibba, the Lotus Mahal and Elephant Stables. The spatial logic of this area was hierarchical, the architectural enclosure being more sacred and more exclusive in each step, culminating in Mahanavami Dibba as a ceremonial platform when the royal ceremonies took place. The geometry of the designs for courtyards, entrances and walls was exact and in designing them they had both aesthetic, military considerations in mind⁵². The processional walkways from the west to east, from the north to the south and from the east to the west, which converged at the axial centre to the royal and the holy zones, constituted the one between religion and government which constituted the Vijayanagar polity.

The urban-commercial layout spread outward from the centre core, creating a complex network of bazaars, caravan serais and artisan quarters. Excavations have uncovered indications of urban planning which has specific areas for metals, textiles, and gemstone trade⁵³. The markets of Hampi, particularly those in front of the Virupaksha and Vitthala temples were lined with stone platforms where shopkeepers displayed their wares during festivals. This coming together of commercial and religious activities sustained urban vibrancy and allowed the flow of cash to temples via gifts and endowments. The end result was a self- sustaining urban life in which spirituality, business, and politics worked together effortlessly.

Vijayanagar's urban development was distinguished by its integration with natural terrain. The architects of Hampi designed the city's layout around the rocky granite hills, which served as natural defences. Reservoirs, tanks, and aqueducts were expertly designed to capture seasonal rainfall and river flow, meeting both residential and ceremonial demands. The blend of manmade and natural components established an environmental equilibrium that supported enormous populations and demonstrated a deep regard for the area. Defensive Architecture was a major part of the urban design in Hampi. The city had several concentric defence systems such as bastions, watch towers and controlled gates. Defensive ridges and natural obstacles were deliberately aligned on the roads connecting the various zones, to boost the protection of the capital. These walls served not only militarily but they also served as a metaphor for the city's status as a cosmic strongpoint, a terrestrial form of heaven's order guarded by the power of the kings. Thus, the capital of Vijayanagar stood as a symbol of

vāstu (order of space) and rājadharmā (Order of rule). The architecture and planning demonstrate a Cosmological worldview, with the city being not only a living space, but also a sacred instrument through which the divine order was expressed and maintained. In fact, the city of Hampi represented in the ancient Indian treatises (Manasāra and Mayamata) the ideal form of an urban space, but applied these concepts to a dynamic and monumental form of the urban.

5.9 Vijayanagar Art in Comparative and Historiographical Perspective

The art and architecture of Vijayanagar has greatly contributed to the development of south Indian aesthetic traditions. The Vijayanagar State which arose in the fourteenth century, when the Hoysalas and the Pandyas had declined, was a creative synthesis of new styles shaped by intercultural, religious and political contacts and processes and the continuation of older Dravidian styles. Using a comparative and historical approach to Roman art, the dual roles of the empire as both a promoter of massive expression and a guardian of classical ideals are illustrated. Artistic comparisons, as far as Vijayanagar art is concerned, its features were greatly influenced by the previous traditions it got and imbibed its characteristics to accommodate the changing political and religious climate. The emphasis of the Chola temples at Thanjavur and Gangaikondacholapuram was verticality and axial symmetry, while the Hoysala temples at Belur and Halebid were sculpturally complex and displayed intricate stellate designs. On the contrary the temples built at Vijayanagar emphasized monumental grandeur, spatial coherence, considerably strong outlines, towering enclosures and soaring Raya gopurams that dominated the horizon. From the smallest element to the greatest scale, this was an intentional aesthetic statement from Michell, blending the form of the architecture with the ambition of the empire.

The vocabulary of the architecture of Vijayanagar is developed through selective adaption. The Chola-Hoysala pillars were replicated in the mandapas, but the filigree work on them was replaced by heavy pillars and warrior, dancer, and mythological figurative capitals. This melding of artistic energy and imperial tenets was reflected in the development of the composite column, often equipped with rearing yalis or horses trampled the opposition. Rather than just representing legendary stories, the narrative friezes included images from royal processions and ordinary life, implying a more comprehensive artistic vision that combined sacred and profane themes.⁵⁴

The Vijayanagar art was a stylistic transitional art between Pandya tradition and later Nayaka tradition. During the later Vijayanagar period, gigantic rayas were constructed and later the

towering gates of the Nayaka temples in Madurai, Tiruchirappalli and Srirangam were built on the model of these rayas. The use of the Corridor Mandapas, Melodic Pillars and Multi-shrine complexes in the Vijayanagar architecture, similarly, prefigured future developments in Tamil temple architecture. The continuity of the styles of the two reigning series illustrates the continued vitality of the cultural legacy of the Vijayanagar empire which continued after its political collapse.

In addition to stylistic similarities, the historiography of Vijayanagar art shows overall shifts in our understanding of the broader history of South Indian culture. Early colonial writers like James Fergusson viewed Vijayanagar architecture as a debased variety of Dravidian art, which had been mechanicalised by over-elaborate ornamentation and lacking in refinement⁵⁵. Eurocentric concepts of classical purity persisted into the early 20th century in this perspective. But mid- and late-twentieth-century studies, such as those by George Michell, Anila Verghese and John Fritz, challenged these views, suggesting that Vijayanagar was a dynamic cultural and artistic hub, built up from a fusion of regional styles into a cohesive imperial vision.

In the contemporary study of Indian art, Vijayanagar art has gained importance because of its context in how it was used to define the status of the government, the diverse set of religions and the urban identity. It is not just architecture, Verghese argues, that should be the subject of study of the Hampi monuments; they are part of a living ritual and social setting. Likewise, Sinopoli and Morrison viewed monuments as emblems of imperial power and cosmic order in the city⁵⁶. These changes have shifted the focus from the stylistic standardization to interpreting the functions and ideologies, and have rendered art of Vijayanagar a reflection and a tool of its historical context. Of interest it may be noted that the elements of Islamic architecture like arches, domes and stucco decorations were employed, especially in the secular works of Vijayanagar, as in the Elephant Stables and Lotus Mahal. The borrowings do not signify any cultural subservient but rather the cosmopolitanism of the empire, in which Hindu, Islamic and local vernacular forms were creatively harmonious. This hybridity has rejuvenated the interest of postcolonial researchers, as an example of the adaptive resilience and cultural diplomacy of Vijayanagar. History has been supplemented by archaeological and documentation (for instance, by Fritz and Michell's Vijayanagar Research Project) in recent decades, in a way that provides new empirical evidence. The detailed surveys, the 3D reconstruction and GIS mapping has made clear the chronology, spatial logic and building processes of the monuments and has demonstrated the technical competence, which has

always been a good trait of traditional art historians.

Finally, the comparative and historiographical study of Vijayanagar art highlights the transitional yet transformative character of Vijayanagar art. It inherited the Cholas religious spirit and the Hoysalas sculptural refinement but it went beyond both with its massive vision and incorporation of political theology. How modern scholarship had progressed from colonial rejection to cultural rediscovery of Vijayanagar is also a reflection of how Vijayanagar itself has evolved from being a rejected ruin city to an acknowledged masterpiece of South Indian civilization.

5.10 Comparative Scientific Perspectives: Vijayanagar and Mughal Art & Architecture

Two of South Asia's most notable architectural cultures were created by the contemporaneous customs of Vijayanagar and the Mughal courts. Despite the fact that both possessed cross-cultural influences as well as having engaged in large-scale construction programs, significant differences were found in materials science, structural engineering, hydraulic systems, acoustic and optical skills, workshop and ecological adaptability. It does not presuppose either scientific dominance or the supremacy of the one tradition over the other but rather it shows how different are the scientific logics being put into practice in Vijayanagar, the stone engineering and ecological urbanism based on experiments and the Mughal synthesis of masonry, vaulting technology and integrated hydraulic formalism.

5.10.1 Materials Technology and Stone vs. Brick/Mortar Systems

Vijayanagar. The monuments of Hampi were primarily constructed from hard local granite, which required advanced quarrying and stone-working techniques. Builders employed methods such as wedge-splitting in quarries, careful dressing and polishing of stone blocks, and dry masonry joints reinforced with iron dowels and lead infill, enabling durable construction suited to the region's rocky terrain and climatic conditions.⁵⁷

Mughal. Fired brick, rubble core masonry, lime-based mortars, and opulent marble and sandstone facing were the mainstays of Mughal architecture. Large-scale dome and vault building, long-span covered areas, and elaborately inlaid stonework were made possible by the development and mastery of hydraulic lime mortars and lime pozzolans.⁵⁸ In contrast to the corbelled and dry-stone traditions of the south, Mughal science placed a strong emphasis on binding chemistry and large-scale composite masonry, which allowed for continuous surfaces, domes, and pendentives.

Implication. Vijayanagar science emphasised **mechanical interlock and stone mechanics**;

Mughal practice emphasised material chemistry and vaulting physics. Both represent different but rigorous technological problem-solving traditions.

5.10.2 Structural Engineering, Load Distribution and Seismic Response

Vijayanagar. An empirical grasp of load routes, local geology, and foundation drainage is demonstrated by stone monolithics, clustered pillars, corbelled mandapas, and multi-tiered plinth isolation. Under dynamic loads, graded rubble cores in dry masonry offered regulated flexibility.

Mughal. Understanding buttressing and line-of-pressure geometry was necessary for vaults and domes. The Mughals employed double-shell domes, pendentives, and buttressed iwans in a methodical manner; mortar chemistry and structural form-finding were combined to control tensile and peel stresses over enormous curvatures.⁵⁹

Where Vijayanagar used mass, interlock and elasticity to resist lateral forces, Mughal builders used curved-geometry solutions (domes/vaults) supported by mortar technology.

5.10.3 Hydraulics, Water Management and Urban Ecology

Vijayanagar. Hampi's tiered tanks (pushkarini), gravity-fed canal networks, and temple-linked conduits demonstrate an integrated hydrological urbanisation that combined agriculture, microclimate, and ritual into planning. Designs made advantage of percolation recharge, filter-stone overflows, and long, mild gradients, practical hydrology tailored to a rocky, seasonal setting.

Mughal. Formal hydraulic control was highlighted in Mughal towns and gardens, including Charbagh designs with axial water lines, hydraulic heads controlled by sluices, and decorative cascades that, when appropriate, relied on far-off reservoirs and qanat-like configurations. Their hydraulic science animated terraces and fountains by combining aesthetics with pressure and head control.⁶⁰

Vijayanagar hydraulics prioritised ecological recharge and functional irrigation, while Mughal hydraulics focused on pressure-controlled formal water display and garden microclimates, both technically advanced but differently purposive.

5.10.4 Acoustics, Optics and Experiential Science

Vijayanagar. Empirical acoustics and archaeo-optics integrated in ritual design are attested to by camera-obscura effects, calculated sunlight alignments in temple grids, and musical pillars adjusted by mass/density modulation.

Mughal. Additionally, intentional sightlines in charbagh and mausoleum gardens, reflected water surfaces that improve visual perception, and acoustic vaulting in huge rooms were also

utilised. Using light, ornamentation and inlay created reflecting and multicoloured effects. Mughal builders developed compositional optical/reflective techniques employing water, polished marble, and inlay; Vijayanagar exhibits stone-based research in acoustics/optics depending on regional materials.

5.10.5 Workshop Organisation, Standardisation and Knowledge Transmission

Vijayanagar. Modular stone prefabrication, numbered elements, and guild-based apprenticeship (sthapatis, éilpins) are all visible in large-scale temple constructions. An oral-text hybrid pedagogy was used to disseminate technical knowledge through artisan schools and temple-matha networks.

Mughal. The Mughal court maintained patron-driven treatises and drawings, recruited specialised artisan corps (stonecutters, inlayers, calligraphers), and established imperial karkhanas (workshops). Ornament, inlay patterns, and structural formulae (marble polishing, lime mortar mixes) were systematized across projects by imperial ateliers.

Both traditions formalized craft knowledge; however, Mughal knowledge was court-centered and bureaucratised, allowing for uniform imperial style distribution, whereas Vijayanagar knowledge was more guild/temple-centered.

5.10.6 Decoration, Material Science and Conservation Practices

Vijayanagar. Applied material science is demonstrated in surface protection (chunam mixtures, lime-silica plasters) and pigment chemistry for murals (natural earths, binders) to improve weather resistance.⁶¹

Mughal. Mughal finishing techniques included marble polishing, pietra dura inlay, and pigment fixatives for murals; later restoration techniques demonstrate the materials' resilience to environmental deterioration as well as their durability.

Both systems produced regionally optimised surface technologies; cross-tradition best practices can be obtained through comparative conservation studies.

5.10.7 Patronage Logic and Scientific Intent

Vijayanagar. Temple patronage produced projects where ritual, civic utility, and empirical engineering were fused. Scientific work appears often motivated by religious function (ritual tanks, acoustic halls), civic provisioning (granaries, aqueducts), and political theology.

Mughal. Imperial patronage aimed at state representation and universality (mausolea, congregational mosques, gardens), encouraging innovations that combined aesthetics with demonstrable state capacity (sophisticated hydraulics, monumental domes).

Implication. Scientific choices were shaped by patron priorities. Vijayanagar priorities were tilted toward ecological utility and ritual science whereas Mughal projects emphasised representational universality and controlled spectacle.

5.10.8 Comparative Summary Table

A systematic comparison of contrasting scientific and technological approaches undertaken by the Vijayanagar and Mughal polities has been presented in “**Table 5.1**”. It emphasizes the variations in building materials, structural conceptions, hydraulic mechanisms, workshop organization and patronage principles. The table reveals that the Mughals were focused on imperial monumentalism, symmetry and visual effects in their engineering, whereas Vijayanagar science and technology were highly influenced by local ecology, material limitations and the ritual–civic requirements. The focus on granite-based interlocking structures, gravity-driven water management and the integration of water systems with religious institutions highlights a pragmatic approach to urban engineering focused on durability, sustainability, and long-term resilience. **Table 5.1** is used to support the argument that scientific development in the Vijayanagar Empire was not following the same tradition as the other contemporary imperial traditions but rather a South Indian tradition of adaptation to the environment, knowledge transfer by means of decentralisation and the integration of science into religious and civic life.

Scientific Dimension	Vijayanagar (South Indian)	Mughal (North-Central/Imperial)
Dominant building materials	Hard granite, dry interlock & iron dowels	Brick/rubble cores, lime mortars, marble facing
Structural strategy	Mass/interlock, plinth isolation, corbelling	Vaults/domes, double-shell geometry, pendentives
Hydraulic logic	Gravity-fed irrigation, recharge, temple-linked tanks	Formal pressurised fountains, charbagh hydraulics
Acoustics/Optics	Musical pillars, solar alignments, camera-obscura effects	Acoustic vaulting, reflective water optics, axial vistas
Workshop organization	Temple/guild-based apprenticeships, modular stone	Imperial karkhanas, standardised court ateliers
Surface tech & pigments	Chunam plasters, organic binders for murals	Marble polishing, pietra dura, long-lasting pigments
Urban ecology	Integration with rocky topography, recharge emphasis	
Patronage logic	Ritual-civic hybrids, ecological utility	Imperial representation, ceremonial spectacle

Table 5.1: Comparative Civil Engineering and Hydraulic Technologies of the Vijayanagar and Mughal Empires

5.11 Legacy and Continuity of Vijayanagar Aesthetics

The Vijayanagar Empire's art and architecture were more than just the culmination of older South Indian traditions, instead they represented a shift of the subcontinent's aesthetic and spiritual consciousness. Vijayanagar's cultural vision combined religion, politics, technology and creativity to create an enduring architectural language that outlasted the empire. Its monuments, scattered throughout the granite plains of Hampi, serve as powerful reminders of a civilisation that tried to manifest divine order via geometry, proportion and devotion.

The Vijayanagar style was distinguished by the combination of grandeur and utility. It preserved the Dravidian temple's symbolic depth while increasing its size and intricacy to express imperial aspirations.

The towering *raya gopurams*, the rhythmic arrangement of *mandapas*, and the sculptural programs of friezes and reliefs all communicated a united feeling of authority and piety. As a result, the temple served as both a spiritual centre and a civic monument, a location where ritual, art, and commerce all coexisted together. The architects' technical knowledge of material, measurement, and acoustics, as previously discussed, highlighted the intellectual depth that underpins their creative vision.

The impact of Vijayanagar lasted long after its political demise in 1565 CE. The Nayaka kings of Madurai, Thanjavur and Gingee inherited it and refined it, rendering it more lavish and beautiful. The monumental scale of the *gopurams* at Meenakshi Temple, Madurai and Ranganathaswamy Temple, Srirangam, as well as the urban layout of Madurai as a temple-town are direct descendants of the Vijayanagar tradition⁶². The Vijayanagar techniques were also carried on from generation to generation by the continuity of architectural craftsmanship of *sthapati* and *silpin* guilds, which made a great contribution to the development of the modern south Indian temple architecture.

The aesthetic concepts of Vijayanagar were also manifested in other art forms such as bronze casting, mural painting, performance tradition etc. The bronzes at Tirupati and Lepakshi are as dynamic and spiritual as the stone bronzes. The mural paintings of Virabhadra Temple at Lepakshi are more complex in their color schemes and have a more complex, and advanced, narrative life, anticipating later Nayaka painting styles. The temple festivals and the dance processions and ritual theatre of the Vijayanagar period laid the foundation for the South Indian classical traditions today, such as Bharatanatyam and Yakshagana, that use buildings to stage performances.

Philosophically, Vijayanagar art embodies the concept of integration and the confluence of the sacred and the temporal, cosmic and the human. All of its physical features, from the orientation of the sanctum to the decoration of the pillars, were part of a whole that embraced aesthetics and metaphysics. The concept of 'holy building as a living organism' continued to play a role in temple planning well into the colonial and postcolonial eras, and in the current conservation process and the heritage discourse of Hampi.⁶³

Historically, the rediscovery of Vijayanagar in modern studies has given it the rightful status of an important phase in the creative development of Indian history. Through the work of art historians, archaeologists and architectural scientists, it has been proven that Vijayanagar was not a static mediaeval kingdom but rather a creative and experimental art culture. It is a product of the architectural and craft skills of its builders, who worked with mathematical precision, environmental sensitivity and cosmological awareness, all of which remain relevant in the current research into sustainable design and heritage conservation in South Asia.

The Vijayanagar architecture is a unique chapter in the art and architecture of India. The Vijayanagar Empire's rich heritage is still evident in its unique features, creative constructions, technical achievements and cultural significance, which continue to captivate historians, archaeologists and visitors alike. Stone was the key to the technological development of the Vijayanagar architecture. The art and architecture of the Vijayanagar Empire is significant as a meeting point of art and practical scientific knowledge in premodern India. The huge structures of the empire are by no means symbolic or religious, but illustrate a systematic application of technical concepts, materials technology, hydrology, and environmental planning. The artists and architects of Vijayanagar demonstrated that artistry and mechanical intuition could go hand in hand, inspiring and complementing each other. Vijayanagar architecture is truly an experiment at the level of the whole civilization in application of empirical science. The use of the interlocking granite courses of the Royal Enclosure, the tuned resonance of the pillars of Vitthala Temple, and the expertise in building materials and techniques are all testament to their understanding of mechanical, acoustic, and material science. The dry-masonry bonding of massive granite blocks shows an innate knowledge of the distribution of compressive stress, and the use of tiered foundations and plinth isolation ahead of later concepts of seismic base dampening.

Massive granite blocks could be mined, transported and carved with great skill by the

architects and craftsmen of the empire to build elaborate temple complexes with grand gateways and gopurams (gateway towers). The temples discussed earlier are examples of the empire's mastery of large-scale stone construction due to their size and accuracy. One notable achievement is the use of a technique known as "plinth isolation". In this method, structures were constructed on raised platforms (plinths). The foundations and superstructures were separated by gaps or by using flexible joints. These gaps enabled the structure to absorb seismic shocks and vibrations, hence it lowered the possibility of damage during earthquakes. There is also the use of resilient materials such as granite and laterite stone in the construction of Vijayanagar, which provided strength and resistance to earthquakes. To increase stability they also made use of advanced load distribution strategies and well-planned structural element placement. Leading examples of these seismic-resistant design principles are the huge number of temples, palaces and public buildings in Hampi. A majority of these structures have survived for centuries even in an earthquake prepotential zone, fabricating the practice of the Vijayanagar architects in minimising earthquake damage.

The Vijayanagar architects also developed the techniques for water management for drinking and other purposes. It consisted of a complicated system of aqueducts, tanks and canals, not only supplying water for the needs of the city's residents but also giving encouragement to agriculture and assisting in the provision of food for the growing population. They show their understanding of hydraulics and their ability to make use of ecological resources in urbanisation by their complex network of tanks such as Pushkarani near the Vitthala's temple. Another feature was the original layout structure of the buildings of Vijayanagar. Building connected with a framework of "dry stone" (interconnected stone without mortar) construction, temples and palaces were constructed. This not only illustrated their anticipatory engineering judgments and understanding of the physics of buildings, but also their sense of change and even survival under seismic activity. Moreover, there were other architectural achievements of the Vijayanagar Empire apart from the temples. The royal palaces and the state buildings of the capital city also served as models of palace architecture and urban design to which they excelled. Their high level of ventilation and cooling knowledge is demonstrated in the Queen's Bath which was constructed "with both architectural economy and artistic interest", for relief in a hot climate.

Another part of the architectural synthesis of Vijayanagar empire was cross-cultural technical borrowing. The concepts of architectural structures of Deccan Sultanates were taken up in the granite frame work and the principles of Vastu Shastra were maintained for cosmological and

climatic compatibility. The result was a somewhat globalised yet very singularly Indian architectural mode which learned the innovations of architecture and was attuned with spiritual meanings.

All such lessons are still very relevant to the present scenario of India. The principles of resource use efficiency, climate adaptability and sustainable urban water management in the empire provide some ideas for the design and planning of today. Knows about the creative and technological legacy of Vijayanagar and turns it into a symbol of future creations inspired by native scientific paradigms.

Unfortunately, many of the architectural wonders of the Vijayanagar Empire had also not received the care and attention they deserve as the Vijayanagar Empire declined. Preservation has commenced on several weathered and vandalized buildings that are not well protected and are threatened with loss. A comprehensive strategy is required, including historical study, public participation, sustainable tourism and effective conservation techniques to ensure that these cultural treasures are handed down through the ages.

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Chapter 6: Conclusion

This study aimed to explore the Vijayanagar Empire (1336-1646 CE) as a model of scientific government, a fusion of statecraft, technical ingenuity, artistic excellence and ethical ideals. The earlier chapters have brought to life the scientific, intellectual and cultural setting of a civilization that flourished from the 14th to the 17th century CE, known as the Vijayanagar Empire. Vijayanagar rose in the wake of the political disintegration of peninsular India, reasserting the political independence of South India, and at the same time ushering in one of the most dynamic eras of scientific, architectural and philosophical development in premodern India. The main purpose of this research was to examine the development of natural sciences, particularly medicine, mathematics, astronomy and architecture in the context of education, government, and society. Drawing on evidence from inscriptions, architecture, textual and astronomical documents, the study traces the process by which the rulers of Vijayanagar instituted the scientific imagination as part of its cultural identity. The previous five chapters have all made this point: the empire's achievements were not only signs of artistic and political achievement, but also the result of a structured network of knowledge within a context that is provided by rational policy, public institutions and intellectual diversity.

Literary, epigraphic and archaeological evidence reveals that the empire was responsible for the growth of an attitude of empirical and rational thinking, paralleling the events in Europe and Islamic world. The results indicate that Vijayanagar was neither a cultural monolith nor an enclosed intellectual world, but a space where local and foreign cultures met and-in many instances-intermingled.¹ Physicians and scholars of various cultural backgrounds were found, reflecting intellectual exchange in medieval South India. At the same time, physicians from the Islamic world came to India and worked at the royal courts and the Kerala school of astronomy and mathematics made contributions to mathematical astronomy and mathematical astronomy advanced in Kerala², with scientific thought in Vijayanagar taking place in a cosmopolitan and experimental setting.

In the opening chapter, it was shown that the study of science in premodern India should take into account its indigenous epistemology, namely *śāstra* (codified knowledge), *vidyā* (applied skill), and *yukti* (rational inference). This theoretical basis provided a basis for breaking away

from models of science that are Eurocentric. After analysis of the historiographical review, five phases between colonial romanticism and postcolonial scientific historiography were identified, characterizing the need for integrative reinterpretation. So, the political and the intellectual was the base of the empire. The design of hydraulic engineering and urbanization were influenced by environmental geography of the Tungabhadra Basin. Under the rational Vedāntic principles of Vidyaranya, the founders established knowledge and rationality in the administrative reforms, the measurement systems and the irrigation technologies of the state. The medicine of the Vijayanagar was a blend of Ayurvedic, Unani and folk medicine. State sponsored hospitals (ārogyasālās) and pharmacologic gardens are attested by inscriptions. Empirical observations, surgical instruments, and proto-public-health ethics are found within texts like Vaidyavallabha and local compilations. This chapter exhibited continuity with the Kerala School and incorporation of astronomical knowledge into the ritual calendars and architecture. Mathematicians such as Nilakantha Somayaji demonstrated innovation (series expansions, planetary models). Near temples are astronomical observatories to emphasize the application of science in public life.

Art was not for ornamentation, but scientifically designed. The mathematical ratios, acoustical perfection and experimentation of materials are reflected in monumental structures like Vitthala and Hazara Rāma temples. With such creative expression, artistic physics and geometry became united and the boundaries between art and science were blurred. Its intellectual legacy lies in its intellectual attitude and logical enquiry that is fostered in a spiritual and political setting. The learning of the Vedantic metaphysics and factual knowledge was a mixture of Vidyaranya's direction and Sayana's learning, which gave the empire its unique direction. Sayana's Rig-Veda Bhashya, which employed geometric and astronomical reasoning to religious scriptures, is a prime example of a philosophical blending of science and religion. The culmination of this rational approach was the reign of Krishnadeva Raya. He was patron to poets, surgeons and astronomers, for whom he felt that intellectual energy strengthened the power of government. The Amuktamalyada explores statecraft, but also public health ethics and economic sense: a blending of administration and science.

Vijayanagar rulers and academics across all fields of hydraulic engineering, medicine, mathematics and architecture showed a methodical awareness that was based on observation, experimentation and recording. This method of working is in line with contemporary

Pico was named for the unit of length, "picometer", which scientists use for objects that are very small. The other paradigm of Vijayanagar, on the other hand, could be characterised as an intellectual climate in which the thinkers sought to harmonise theology and reason in the Renaissance. However, Vijayanagar's rationalism was distinct. It percolated into the moral and environmental awareness of the society and anticipated the sustainable and interdisciplinary thinking that is valued today in the academic world.

The scientific culture of the Vijayanagar Empire did not just appear on its own. It was supported by a well established system of knowledge transmission, which included religious institutions, scholarly genealogies, craft associations, and court-based collections of intellectuals. The explanation of the construction of scientific rationality would be impossible without the knowledge of these pedagogical structures, which were used to preserve, create and spread scientific rationality throughout the empire. The heart of this ecosystem were the mathas (monastic centres) and the temple universities, especially Sringeri, Kanchi, Tirupati and Srisailem. These were schools where the knowledge of astronomy, mathematics, grammar, logic, medicine and the knowledge of the ritual sciences was taught. They believed that the following pedagogical methods should be emphasised:

- **Śāstra-based learning**, where canonical texts served as the foundational curriculum
- **Yukti (reasoned justification)** as a means to interpret and validate textual knowledge
- **Anubhava (experiential understanding)** through observation, measurement, and practical activity
- **Intergenerational transmission** via guru-śiṣya lineages that preserved intellectual continuity

The Vijayanagar rulers acted as patrons of scholarship, granting land, tax exemptions, and endowments to educational centres. Patronage of intellectual infrastructure is reflected in the copperplate grants of Harihara II to Sringeri and Krishnadeva Raya to Kanchi and Tirupati. This aid brought stability to the development of the sciences of jyotiṣa (astronomy), gaṇita (mathematics), and āyurveda (medicine). The empire continued to have a wealth of traditions in apprenticed skills as well as academic institutions, where scientific knowledge was handed down through guilds of metalworkers, weavers, military engineers, sculptors (śilpin), and

architects (sthapati). In this context, formal text was not as important in the knowledge transmission as:

1. Apprenticeship models in which apprentices served an apprenticeship through repeated demonstration and supervised practice
2. The conservation of techniques of metallurgy, acoustics, water engineering, and textile dyeing in the form of guild memory.
3. Collective innovation, in which technological innovations emerged from joint experimentation

This combination of academic learning and practical work in geometry, physics, and chemistry translated into practical achievements such as building temples, irrigating fields, and creating metals. Further, there was an extensive exchange of information between the regions of the empire. Regularly, astronomers, doctors and academics came and went between Vijayanagar, Kerala, Odisha, Golkonda and even Southeast Asia. Manuscripts were copied and distributed using palm-leaf libraries, and merchandise was transported between regions by merchant guilds, which included metallurgical tools, astronomical instruments and medicinal herbs. This movement enabled the creation of a circulatory knowledge economy, where concepts were not limited to specific organisations or were static.

Another important aspect of the educational environment of the Vijayanagar was the court culture, which was a place where ideas and concepts were synthesized. Kings were patronizers and evaluators of learning; they were the recipients of works by poets, philosophers, mathematicians, and engineers. The empire's conception of knowledge as a unification is reflected in the presence of poly-sophia (the knowledge of many), the polymaths, who are knowledgeable in the humanities as well as in the sciences.

In fact Vijayanagar's knowledge transfer was based on:

- Schools (primary and secondary)
- Guild-based artisanal training
- Interregional manuscript exchange

- Combination of theory (śāstra) and reasoning (yukti)

It is important to remember that although the achievements of great scholars, immense buildings, and royal inscriptions often depict advances in science in the Vijayanagar Empire, the social fabric was equally significant in perpetuating and disseminating knowledge. Scientific methods were not confined to the hands of the elite scholars or state institutions: they diffused among the different caste groups, professional guilds, gendered spaces, rural-urban networks, etc. during this period. From understanding these modes of transmission, it is clear that Vijayanagar has a very dispersed, social and participatory scientific culture.

The artisans were very important in this circulation, since their skill in metallurgy, stone-working, irrigation technology, and textile manufacture provided the practical roots for the empire's scientific achievements. These were the guilds, such as Devanga weavers, Vaddars (stone masters), Sthapatis (architects), and Kammalar (metalworkers) who retained the technological skills. Their contributions included:

- Developing advanced iron-smelting and alloying techniques
- Executing precise geometric layouts for temples and fortifications
- Constructing hydraulic structures using empirical engineering principles
- Innovating in dye chemistry, weaving patterns, and fiber technology

These craft traditions helped to create a form of “everyday science,” in which experimentation and skill development was a regular feature, even absent the formal language of śāstric learning. The role played by the women in the spread of domestic, botanical and medical technology is not less significant. Women worked as midwives, carers, herbalists, and home managers, yet their roles were hardly recorded in royal records. Their expertise included:

- Preparation of medicinal decoctions and dietary remedies
- Care and treatment related to childbirth and early childhood
- Preservation of seeds and food through natural methods
- Ritual and seasonal knowledge relating to agriculture and ecology

Scientific knowledge also moved across communities through ritual specialists, astrologers, temple musicians, and agricultural workers. For instance:

- Temple almanac-makers (*panchangakartas*) circulated astronomical calculations to the public.
- Musicians interacted with the acoustic science embedded in temple halls.
- Farmers practiced indigenous meteorology and irrigation timing based on observation, experience, and inherited knowledge.
- Traders transported medicinal herbs, minerals and technical instruments which linked distant markets with local practitioners.

Furthermore, cross-cultural transmission was made possible by the social structure of the empire. New methods in mapping, navigation, artillery casting and horse medication were brought about via contacts with Portuguese, Arab and Persian traders. This shows the empire's adaptable scientific nature as they were modified by regional practitioners and incorporated into pre-existing knowledge systems.

Therefore the Knowledge of Science was disseminated through:

- Rural local labor associations, such as artisan guilds and occupational communities.
- Women's medical and ecological skills.
- Religious officials specializing in ritual and temple functions Agricultural and rural knowledge systems.
- Contact with other cultures and foreign traders and travellers.
- Networks of markets that connected materials, technologies and practices.

This pervasive social involvement challenges previous perceptions of a scientific life in pre-modern India that was restricted to the Brahmanical elites or the court. Instead, it highlights the dissemination of the scientific spirit, its social base, and the fact that it was a product of the entire Vijayanagar community, enabling scientific discoveries to flourish in diverse geographical, cultural, and economic environments. The Vijayanagar Empire had a sophisticated government, where scientific knowledge was used to inform economic planning, military organization, environmental management and administration. The state incorporated into its political apparatus empirical observation, measurement and methodical record-keeping alongside other sources of legitimacy, such as religious and military force. This inspired a logical approach to decision-making that resulted in what might be

considered a scientific statecraft, one that bolstered the stability and longevity of the empire. The unification of measurements was central to the administration of Vijayanagar which was an important factor for tax collection, land valuation, trade and building construction. The units used for land (kuli) and weight (tola) and money ³(gadyana, varaha) enabled the revenue to be collected in a predictable way and reduced disputes over agricultural produce or business transactions. Measurement was not only a technical process but a part of a larger state philosophy of justice, accuracy, and neatness. An understanding of the quality of the land, the cycles of the crops, the rainfall and the irrigation ability was important to the government of the empire and this was known as empirical land management. This meant that land acreage was taken into consideration, along with crop type, fertility and water availability⁴, which was a highly eco-friendly approach by the administrators, making Vijayanagar the most environmentally conscious polity in South Asia during the mediaeval period.

One prime example of application of advance scientific knowledge was water management. Hydraulic engineering was incorporated into administrative duties as kings and regional governors oversaw the building of canals, tanks, and anicuts. Village-level committees (nāḍu, sthala), whose responsibilities were outlined in inscriptions, were responsible for maintaining these structures. This combination of localised scientific work and central control is a prime example of Vijayanagar's cooperative environmental governance.

Scientific concepts were also mirrored in military management. The Vijayanagara military system was closely integrated with land administration through the **Amara-Nayaka system**, in which military chiefs received revenue assignments (*amaram*) and were required to maintain troops proportional to their holdings. These contingents, including cavalry and elephants, could be mobilized for imperial campaigns, while failure to meet obligations could lead to confiscation of the grant.⁵

Temple institutions, too, were embedded in statecraft as centres of economic management, education, and environmental stewardship. Temples maintained detailed accounts of land, water resources, festivals, and personnel. Their records reveal a high degree of administrative wisdom in recording crops, irrigation dues, craft payments and trade obligations, which contributed to the empire's economic stability and knowledge continuity.

Lastly, the government of Vijayanagar used scientific intelligence in international policy and diplomacy. The Vijayanagara state relied on extensive diplomatic and commercial

networks to acquire strategic resources and military technologies. High-quality war horses were imported from Arab and Persian traders through ports such as Goa, while contact with Portuguese merchants facilitated access to firearms and artillery.⁶ These interactions reveal that foreign trade and diplomacy played a crucial role in the technological and military development of the empire. Global scientific connections were thus integrated into domestic governance through political decision-making.

In essence, scientific governance in Vijayanagar rested on:

- Standardisation of units, weights, and currency
- Empirical land and ecological assessment
- Hydraulic engineering as state responsibility
- Rational military logistics and audits
- Temple-based administrative record systems
- Integration of foreign technologies through diplomacy

These practices depict Vijayanagar as an empire where **science and governance were mutually reinforcing**, and where the exercise of power was grounded in rational, evidence-based administrative culture.

6.1 Historical Insights and Contemporary Relevance

The scientific practices adopted during the Vijayanagara Empire period indicate a complex relationship between the knowledge of the environment, its institutional organisation and technological experimentation. These practices were born in a particular historical context, but the principles they embody offer insights into the solutions provided to pre-modern societies' resource management, urban organisation, education and healthcare challenges. To bring out the wider relevance of the scientific traditions of Vijayanagar for understanding sustainable and integrative knowledge systems, the following text does not offer prescriptive solutions.

These scientific practices have been developed during the Vijayanagar era, and show a highly complex relationship between environmental knowledge, institutional organization and technological experimentation. These practices were developed in a particular historical context, but their principles offer important insights into the way that pre-modern societies faced issues of resource management, urbanisation, education and health care. If prescriptive solutions are to be offered, it is not relevant to highlight how scientific traditions of Vijayanagar are relevant to the

understanding of sustainable and integrative knowledge systems.

A. Water Management and Environmental Organisation

The water infrastructure of Vijayanagar is one of the highest level of pre-modern water management systems in South Asia. A system of reservoirs, canals and check dams were planned to adapt to the topography and the seasonal monsoons. These systems were used for not only agricultural production but also to help provide water for the city and balance the ecological system.

The historical evidence shows that the governance of water was linked to the local administrative units and participation of communities, reflecting the local socio-political context of environmental governance. The arrangements are examples of the need to integrate engineering knowledge and collective stewardship of finite natural resources.

B. Urban Planning and Spatial Organisation

The layout of the capital around Hampi is an advanced planning approach, where sacred, royal and commercial spaces were distinctly differentiated. This zoning system organized ritual movements, economic activity and, at the same time, combined religious institutions and market networks with political power. However, the awareness of climatic conditions, acoustics and structural stability is also reflected in architectural features like temple complexes, bazaars and ceremonial platforms. These factors all indicate that the theoretical knowledge of environment and engineering was behind urban planning in Vijayanagar, and its practical knowledge as well.

C. Knowledge Transmission and Educational Traditions

In Vijayanagar, scientific knowledge was passed on by a combination of textual scholarship, craft traditions and the temple-centred learning institutions. The connection between theoretical knowledge (*śāstra*), deductive reasoning (*yukti*), and observation (*anubhava*) were often highlighted when discussing intellectual practices. The tripartite nature of this shows that knowledge creation in south India before modern times was not only a formal enterprise but one that included experimentation. The dialogue between scholars, artisans and temple institutions thus established created an important system of dissemination and archival of scientific knowledge.

D. Medical Knowledge and Botanical Traditions

They relied on classical ayurvedic knowledge, along with knowledge of the flora and alchemical

experimentation of the region, when practicing medicine in Vijayanagar. The usage of herbal pharmacology, dietetic regimens, and surgical treatments was used both at home and in institutions. Reliance on medicinal plants and mineral medicines indicate a deep knowledge of the local ecology for health care systems. Such traditions reflect the process of the knowledge of medicine being passed on through writing, observation and local environment.

E. Preservation of Knowledge and Material Heritage

The preservation of inscriptions, manuscripts and architecture have had very significant role in the reconstruction of the scientific culture of Vijayanagar. The materials reveal how knowledge was written, communicated and recorded in the religious institutions. An examination of such sources underlines the need for interdisciplinary methods to investigate the scientific traditions of pre-modern societies, where combination of archaeology, textual analysis and environmental history is the guideline.

6.2 Contributions to Rewriting the History of Science

This thesis adds to the expanding database of research that uses interdisciplinary approaches to reassess pre-modern India's scientific legacy. The study emphasises science as a key component of civilisational vitality rather than an ancillary field by concentrating on the Vijayanagar Empire, a polity frequently praised for its political and cultural accomplishments. It claims that scientific innovation was socially rooted, empirical and institutional in premodern India. Conventional scientific historiography has often placed the scientific revolution exclusively in Renaissance Europe, favouring Eurocentric narratives. Scientific advancements in the global South are frequently viewed by these frameworks as isolated, derivative or pre-scientific. In contrast, the current thesis shows that Vijayanagar:

- **Cultivated rational governance** based on standardisation, quantitative measurement, and bureaucratic accountability
- Advanced systematic hydraulic engineering, metallurgical chemistry and structural physics
- Institutionalised knowledge transmission through temple universities and guild-based apprenticeship
- Encouraged experiment-driven practice in architecture, acoustics, agriculture, and medicine

- Integrated global knowledge flows through diplomacy and trade networks

These results demonstrate that science in Vijayanagar was neither accidental nor occasional, but rather resulted from a long-term epistemic culture that included anubhava (experimentation), yukti (logic and creativity), and sāstra (codified knowledge).

Additionally, by acknowledging the contributions of rural ecological experts, women practitioners, and craftspeople, this thesis broadens the definition of scientific community. By doing this, it depicts scientific work as multifaceted and socially diffused, going beyond elite-centric historiography. By using environmental history, architecture–archaeology relationships, and textual interpretation to recreate scientific systems from fragmented evidence, this work also makes a methodological contribution. Future study avenues are further opened by the suggested incorporation of digital humanities tools.

The broader historiographical contributions of the present study are synthesised in **Table 6.1**, which highlights how the Vijayanagar Empire can be reinterpreted beyond its conventional portrayal as a primarily cultural or religious polity. By foregrounding scientific activity, collaborative knowledge ecosystems, and empirically informed governance, **Table 6.1** situates Vijayanagar within a multi-centred early modern scientific world.

Theme	Contribution to Historiography
Reframing Vijayanagar	From cultural empire → scientific civilization
Knowledge ecology	Science as a collaboration among scholars, artisans, and communities
Rational governance	Linking statecraft with empirical resource and environmental planning
Global scientific history	Situating Vijayanagar in a multi-centered early modern world
Methodology	Advocating interdisciplinary and STEM-linked heritage studies

Table 6.1: Historiographical Contributions of the Study on Vijayanagar's Scientific Culture

Vijayanagar's scientific culture was distinguished by its interdisciplinary integration, the combination of theoretical knowledge with practical, social, and ecological applications. The study of science was not only present in scholars' manuscripts, but also in town construction, temples, and daily activities. Temples were aligned astronomically, hydrological systems were used for urban cleanliness and temples also housed medicinal clinics. Educational centres established in Sringeri and Kanchipuram taught students both metaphysics and empirical education, and suggested that there is no distinction between intellectual and moral education. This led to a unified science that was able to claim that the universe, the body, and

the built world were all the products of one rational order. The engineers of the empire showcased their novel concepts of sustainability such as passive cooling, load distribution, and rainwater utilization. Eco-medicine was predicted by physicians who introduced environmental awareness into the pharmacology by using plant remedies peculiar to the area. Hence, the paradigm of Vijayanagar is a convincing historical example for the synergy of science, ethics and environment in which an old civilization operated in a sustainable way with scientific reasoning.

6.3 Final Reflections

The Vijayanagar Empire was a symbol of rational administration and of artistic creativity and ethical humanism as a whole civilisation. Its scientific results were not only of a technical nature, but they were indicative of a culture with a focus on balance of knowledge and morality. So, today's Vijayanagar in the disunited academic world is a reminder to Science to serve human beings and not efficiency and conquest.

6.4 Prospects for future research

1. **Digital Archaeo-informatics:** Use LIDAR and GIS analysis of hydraulic systems and urban layout.
2. **Textual Philology:** Prepare critical editions and translation of less known scientific manuscripts of Vijayanagaram period.
3. **Comparative Studies:** Discuss similarities between the scientific cultures of Vijayanagar and Mughal or between the scientific cultures of the South-East Asia region.
4. **Gender and Science:** Explore women's role in medicine and education using epigraphic studies.
5. **Sustainability Models:** Adopt an integrated ecology-urbanism approach for Vijayanagar for sustainable city planning in the modern times.

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Appendix "A" Conjeevaram Plate of Krishnadeva Raya

8. ROMAN

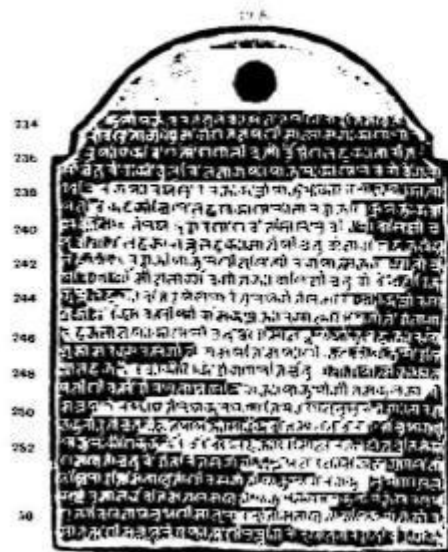
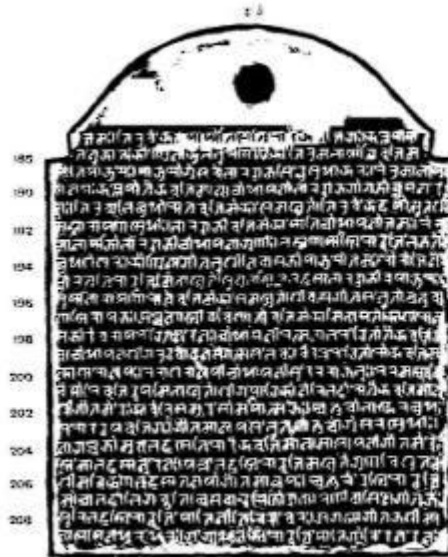
SCALE ONE INCH

M. CHIDAMBARAM & SONS, LTD. PHOTO-LITH.



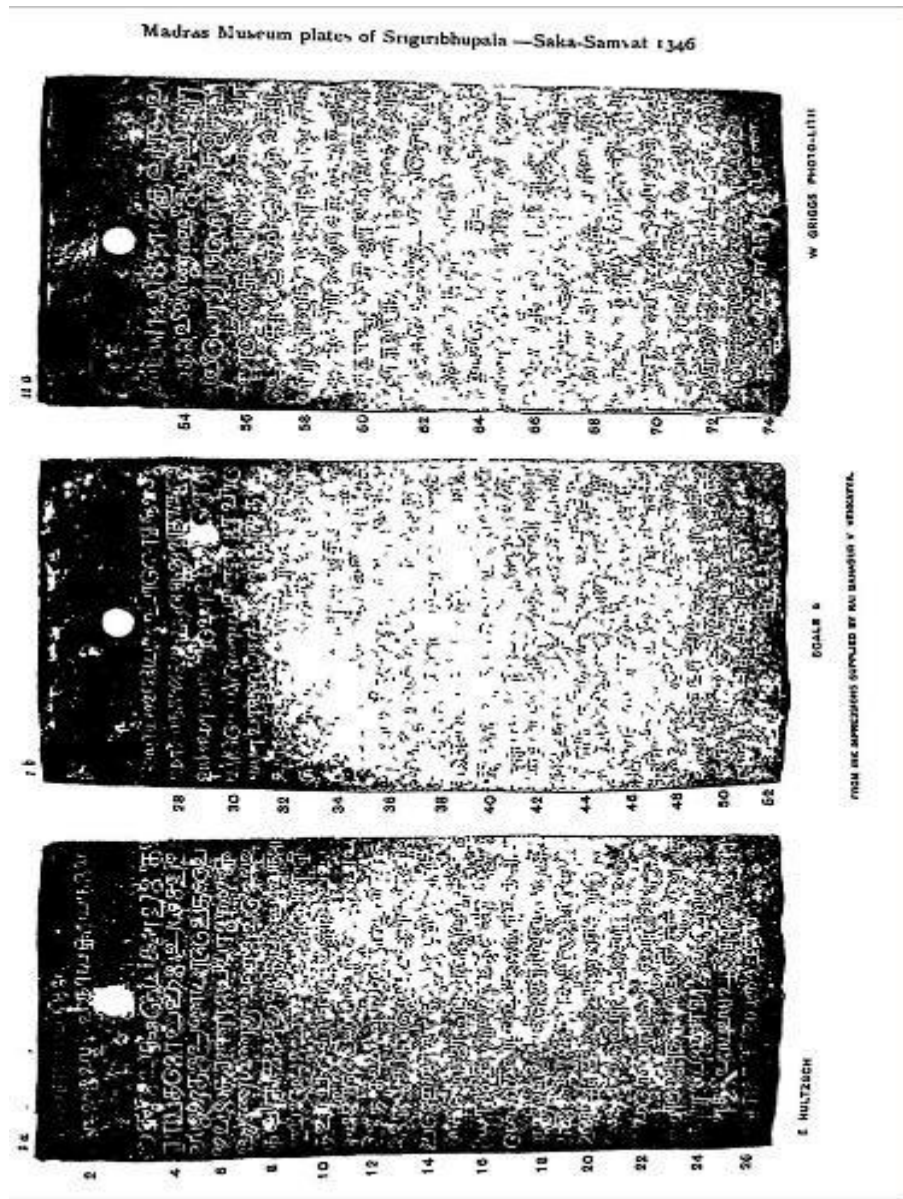
Appendix “B”

Padmaneri Grant of Venkatapati Raya



Appendix “C”

Srigiribhupala plate of Madras



Appendix “D”

Srisailam Copper-Plate Charter of Vijayanagara King Mallikarjuna

