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Engineering Solutions for Preserving Traditional Medicine Knowledge

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ABSTRACT

Traditional medicine (TM) remains a critical health resource for over 75% of the global population, particularly in developing regions where biomedical care is limited. Rich in cultural, spiritual, and environmental knowledge, TM faces extinction due to modernization, environmental degradation, and generational disinterest. Engineering approaches offer powerful solutions for preserving, documenting, and integrating TM knowledge into contemporary healthcare systems. This paper examines digital archiving, artificial intelligence, ethnobotanical databases, and community-engaged design to protect and modernize TM practices. It highlights case studies of successful preservation efforts and outlines ethical, legal, and technological considerations involved in the process. The role of stakeholders, including traditional health practitioners, policymakers, and engineers, is critically examined. By leveraging digital tools, database design, and community-driven platforms, engineering can facilitate the conservation and responsible sharing of traditional medicine knowledge, ensuring its relevance and accessibility for future generations.

Keywords: Traditional Medicine (TM), Indigenous Knowledge, Engineering Solutions, Digital Archiving, Ethnobotany, Artificial Intelligence, Biocultural Conservation, Intellectual Property, Knowledge Preservation, Healthcare Integration.

INTRODUCTION

It has been estimated that 75-80% of the world's population uses traditional and herbal medicines. For many of these people, the use of TM (Traditional Medicine) is far more than merely being effective holistic treatment of disease or a mere collection of herbal folk remedies. For the vast majority of the world's population, TM is a living practice, embedded and validated with their own diverse cosmologies, languages, cultures, institutions and practices. For thousands of years, humankind has relied on the plant, animal and mineral resources of the environment for the prevention and treatment of disease. It is only in the last hundred and fifty years or so that Allopathy, the mode of medical practice using synthetic compounds, has developed as a medical science. A number of studies have proved that the traditional knowledge systems of medicine have considerable similarities among different knowledge systems as well. The inevitable outcome of this was the acceptance of traditional medical systems in some parts of the globe. In India, the indigenous medical knowledge systems have assimilated many ideas and practices from each other. They either exist in codified or uncodified forms, often influencing each other. However, both the codified and uncodified medical knowledge systems exist as a treasure trove of knowledge amongst Indian people. Kerala, the land of Ayurveda, is perhaps the best example. Here, both indigenous folk systems of medicine and such formally practiced modern medical systems have co-existed in a single geographic area. Traditionally, in the context of Kerala, the local folk medicines and the formal systems of modern practice have interacted closely. Even now, rural folk practice health promoting traditional knowledge, which on the one hand keeps the people self-reliant as far as the health of the household is concerned and on the other hand is ecological preservation by way of conserving a number of important species of plants which have medicinal uses [1, 2].

Importance of Traditional Medicine

Today, in Africa and the developing world, a significant portion of health care is provided by traditional medicine (TM) practitioners, representing diverse cultures, beliefs, and historical contexts. TM encompasses a wide range of practices unique to each culture but often shares elements with others. This body of knowledge addresses disease causes, diagnosis, prognosis, and treatments. While TM practices vary greatly, they may be distilled into fewer basic treatment categories that align with cultural beliefs and social structures. Most TM methods stem from ancient knowledge, often linked to myths and transmitted orally, retaining valuable insights about medicinal substances. The global status of TM varies, with modern medicine and the pharmaceutical industry increasingly interested in its practices for financial gain. Simultaneously, there's a growing demand for accessible health care in rural, impoverished regions of the developing world. The interplay between Western biomedicine and TM raises significant issues that require careful exploration. It's essential to study and define TM knowledge and practices, ensuring their preservation and appropriate integration with modern health care systems. The interface between TM and biomedicine invites cross-disciplinary interest, prompting examinations of the effectiveness and validity of TM therapies. Urgent action is needed to document and safeguard TM knowledge at risk of being forgotten [3, 4].

Challenges in Preservation

Traditional medicine in Ghana has been orally passed through generations, facing challenges in preservation. A literature review identified threats categorized as environmental, socio-cultural, modernization, legal, and ethical. Key issues include habitat loss due to logging, farming, urbanization, and infrastructure, alongside overharvesting and unsustainable practices threatening medicinal plants. Globally, traditional medicine relies on about 30,000 plant species; only around 2,000 are traded, with Ghana listing 67 species. Traditional knowledge (TK) associated with these practices is also under threat, as many non-indigenous practitioners compete with indigenous healers. Approximately 2 billion people use traditional or alternative medicine, particularly in developing nations like Ghana. In conflict-affected regions, traditional medicine has been crucial in combating diseases like malaria in the absence of modern healthcare. However, modernization is encroaching upon traditional practices, with calls for preservation and ethno-botanical studies gaining traction only after significant erosion of knowledge. TK is typically passed down orally through mentorship, highlighting the urgent need for documentation as older traditional healers retire and younger generations lose interest [5, 6].

Role of Technology in Preservation

Traditional medicine knowledge is crucial for protecting indigenous biodiversity. Indigenous communities possess extensive understanding of medicinal plants and their applications. Documenting this knowledge is vital for informing decision-makers, conservationists, researchers, and the public about the importance of these plants. Traditional knowledge helps outline the exploitation status of medicinal plants, their socioeconomic significance, and cultural importance. Increased awareness regarding medicinal plants can reduce their extinction risks. European settlers adopted indigenous medicinal plants for various uses, passing this knowledge down through generations. Cultural sources often resonate more than scientific data. Historically, societies have relied on medicinal plants to treat various ailments, with many plants being economically important for healthcare. The rise of pharmaceutical industries has made local communities view these plants as vital for their livelihoods. However, environmental threats such as soil erosion, deforestation, urbanization, agricultural expansion, and invasive species jeopardize these plants, putting them at risk of local extinction. Furthermore, the difficulty in accessing traditional knowledge exacerbates conservation challenges. Growing interest in traditional medicinal plants has drawn attention to their conservation and sustainable use. Local communities are deeply concerned about these plants for disease treatment, highlighting the need to document and study this knowledge for sustainable management [7, 8].

Digital Archiving Techniques

The digital archive is essential for preserving and recalling traditional medicine ethnobiology knowledge, particularly about medicinal plants, fungi, and animals. It is a systematic collection of digital materials, including data, metadata, and related documentation, which organizes and promotes access to these resources. Preservation involves safeguarding digital materials against decay and obsolescence, using backup and migration systems. Digital tools provide support for automatic, server-based data storage. The advantages of digital archives over traditional methods include greater analytical capabilities, easier access, and extended longevity. They integrate various functionalities to restore and preserve traditional medicine knowledge. The primary goal is the long-term preservation of data for future accessibility and usability, with the choice of physical storage determined by hardware and software capabilities and

associated costs. Hardware must ensure accessibility for years, while software must secure appropriate archival formats and metadata for effective in-house systems. Policies regarding intellectual property rights and ownership govern digital archives, protecting organizations and clients. They assist organizations in identifying user needs and selecting the best records, informing strategies for developing digital collections and partnerships [9, 10].

Case Studies of Successful Preservation

Research on traditional medicine largely focuses on its knowledge and usage, with some civil society organizations' impacts highlighted. The case studies, while detailed and rich, often lack clarity, presenting issues in articulation. Some publications feature thorough studies on public perceptions of traditional medicine, which is urgently needed in India. Others describe organizations' activities in preserving and promoting traditional knowledge, typically offering broader themes with limited quantitative insights. Both domestic and international efforts to safeguard traditional medicine are recognized, with research by scholars dominating the case studies. These studies include valuable data on medicinal plants and public perceptions, though clarity issues often arise. Many case studies come from civil society organizations engaged in various projects, ranging from training healers to translating botanical knowledge into local languages. Notable efforts to promote traditional medicine are documented, along with a significant herbal medicine project. Given that traditional medicine relies on oral transmission, the risk of losing this knowledge with older generations highlights the need for ongoing documentation to prevent its extinction. The report from an international seminar on herbal medicine emphasized preserving indigenous restorative knowledge. A gene bank for endangered medicinal plants has also been established in Chinnambedu, underscoring the importance of these preservation initiatives [11, 12].

Community Involvement

The preservation of traditional medicine knowledge requires collaboration among traditional medicine practitioners, knowledge custodians, and community members. Traditional health practitioners (THPs) are key in this effort, skillfully passing down knowledge to family. They seek to create educational manuals, document practices through recordings, and engage the community in caring for medicinal plants. THPs emphasize the need for workshops and notices to educate the community on the importance and proper use of traditional medicine. Engaging custodians of traditional knowledge fosters a sense of ownership and ethical stewardship. However, entrusting their intellectual property to intergovernmental organizations can diminish this sense of ownership and hinder preservation efforts. That said, custodians benefit from protection against misuse of their intellectual property, ensuring access to sacred sites for cultural practices. The motivation to conserve biodiversity by custodians often stems from altruism, based on the idea that preserving biodiversity benefits humanity. Given that traditional medicine knowledge is ingrained in community practices, custodians are essential to preserving and protecting it. Prioritizing the custodians' role ensures the preservation of traditional medicine in its fullest context, involving all stakeholders for immediate action [13, 14].

Ethical Considerations

The preservation of traditional medicine knowledge and practices has both practical and ethical ramifications. Designing traditional knowledge (TK) databases is valuable from an ethnopharmacological perspective, as they directly assist primary research. However, the design and usability of such sites for global public health, management of intellectual property, and the avoidance of biopiracy are ethical considerations that warrant more investigation. By dealing with TK databases, an initial understanding of some of these ethical considerations for the application of the database to ethnomedicinal research is proposed. Ultimately, engineering solutions used to create ethnobotanical databases have implications far beyond the preservation of TK. For research that utilizes such ethnobotanical databases, there are even larger ramifications, as the database helps to manage intellectual property rights and gain community trust, while increasing the efficacy and relevance of traditional medicine in health care. Ethnopharmacologists can collaborate with local health care providers to ensure the local implementation of ethnopharmacological research findings. Non-Indigenous governments, NGOs, and health professions have an obligation of care to assist Indigenous health care systems to prevent ill health. Indigenous ownership of TK must first be secured and mechanisms developed to ensure any benefits accrue to the TK holders. The design of ethical solutions and governance systems for the protection of TK will not only preserve ethnobiological diversity but also enhance the quality of health care and quality of life for all stakeholders [15, 16].

Future Directions in Engineering Solutions

While there has been preliminary reporting on TM knowledge in some countries, this initial work must be underpinned by engineering approaches capable of covering these topics on a larger scale with a focus

on designing systems to capture the requirements and knowledge of TM practitioners. These systems can then be used to relate TM prescriptions to therapeutic principles in systems such as TCM, Ayurveda, and others. Efforts to take TM prescriptions and categorization as biological systems and relate them to cellular and molecular mechanisms should also continue. Most importantly, a thoughtful exploration of AI approaches to simulate the diagnosis process and TCM pathway- and goal-directed searching of the TM literature is needed. There are a number of relevant efforts, particularly the deep learning approaches in which they take the TM prescription as inputs and machine-learn deep networks that simulate the pathway from herbal targets and cellular and molecular mechanisms to therapeutic outcomes. However, there has not been enough effort regarding system-biology-based explanation of TM knowledge and prescriptions. In the TCM literature, there is enough knowledge containing explanations of TM knowledge and prescriptions captured by illustrative graphs. The explanations not only reveal knowledge on herbal and medicinal species but also on treatment processes with an emphasis on goal-directed usage of multiple prescriptions called "Zheng-Lun" in Chinese, which is the ultimate wisdom in TCM that retains its effectiveness over thousands of years but remains challenging and elusive regarding its general understanding. These systems of TM knowledge and herbal prescriptions are richly multi-modal with diverse contents including text, figures, voice. Their complexity presents challenges for computer algorithms to fully exploit and understand the TM knowledge and prescriptions, and convert them into machine-assimilable rules for the construction of systematic databases. To develop knowledge-based databases and HM selection systems, existing knowledge/semantic-based understanding approaches must be integrated with recent advances in deep learning-based representation understanding and text/knowledge generation models [17, 18].

Policy Recommendations

The development of policy recommendations and intervention strategies to address the loss of knowledge about TKM is based on the results of the study that were highlighted in the previous sections. These recommendations are grouped into three aspects. After the analysis of acquired information from focus groups, the recommendations are categorized in a way that can be directed to a targeted audience. The recommendations made include traditional medical practitioners, local government officials, and the general public. Education about TKM among the community members of the Tserorot community by traditional medical practitioners is highly recommended and further reach is urged. This provides communities with information about their medicinal plants and the loss of information about TKM. It also provides information about how to identify TKM practitioners. Educating members of the community on TKM also empowers individuals to pursue TKM when a plot against TKM practitioners is presented. Policy recommendations directed to the local government officials include holding community-initiated meetings, where discussions about the loss of knowledge about TKM are held. This would allow the voices of the community to be heard. Encouraging meetings allows for empowering the community members of the Tserorot community and prompting them to pursue the education and documentation of TKM. The Tserorot community is encouraged to communicate with the community at large through social media. Recordings of education regarding TKM between traditional medical practitioners and the video of the focus group can be posted on social media to educate the general public on the loss of information on TKM. Protecting the TKM practitioners from community plots against them can be executed by reporting those perpetrators to law enforcement [19, 20].

Funding and Resources

Funding, human resources, and infrastructure are essential for gathering traditional medicine knowledge. Initial funding is crucial to explore cultural areas where this medicine is prevalent. This can be used to hire local researchers fluent in the local language to collect qualitative ethnopharmacological data. Graduate students should also be recruited to conduct interviews and validate this knowledge. Finding interested researchers is challenging, so nurturing graduate students in developing countries with unexplored flora is vital. Knowledge assignments must be created for organizing and analyzing the gathered information. A comprehensive data system linking geographic and taxonomic data with local uses, preparation methods, and literature is crucial. A data center for traditional medicine should be established at a prominent research institution where data is analyzed to generate publications. Some universities are willing to collaborate with local researchers to set up these centers. A preservation policy is essential for knowledge valuation in partnership with local researchers. Local floras should be published for local researchers and health ministries to corroborate knowledge. Comprehensive reviews of medicinal plants and their potential commercial use should be published for visibility. Local researchers should also publish reviews in local journals. Data centers are expected to develop new medicinal products from this knowledge for commercial benefits [21, 22].

Evaluation Metrics for Success

To gauge the project's accomplishments, evaluation benchmarks will be considered. The numerical and analytical techniques developed to preserve traditional medicine knowledge were integrated into the project's master plan. New methods for managing digital infographics and cross-referencing images and hyperlinks will create user-friendly encyclopedias of traditional Tibetan medicine. These digital encyclopedias will enhance preservation of skilled expertise. Additionally, a machine-learning model was created to semi-automatically annotate digital resources by identifying quality and rare plants, which was implemented and fine-tuned. The model's architecture was updated with cluster computing, significantly reducing training and prediction time. The trained model was assessed to ensure a good balance of required human verifications post-prediction. Thirdly, rule-based plants-text-enforcements and methods for identifying guideline texts were implemented, but manual filtering remains necessary for improving results. Keyword-based text enhancement was generated in target languages and can be handled by the first-stage automatic annotation model. While the practical incorporation of annotated data into the encyclopedias was not completed, workflows for each inquiry type were established as a foundational step [23, 24].

Impact on Healthcare Systems

Ghana spends around six percent of its gross domestic product (GDP) on health care in a decentralized health care system. In theory, a comprehensive model merging several different curative practices with a referral system ought to provide efficient primary health care. However, patient records, referral letters, and clinic registers indicate that traditional medicine users are disregarded in the public health system, even when presenting with serious complications. The Biomedicine-Only Health System is used by less than ten percent of patients. Biomedicine's distinctiveness implies a different understanding of health/disease and thus health-seeking behaviors. In view of Traditional Medicine-Only health seeking, patients' beliefs and practices thus seem 'irrationally' incompatible with health professionals' biomedical knowledge. A lack of understanding coupled with discrimination seems to result in highly dysfunctional interactions when TM and biomedicine collide. Data indicates five challenges to integration can be discerned: Insufficient Knowledge of Traditional Medicine; Discriminatory Approach Towards Traditional Medicine; High Turnover of Biomedical Health Staff; Demarcation of Responsibilities; Lack of Resources. Interview data shows biomedical healthcare workers have limited insight into local understandings of health. Many are graduates or students doing a mandatory internship. A significant number does not speak the local language. Furthermore, 'alien' staff is unacquainted with local cultural beliefs and practices that influence health choices. Data suggests insufficient understanding coupled with status differences (based on education) leads to discrimination of healers and their patients. Patients mention insults and the denial of care at biomedical facilities in case of exhibiting signs of the use of TM. Such poor treatment results in reluctance to seek help. It thus complicates diagnoses and increases the risk of complications from interacting medication/treatment. The turnover of staff resulting from temporary staff appointments and internships undermines the establishment of a relationship of trust between healers and biomedical health staff [25, 26].

Integration with Modern Medicine

Integrating findings of traditional medicine with modern pharmaceutical research has not yet proved feasible. Presently only the initial steps are presented on a 'bridge' linking findings from traditional medicines to those of modern pharmaceutical research. However, it is expected that once a sufficient number of databases about traditional medicines are publicly accessible, there will be widespread opportunities to connect them with chemical and molecular data that are now routinely used in modern research. A concerted community effort is required to ensure that such opportunities become practically accessible to those involved in both traditional medicine and modern pharmaceutical research. This effort will entail community outreach, education of those working with traditional medicines, infrastructure development and training in unaccustomed technology. On the scholarly front, there is the urgent need for guidelines and recommendations on data selection, normalization and curation to ensure high-quality, interoperable information about traditional medicine. Preservation of traditional medicine by Native American tribes is an important topic on many levels. As modern society pushes for advancement and intellectual property rights, traditional medicine knowledge, practices and beliefs are at risk. Each Native American tribe has different medicinal plants, diseases, cultural beliefs, methods and ways of use concerning traditional medicine. These differences not only differ from tribe to tribe but also change for each community of several hundred people. It is also the reason why some tribes become interested in improving the quality of health and medical care, knowledge oftentimes has to be sacrificed. Therefore,

collecting this knowledge can help tribal members understand the plant or beverage better. Knowledge is protective. It can help preserve traditional medicine knowledge [27, 28].

Educational Initiatives

At the beginning of the 21st century, there was a growing need for an ethical framework to assess traditional medicine knowledge systems (TKS) and address issues related to bioprospecting and bio-piracy, while protecting TKS markets from misuse. In 1994, a custodianship framework was established to guide a pragmatic approach to TKS, emphasizing ethical and contractual norms. Both academic and non-academic institutions have come together to evaluate the traditional ecological knowledges (TEKs) of indigenous peoples, developing various processes and benefit-sharing approaches. Typically, the dominant culture, through academic institutions and private companies, assesses indigenous knowledge and seeks market-based benefits, negotiating for the right to use traditional knowledge, effectively becoming its custodians. The dominant culture controls the processes for gathering and evaluating this wisdom. Coordinated conventions and processes to address bioprospecting and bio-piracy need to be collaboratively designed by governments and indigenous peoples. While some agreements exist between indigenous custodians, resource developers, and governments, these are often disregarded. Educational initiatives promoting ethical principles have emerged from translational justice, involving custodians of knowledge systems, aiming to facilitate engagement. Current efforts to establish ethics codes for ceremonial, academic, and commercial transactions can serve as foundational elements. It is recommended that different agents take responsibility for specific ethical issues to create a framework for accountability for everyone involved [29, 30].

CONCLUSION

The preservation of traditional medicine knowledge is both a scientific necessity and a cultural imperative. As modernization and ecological pressures threaten centuries of orally transmitted health wisdom, engineering solutions provide a viable path to safeguard and revitalize TM. From digital databases and ethnobotanical archives to AI-driven modeling and system biology integration, the tools of engineering can codify, structure, and validate TM knowledge for future use. Importantly, these efforts must involve ethical frameworks, community ownership, and culturally sensitive approaches that honor the intellectual property of indigenous healers. The success of such preservation strategies depends on inclusive collaborations between engineers, traditional practitioners, policymakers, and communities. With thoughtful application, engineering can not only protect but also elevate traditional medicine as a legitimate, accessible, and sustainable pillar of global health systems.

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