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Artificial Intelligence-Enabled Perspectives on Natural Resources for Human Health: An Integrated Review of Medicinal Plants, Ecosystem Services, and Sustainable Resource Systems for Health and Well-Being

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ABSTRACT:

Background: Natural resources such as medicinal plants, forests and greenspaces, aquatic and microbially mediated ecosystems, water, soil, and air form the biophysical bases of human health constituting up to 25-40% of modern drugs and being the major means of treating a substantial share of the world's population owing to the unavailability of conventional healthcare. Although the amount of evidence about the association of biodiversity, ecosystem services, and health outcomes grows continuously, literature in this field is extremely scattered between pharmacology, ecology, nutrition, and public health without much interconnection in terms of how specific resources affect health.

Objectives: The purpose of this systematic review is to synthesize multidisciplinary literature about the role of natural resources in health and wellbeing of people, analyze the state of evidence in each type of resources, outline the main knowledge gap, which is the absence of a conceptual framework linking the availability of natural resources, their bioactivity, ecologic mechanisms and sustainability constraints to health outcomes and propose a novel conceptual framework.

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Methods: A structured narrative review was conducted following elements of the PRISMA approach to literature identification and screening. Peer-reviewed literature (2020–2026), WHO technical reports, and recognized international assessments were retrieved from PubMed, Scopus-indexed journals, ScienceDirect, Springer, Wiley, MDPI, and Nature Portfolio outlets, using structured search terms across five domains: medicinal plants and bioactive compounds; forests, green/blue space and ecosystem services; marine and microbial natural products; nutrition, gut microbiota, and food biodiversity; and sustainability, biotechnology, and artificial intelligence applications in natural-product discovery. Records were screened for relevance, recency, and methodological transparency; systematic reviews and meta-analyses were prioritized where available.

Results: Evidence is strongest and most consistent for the therapeutic potential of plant- and marine-derived bioactive compounds (polyphenols, alkaloids, terpenoids, marine alkaloids and peptides) in oncology, metabolic disease, and infection, and for the mental-health and cardiovascular benefits of green- and blue-space exposure. Evidence is emerging but less conclusive for gut-microbiome-mediated effects of dietary bioactives and for artificial-intelligence-accelerated natural-product discovery. Cross-cutting limitations include inconsistent standardization and quality control of herbal products, under-investment in clinical validation of traditional therapies, and accelerating biodiversity loss that threatens the future supply of bioactive resources.

Implications and Conclusion: Realizing the health potential of natural resources requires simultaneous attention to scientific validation, regulatory harmonization, biodiversity conservation, and equitable benefit-sharing with the traditional and Indigenous knowledge-holders who first identified many of these resources. The proposed Sustainable Natural Resources for Human Health (SNRHH) framework integrates these dimensions and offers a template for future empirical and policy research. Well-established evidence (e.g., plant-derived oncology drugs, green-space mental-health benefits) is distinguished throughout from emerging evidence (e.g., microbiome-mediated nutrition effects) and from areas requiring further clinical validation (e.g., most traditional herbal formulations).

1. INTRODUCTION

Human health has never been separable from the natural world. Before the development of pharmacology, people across the world used plants, fungi, minerals, animals, and intact ecosystems including forests, rivers, soils, and coasts to fend off and treat diseases and obtain clean air, water, nutrients, and psychologically restorative properties. Far from making these dependencies obsolete due to industrialization and biomedical advances, they have gained additional scientific plausibility. Contemporary phytochemistry, marine pharmacology, microbiome research, and studies of ecosystem services explain the mechanisms of the effects that have been known for centuries in various traditional medicine systems.

Up to 25-40% of present-day drugs have been derived from nature directly or indirectly, and natural products remain a major source of novel structural scaffolds that cannot be created by synthetic chemical methods (Newman & Cragg, 2020). Apart from that, there is a growing amount of data collected with the help of environmental epidemiology demonstrating associations between access to green/blue spaces and lower risks of heart disease, better mental well-being, and mortality (Twohig-Bennett & Jones, 2018; Kotera et al., 2022). It has been shown that bioactive compounds in nutrition affect our health through the interaction with the gut microbiome, which gives mechanistic insight into well-established connections between nutrition, ecosystems, and diseases (Zheng et al., 2024).

At the same time, the natural resources that underlie these effects are becoming more vulnerable. The Living Planet assessments carried out by the WWF reveal dramatic reductions in the populations of monitored wild species, while the organizations aimed at preserving biodiversity consider one million species to be in danger of extinction within several decades (World Economic

Forum, 2023; Planetary Health Alliance, 2025). As most of the pharmacologically active compounds have been found within a very limited range of organisms that make up only a tiny part of plant, fungal, and marine diversity, it is not only ecological but also medical issue (World Health Organization, 2025a).

Global health systems, meanwhile, face a convergence of pressures — rising noncommunicable disease burden, antimicrobial resistance, mental-health strain, and unequal access to conventional care — that has renewed interest in nature-based and traditional approaches as complements to, rather than substitutes for, conventional medicine. The World Health Organization's Global Traditional Medicine Strategy 2025–2034, adopted by the Seventy-eighth World Health Assembly, explicitly frames this as an evidence-building and integration challenge rather than a validation-versus-rejection debate (World Health Organization, 2025a, 2025b).

1.1 Research Problem and Research Gap

Although each of the constituent literatures — ethnopharmacology, marine natural-product chemistry, forest and green-space epidemiology, nutrition–microbiome science, and conservation biology — has matured considerably since 2020, these bodies of work remain largely siloed. Reviews of medicinal plants rarely engage systematically with ecosystem-service or planetary-health literature; reviews of green-space health benefits rarely engage with the bioactive-compound literature; and sustainability and conservation science is frequently treated as a downstream policy concern rather than an input variable that determines the future availability of health-relevant natural resources. This fragmentation obscures a central empirical and conceptual gap: there is no widely used integrated framework that connects (a) the availability and diversity of natural resources, (b) the bioactive or ecosystem-service mechanisms through which those resources affect physiology and well-being, (c) the health determinants and outcomes that result, and (d) the sustainability and governance conditions required to keep the resource base intact for future generations. This review addresses that gap directly.

1.2 Research Objectives

- To critically evaluate the existing literature on the involvement of natural resources (medicinal plants, forest, water/air/soil environments, marine/microbe resources) in the improvement of human health and well-being.
- To distinguish different kinds of natural resources that contribute to the improvement of human health and to evaluate the strength of evidence that exists on the correlation between the natural resources and human health outcomes.
- To critically evaluate the safety, standardization, quality control, and sustainability issues associated with the use of natural resources in health care.
- To identify the main research question that is implied by the existing body of knowledge and to construct the original theoretical model, namely, the Sustainable Natural Resources for Human Health (SNRHH).
- To propose a prioritized agenda for future research, policy, and practice at the interface of natural resources, biotechnology, and human health.

1.3 Research Questions

- RQ1: What categories of natural resources contribute meaningfully to human health, and through what mechanisms?
- RQ2: How strong and consistent is the evidence linking each resource category to specific health outcomes, and where does the evidence remain emerging or unvalidated?
- RQ3: What safety, quality-control, and sustainability risks accompany natural-resource-based healthcare, and how are they currently being addressed?
- RQ4: How can natural-resource availability, bioactive/ecosystem-service mechanisms, health determinants, and sustainable-development considerations be integrated into a single explanatory framework?
- RQ5: What research, technological, and policy priorities would most effectively advance the safe, equitable, and sustainable use of natural resources for human health?

2. LITERATURE REVIEW

2.1 Medicinal Plants and Herbal Resources

Medicinal plants remain the most extensively studied category of health-relevant natural resource. Recent comprehensive reviews describe a wide pharmacological repertoire — antioxidant, anti-inflammatory, antidiabetic, hepatoprotective, neuroprotective, and anticancer activity — attributed principally to secondary metabolites such as polyphenols, alkaloids, terpenoids, and polysaccharides (Riaz et al., 2023; Shen et al., 2024). Plant-derived bioactives have shown particular promise in neurodegenerative disease management, where polyphenols and alkaloids modulate oxidative stress and neuroinflammatory pathways implicated in Parkinson's and Alzheimer's disease (Shoaib et al., 2023). Many more examples of the application of natural products based on their traditional uses can be found in modern ethnopharmacological literature. On the other hand, the need for conducting clinical tests regarding the efficiency of traditional uses after preclinical and in vitro studies can be found in modern ethnopharmacological literature (Singla et al., 2025; Wang et al., 2024).

One of the common trends found in the literature in question is the difference between the indication of biological activity in case of traditional usage of many plant products and proving the clinical efficacy of these products. The lack of well-conducted randomized trials compared to the number of in vivo phytochemical studies is the main barrier to applying ethnobotany in medicine (Balkrishna et al., 2024).

2.2 Natural Products and Bioactive Compounds

In addition to terrestrial flora, marine organisms have also started gaining prominence as sources of potentially valuable novel structural bioactive compounds. More than 39,500 biologically active marine natural products have so far been reported, with 17 marine-based drugs being employed in the treatment process, as well as more than 30 others undergoing clinical trials, especially in the field of oncology (Zhang et al., 2024; El-Seedi et al., 2025). Recent progress in techniques of drug discovery such as bioactivity screening, metabolomics-based dereplication, and genomics have allowed great advances in discovering novel marine natural compounds (Gaudêncio et al., 2023). Even activity against some neglected tropical diseases has been shown by marine natural compounds, expanding the sphere of application of marine biodiversity to therapeutic purposes outside the interest of wealthier countries (Rai et al., 2024).

From the perspective of structure, natural products occupy special areas in the map of chemical space not easily recreated through synthetic combinatorial libraries. As a result, natural products make up a greater share of drugs than any other set of screening compounds (Newman & Cragg, 2020). This novelty, being a basis for the therapeutic applicability of natural products, is one of the key issues in the development process due to complexity of some natural scaffolds.

2.3 Forests, Green Spaces, and Ecosystem Services

There is a considerable amount of epidemiological research that shows significant health effects associated with access to green spaces such as forests, parks, and other vegetated or blue areas. According to systematic reviews and meta-analysis, there is a strong connection between green space exposure and health benefits for mental health, general health, cardiovascular, and metabolic health outcomes, a somewhat conflicting connection for respiratory, maternal, and cancer outcomes (Twohig-Bennett & Jones, 2018). In particular, systematic reviews on shinrin-yoku or forest bathing practice as an intervention method that implies exposure to forested environment showed salivary cortisol and stress biomarkers decrease, improvement in mood, anxiety, and blood pressure (Antonelli et al., 2019; Kotera et al., 2022; Siah et al., 2023). Besides, experimental research indicates that natural interventions such as shinrin-yoku, green exercise, gardening, and nature viewing can offer cardiovascular risk reduction and quality of life improvement in cancer patients, however, the evidence on cancer outcomes is less robust than cardiovascular and mental health outcomes.

The reasons behind the health benefits associated with natural interventions include reduced psychological stress and attention recovery, more opportunities for physical activity, better air quality, various environmental microbials, and social and community aspects of green infrastructure. Nevertheless, the role of all these factors is yet to be clarified, and all reviews of the existing evidence note that primary studies used for the analysis suffer from high or unknown bias.

2.4 Water, Soil, Air, and Environmental Resources Affecting Health

Environmental media constitute another essential but somewhat hidden natural resource that plays a role in determining our health status. Access to safe water and sanitation affects the prevalence of infectious diseases in many places across the globe;

soil quality affects the nutrient content of our food; and air quality affects cardiovascular, respiratory and neurological diseases. Planetary-boundary studies help us understand how environmental media function as interconnected systems where their deterioration through pollution, new substances and land use changes have direct implications on our health, which is studied mainly in wealthy nations and insufficiently in Africa and Oceania.

2.5 Marine and Microbial Natural Resources

Apart from their involvement in drug discovery, there has also been growing relationship between marine and microbiodiversity and human biology as a result of the interplay of the marine and microorganisms with the gut microbiome. Various bioactive components in the diet like polyphenols, dietary fibers, and marine lipids have been seen to interact with the gut microbiota in influencing short-chain fatty acids, gut-barrier integrity, immunity, and metabolism (Zheng et al., 2024). Fermented foods and the microbial ecosystem have been shown to influence the amount of good microbes in the body.

2.6 Traditional Knowledge and Indigenous Healthcare Practices

Nevertheless, traditional, complementary, and integrative medicine (TCIM) still continues to offer the most important health service to many people around the world, particularly in poorer countries and rural communities. According to the World Health Organization (WHO) Global Traditional Medicine Strategy 2025-2034 adopted during the Seventy-eighth World Health Assembly, the sector has achieved immense progress because of the increase in national regulations on herbal medicines from 65 to 116 Member States and also an increase in national TCIM agencies from 49 to 100 Member States (World Health Organization, 2025a). On the other hand, the strategy also acknowledges the presence of tensions in the sector in terms of fear of compromising the indigenous epistemology through emphasizing Western standards of evidence, concerns of benefit sharing and possible exploitation of the traditional knowledge, among others, and inadequate investment in TCIM infrastructural capacity relative to its reach (Health Policy Watch, 2025).

2.7 Natural Resources in Disease Prevention and Therapeutic Development

Natural resources as preventive and therapeutic agents have a role in many branches of clinical practice. In oncology, plant and marine derivatives remain one of the primary sources of novel chemoactive compounds. Regarding CKD, there exists some promising data from meta-analyses concerning the use of plant-derived biologically active agents (curcumin, propolis, sulforaphane, flavonoids, and many other), which demonstrates moderate clinical efficacy in trials, but larger studies are needed. In cardiometaolic and mental health disorders, natural medicine approaches and dietary biologically active agents become convergent preventive approaches applicable in primary medicine and public health projects, according to WHO Traditional Medicine Strategy.

2.8 Sustainable Utilization and Conservation of Natural Resources

The sustainability issues are pertinent to all the above resources. The unsustainable harvesting of wild medicinal plants, unsustainable wild crafting of marine resources, and habitat destruction due to land use changes and climatic variations are all issues that threaten the sustainability of the biodiversity that is important for health purposes. Sustainable and green extraction processes including the use of microwave assisted, ultrasonic assisted and supercritical fluid extractions have been recommended as a means through which biological resources can be conserved through efficient extraction of bioactive compounds with low energy and solvent use but increased yield and purity of the compound (Ajala et al., 2026).

2.9 Synthesis and Identification of the Research Gap

Table 5 (see Results and Analysis, below) gives a general description of some representative publications about these eight topics. The conclusions that can be drawn from all of the above points are the following. First of all, the quality of evidence varies from relatively high number of systematic reviews and meta-analyses for green spaces and mental health, and marine and plant compounds for use in oncology, compared to very low number of such works for almost all traditional herbal formulae due to their high plausibility compared to clinical evidence. Secondly, sustainability is perceived as a separate topic, not as the determiner of the future evidence base, but an additional one. Thirdly, interdisciplinary connections are rare among ecosystems services for health effects and bioactive compounds research. The novelty of the current review consists in connecting these two approaches in one conceptual framework (Section 6).

3. RESEARCH METHODOLOGY

This manuscript uses a structured narrative (integrative) review approach, chosen because the research questions fall within more than one discipline (pharmacology, ecology, nutrition, and sustainability sciences) and thus are not appropriate for a systematic review approach in which an outcome and intervention need to be determined beforehand. In cases where systematic reviews or meta-analyses had been carried out within the relevant disciplines and pertained to the research questions (forest bathing and mental health; greenspace and cardiovascular outcomes), preference was given to such over original research studies.

3.1 Database Selection

Literature was retrieved from PubMed/MEDLINE, ScienceDirect, Springer Nature Link, Wiley Online Library, MDPI journals, Frontiers journals, and official publications of the World Health Organization and allied international bodies (Convention on Biological Diversity, World Economic Forum, World Wildlife Fund, Planetary Health Alliance). These sources were selected for their indexing in Scopus and/or Web of Science and their relevance to the five review domains specified in Section 3.3.

3.2 Search Strategy and Keywords

Structured search strings combined resource-category terms ("medicinal plants," "marine natural products," "greenspace," "forest bathing," "gut microbiome," "biodiversity," "traditional medicine") with outcome and mechanism terms ("bioactive compounds," "human health," "systematic review," "meta-analysis," "sustainability," "quality control," "artificial intelligence," "drug discovery"). Searches were restricted to English-language publications from January 2020 to mid-2026, with a small number of foundational pre-2020 sources retained where they remain the primary reference point for a field (e.g., the Newman and Cragg natural-product drug-approval series; the Millennium Ecosystem Assessment).

3.3 Inclusion and Exclusion Criteria

Inclusion criteria: (a) peer-reviewed journal articles, WHO/international-body technical reports, or recognized assessments; (b) direct relevance to at least one of the five review domains; (c) publication in or after 2020, or foundational status for the field; (d) availability of sufficient bibliographic detail (author, year, title, source, and, where applicable, DOI) to permit independent verification.

Exclusion criteria include: (a) Any non-peer reviewed blog entries or marketing content; (b) Information sources that make unverifiable claims about health benefits; (c) Papers where less than five subjects were used or there was no mention of methodology because primary papers had been utilized for analysis and not a secondary source review; (d) Duplicated datasets where the more detailed or recent one was chosen.

3.4 Study Selection, Data Extraction, and Analysis Approach

The titles and abstracts were first reviewed to determine the relevancy of the topics, after which the full-text articles (or structured abstracts and results if the full text was not accessible) were critically appraised based on their methodology and compliance with the inclusion criteria. Information collected from each of the chosen articles includes the following: authors and date of publication, nature of study/systematic review, nature of the resource used, healthcare outcomes in primary care, key findings, and any weaknesses noted. The findings were finally classified into thematic categories (Section 2) and tabulated for an evidence comparison table (Table 5).

3.5 Conceptual and Analytical Framework

To make sense out of diverse research findings, we use the pathway approach that connects Natural Resources to Bioactive/Ecosystem Services to Health Determinants to Human Health Impacts to Sustainable Development, as illustrated in Figure 1 and Figure 2, and formally defined in the paradigm of Sustainable Natural Resources for Human Health (SNRHH) in Section 8. The pathway approach provides the ability to analyze a diverse range of resources in a similar manner using one pathway: resource → mechanism → determinant → impact → sustainable development loop.

4. RESULTS AND ANALYSIS

Synthesizing across the 2020–2026 literature retrieved for this review, natural resources relevant to human health can be organized into six broad categories: (1) terrestrial medicinal plants and their phytochemicals; (2) marine and aquatic bioresources; (3) forests, green space, and blue space as restorative environments; (4) soil, water, and air as environmental health media; (5)

microbial resources, including the human gut microbiome and its dietary modulators; and (6) traditional and Indigenous knowledge systems that encode centuries of empirical resource use. Table 1 presents this classification alongside representative health contributions.

Across these categories, the strongest and most reproducible evidence concerns (a) plant- and marine-derived bioactive compounds with defined pharmacological mechanisms in oncology, metabolic disease, and infection, supported by an expanding pipeline of approved and trial-stage agents, and (b) the mental-health and cardiovascular benefits of structured nature exposure, supported by multiple systematic reviews and meta-analyses despite heterogeneous primary-study quality. Evidence is more emergent — mechanistically plausible but less clinically validated — for microbiome-mediated effects of dietary bioactives, for the majority of individual traditional herbal formulations outside a small set of well-studied examples, and for AI-accelerated natural-product discovery, which is methodologically promising but still generating relatively few validated clinical leads to date.

A consistent limitation across all categories is the gap between preclinical/in vitro evidence and confirmatory clinical trials. This gap is narrowest for marine oncology agents (where clinical pipelines are relatively mature) and widest for traditional herbal formulations evaluated outside their country of origin. Quality assurance was the second most recurring theme, with issues like adulteration, species misclassification of plants, and inadequate standardization of analysis identified as possible obstacles to consumer safety and replication of clinical studies regarding herbal medicine (Wang et al., 2023). Sustainability is the third theme, with multiple resources types – wild medicinal plants, marine organisms living in coral reefs and deep sea, and old forests – experiencing conservation challenges that could prevent future study and treatment unless managed using cultivation, synthetic biology, and protected areas.

Table 2 represents several examples of medicinal plants, their active components, and therapeutic applications. Table 3 illustrates natural resource interventions used for different diseases, noting the level of scientific proof of each. Table 4 provides an overview of the advantages, disadvantages, and limitations of natural resource-based health care. Table 5 lists sources utilized for this literature review along with their methodology, conclusions, and gaps in evidence. Table 6 shows sustainability factors for each resource type.

5. TABLES

Table 1. Classification of Major Natural Resources and Their Contribution to Human Health

Resource Category	Representative Components	Primary Health Contribution	Evidence Maturity
Terrestrial medicinal plants	Roots, leaves, bark, seeds; polyphenols, alkaloids, terpenoids	Antioxidant, anti-inflammatory, antimicrobial, anticancer, antidiabetic activity	Well-established (compound level); variable (formulation level)
Marine & aquatic bioresources	Algae, sponges, corals, marine microorganisms, fish oils	Novel anticancer and anti-infective scaffolds; omega-3 fatty acids for cardiometabolic health	Well-established (oncology leads); emerging (broader applications)
Forests & green space	Woodlands, urban parks, community gardens	Stress reduction, improved mood, cardiovascular and respiratory benefits, physical activity	Well-established (mental health); moderate (cardiometabolic, cancer)

Resource Category	Representative Components	Primary Health Contribution	Evidence Maturity
Blue space	Rivers, lakes, coastlines, wetlands	Psychological restoration, recreational physical activity, thermoregulation	Emerging; smaller evidence base than green space
Soil, water & air	Agricultural soils, freshwater systems, ambient air	Food-system nutrient density; infectious-disease control; cardiorespiratory health	Well-established (as risk factors when degraded)
Microbial resources	Gut microbiota, fermented-food microbiomes, soil microbiota	Metabolic regulation, immune modulation, gut-barrier integrity	Emerging; mechanistic evidence stronger than clinical outcome evidence
Traditional/Indigenous knowledge	Ethnobotanical and ethnomedical practice systems	Primary healthcare source for large populations; source of leads for drug discovery	Well-established as a knowledge source; efficacy validation ongoing

Table 2. Selected Medicinal Plants, Principal Bioactive Compounds, and Therapeutic Applications

Plant / Source	Principal Bioactive Compound(s)	Reported Therapeutic Application	Representative Evidence
Curcuma longa (turmeric)	Curcumin (polyphenol)	Anti-inflammatory; adjunct in chronic kidney disease and metabolic conditions	Systematic review of RCTs, CKD/dialysis populations
Camellia sinensis (green tea)	Catechins, polyphenols	Antioxidant, cardiometabolic and gut-microbiota modulation	Reviews of polyphenol–microbiota interactions
Annona squamosa	Palmatine and related alkaloids	Analgesic and anti-arthritic activity (preclinical)	In vivo pharmacological study
Various Cactaceae genera	Betalains, flavonoids, terpenoids	Antioxidant and anticancer potential	Ethnopharmacology review
Hippophae rhamnoides (sea buckthorn)	Isorhamnetin, quercetin, gallic acid, protocatechuic acid	Antitumor and hepatoprotective activity	Systematic review of extraction and application
Astragalus membranaceus	Polysaccharides, flavonoids	Immunomodulatory support in chronic kidney disease	Systematic review of RCTs, CKD/dialysis populations

Plant / Source	Principal Bioactive Compound(s)	Reported Therapeutic Application	Representative Evidence
Various neuroprotective botanicals	Polyphenols, terpenes, alkaloids	Investigational management of Parkinson's disease pathways	Mechanism-focused literature review (2019–2023)

Table 3. Comparison of Natural-Resource-Based Interventions Across Health Conditions

Health Condition	Natural-Resource Intervention	Reported Effect	Strength of Evidence
Anxiety, depression, and stress	Forest bathing / structured nature exposure	Reduced salivary cortisol; improved mood, anxiety, and quality-of-life scores	Well-established (multiple systematic reviews/meta-analyses)
Cardiovascular risk	Greenspace exposure; forest bathing; omega-3 marine lipids	Lower blood pressure; favorable hemodynamic and lipid markers	Well-established to moderate, depending on intervention
Oncology (adjunct/lead discovery)	Marine- and plant-derived bioactive compounds	Novel chemotherapeutic scaffolds; approved and trial-stage agents	Well-established at compound-discovery level
Chronic kidney disease	Curcumin, propolis, sulforaphane, flavonoid-rich botanicals	Modest improvements in inflammatory and renal-function markers in RCTs	Emerging; requires larger confirmatory trials
Metabolic/gut health	Polyphenol- and fiber-rich diets; fermented foods	Favorable shifts in gut-microbiota composition and metabolite profiles	Emerging; mechanistic evidence stronger than outcome trials
Neurodegenerative disease	Plant polyphenols, terpenes, alkaloids	Preclinical neuroprotective and anti-neuroinflammatory activity	Requires further clinical validation

Table 4. Benefits, Risks, Challenges, and Limitations of Natural Resources for Healthcare

Dimension	Benefits	Risks / Challenges / Limitations
Pharmacological	Structurally novel scaffolds; multi-target activity; historically productive drug-discovery source	Complex extraction and synthesis; batch-to-batch chemical variability; limited clinical-trial coverage relative to preclinical volume
Safety & quality	Long history of traditional use provides preliminary safety signal for some remedies	Adulteration, misidentification, contamination (heavy metals, mycotoxins, pesticide residues); inconsistent standardization across markets

Dimension	Benefits	Risks / Challenges / Limitations
Regulatory	Growing number of national frameworks (116 WHO Member States) and a new global strategy (2025–2034)	Regulatory harmonization across countries remains incomplete; variable pharmacovigilance capacity
Equity & knowledge governance	Recognition of traditional/Indigenous knowledge as a formal WHO strategic priority	Risk of knowledge misappropriation; benefit-sharing with originating communities often inadequate
Environmental/sustainability	Renewable if managed sustainably; green extraction technologies reduce ecological footprint	Overharvesting, habitat loss, and climate change threaten wild populations and future resource supply
Access & health-systems	Often lower-cost and more accessible than conventional care in resource-limited settings	Risk of delayed conventional treatment if used as a substitute rather than a complement without adequate guidance

Table 5. Summary of Key Studies Referenced in this Review

Author(s), Year	Objective / Focus	Design	Key Finding	Identified Gap
Newman & Cragg (2020)	Natural products as sources of new drugs, 1981–2019	Bibliometric/retrospective analysis	Natural products and derivatives account for a large share of approved drugs, especially in oncology and infection	Declining natural-product screening investment relative to combinatorial chemistry
Twohig-Bennett & Jones (2018)	Greenspace exposure and health outcomes	Systematic review & meta-analysis	Consistent associations with reduced cardiovascular risk, improved mental health, lower mortality	High heterogeneity and risk of bias in primary studies
Kotera, Richardson & Sheffield (2022)	Shinrin-yoku (forest bathing) and mental health	Systematic review & meta-analysis	Significant reductions in depression, anxiety, and stress-related biomarkers	Few long-term follow-up studies; limited non-Asian samples
Antonelli, Barbieri & Donelli (2019)	Forest bathing and cortisol as stress biomarker	Systematic review & meta-analysis	Significant post-intervention reduction in salivary cortisol	Small sample sizes; variable intervention duration
Zhang, Lv & Wang et al. (2024)	Bioactive marine natural products in drug discovery	Narrative/technical review	17 marine-derived drugs in clinical use; 33 candidates in trials	Bioprospecting concentrated in shallow/accessible marine zones

Author(s), Year	Objective / Focus	Design	Key Finding	Identified Gap
El-Seedi et al. (2025)	Marine natural products as anticancer drugs, 2019–2023	Updated review	Continued expansion of marine-derived anticancer chemotypes	Translational bottleneck from discovery to clinical development
Wang, Chen, Wang et al. (2023)	Herbal medicine quality control practices	Narrative review	Adulteration and inconsistent standardization remain major safety risks	Lack of harmonized international quality standards
Zheng, Qin, Wen et al. (2024)	Food nutrients, bioactive compounds, and gut microbiota	Comprehensive review	Dietary fiber, polyphenols, and unsaturated fats shape microbiota composition and function	Limited long-term human RCT evidence for specific compounds
Mullowney et al. (2023)	Artificial intelligence for natural-product drug discovery	Review	AI/omics integration accelerates compound identification and bioactivity prediction	Data scarcity and standardization limit model generalizability
World Health Organization (2025a)	Global Traditional Medicine Strategy 2025–2034	Policy strategy document	Substantial institutional growth in TCIM regulation and integration since 1999	Persistent underfunding of TCIM-specific research relative to reliance on it

Table 6. Sustainable Strategies for Balancing Natural Resource Utilization, Conservation, and Human Health

Strategy	Description	Relevant Resource Category
Green/sustainable extraction technologies	Microwave-, ultrasound-, and supercritical-fluid-assisted extraction reduce solvent use and energy demand while improving compound yield	Medicinal plants; marine bioresources
Cultivation and domestication of wild medicinal species	Shifting from wild harvest to controlled cultivation reduces pressure on wild populations	Medicinal plants
Marine protected areas and regulated bioprospecting	Conservation zoning combined with access-and-benefit-sharing agreements	Marine & aquatic bioresources
Urban greening and nature-based public-health programming	Investment in accessible green/blue space as low-cost preventive-health infrastructure	Forests, green and blue space

Strategy	Description	Relevant Resource Category
Biotechnology and synthetic biology	Microbial or cell-culture production of scarce bioactive compounds to reduce extraction pressure on source organisms	Medicinal plants; marine bioresources
Traditional-knowledge protection and benefit-sharing frameworks	Formal recognition, documentation, and equitable compensation for Indigenous and traditional knowledge contributing to drug discovery	Traditional/Indigenous knowledge systems
Harmonized international quality and safety standards	Convergence toward WHO quality-control and pharmacovigilance guidelines across national regulatory systems	All categories (herbal/natural products)
Biodiversity governance implementation	National-level implementation of the Kunming-Montreal Global Biodiversity Framework targets	All categories (cross-cutting)

6. FIGURES

The five figures below are rendered as publication-ready diagrams, each followed by a short descriptive caption explaining its structure and interpretation.

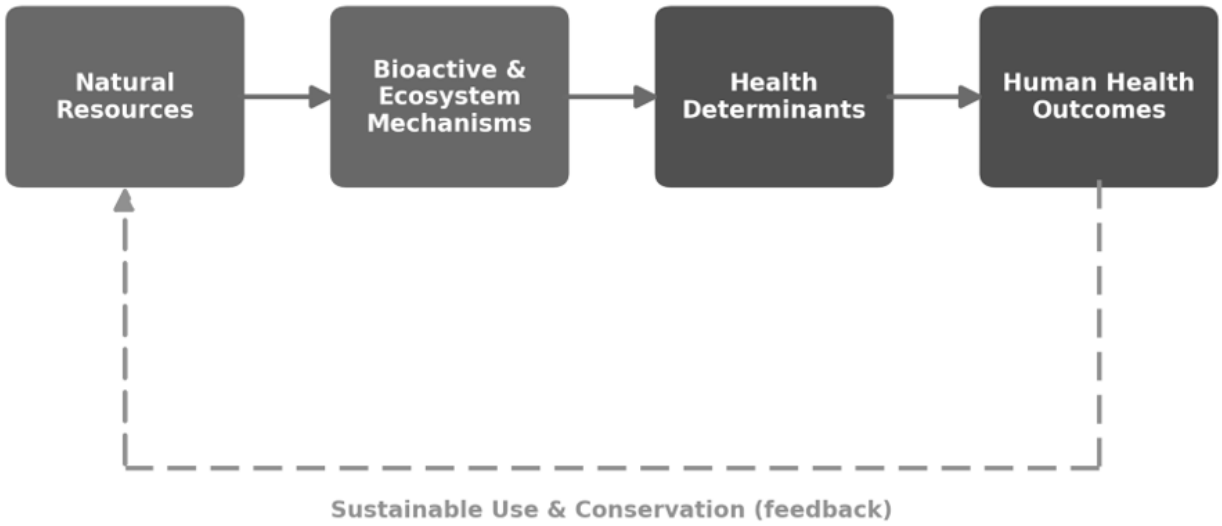

Figure 1. Conceptual Framework: Natural Resources and Human Health

Flowchart in horizontal orientation with four boxes. Natural Resources flowing into Bioactive and Ecological Mechanisms, resulting in Health Determinants which then give Human Health Outcomes. Flowchart shows the feedback process in an orange dotted line called Sustainable Use and Conservation, connecting Human Health Outcomes with Natural Resources, completing the circle and emphasizing how today's health benefits are dependent on the management of tomorrow's natural resources.

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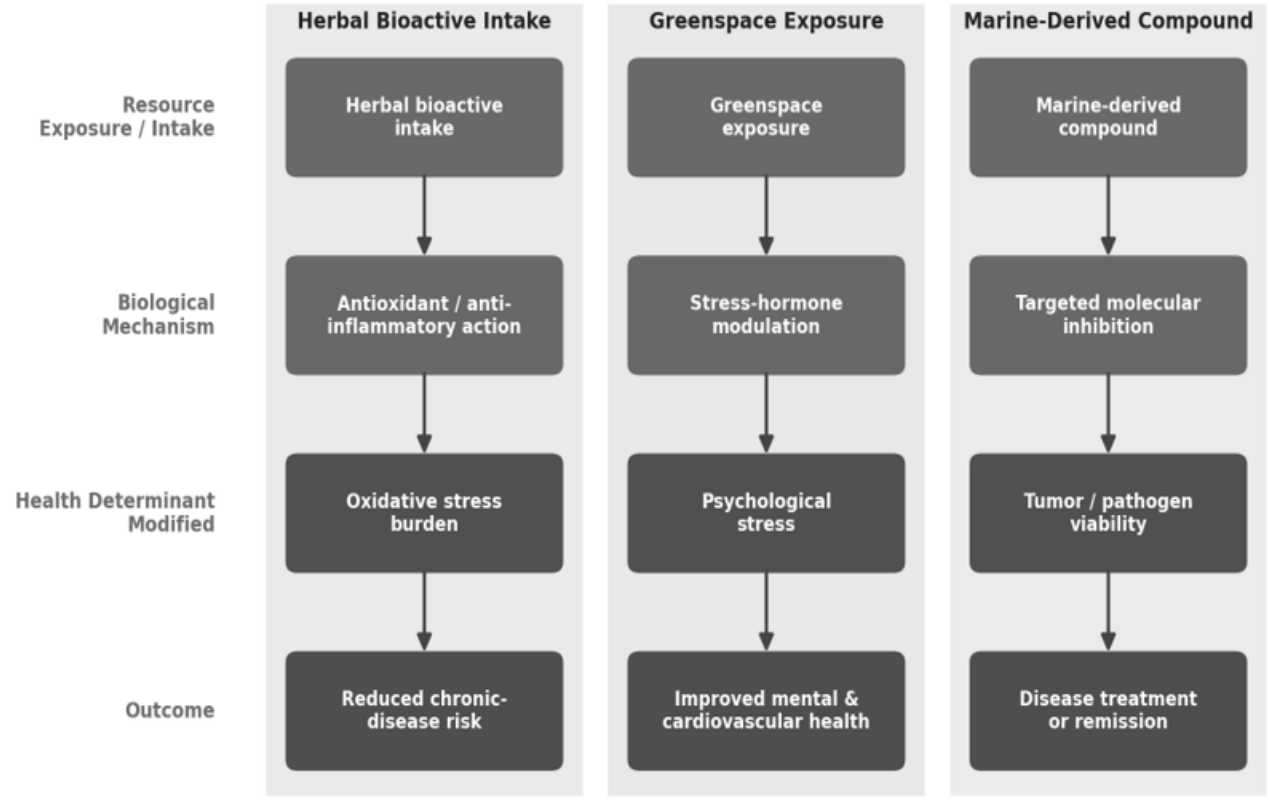

Figure 2. Pathway from Natural Resources to Disease Prevention and Health Promotion

Four tiers process flow chart of vertical arrangement for three distinct parallel cases including herbal bioactive compound, greenspaces, and marine compounds where each one goes through the same four-tier process including Resource Exposure/Intake, Biological Mechanism, Modification of Health Determinant and the Outcome. The purpose is to demonstrate that despite differences in the structure of natural resources, they all follow the same four-tier process of explanation.

Figure 3. Classification of Natural Resources Relevant to Human Health

A radial (sunburst) classification with a central hub, "Natural Resources for Health," surrounded by the six primary resource categories from Table 1, each further divided into illustrative sub-categories in the outer ring.

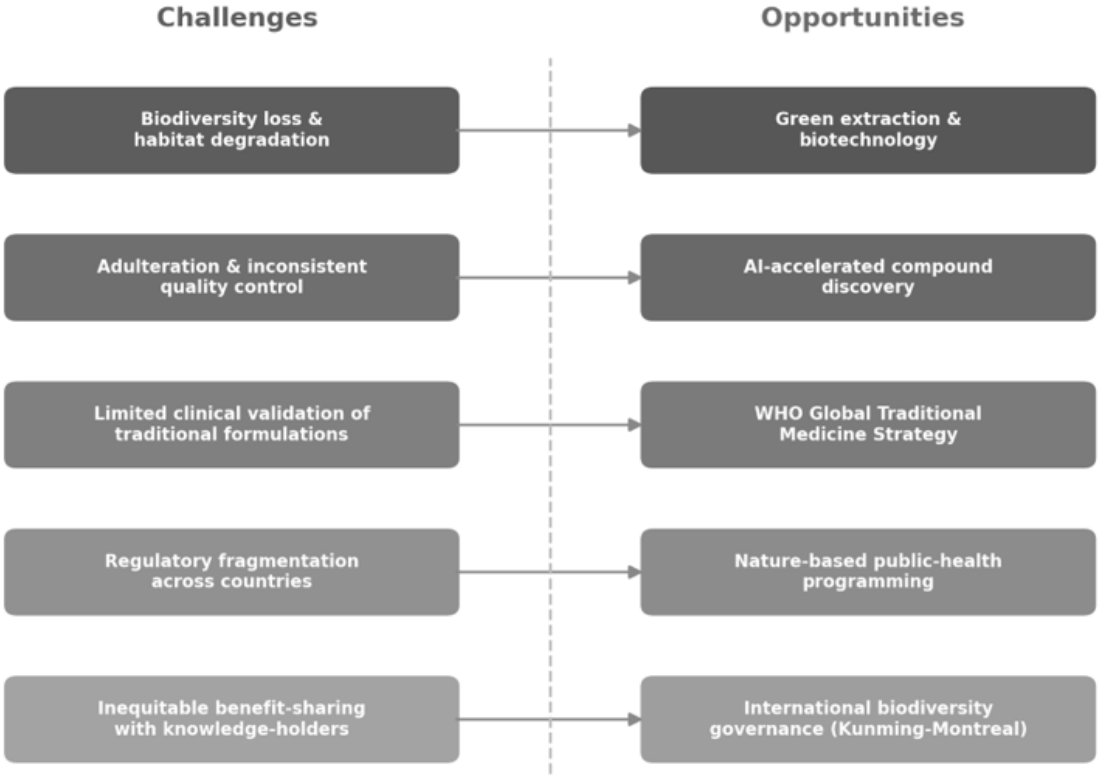

Figure 4. Major Challenges and Opportunities in Sustainable Natural-Resource-Based Healthcare

A paired two-column comparison of the five most significant challenges identified in this review (left, red) against their most directly corresponding opportunities (right, green), connected by horizontal linking arrows.

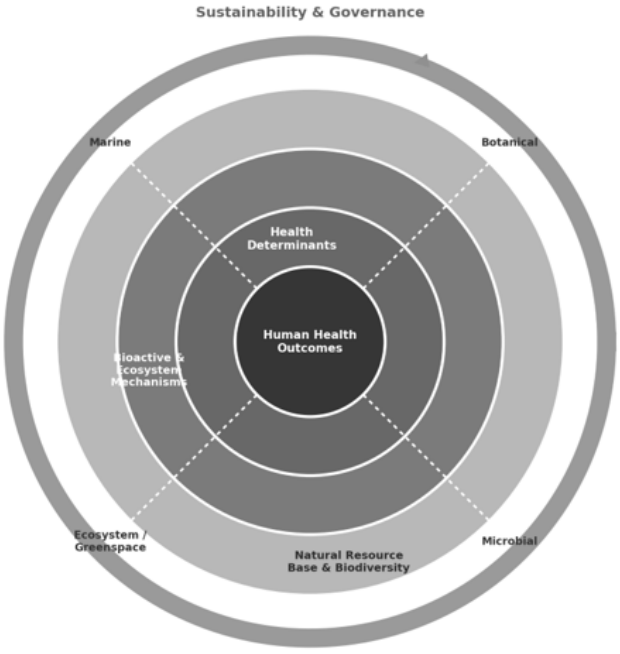

Figure 5. Proposed Integrated Framework: Natural Resources–Environment–Health–Sustainability

Diagram of Concentric rings. Starting from the center, we have "Human Health Outcomes"; proceeding outward we have "Health Determinants," "Bioactive/Ecosystem Mechanisms," and "Natural Resource Base/Biodiversity." In the outer ring, there is a "sustainability/governance" circle of "amber" color regulating the whole process. We have four arrows emanating from the center of the diagram, representing the four pathways connecting the outer "resource" circle to the inner "health outcome" circle. This diagram represents the SNRHH model presented in section 8.

7. DISCUSSION

7.1 Significance for Modern Healthcare

As a matter of fact, as is evident from the information provided above, the role of natural resources in the contemporary medicine is not incidental, but fundamental, because many medicines originate from the nature today and there are many medicines being developed based on the natural compounds (Newman & Cragg, 2020; Zhang et al., 2024). However, in addition to it, greenery and forests constitute another, distinct source of good health which is more often recognized now in connection with the mental and cardiovascular health benefits (Twohig-Bennett & Jones, 2018; Kotera et al., 2022). Nevertheless, while in the past, these two areas have been separated in the contemporary health care system along with their respective disciplines (e.g., pharmacology and environment/behavioral health), the very source of both of them has remained the same.

7.2 Integration of Traditional Knowledge with Modern Science

Institutionally, the WHO Global Traditional Medicine Strategy 2025-2034 is the most explicit signal that the course of traditional medicine and conventional medicine is moving toward integration and not parallelism (World Health Organization, 2025a, 2025b). The findings from this review reinforce the direction of the institution, as there are various traditional formulations made from plants that have a valid mechanism of bioactivity, but the necessary clinical trials for these formulations are inconsistent enough to allow for integration into mainstream medicine. In fact, the data collected from the Strategy demonstrates a notable development in the institution's governance, as the number of Member States with regulatory policies on traditional medicines has increased from 65 to 116, and the number of national offices of TCIM has increased from 49 to 100.

7.3 Safety, Standardization, and Quality-Control Challenges

Adulteration, species misidentification, and contamination remain the most consistently cited safety concerns across the herbal-medicine quality-control literature (Wang et al., 2023). These are not peripheral technical issues; they directly undermine both consumer safety and the reproducibility of clinical research, since inconsistent raw-material quality introduces uncontrolled variability into trial outcomes. Analytical tools — HPLC/HPTLC fingerprinting, DNA barcoding for species authentication (Antil et al., 2023), and harmonization around WHO quality-control guidelines — offer a technically mature solution set; the primary barrier is uneven adoption and enforcement across national regulatory systems rather than a lack of available methodology.

7.4 Environmental Degradation and Its Impact on Health

Biodiversity loss operates as both a direct health threat (through degraded ecosystem services — clean water, air, food security) and an indirect one (through the erosion of the biological raw material from which future medicines are discovered). The Living Planet and IPBES-type assessments documenting large-scale wildlife population decline and extinction risk should therefore be read by health researchers not only as an environmental concern but as a leading indicator of future constraints on natural-product drug discovery and traditional-medicine resource availability (World Economic Forum, 2023; Planetary Health Alliance, 2025).

7.5 Biodiversity Conservation and Sustainable Resource Management

Green and sustainable extraction technologies, cultivation of previously wild-harvested species, and marine protected areas each offer partial solutions, but none is sufficient in isolation. A more systemic response requires embedding conservation targets — such as those established under the Kunming-Montreal Global Biodiversity Framework — directly into health-sector planning and pharmaceutical-industry sourcing policy, rather than treating conservation purely as an environmental-ministry responsibility disconnected from health outcomes.

7.6 Ethical and Policy Considerations

However, benefit sharing which is fair to the indigenous and traditional people, whose knowledge sometimes pre-dates any scientific discovery, remains a moral issue which has been emphasized in the discussion on the development of the WHO's strategy. In this case, they were afraid that scientific verification would give precedence to the Western epistemology over the indigenous one (Health Policy Watch, 2025). It therefore means that policy frameworks should try to achieve the two together, rather than separately.

7.7 Biotechnology, AI, and Data-Driven Discovery

AI and ML tools, including generative molecular design, metabolomics-assisted dereplication, and ethnopharmacological literature mining using NLP methods, are already starting to address some of the classic limitations in natural products research, including the slow speed of dereplication, limited data set size, imbalanced composition, and poor experimental validation ability (Mullowney et al., 2023). These approaches are most effective as complements to natural products research and ethnobotanical fieldwork, not as replacements, and their direct usefulness lies in prioritization and hypothesis generation rather than clinical validation.

Beyond compound discovery, artificial intelligence is increasingly being applied across the wider natural-resource-health pipeline described in this review. Machine-learning models trained on remote-sensing and biodiversity-monitoring data are being used to forecast habitat loss and species-extinction risk, offering an early-warning capability that could help prioritize conservation of the specific ecosystems most likely to harbor novel bioactive compounds. In parallel, AI-assisted image and acoustic analysis is being trialed for real-time authentication of raw herbal materials, a potential complement to the DNA-barcoding and chromatographic methods discussed in Section 7.3 for combating adulteration and species misidentification. Large language models and NLP pipelines are also being explored to digitize and cross-reference scattered ethnobotanical and traditional-knowledge records, which could support the equitable-benefit-sharing and knowledge-governance goals discussed in Section 7.6, provided such digitization is undertaken with the informed consent and involvement of the originating communities. As with AI-driven drug discovery itself, these applications remain at an early, exploratory stage: they are best understood as decision-support tools that augment expert judgment and fieldwork, not as autonomous substitutes for ecological monitoring, quality-control laboratories, or community-led knowledge stewardship.

7.8 Novel Contribution of This Review

The most significant contributions of this manuscript in terms of existing literature on the single domain are as follows: (1) the analysis of the evidence base from different domains of resources that were viewed independently and thus making it possible to compare evidence maturity within these domains (Chapter 4, Table 5); (2) the acknowledgement of sustainability and biodiversity conservation as an input and not co-benefit for future health evidence; and (3) the creation of a novel model (Chapter 8), which provides an explanation of the evidence base pathway.

8. PROPOSED FRAMEWORK: SUSTAINABLE NATURAL RESOURCES FOR HUMAN HEALTH (SNRHH)

Based on the pathway model that was discussed in section 3.5 and represented by figures 1, 2, and 5, we will propose the SNRHH (Sustainable Natural Resources for Human Health) framework as the new synthesis that unites all eight components. The proposed framework must be viewed as a tool for analysts or strategists who are developing or assessing health interventions through the use of natural resources, considering sustainable constraints.

8.1 Components of the SNRHH Framework

- Natural Resource Availability: The starting amount and distribution of the relevant biological and environmental resources (plants, marine life, forest, and condition of water and soil).
- Biodiversity: Genetic and species biodiversity critical for the resource resilience as well as for the discovery of new bioactive chemicals.
- Traditional Knowledge: Empirical and cultural knowledge concerning the identification, extraction, and use of natural resources for medical and public health purposes.
- Validation: The scientific validation process, ranging from preclinical to clinical and pharmacovigilance studies.

- Discovery of Bioactive Substances/Ecosystem Services: The identification of the specific substances or ecosystem services responsible for the observed health effects.
- Using Natural Resources in Healthcare: The process by which validated natural resources become healthcare interventions.
- Safety and Regulation: Systems ensuring quality control, standardization, pharmacovigilance and regulatory compliance.
- Sustainable Utilization: Conservation, cultivation, green extraction and regulation processes which will ensure the sustainable use of the resource base mentioned in Component 1.

8.2 Relationships Among Components

The SNRHH model is meant to be cyclical rather than linear in nature. Natural Resource Availability and Biodiversity together define the number of raw materials at the disposal of Traditional Knowledge System and Science Validation. Bioactive Compound/Ecosystem Service Discovery and Healthcare Application are interrelated and they rely on knowledge flow from the first two knowledge systems; Safety and Regulation serves as an intermediate stage ensuring that only validated raw materials will be used. The important thing about this model is that Healthcare Application cannot be the final step of the cycle, as there is a particular feedback arrow from Healthcare Application and Safety/Regulation to Sustainable Utilization and back to Natural Resource Availability, meaning that benefits gained from the health system should be taken into account while conserving natural resources for the future.

Applied to the evidence reviewed here, the SNRHH framework helps explain observed patterns of evidence maturity: domains where Scientific Validation and Safety/Regulation are relatively advanced (marine oncology agents, greenspace mental-health interventions) show correspondingly mature Healthcare Applications, whereas domains where Sustainable Utilization is under acute pressure (wild-harvested medicinal plants, reef-associated marine organisms) face compounding risk to both current supply and future discovery potential, regardless of how promising the underlying bioactivity may be.

9. THEORETICAL AND PRACTICAL IMPLICATIONS

9.1 Theoretical Implications

This review contributes to natural-resource and health scholarship by offering a cross-domain conceptual structure (SNRHH) that can be applied consistently across otherwise disconnected literatures — pharmacology, environmental epidemiology, nutrition science, and conservation biology. It reframes sustainability from an externality of natural-resource-based healthcare to an intrinsic, feedback-linked component of the health-production process itself, a reframing that subsequent empirical and modeling work could test directly, for example by quantifying how measured biodiversity decline in a given region corresponds to changes in the discovery rate of novel bioactive compounds from that region.

9.2 Practical Implications

- For health system policymakers: Nature-based interventions (access to green space programs and forest therapy) can be considered as cost-effective and evidence-based approaches that can be added to existing preventive programs in relation to stress and cardiovascular disease prevention.
- For pharmaceutical/biotechnology professionals: Increased investment in marine and microbial bioprospecting along with the use of green extraction technologies and manufacturing using synthetic biology approach would maintain the pipeline of natural products and reduce the burden of harvest from wild populations.
- For regulatory authorities: Standardization of the control of herbal products according to WHO guidelines as well as further development of authentication of plant material using DNA barcoding technology would address the issues mentioned in reviewed publications.
- For conservation and biodiversity policymakers: Incorporation of health sector data in biodiversity governance process (e.g., implementing of Kunming-Montreal Global Biodiversity Framework at the national level) would strengthen the justification of conservation financing by demonstrating the clear health benefits for humans.
- For research funders: Implementation of the infrastructure for clinical trials of traditional multi-compound medicine would address the most significant evidence gap identified in this review.

10. CONCLUSION

Natural resources comprise not only medicinal plants, biodiversity of sea organisms and microorganisms, forests and green/blue environments, but water, soil and air environmental media as well. In this review, multidisciplinary literature in the area of each of these resources has been compiled and divided into well-known findings (pharmacological productivity of natural compounds and mental and cardiovascular health effects of natural contact), novel research (microbiome-mediated effects of diet and artificial intelligence-assisted discoveries) and research gaps (majority of traditional herbal products).

The major scientific contribution made by this review is that all of the above-mentioned aspects have been discussed within the framework of the Sustainable Natural Resources for Human Health (SNRHH) paradigm, which states that the interaction between the natural resource availability, their scientific validation, implementation in the healthcare system and sustainability has a cyclical nature. It follows from that fact that the long-term health effects of natural resources cannot be ensured by means of pharmacology and clinical research alone, it is essential to provide biodiversity protection, quality control and integration of the traditional/Indigenous knowledge in working with natural resources. Policy efforts to address the issue have been made (WHO Global Traditional Medicine Strategy 2025-2034, etc.), but the pace of institutionalization and regulation development contradicts the amount of clinical research done. Bridging that gap, while safeguarding the ecological systems from which these resources originate, represents the central challenge and opportunity for the next decade of research at the interface of natural resources and human health.

11. LIMITATIONS

- As a narrative/integrative review rather than a formal systematic review with pre-registered protocol, study selection, while structured and transparent, retains an element of author judgment regarding source inclusion and thematic weighting.
- The English-language restriction on searches likely underrepresents traditional-medicine literature published in other languages, particularly Chinese-, Korean-, Spanish-, and Arabic-language sources, several of which were noted even within the retrieved English-language reviews as containing relevant additional evidence.
- The pace of publication in AI-driven natural-product discovery and in WHO traditional-medicine policy is rapid; some details (particularly institutional statistics and strategy implementation status) may have been updated since the literature search was conducted.
- This review synthesizes secondary and tertiary sources (systematic reviews, meta-analyses, and technical reports) rather than reanalyzing primary datasets, meaning that any biases present in the underlying primary literature (frequently noted risk-of-bias concerns in greenspace and forest-bathing studies, for example) propagate into this synthesis.
- The tables presented (Section 5) are illustrative, evidence-based syntheses intended to organize and compare the reviewed literature; they are not exhaustive catalogs of all medicinal plants, marine compounds, or health conditions relevant to natural-resource-based healthcare.
- The proposed SNRHH framework is conceptual and has not yet been empirically tested or validated through primary data collection; it is offered as a structure for future research rather than as a confirmed causal model.

12. FUTURE RESEARCH DIRECTIONS

- Artificial intelligence and machine learning for natural-product discovery: further development and validation of AI-driven dereplication, bioactivity prediction, and generative-design tools, with attention to dataset standardization across laboratories.
- Personalized natural-resource-based healthcare: integration of individual genetic, microbiome, and metabolic profiles to tailor natural-product and nutrition-based interventions.
- Genomics and metabolomics of medicinal and marine organisms: expanded omics-based characterization of underexplored species to identify novel bioactive chemotypes before habitat loss forecloses the opportunity.
- Climate change and natural-resource availability: longitudinal research tracking how shifting climate zones affect the geographic distribution, potency, and yield of medicinal plant and marine bioactive resources.

- Biodiversity conservation linked to health outcomes: empirical studies quantifying the relationship between local biodiversity indices and measurable human-health or drug-discovery outcomes.
- Digital databases and knowledge platforms: continued development of interoperable, rights-respecting digital libraries of medicinal-resource and traditional-knowledge data, building on efforts such as the WHO Traditional Medicine Global Library.
- Clinical validation of traditional medicines: expansion of adequately powered randomized controlled trials specifically designed for multi-compound traditional formulations, rather than single-molecule trial templates.
- Sustainable and green extraction technologies: scale-up research on microwave-, ultrasound-, and supercritical-fluid-assisted extraction to reduce the environmental footprint of bioactive-compound production.
- Nanotechnology-enabled delivery of natural bioactive compounds: further clinical-stage research on nanocarrier systems (phytosomes, nanostructured lipid carriers) to address the bioavailability limitations common to many natural compounds.
- One Health and planetary-health integration: research explicitly connecting human, animal, and environmental health surveillance systems to anticipate how ecosystem degradation will affect future natural-resource-based healthcare capacity.

REFERENCES

[1] Ajala, O. J., et al. (2026). Green extraction technologies for medicinal plant bioactive compounds: Applications in pharmaceuticals, cosmeceuticals, and nanotechnology. Biofuels, Bioproducts and Biorefining. https://doi.org/10.1002/bbb.70159

[2] Antil, S., Abraham, J. S., Sripoorna, S., Maurya, S., Dagar, J., Makhija, S., Bhagat, P., Gupta, R., Sood, U., & Lal, R. (2023). DNA barcoding, an effective tool for species identification: A review. Molecular Biology Reports, 50(1), 761–775. https://doi.org/10.1007/s11033-022-08015-7

[3] Antonelli, M., Barbieri, G., & Donelli, D. (2019). Effects of forest bathing (shinrin-yoku) on levels of cortisol as a stress biomarker: A systematic review and meta-analysis. International Journal of Biometeorology, 63, 1117–1134. https://doi.org/10.1007/s00484-019-01717-x

[4] Balkrishna, A., Sharma, N., Srivastava, D., Kukreti, A., Srivastava, S., & Arya, V. (2024). Exploring the safety, efficacy, and bioactivity of herbal medicines: Bridging traditional wisdom and modern science in healthcare. Future Integrative Medicine, 3(1), 35–49. https://doi.org/10.14218/FIM.2023.00086

[5] Carroll, A. R., Copp, B. R., Grkovic, T., Keyzers, R. A., & Prinsep, M. R. (2024). Marine natural products. Natural Product Reports, 41(2), 162–207. https://doi.org/10.1039/d3np00061c

[6] Convention on Biological Diversity. (2022). Kunming-Montreal Global Biodiversity Framework. United Nations Environment Programme.

[7] El-Seedi, H. R., Refaey, M. S., Elias, N., El-Mallah, M. F., Albaqami, F. M. K., Dergaa, I., Du, M., Salem, M. F., Tahir, H. E., Daglia, M., Yosri, N., Zhang, H., El-Seedi, A. H., Guo, Z., & Khalifa, S. A. M. (2025). Marine natural products as a source of novel anticancer drugs: An updated review (2019–2023). Natural Products and Bioprospecting, 15, Article 12. https://doi.org/10.1007/s13659-024-00493-5

[8] Ferreira, F. J. N., & Carneiro, A. S. (2025). AI-driven drug discovery: A comprehensive review. ACS Omega. https://doi.org/10.1021/acsomega.5c00549

[9] Gaudêncio, S. P., Bayram, E., Lukić Bilela, L., et al. (2023). Advanced methods for natural products discovery: Bioactivity screening, dereplication, metabolomics profiling, genomic sequencing, databases and informatic tools, and structure elucidation. Marine Drugs, 21(5), 308. https://doi.org/10.3390/md21050308

[10] Health Policy Watch. (2025, May 28). WHO's big push to integrate traditional medicine into global healthcare framework. Health Policy Watch. https://healthpolicy-watch.news/whos-big-push-to-integrate-traditional-medicine-into-global-healthcare-framework/

[11] Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). (2019). Global assessment report on biodiversity and ecosystem services. IPBES Secretariat.

[12] Kotera, Y., Richardson, M., & Sheffield, D. (2022). Effects of shinrin-yoku (forest bathing) and nature therapy on mental health: A systematic review and meta-analysis. International Journal of Mental Health and Addiction, 20, 337–361. https://doi.org/10.1007/s11469-020-00363-4

[13] Millennium Ecosystem Assessment. (2005). Ecosystems and human well-being: Health synthesis. World Health Organization / Island Press.

[14] Mullowney, M. W., Duncan, K. R., Elsayed, S. S., Garg, N., van der Hooft, J. J. J., Martin, N. I., Meijer, D., Terlouw, B. R., Biermann, F., Blin, K., et al. (2023). Artificial intelligence for natural product drug discovery. Nature Reviews Drug Discovery, 22(11), 895–916. https://doi.org/10.1038/s41573-023-00774-7

[15] Nashwan, A. J., Joy, G. V., & Chaabna, N. (2026). Integrating planetary health into interprofessional education: A scoping review. Cureus, 18(2), e103662. https://doi.org/10.7759/cureus.103662

[16] Newman, D. J., & Cragg, G. M. (2020). Natural products as sources of new drugs over the nearly four decades from 01/1981 to 09/2019. Journal of Natural Products, 83(3), 770–803. https://doi.org/10.1021/acs.jnatprod.9b01285

[17] Planetary Health Alliance. (2025). Biodiversity loss. Planetary Health Alliance. https://planetaryhealthalliance.org/themes/biodiversity-loss/

[18] Rai, T., Kaushik, N., Malviya, R., & Sharma, P. K. (2024). A review on marine source as anticancer agents. Journal of Asian Natural Products Research, 26(4), 415–451. https://doi.org/10.1080/10286020.2023.2249825

[19] Riaz, N., et al. (2023). Phytobioactive compounds as therapeutic agents for human diseases: A review. Food Science & Nutrition. https://doi.org/10.1002/fsn3.3308

[20] Shen, Y., Zhao, H., Wang, X., Wu, S., Wang, Y., Wang, C., Zhang, Y., & Zhao, H. (2024). Unraveling the web of defense: The crucial role of polysaccharides in immunity. Frontiers in Immunology, 15, 1406213. https://doi.org/10.3389/fimmu.2024.1406213

[21] Shoaib, S., Ansari, M. A., Fatease, A. A., Safhi, A. Y., Hani, U., Jahan, R., Alomary, M. N., Ansari, M. N., Ahmed, N., & Wahab, S. (2023). Plant-derived bioactive compounds in the management of neurodegenerative disorders: Challenges, future directions and molecular mechanisms involved in neuroprotection. Pharmaceutics, 15(3), 749. https://doi.org/10.3390/pharmaceutics15030749

[22] Siah, C. J. R., Goh, Y. S., Lee, J., Poon, S. N., Ow Yong, J. Q. Y., & Tam, W. (2023). The effects of forest bathing on psychological well-being: A systematic review and meta-analysis. International Journal of Mental Health Nursing, 32(4), 1038–1054. https://doi.org/10.1111/inm.13131

[23] Singla, R. K., Ielciu, I., Hanganu, D., & Frederich, M. (2025). Editorial: Reviews in ethnopharmacology: 2023. Frontiers in Pharmacology, 16, 1589249. https://doi.org/10.3389/fphar.2025.1589249

[24] Twohig-Bennett, C., & Jones, A. (2018). The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. Environmental Research, 166, 628–637. https://doi.org/10.1016/j.envres.2018.06.030

[25] Wang, D., Chen, Y., Li, J., Wu, E., Tang, T., Singla, R. K., et al. (2024). Natural products for the treatment of age-related macular degeneration. Phytomedicine, 130, 155522. https://doi.org/10.1016/j.phymed.2024.155522

[26] Wang, H., Chen, Y., Wang, L., Liu, Q., Yang, S., & Wang, C. (2023). Advancing herbal medicine: Enhancing product quality and safety through robust quality control practices. Frontiers in Pharmacology, 14, 1265178. https://doi.org/10.3389/fphar.2023.1265178

[27] World Economic Forum. (2023, November 23). How biodiversity loss impacts medicine and human health. World Economic Forum. https://www.weforum.org/stories/2023/11/biodiversity-nature-loss-health-medicine/

[28] World Health Organization. (2004). WHO guidelines on safety monitoring of herbal medicines in pharmacovigilance systems. World Health Organization.

[29] World Health Organization. (2011). Quality control methods for herbal materials. World Health Organization.

[30] World Health Organization. (2025a). Global traditional medicine strategy 2025–2034. World Health Organization. https://www.who.int/publications/i/item/9789240113176

[31] World Health Organization. (2025b). WHO Global Traditional Medicine Centre: Annual report 2025. World Health Organization. https://www.who.int/publications/i/item/9789240123656

[32] World Wildlife Fund. (2024). Living Planet Report 2024. WWF International.

[33] Zhang, Q., Lv, L., Wang, W., et al. (2024). Recent advances of bioactive marine natural products in drug discovery. Journal of Ocean University of China, 23, 1297–1318. https://doi.org/10.1007/s11802-024-5975-4

[34] Zheng, Y., Qin, C., Wen, M., Zhang, L., & Wang, W. (2024). The effects of food nutrients and bioactive compounds on the gut microbiota: A comprehensive review. Foods, 13(9), 1345. https://doi.org/10.3390/foods13091345