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SJIF-2023: 3.825, 2024: 5.333

TECHNICAL SCIENCE RESEARCH IN UZBEKISTAN

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TECHNICAL SCIENCE RESEARCH IN UZBEKISTAN

Research Science and Innovation House

VOLUME 4 ISSUE 10

OCTOBER 31, 2026

editor@universalpublishings.com

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ISSN (E): 2992-9148
ResearchBib Impact Factor: 9.576 / 2024
SJIF-2024: 3.825, 2024: 5.333

«TECHNICAL SCIENCE RESEARCH IN UZBEKISTAN» ilmiy-uslubiy jurnali: 31.10.2026-yil.

Ushbu to'plamda **«TECHNICAL SCIENCE RESEARCH IN UZBEKISTAN»** ilmiy-uslubiy jurnali 2026-yil 4-soni 10-qismiga qabul qilingan maqolalar nashr etilgan.

Jurnal tarkibidagi barcha maqolalarga **DOI** unikal raqami biriktirilib, **Directory of Research Journals Indexing, Researchbib, Index Copernicus, Zenodo, Open Aire, Google Scholar** xalqaro ilmiy bazalarida indekslandi.

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ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

THE TIRED BRAIN ON FIRE: THE RELATIONSHIP BETWEEN SLEEP DEPRIVATION, MIGRAINE, AND DEPRESSION IN YOUNG ADULTS

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Abstract

Sleep is often the first thing young adults sacrifice when academic demands, employment, social commitments, digital media, or irregular schedules become difficult to balance. Yet sleep is not simply a period of rest: it supports emotional regulation, pain processing, memory, and recovery. This narrative review examines the interconnected relationship between insufficient or disturbed sleep, migraine, and depressive symptoms in young adults. Available evidence suggests that the relationship is bidirectional. Poor sleep may lower the threshold for migraine attacks and is associated with greater headache burden, while migraine-related pain can further disturb sleep. Sleep disturbance is also closely linked with depression, and experimental evidence indicates that sleep loss can worsen emotional functioning. In college and university populations, poor sleep quality is common and is associated with depressive symptoms, although causality is difficult to establish from observational studies. Shared biological pathways involving hypothalamic and brainstem networks, circadian regulation, serotonin and other neuromodulatory systems, stress responses, and pain sensitivity may partly explain the overlap. The practical implication is not that every young adult with poor sleep will develop migraine or depression, but that persistent sleep problems deserve attention as part of a broader health assessment. Consistent sleep timing, adequate opportunity for sleep, management of migraine triggers, healthy daily routines, and timely professional support for persistent mood or headache symptoms may help reduce the burden.

Keywords: sleep deprivation; sleep quality; migraine; depression; depressive symptoms; young adults; insomnia; circadian rhythm; headache

1. Introduction

Young adulthood is a period of major change. Students may move away from home, begin demanding courses, work part-time or full-time, develop new relationships, and take responsibility

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

for their own routines. Sleep can become surprisingly easy to postpone. A late night followed by an early morning may seem manageable, but repeated sleep restriction can affect attention, mood, pain sensitivity, and daily functioning. A systematic review of college students found that poor sleep quality is common and that sleep quality is significantly associated with depression or depressive symptoms in this population [1].

Migraine adds another layer to the problem. People living with migraine frequently report that inadequate, fragmented, or irregular sleep can precede an attack, while the pain and associated symptoms of migraine can make normal sleep more difficult. Reviews describe this relationship as complex and bidirectional rather than a simple one-way pathway [2–4]. Depression is also more common among people with migraine than in the general population, and depressive symptoms may be associated with greater headache burden [5].

The phrase “tired brain on fire” is used here as a metaphor for the combination of sleep-related strain, heightened pain sensitivity, and emotional dysregulation. It should not be interpreted as literal brain inflammation in every person with sleep deprivation.

2. Sleep in Young Adulthood

Healthy sleep is shaped by both sleep pressure and the circadian clock. Young adults may naturally prefer later sleep and wake times, but early classes, work schedules, commuting, and social obligations can force a mismatch between biological timing and daily demands. This mismatch may result in shortened sleep or irregular sleep timing. Importantly, sleep duration is only one dimension of sleep health; quality, continuity, timing, and regularity also matter.

Sleep loss affects more than daytime tiredness. A 2024 systematic review and meta-analysis of experimental sleep-loss studies involving more than 5,700 participants found that sleep loss reduced positive affect and increased anxiety symptoms across studies, supporting the broader connection between inadequate sleep and emotional functioning [6]. This does not mean sleep deprivation alone causes clinical depression in every person, but it supports biological plausibility.

Sleep-related problem	Possible consequence	Relevance to migraine and mood
Short sleep duration	Daytime sleepiness, reduced attention, poorer emotional regulation	May reduce resilience to pain and stress.
Irregular sleep timing	Circadian disruption and inconsistent recovery	May act as a headache trigger for some people.

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Fragmented sleep	Reduced restorative sleep and fatigue	Can coexist with migraine and mood symptoms.
Insomnia symptoms	Difficulty initiating or maintaining sleep	Closely linked with emotional distress and headache burden.
Large sleep-schedule shifts	Abrupt changes in routine	May trigger symptoms in susceptible individuals.

3. Sleep Deprivation and Migraine

Migraine is a neurological disorder characterized by recurrent attacks that may include moderate or severe headache, nausea, and sensitivity to light or sound. Sleep and migraine have an unusually close relationship. Reviews report that many people with migraine identify poor or insufficient sleep as a trigger, while sleep can also help terminate an attack [2–4].

The relationship is not simply “less sleep equals more migraine.” Both insufficient and excessive sleep, abrupt changes in routine, and poor sleep quality may be relevant for susceptible individuals. A person may sleep poorly because an attack is developing, then experience a migraine because disrupted sleep lowers their threshold for the next attack. This feedback loop can make it difficult to identify which problem came first.

Several mechanisms have been proposed. Brain regions involved in sleep–wake regulation overlap with networks implicated in migraine, while signaling systems involving serotonin, dopamine, melatonin, adenosine, and orexin may influence both sleep and headache biology. These mechanisms are still being studied and should be regarded as plausible contributors rather than a complete explanation [3,4].

4. Sleep Disturbance and Depression

The connection between sleep and depression is also bidirectional. Persistent sleep disturbance can precede the onset or recurrence of depression in some people, while depression can alter sleep timing, continuity, and perceived quality. Reviews describe sleep disturbance as more than a passive symptom in some cases; it may be a contributing risk factor and an important treatment target [7].

Evidence from young people is particularly relevant because delayed sleep-wake patterns and irregular schedules are common in this age group. A 2025 systematic review and meta-analysis of young individuals with delayed sleep-wake phase disorder found that most included studies reported greater depressive symptom severity among those with the disorder, although the evidence base was limited and varied in quality [8]. These findings support attention to circadian timing but do not establish that a late sleep schedule by itself causes depression.

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It is important to distinguish depressive symptoms from a diagnosis of major depressive disorder. Feeling low, irritable, exhausted, or unmotivated after several nights of poor sleep does not automatically mean a person has depression. Persistent symptoms that interfere with school, work, relationships, or daily functioning warrant assessment by a qualified healthcare professional.

5. The Three-Way Relationship: Sleep, Migraine, and Depression

The overlap among these conditions is best understood as a network rather than three separate boxes. Poor sleep may increase pain sensitivity and emotional reactivity. Migraine can interrupt sleep through pain, nausea, or sensitivity to light and sound. Depression can alter motivation, daily structure, and sleep timing, while poor sleep can intensify emotional difficulties. Stress may influence all three at the same time.

A review of migraine, sleep, and emotional factors concluded that sleep disturbance and depression may both contribute to increased pain sensitivity and headache burden [2]. Research also suggests that depression and anxiety are important comorbidities in migraine and may be associated with more disabling headache [5].

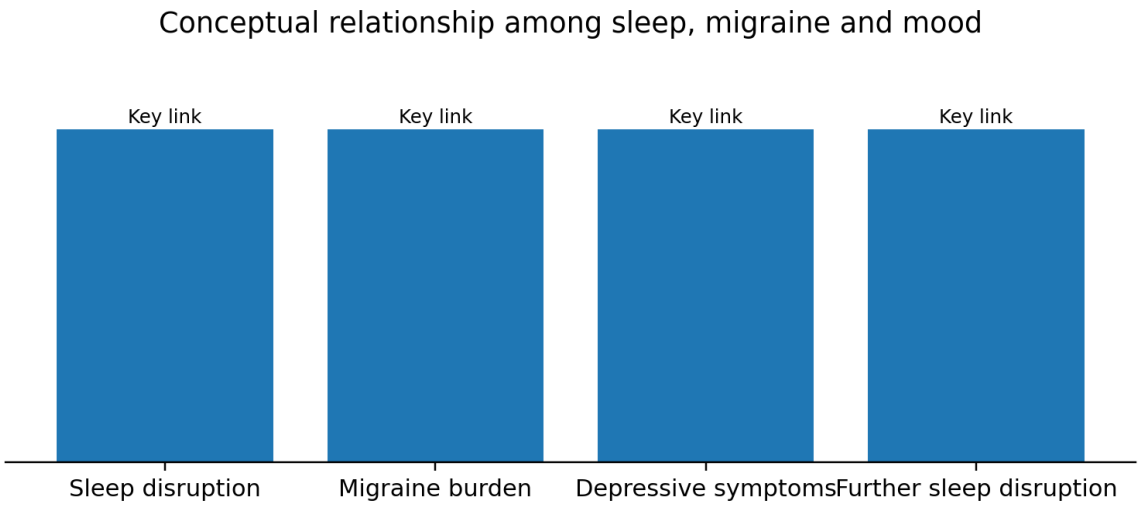


Figure 1. Conceptual model of the bidirectional relationship among sleep disruption, migraine vulnerability, and depressive symptoms. This is a qualitative illustration, not measured effect sizes and not proof of causation.

6. Possible Biological Pathways

One proposed pathway involves altered pain processing. Sleep disruption can increase sensitivity to painful stimuli in some experimental and clinical contexts. In people already vulnerable to migraine, this may reduce the threshold at which an attack is triggered. Depression may further influence pain perception through emotional and central nervous system mechanisms [2].

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A second pathway involves circadian and hypothalamic regulation. The hypothalamus participates in sleep–wake regulation and has also been implicated in migraine biology. Changes in melatonin and other circadian signals may therefore provide a bridge between irregular sleep and headache susceptibility [3,4].

A third pathway involves stress and emotional regulation. Repeated sleep restriction can make everyday stress feel harder to manage and can alter emotional responses. When combined with academic or social stress, poor sleep may contribute to a cycle of fatigue, reduced coping, and worsening symptoms.

Factor	**Migraine relationship**	**Depression relationship**	**Interpretation**
Insufficient sleep	May trigger or worsen attacks in susceptible people	Associated with poorer mood and emotional regulation	Assess pattern and persistence, not one bad night.
Poor sleep quality	Associated with greater headache burden	Strongly associated with depressive symptoms	Quality matters even when hours seem adequate.
Irregular schedule	Can be a trigger for some people	May disturb circadian regulation	Regular timing can be a useful behavioral target.
Migraine pain	Can delay or fragment sleep	Can increase emotional burden	Headache and sleep may need to be addressed together.
Depressive symptoms	Associated with greater migraine burden	May worsen sleep and motivation	Persistent symptoms need professional assessment.

7. Recognizing Warning Signs

A young adult should consider discussing symptoms with a healthcare professional when headaches become frequent or disabling, sleep problems persist despite reasonable routine changes, or low mood and loss of interest continue and interfere with daily life. Morning headaches accompanied by loud snoring, witnessed breathing pauses, or marked daytime sleepiness may also justify assessment for a sleep disorder.

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Urgent medical assessment is appropriate for a sudden, unusually severe headache, a new neurological deficit, confusion, fainting, fever with a stiff neck, or a headache following significant head injury. These features should not be attributed to sleep deprivation without evaluation.

8. Practical Approaches

For young adults, the most useful approach is usually consistency rather than perfection. A regular wake time, adequate opportunity for sleep, morning exposure to natural light, daytime activity, and a predictable wind-down routine can support healthy sleep. If sleep problems continue, cognitive behavioral therapy for insomnia (CBT-I) is an evidence-based treatment that can be considered with professional guidance.

For migraine, a simple diary can help identify patterns such as irregular sleep, missed meals, dehydration, stress, or specific triggers. The purpose is not to create an increasingly restrictive lifestyle but to notice repeatable patterns and discuss them with a clinician. Migraine treatment should be individualized, particularly when headaches are frequent.

When depressive symptoms are present, young adults should not be expected to solve the problem through sleep hygiene alone. Support from a healthcare professional, counselor, or trusted adult may be appropriate. Sleep improvement can be part of care, but persistent depression requires a broader assessment and treatment plan.

Action	Practical idea	Goal
Protect sleep opportunity	Keep a fairly consistent sleep/wake schedule and allow enough time for sleep.	Reduce repeated sleep restriction.
Stabilize mornings	Use natural light and start the day at a consistent time when possible.	Support circadian regularity.
Track symptoms	Briefly record sleep timing, migraine days, and major mood changes.	Identify patterns without excessive monitoring.
Address persistent problems	Discuss ongoing insomnia, frequent migraine, or depressive symptoms with a professional.	Identify treatable conditions.
Avoid self-blame	Recognize that sleep problems can reflect	Use practical problem-solving instead of guilt.

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	schedules, stress, illness, or environment.	

9. Discussion

The literature supports a meaningful association among sleep disturbance, migraine, and depression, but it should be interpreted carefully. Many studies are observational and cannot prove which condition causes another. People with migraine may sleep poorly because of pain, while people with depression may sleep poorly because of mood symptoms. Lifestyle factors such as stress, screen exposure, work schedules, caffeine use, physical activity, and socioeconomic circumstances can influence all three outcomes.

The strongest overall message is therefore not that sleep deprivation is a single cause of migraine or depression. Instead, sleep appears to be a modifiable part of a larger biological and behavioral system. Paying attention to sleep may help young adults and clinicians identify patterns earlier and may provide an accessible target for prevention and supportive care. Future research should prioritize longitudinal studies, objective sleep measurements, diverse young-adult populations, and interventions that examine headache and mood outcomes together.

10. Conclusion

The tired brain is not simply a metaphor for feeling sleepy. Repeated sleep disruption can influence emotional regulation, pain processing, attention, and daily functioning, while migraine and depression can in turn disrupt sleep. In young adults, the interaction may become a self-reinforcing cycle in which irregular sleep increases vulnerability to headache and emotional distress, while headache and low mood make restorative sleep harder to achieve. Current evidence supports a bidirectional relationship, but it does not justify assuming that sleep deprivation alone causes migraine or clinical depression. Consistent sleep routines, attention to migraine patterns, and early recognition of persistent mood or sleep problems are sensible components of a broader health strategy. When symptoms are severe, frequent, or persistent, professional assessment is important.

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ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

PUBLIC HEALTH AND FAMILY HISTORY OF DISEASE: A NARRATIVE REVIEW

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Abstract

Family history is one of the simplest pieces of health information available to individuals and public-health systems, yet it is often overlooked. A family can share genes, behaviours, food practices, living environments, social conditions and patterns of health-care use. As a result, diseases that appear to "run in the family" are not always caused by a single inherited mutation. Many common conditions—including cardiovascular disease, type 2 diabetes, several cancers, asthma and some mental-health conditions—reflect a mixture of genetic susceptibility and environmental or behavioural influences. This narrative review examines the role of family history in public health, explains the difference between familial risk and clearly inherited disorders, and discusses how family history can support prevention, screening, genetic counselling and early detection. It also considers practical challenges such as incomplete records, stigma, privacy, health literacy and unequal access to genetic services. A family history should not be viewed as a prediction of an individual's future; rather, it is a starting point for risk assessment and preventive action. When collected respectfully and updated over time, family health information can connect clinical care with population prevention and strengthen a more personalized approach to public health.

Keywords

Family health history; public health; familial disease; genetic risk; chronic disease; pedigree; screening; prevention; genetic counselling; precision public health

1. Introduction

Public health traditionally looks at patterns of disease across populations, while clinical medicine often focuses on the individual. Family history sits naturally between these two perspectives. A person's family may share biological susceptibility, but relatives also tend to share meals, routines, housing conditions, cultural practices, socioeconomic circumstances and exposure to environmental risks. Therefore, a pattern of illness within a family can provide useful clues even when there is no single disease-causing gene.

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The Centers for Disease Control and Prevention (CDC) notes that family health history can help clinicians develop a more complete picture of health risks and decide whether preventive measures or screening should begin earlier. Importantly, family history is useful even when it is incomplete. The presence of a condition in a close relative can indicate increased risk, but it does not mean that the condition is inevitable. Healthy behaviours and appropriate screening may reduce risk or identify disease earlier. □cite□turn0search0□turn0search2□

From a public-health perspective, this makes family history more than a form to complete at a clinic visit. It can be a low-cost source of information for identifying groups who may benefit from targeted prevention. The concept is closely related to precision public health: using available information to match prevention and early detection more closely to the needs of individuals and communities. □cite□turn0search3□

2. Understanding 'Family Tree Diseases'

The phrase “family tree diseases” is commonly used to describe conditions that occur repeatedly among relatives. Scientifically, however, the pattern can arise through several mechanisms. Some disorders are caused primarily by a pathogenic genetic variant and can follow recognizable inheritance patterns. Other conditions are complex: many genetic variants each contribute a small amount of susceptibility while lifestyle and environmental exposures also influence whether disease develops.

This distinction matters because a family history of diabetes, hypertension or heart disease should not automatically be labelled a genetic disorder. CDC describes most chronic diseases as complex conditions involving multiple genes and environmental factors. In such situations, family history is still clinically meaningful, but genetic testing may not identify one specific mutation responsible for the entire risk. □cite□turn0search5□

Table 1. Examples of disease patterns relevant to family health history

Disease/condition	Typical family-history relevance	Main public-health response	Important caution
Type 2 diabetes	Family history can increase susceptibility alongside diet, activity and other factors.	Risk assessment, healthy lifestyle support, appropriate testing.	Family history does not make disease inevitable.

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Heart disease	Shared genes and shared behaviours may both contribute.	Risk-factor control, prevention and clinically indicated screening.	Risk depends on age, other factors and family pattern.
Certain cancers	Some families show patterns suggesting increased inherited susceptibility.	Earlier or more frequent screening; genetic counselling when indicated.	A mutation or family history raises risk; it does not guarantee cancer.
Asthma	Family susceptibility interacts with environmental exposures.	Reduce relevant exposures and improve early recognition and management.	Asthma is not usually a single-gene disorder.
Rare inherited disorders	A recognizable pedigree may suggest a specific inheritance pattern.	Genetic counselling, diagnostic testing and family-based care.	Testing should be guided by qualified health professionals.

3. Why Family History Matters in Public Health

Family history can be considered a naturally occurring risk map. When several close relatives develop the same condition, particularly at unusually young ages, the pattern may prompt earlier prevention or clinical assessment. CDC recommends recording conditions, ages at diagnosis and causes of death among close relatives, and sharing the information with health-care professionals. □cite□turn0search0□turn0search2□

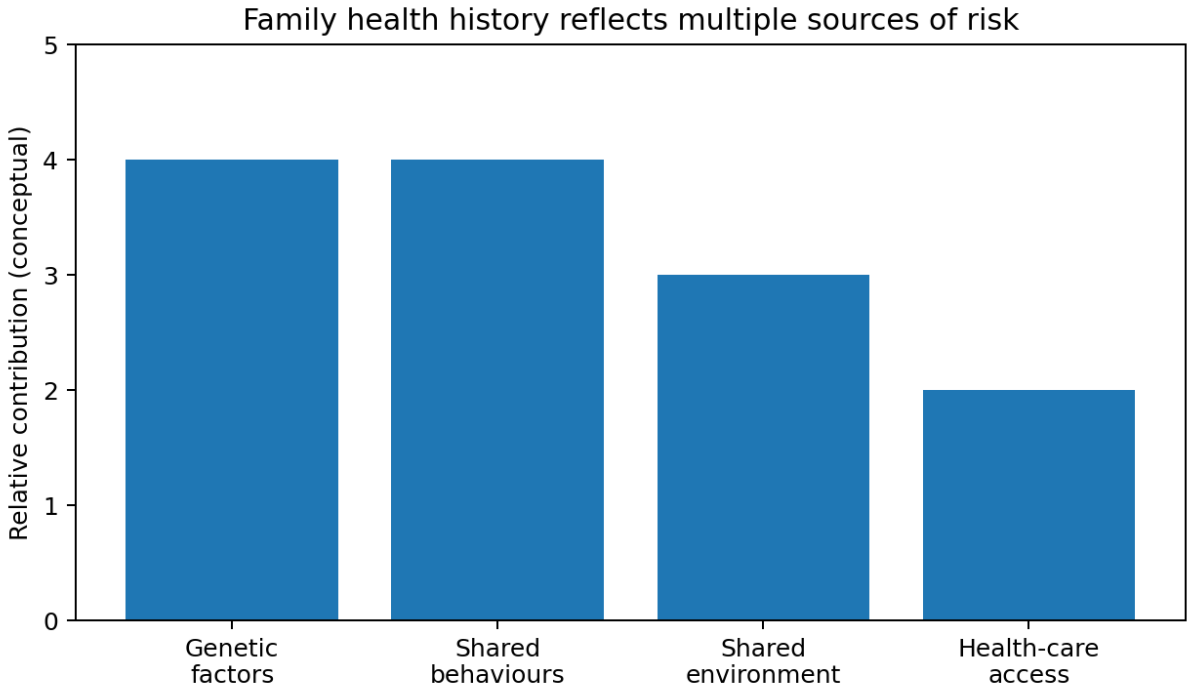
Its value is especially clear for common chronic diseases. For example, diabetes risk reflects a combination of inherited susceptibility and factors such as physical activity, diet and age. A family history can therefore encourage earlier attention to modifiable risk factors. Public-health programmes can use the same principle at a broader level: health education can encourage families to discuss their medical history, while primary-care systems can incorporate family-history questions into routine prevention.

Family history can also help identify people who may need more specialized assessment. In some cancer patterns, for example, a clinician may consider referral for genetic counselling or testing. CDC emphasizes that even a confirmed genetic variant does not automatically mean a person will develop

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

cancer; risk management may include tailored screening and other preventive choices. cite turn0search9

Figure 1. Components represented by a family health history



Conceptual figure: family history reflects overlapping genetic, behavioural, environmental and health-care factors. It is illustrative rather than a quantitative estimate.

4. From Pedigree to Prevention

A pedigree is a structured diagram showing relatives and selected health information across generations. It can make a pattern easier to recognize than a simple paragraph of family history. For public health, however, the goal is not to draw a complicated family tree for every person. The practical goal is to collect enough reliable information to identify meaningful risk patterns and connect people with appropriate prevention.

A useful family-history record usually includes parents, siblings, grandparents, aunts, uncles and other close relatives when relevant. The condition, approximate age at diagnosis and cause and age of death can be particularly informative. CDC recommends updating family history when new diagnoses occur and sharing the information with health-care professionals. cite turn0search0 turn0search2

Table 2. A practical framework for collecting family disease history

Information to collect	Why it matters	Practical approach

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Relationship to the person	Shows how close the affected relative is genetically.	Record parent, sibling, grandparent, aunt/uncle and other relevant relatives.
Disease or condition	Allows recognition of repeated patterns.	Use the known diagnosis when possible rather than a vague description.
Age at diagnosis	Early-onset disease can make some patterns more concerning.	Approximate age is still useful when exact age is unknown.
Cause and age of death	May reveal previously unrecognized disease patterns.	Ask respectfully and verify through records when available.
Both sides of the family	Risk patterns may occur through either maternal or paternal relatives.	Collect information from both sides.
Updates over time	Family health information changes as relatives age.	Review the history periodically and after major diagnoses.

5. Major Categories of Familial Disease Risk

Familial disease can be broadly considered in three overlapping categories. First are strongly inherited disorders, where a specific genetic alteration may have a major effect and a recognizable inheritance pattern can be present. Second are multifactorial conditions, where numerous genetic variants combine with behaviours and environmental exposures. Third are conditions that appear familial largely because relatives share the same social and physical environment.

The third category is especially important in public health. A family that shares a home with tobacco smoke, limited opportunities for physical activity, poor access to nutritious food or environmental pollution may experience clustering of disease even without a strong inherited component. Family history therefore should not be used to blame individuals for their health. Instead, it can help identify opportunities to improve both individual behaviour and the conditions in which families live.

6. Family History, Screening and Early Detection

One of the most practical benefits of family history is its ability to inform screening decisions. Screening is not simply a matter of doing more tests. Unnecessary testing can create anxiety, false-

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positive results and avoidable costs. The useful approach is risk-based: family history helps a clinician decide whether an individual may need a different starting age, frequency or type of screening.

For some hereditary cancer patterns, family history can trigger genetic counselling. CDC explains that counselling can help determine whether genetic testing is appropriate and how results should be interpreted. A genetic result should be understood in context rather than treated as a prediction of certain disease. □cite□turn0search9□

In children, family history can also help clinicians recognize conditions that may become apparent early in life. CDC notes that many genetic diseases first become obvious during childhood and that family information can support diagnosis and timely care. □cite□turn0search1□

7. Public-Health Strategies

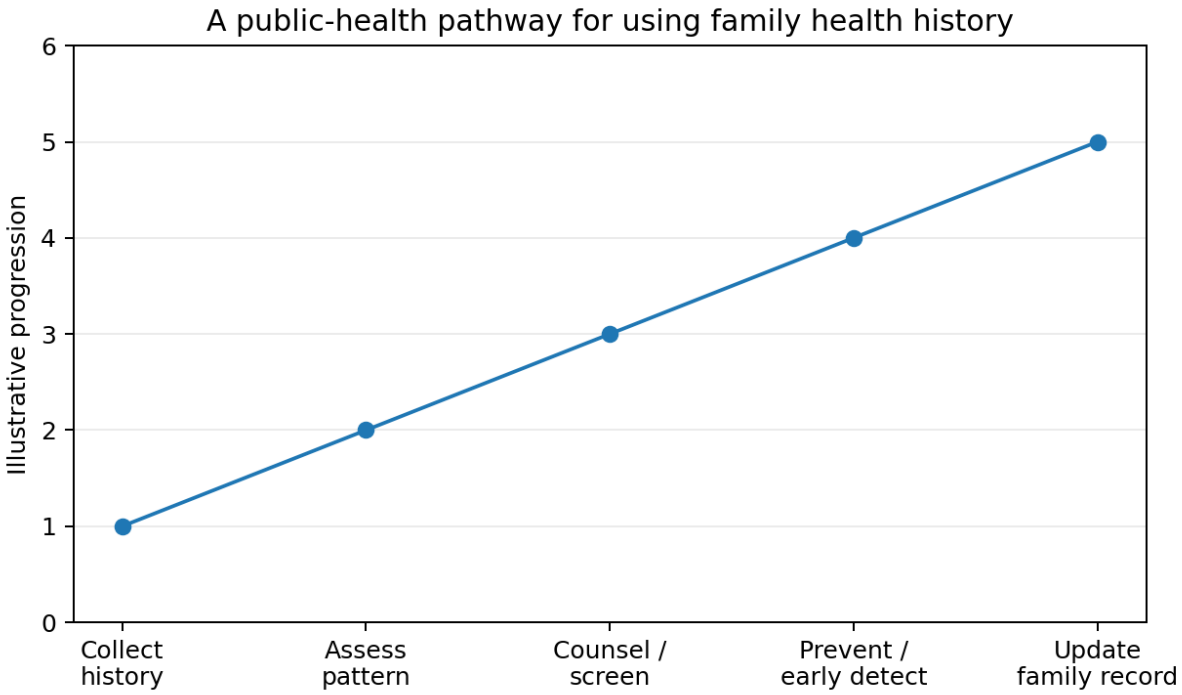
A strong family-history strategy should begin with health literacy. People need to understand that asking relatives about disease is not an attempt to label a family as “unhealthy”; it is a way of gathering information that may support prevention. Community health workers, primary-care teams and schools can encourage age-appropriate conversations about general health history and preventive care.

Primary-care services can include a short family-history assessment in routine health records. Digital tools can make updating information easier, but digital access should not become a barrier. Paper forms, verbal history-taking and community-based assistance remain important where internet access or digital literacy is limited.

Public-health systems should also protect privacy. Family medical information concerns more than one person, and genetic information can have implications for relatives. Data collection should therefore follow appropriate confidentiality, consent and governance principles. The goal is to use family history to improve health, not to stigmatize families or create discrimination.

Figure 2. A practical public-health pathway using family history

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Conceptual figure: a simple pathway from collecting family information to prevention and continued updating. The vertical scale is illustrative and does not represent measured outcomes.

8. Barriers and Ethical Considerations

Family-history collection sounds simple, but real families are rarely simple. Some people do not know the names or diagnoses of older relatives. Adoption, estrangement, migration and limited contact can make records incomplete. Some families may also avoid discussing cancer, mental health, reproductive history or causes of death because these topics are sensitive.

Another challenge is misunderstanding. A person may hear “it runs in our family” and interpret this as certainty. Health professionals should explain the difference between increased risk and inevitability. Conversely, absence of family history does not guarantee low risk because records may be incomplete and new disease can occur without a known familial pattern.

Equity is equally important. Genetic counselling and testing may be less accessible in rural or underserved settings. Public-health planning should therefore avoid creating a system where only people with high health literacy or financial resources can benefit from family-history-informed prevention.

9. Discussion

The most useful way to think about family history is as a bridge between biology and everyday life. Genes matter, but genes do not operate in isolation. Families share food, routines, stressors, housing,

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health beliefs and access to care. This explains why a family can have a noticeable pattern of diabetes or cardiovascular disease without carrying a single inherited mutation.

The public-health opportunity is therefore broader than genetic testing. Family history can be used to motivate healthy behaviours, improve screening conversations, support earlier diagnosis and identify families who may benefit from specialist assessment. CDC describes family health history as a tool that can help people and clinicians act on risk rather than simply document it. □cite□turn0search0□turn0search3□

At the same time, family history should never replace evidence-based population prevention. Vaccination, tobacco control, healthy environments, nutrition, physical activity, access to primary care and social protection remain important regardless of genetic background. A family-history approach is strongest when it adds precision to these broader public-health measures.

10. Recommendations

- Encourage individuals and families to record major diseases, ages at diagnosis and causes of death among close relatives when information is available.
- Include family-history questions in routine primary-care and preventive-health assessments.
- Use family history to guide appropriate screening rather than assuming that every family pattern requires genetic testing.
- Refer people with suggestive patterns to qualified genetic counselling or specialist services.
- Explain clearly that increased familial risk is not the same as certainty of disease.
- Protect confidentiality and use family health information only within appropriate ethical and legal frameworks.
- Improve access to risk assessment and genetic services in underserved communities.
- Update family health histories periodically because new diagnoses can change the overall risk picture.

11. Conclusion

Family history is a practical public-health resource because it captures more than genes. It reflects inherited susceptibility together with shared behaviours, environments and social circumstances. Some diseases are strongly inherited, while many common conditions arise from complex interactions among multiple factors. Recognizing this distinction prevents unnecessary fear while preserving the value of family information.

When families collect health information, discuss it openly and share relevant details with health professionals, family history can support prevention, screening and earlier detection. The most meaningful public-health approach is not to predict a person's future from a family tree, but to use

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the tree as a starting point for sensible action. In this way, family history becomes a tool for empowerment, earlier care and healthier families across generations.

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ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

COMMUNICABLE AND NONCOMMUNICABLE DISEASES: A NARRATIVE REVIEW

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Abstract

Communicable and noncommunicable diseases represent two broad, overlapping dimensions of modern public health. Communicable diseases are caused by infectious agents and can spread directly or indirectly between people, animals and the environment. Noncommunicable diseases (NCDs), in contrast, are generally long-lasting conditions influenced by genetic, physiological, behavioural and environmental factors. Although the two groups are often discussed separately, real communities experience them together. A person may live with diabetes and also face tuberculosis risk; an infectious outbreak can interrupt cancer or hypertension care; and social conditions such as poverty, overcrowding, pollution and limited access to nutritious food can influence both categories. This narrative review examines the major characteristics, determinants, prevention strategies and health-system implications of communicable and noncommunicable diseases. Current WHO estimates show that NCDs accounted for 74% of global deaths in 2023, while lower respiratory infections remained a major communicable cause of death. The review emphasizes that effective public health cannot rely on a single disease programme. Instead, it requires prevention, vaccination where appropriate, sanitation, surveillance, healthy environments, early detection, affordable treatment, community participation and strong primary health care. A balanced approach that addresses infectious threats while reducing chronic disease risk is essential for healthier and more resilient communities.

Keywords

Communicable diseases; infectious diseases; noncommunicable diseases; chronic diseases; public health; prevention; health promotion; surveillance; primary health care; risk factors; health equity

1. Introduction

Public health is often described through disease categories, but people do not experience health problems in neat categories. A family may worry about an infectious illness spreading through a household while also managing hypertension, asthma or diabetes. Communities can face poor

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

sanitation and infectious disease risks at the same time that changing food environments, inactivity and air pollution increase chronic disease.

Communicable diseases arise from infectious organisms such as bacteria, viruses, fungi and parasites. Transmission may occur through respiratory droplets or aerosols, contaminated food and water, direct contact, blood or other body fluids, vectors, or animal-to-human pathways. Examples include tuberculosis, influenza, measles, malaria, dengue and many gastrointestinal infections.

Noncommunicable diseases are generally chronic conditions that are not transmitted from person to person. WHO identifies cardiovascular diseases, cancers, chronic respiratory diseases and diabetes as the major NCD groups. In 2023, NCDs accounted for 74% of deaths globally, and eight of the ten leading causes of death were NCDs. □cite□turn0search8□turn0search3□

The distinction remains useful because the prevention tools differ, but the public-health response should not become fragmented. Both groups are strongly affected by living conditions, income, education, access to health services and the quality of the physical environment.

2. Understanding Communicable Diseases

Communicable diseases begin with an infectious agent, a susceptible host and an environment that allows transmission. Breaking any link in this chain can reduce spread. Hand hygiene, safe water, food safety, vaccination, ventilation, vector control, early diagnosis and appropriate treatment are examples of interventions that interrupt transmission or reduce its consequences.

Communicable diseases can be acute, such as many respiratory infections, or persistent, such as tuberculosis or some viral infections. Their public-health importance is not determined only by the number of cases. A disease that spreads rapidly, causes severe illness, affects vulnerable populations or develops drug resistance can place substantial pressure on families and health systems.

Recent global mortality estimates show that infectious diseases remain important despite the long-term shift toward NCDs. In 2023, lower respiratory infections caused about 2.7 million deaths and were the fourth leading cause of death worldwide. □cite□turn0search3□

3. Understanding Noncommunicable Diseases

NCDs are usually long-duration conditions resulting from a combination of genetic, physiological, environmental and behavioural factors. The major groups include cardiovascular diseases, cancers, chronic respiratory diseases and diabetes. They may develop gradually, sometimes without obvious symptoms until complications appear.

WHO reported at least 43 million NCD deaths in 2021, representing 75% of non-pandemic-related deaths. Cardiovascular diseases accounted for at least 19 million deaths, cancers for about 10 million,

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

chronic respiratory diseases for about 4 million and diabetes for more than 2 million when diabetes-related kidney disease deaths are included. □cite□turn0search0□

NCDs are sometimes described as diseases of old age, but that description is misleading. About 18 million NCD deaths occurred before age 70 in 2021, and 82% of these premature deaths occurred in low- and middle-income countries. □cite□turn0search0□

Table 1. Major differences between communicable and noncommunicable diseases

Feature	Communicable diseases	Noncommunicable diseases
Main cause	Infectious agents such as viruses, bacteria, parasites or fungi.	Complex interaction of genetic, physiological, behavioural and environmental factors.
Transmission	May spread between people, animals and environments depending on the disease.	Generally not transmitted person-to-person.
Examples	Tuberculosis, measles, influenza, malaria, dengue.	Heart disease, stroke, cancer, diabetes, chronic lung disease.
Key prevention	Vaccination, sanitation, hygiene, vector control, ventilation and infection prevention.	Healthy environments, tobacco control, physical activity, healthy diets, risk-factor reduction and screening.
Health-system priority	Surveillance, rapid diagnosis, outbreak response and appropriate treatment.	Prevention, early detection, long-term treatment and continuity of care.

4. Major Risk Factors

The causes of disease rarely exist in isolation. For communicable diseases, risk can increase with overcrowding, unsafe water, poor sanitation, inadequate ventilation, limited vaccination coverage, environmental disruption and barriers to timely diagnosis. For NCDs, WHO highlights tobacco use,

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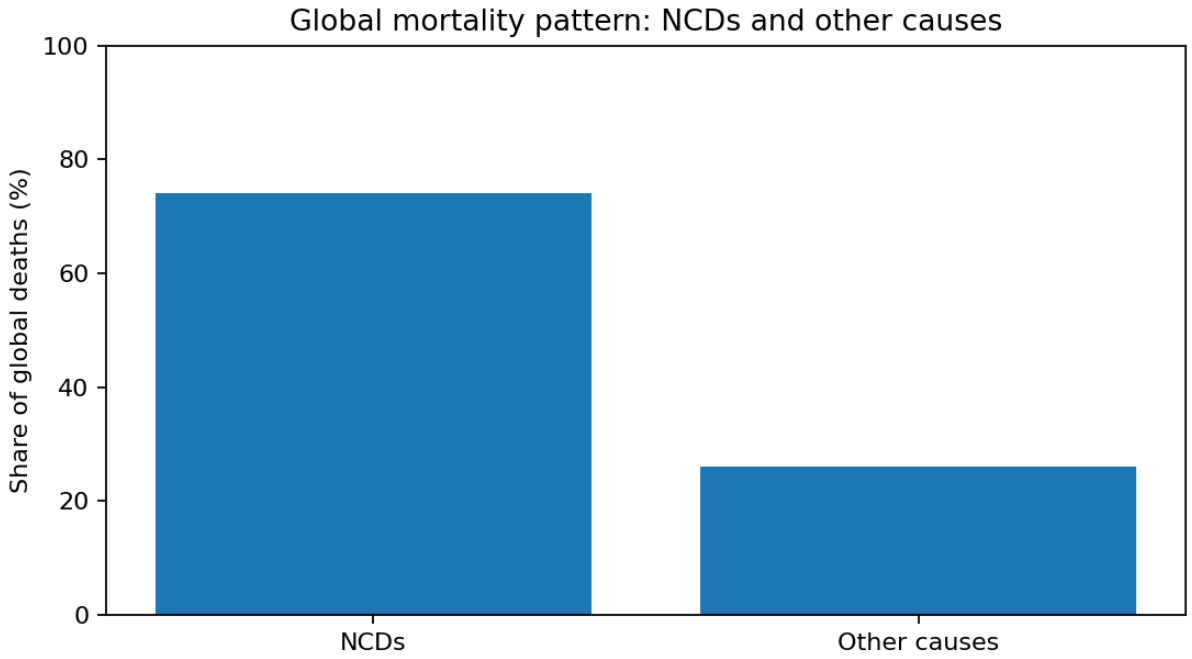
physical inactivity, harmful alcohol use, unhealthy diets and air pollution as major modifiable risk factors. These behaviours are themselves influenced by social, commercial and physical environments. cite turn0search0 turn0search7

This is where the two disease categories begin to overlap. Air pollution, for example, can worsen chronic respiratory and cardiovascular disease while also affecting vulnerability during respiratory infections. Poverty may increase exposure to infectious disease and simultaneously make long-term NCD care difficult to afford. A public-health approach therefore needs to address the conditions that shape health, not just the diseases that appear at the end of the pathway.

5. Global Burden and Changing Disease Patterns

The global disease profile has changed considerably over recent decades. Longer life expectancy, urbanization, economic development, improved vaccination and better infectious-disease control have contributed to an epidemiological transition in many populations. At the same time, ageing, sedentary lifestyles, unhealthy food environments, tobacco exposure and air pollution have increased the importance of chronic disease.

WHO's 2026 Global Health Estimates report that NCDs accounted for 74% of deaths globally in 2023, compared with 58% in 2000. Eight of the ten leading causes of death in 2023 were NCDs. However, communicable diseases have not disappeared. Lower respiratory infections remained a leading cause of death, and infectious threats can become major emergencies when new pathogens emerge or established pathogens spread rapidly. cite turn0search8 turn0search3



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Figure 1. Global mortality pattern using WHO's 2023 estimate for the share of deaths due to NCDs. The figure is descriptive rather than a comparison of individual diseases.

6. Prevention of Communicable Diseases

Prevention begins before infection occurs. Immunization is among the strongest tools for diseases for which effective vaccines exist. Safe drinking water, sanitation, hand hygiene and food safety reduce many gastrointestinal infections. Good ventilation and appropriate infection-prevention practices can reduce respiratory transmission. Vector-control measures are essential for diseases transmitted by mosquitoes and other vectors.

Surveillance is another foundation. A health system needs to know when disease patterns change. Timely reporting can identify clusters, trigger investigation and guide public-health action. Laboratory capacity adds confidence to diagnosis and helps distinguish similar illnesses.

Public education works best when it is practical and respectful. People are more likely to follow preventive advice when they understand why it matters and when recommended actions are realistic within their living conditions.

7. Prevention of Noncommunicable Diseases

Many NCDs are preventable or their complications can be reduced through a combination of individual and population-level measures. WHO emphasizes tobacco control, healthy diets, physical activity, reduction of harmful alcohol use and action on air pollution. □cite□turn0search2□

However, telling people to 'make healthier choices' is not enough. Healthy choices depend partly on whether safe spaces for physical activity exist, whether nutritious food is affordable and available, whether tobacco and alcohol marketing is regulated, and whether people can access preventive care. Public policy can therefore shape health outcomes just as strongly as individual behaviour.

Early detection is also important. Blood pressure measurement, diabetes assessment, appropriate cancer screening and evaluation of persistent respiratory symptoms can identify problems before severe complications develop. Once disease is diagnosed, continuous treatment and follow-up are needed.

Table 2. Practical public-health strategies

Level	Communicable disease actions	NCD actions
Individual/family	Vaccination where indicated, hand hygiene, safe food/water practices,	Avoid tobacco exposure, regular activity, balanced diet, healthy sleep and

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

	appropriate respiratory precautions.	appropriate preventive checks.
Community	Health education, sanitation, vector control, outbreak preparedness and accessible testing.	Healthy schools and workplaces, safe public spaces, healthy food environments and community screening.
Health system	Surveillance, laboratory services, vaccination programmes, infection prevention and rapid response.	Primary-care screening, affordable medicines, continuity of care and rehabilitation.
Policy level	Preparedness plans, vaccination policy, sanitation infrastructure and cross-border coordination.	Tobacco and alcohol regulation, air-quality policies, food policy and universal health coverage.

8. The Role of Primary Health Care

Primary health care is the natural meeting point between communicable and noncommunicable disease prevention. The same clinic can provide childhood vaccination, blood-pressure measurement, health education, maternal care, infection assessment and chronic disease follow-up. Integrating services reduces the need for families to navigate separate systems for every health concern.

For NCDs, WHO emphasizes that detection, screening and treatment can be delivered through a primary-health-care approach. Early and affordable management can reduce complications and the need for more expensive care later. □cite□turn0search4□

For communicable diseases, primary care provides the first opportunity to recognize unusual symptoms, initiate appropriate treatment, provide vaccination and refer patients when necessary. Strong primary care therefore acts as both a shield and an early-warning system.

9. Health Inequality and Social Determinants

Disease burden is strongly shaped by social conditions. People living in poverty may face overcrowded housing, unsafe water, environmental pollution and limited access to nutritious food.

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The same person may also have difficulty paying for long-term medicines or travelling to a health facility.

WHO reports that 73% of NCD deaths occurred in low- and middle-income countries in 2021, and 82% of premature NCD deaths occurred in these settings. cite turn0search0 These figures show why NCD prevention cannot be separated from economic and social policy.

Communicable disease control also depends on equity. Vaccination, diagnostic services and preventive information have to reach people in remote communities, displaced populations and other groups who may be poorly served by routine systems. Public health succeeds when services reach the people who need them most, not only those who can reach services easily.

10. Interaction Between Communicable and Noncommunicable Diseases

The relationship between the two groups is increasingly important. Infectious disease can worsen outcomes in people with chronic conditions, while NCDs can increase vulnerability to severe outcomes from some infections. Health emergencies can also interrupt routine care, leaving people without medicines, screening or follow-up.

There are also shared environmental drivers. Air pollution contributes to chronic respiratory and cardiovascular disease and can make respiratory health more difficult. Poor housing and sanitation increase infectious disease risk while reflecting the same structural inequalities that influence chronic disease.

The practical lesson is that health systems should avoid treating communicable and noncommunicable diseases as competing priorities. Both require investment in prevention, surveillance, primary care, health workers, reliable data and community trust.

11. Health Promotion and Community Participation

Humanized public health begins with listening. Communities have local knowledge about disease patterns, barriers to care and acceptable solutions. Health messages are more effective when they respect language, culture, literacy and lived experience.

For communicable disease prevention, community participation can improve vaccination uptake, hygiene practices, early reporting and outbreak response. For NCDs, communities can support physical activity, healthy eating, tobacco-free environments and adherence to long-term treatment.

The goal is not to make every person responsible for every health problem. Instead, responsibility should be shared among individuals, families, schools, workplaces, communities, health professionals, governments and the private sector.

12. Surveillance and Health Information

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Good decisions depend on good information. Communicable disease surveillance focuses on identifying cases, clusters and changes in transmission. NCD surveillance monitors mortality, risk factors, disease prevalence, treatment coverage and health-system performance.

Digital records and population-level data can improve continuity of care, but data must be collected ethically and used responsibly. Simple indicators can be powerful when they are timely and linked to action. A health department that knows where vaccination coverage is low or hypertension treatment is failing can direct resources more effectively.

13. Integrated Prevention and Care

A practical public-health model is a continuum rather than a collection of separate programmes. Primary prevention aims to stop disease before it begins. Early detection identifies problems when treatment can be more effective. Treatment and long-term control reduce complications, while rehabilitation and palliative care help people live as well as possible with serious illness.

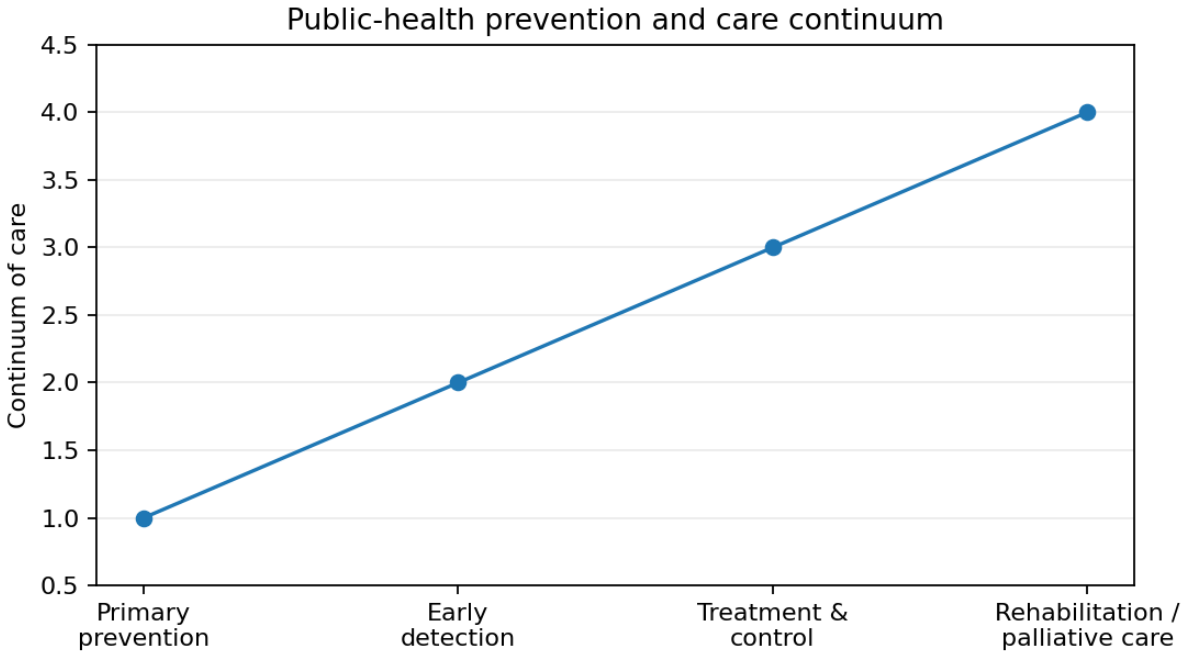


Figure 2. Conceptual prevention-and-care continuum applicable across communicable and noncommunicable diseases.

14. Challenges for Public Health

- Unequal access to preventive and curative health services.
- Limited health workforce and health-system capacity.
- Urbanization, pollution and changing food environments.
- Antimicrobial resistance and emerging infectious threats.

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- Low awareness of chronic disease risk and symptoms.
- Interrupted care during epidemics, disasters or conflict.
- Financial barriers to medicines, diagnostics and follow-up.
- Health misinformation and declining trust in institutions.
- Fragmented programmes that separate infectious and chronic disease services.

15. Recommendations

- Strengthen primary health care as the shared foundation for communicable and noncommunicable disease services.
- Maintain vaccination, sanitation, infection prevention and disease surveillance systems.
- Expand early detection and affordable treatment for hypertension, diabetes, cancers and chronic respiratory disease.
- Address tobacco exposure, unhealthy diets, physical inactivity, harmful alcohol use and air pollution through both policy and community action.
- Use local data to identify underserved populations and direct resources toward them.
- Protect essential health services during outbreaks and other emergencies.
- Train health workers to communicate clearly, respectfully and without stigma.
- Integrate health education and prevention into schools, workplaces and community settings.
- Measure health equity, not only overall national averages.

16. Discussion

The traditional separation between communicable and noncommunicable diseases is useful for classification but less useful when designing real-world health services. Both categories are shaped by social determinants, environmental conditions, health-system strength and access to care. The global shift toward NCDs does not mean infectious diseases can be ignored. Likewise, the continued presence of infections should not delay investment in chronic disease prevention.

The strongest response is therefore integrated. Vaccination, sanitation and outbreak preparedness should continue alongside tobacco control, healthy environments, screening and chronic disease management. Primary care can bring these functions together in a way that is more convenient for families and more efficient for health systems.

A humanized approach also recognizes that health behaviour occurs within circumstances. Prevention messages should be accompanied by practical opportunities to act. If healthy food is unaffordable, a simple nutrition lecture is unlikely to change outcomes. If a vaccination clinic is inaccessible, telling families to vaccinate does not solve the underlying problem. Public health must combine information with supportive systems.

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17. Conclusion

Communicable and noncommunicable diseases remain major and interconnected public-health challenges. Infectious diseases can spread rapidly and require surveillance, prevention and timely response, while NCDs often develop over years and require sustained risk reduction, early detection and continuing care. The current global pattern shows a large and growing NCD burden, but infectious diseases continue to cause substantial illness and death and can generate sudden health emergencies.

The most effective response is not to choose one disease group over the other. Public health should build strong primary care, equitable access, reliable surveillance, health-promoting environments and community trust. Vaccination, sanitation and infection prevention must sit alongside tobacco control, healthy diets, physical activity, pollution reduction and affordable chronic disease care.

Ultimately, healthier communities are created when prevention becomes part of everyday systems rather than an occasional campaign. By addressing both communicable and noncommunicable diseases together, health systems can protect people from immediate infectious threats while also reducing the long-term burden of chronic illness.

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ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

EVALUATION OF A NATIONAL HEALTH PROGRAMME AT THE PRIMARY CARE LEVEL

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Abstract

National health programmes are often judged by whether planned activities were completed, yet effective evaluation at the primary care level requires a broader view. Primary care is where many national policies become real services: vaccination, maternal and child health, screening, infectious disease control, chronic disease management, health education and referral. This narrative review explains how a national health programme can be evaluated at this level using a practical framework that connects resources and implementation processes with service coverage, quality, equity, continuity and health outcomes. The review emphasizes the value of mixed methods because routine statistics can show what happened, while interviews, observation and community feedback help explain why it happened. Key evaluation dimensions include relevance, effectiveness, efficiency, quality, accessibility, equity, sustainability and resilience. WHO and UNICEF's primary health care measurement framework provides a useful basis for selecting context-appropriate indicators across inputs, processes, outputs, outcomes and impact. A good evaluation should not simply produce a score; it should help frontline teams identify gaps, learn from local strengths and make practical changes. The article concludes that programme evaluation is most useful when it is continuous, participatory and linked to decision-making rather than treated as an end-of-project exercise.

Keywords

Primary health care; national health programme; programme evaluation; monitoring; health indicators; quality of care; equity; health systems; universal health coverage; community participation

1. Introduction

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

National health programmes are designed to translate public-health priorities into organized action. They may focus on immunization, tuberculosis control, maternal health, nutrition, noncommunicable diseases, school health, mental health or other priorities. However, the success of a national programme is rarely determined at the national headquarters alone. It is experienced at health centres, outreach sessions, community clinics and referral points where people meet the health system.

Primary care therefore provides a particularly important level for evaluation. It shows whether a programme is reaching the intended population, whether services are available and acceptable, whether providers have the resources to deliver them, and whether people actually benefit. WHO and UNICEF describe primary health care as a broad approach combining integrated health services, multisectoral action and empowered people and communities, with quality, equity and resilience considered across the measurement framework. [1,2]

Evaluation is different from routine monitoring. Monitoring asks whether activities and indicators are moving as expected. Evaluation asks the deeper questions: Was the programme relevant? Did it work? For whom did it work? What helped or hindered implementation? Was it efficient and sustainable? A strong primary-care evaluation brings these questions together and turns findings into decisions.

2. What Does Programme Evaluation Mean at Primary Care Level?

Programme evaluation is a systematic process of judging the value, implementation and results of an intervention. At primary care level, the unit of analysis may be a clinic, health centre, catchment population, district or network of facilities. The evaluator can examine both programme performance and the local context in which performance occurs.

A useful evaluation follows a results chain: resources are provided, activities are implemented, services are produced, people use those services, and health outcomes change. Importantly, the chain is not automatic. Staffing shortages, medicine stock-outs, transport barriers, workload, social norms, financing and community trust can interrupt the pathway. Evaluation should therefore examine both results and the mechanisms behind them.

Table 1. Core dimensions for evaluating a national programme at primary care level

Dimension	Main question	Examples of evidence
Relevance	Does the programme address important local needs?	Burden of disease, community priorities, policy objectives

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Effectiveness	Is the programme achieving intended results?	Coverage, treatment success, disease control, outcome trends
Efficiency	Are resources being used well?	Cost per service, staff time, wastage, productivity
Quality	Are services safe, appropriate and people-centred?	Clinical standards, waiting time, continuity, patient experience
Equity	Who is reached and who is left behind?	Disaggregated coverage by sex, age, income, geography or vulnerability
Sustainability	Can benefits continue over time?	Financing, workforce, local ownership, supply systems
Resilience	Can services continue during shocks?	Service continuity during outbreaks, disasters or supply disruption

3. Building an Evaluation Framework

WHO's primary health care measurement framework recommends selecting a manageable set of indicators that fit national and local priorities rather than attempting to measure everything. The framework spans the results chain and places quality, equity and resilience across the system. [1,2]

For a national programme, the evaluation plan should begin by defining the programme theory: what the programme is trying to change, how activities are expected to produce change, and which assumptions must hold true. Once this is clear, indicators can be selected for inputs, processes, outputs, outcomes and impact.

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Figure 1. A practical evaluation pathway for a national health programme

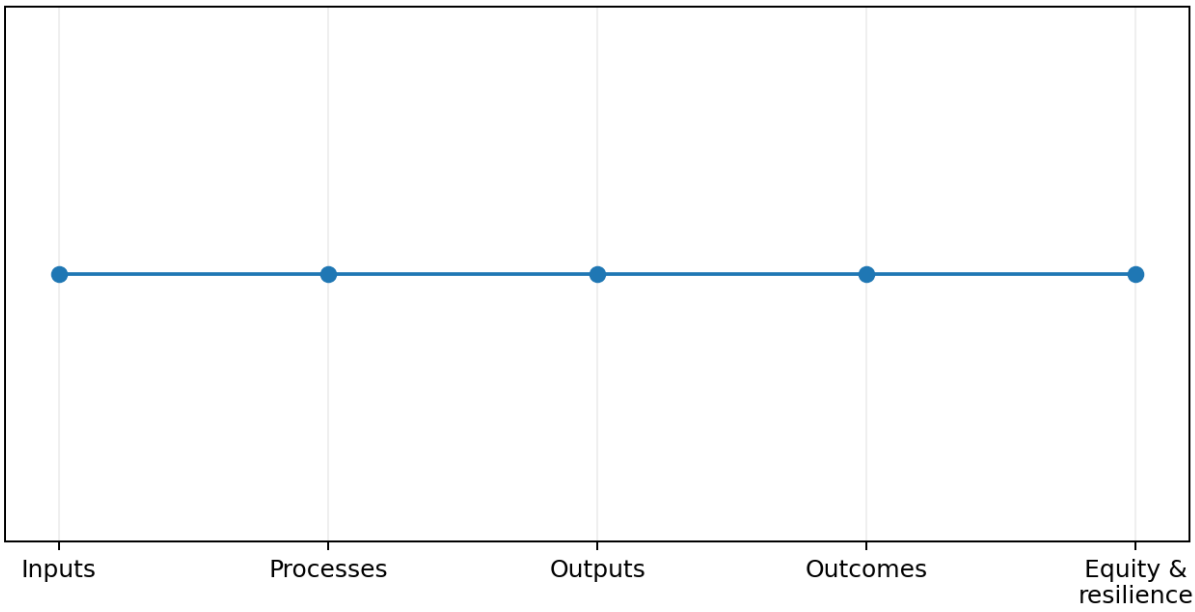


Figure 1. A practical evaluation pathway. The sequence is conceptual and can be adapted to the programme being assessed.

4. Indicators Used in Primary Care Evaluation

Indicators are useful because they convert broad programme objectives into measurable signals. A balanced dashboard should include more than service counts. For example, the number of consultations may rise while quality falls because staff are overburdened. Similarly, high average coverage can hide poor access among remote communities. Indicators should therefore be interpreted together and, whenever possible, disaggregated to reveal differences between population groups.

Table 2. Example indicator set for a national primary-care programme

Level	Indicator example	Why it matters
Input	Percentage of facilities with required staff	Shows readiness to deliver the programme
Input	Availability of essential medicines/supplies	Identifies supply constraints
Process	Proportion of staff receiving programme training	Assesses implementation capacity
Output	Service coverage among target population	Shows whether services are reaching people

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Quality	Adherence to clinical or programme standards	Shows whether services are delivered appropriately
Equity	Coverage gap between highest- and lowest-served groups	Makes inequalities visible
Outcome	Control or improvement in the target health condition	Shows whether services are making a difference
Experience	Patient-reported satisfaction or respectful care	Captures the user's perspective

Figure 2. Example dashboard for programme review (illustrative data)

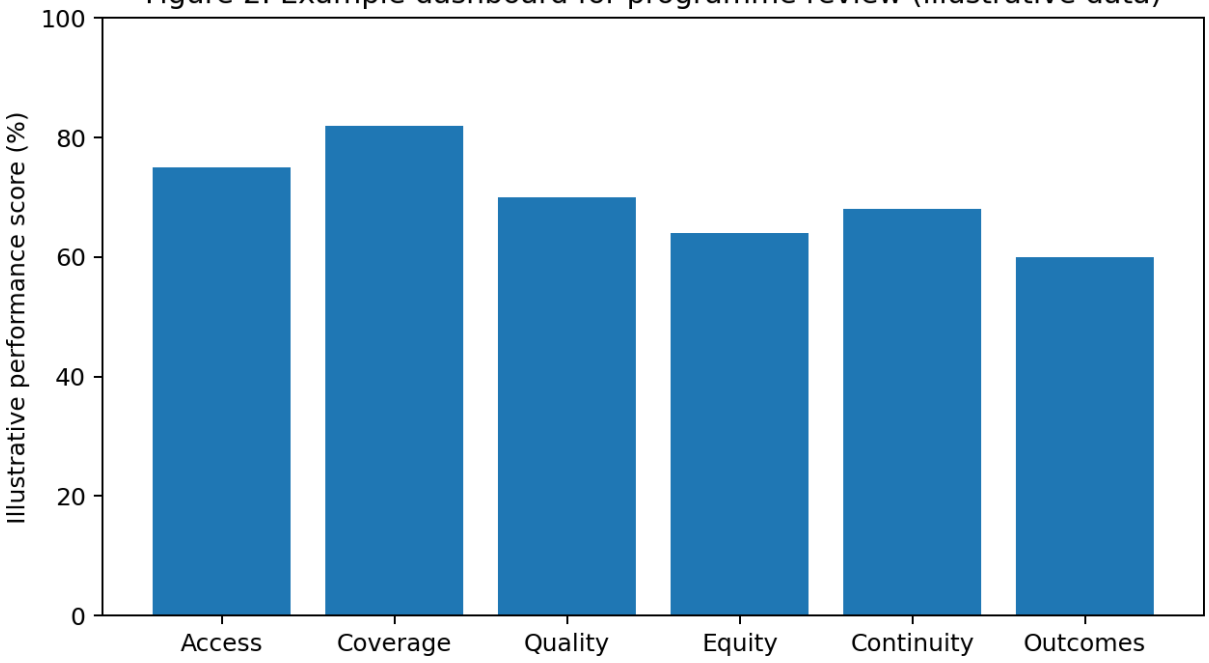


Figure 2. Example primary-care programme dashboard using illustrative—not measured—performance values.

5. Data Sources and Methods

A practical evaluation uses multiple data sources. Routine health information systems can provide monthly or quarterly service data. Facility assessments can examine staffing, equipment, medicines, infection-prevention practices and readiness. Patient records may provide information on continuity and clinical outcomes. Household or community surveys can identify people who never reached the

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

facility. Qualitative interviews and focus groups can explain barriers that numbers alone cannot reveal.

WHO's technical specifications for the PHC measurement framework emphasize clear indicator definitions, numerator and denominator rules, possible disaggregation and appropriate data sources. [2] This is important because an indicator is only useful when different facilities interpret and calculate it consistently.

A mixed-methods design is often particularly valuable. Quantitative data can answer 'how much' and 'how often', while qualitative information can answer 'why' and 'how'. For example, a low vaccination rate may reflect hesitancy, but it may also reflect clinic hours, transport difficulties, missed outreach sessions or vaccine supply problems. Evaluation should distinguish among these explanations before recommending a solution.

6. Evaluating Access, Coverage and Continuity

Access is the starting point for most primary-care programmes. Evaluation should consider geographic distance, opening hours, affordability, availability of services, cultural acceptability and whether people know how to obtain care. Coverage should be examined not only as a national average but also across districts and population groups.

Continuity is equally important. A programme may achieve high initial contact but lose people during follow-up. Chronic disease care is a clear example: diagnosis, treatment initiation, medicine availability, follow-up and referral must work as a connected pathway. Evaluators should therefore track drop-off between stages of care rather than focusing only on the first service contact.

7. Evaluating Quality of Care

Quality at primary care level has several dimensions. Services should be clinically appropriate, safe, timely, people-centred and coordinated. Quality evaluation can combine record review, direct observation, clinical audits, waiting-time measurement, medicine availability and patient experience.

An important lesson is that quality should not be reduced to provider performance alone. A health worker cannot consistently deliver a high-quality service if essential medicines are unavailable, staffing is inadequate or referral systems do not function. Evaluation should therefore look at the system conditions surrounding frontline practice.

8. Equity and Community Participation

National programmes can appear successful while leaving certain groups behind. Equity-focused evaluation asks who benefits, who does not, and why. Useful disaggregations may include age, sex, residence, socioeconomic position, disability or other locally relevant characteristics, provided that data collection is ethical and protects privacy.

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Community participation strengthens interpretation. People can identify practical barriers that are invisible in facility statistics, such as inconvenient clinic schedules, communication problems, stigma or concerns about respectful treatment. WHO's PHC approach explicitly recognizes empowered people and communities as one of its three major components. [1]

9. Efficiency, Financing and Sustainability

Evaluation should also consider whether programme resources are being converted into useful services. Efficiency does not simply mean spending less. It means achieving appropriate results with available resources while maintaining quality and equity. Measures can include cost per beneficiary, staff time, stock wastage, duplication between programmes and avoidable referral costs.

Sustainability asks whether the programme can continue after temporary funding, external technical assistance or special campaigns end. Programmes embedded in routine primary care, supported by stable financing, trained local staff, reliable information systems and community ownership are more likely to last.

10. Common Challenges in Programme Evaluation

Evaluation at primary care level faces several practical problems. Data may be incomplete or delayed, indicators may be interpreted differently, and frontline workers may experience reporting fatigue. Another challenge is attribution: health outcomes are influenced by many factors, so a change cannot automatically be credited to one programme.

Political and organizational pressures can also influence evaluation. A programme may be viewed as successful because it met administrative targets even when population-level benefit remains uncertain. Independent methods, transparent definitions and triangulation of multiple sources help reduce this risk.

11. From Evaluation Findings to Action

An evaluation becomes valuable when findings lead to improvement. Results should be discussed with programme managers and frontline teams, not simply sent upward as a report. Each major gap should ideally be linked to an action, responsible person or team, timeline and follow-up indicator.

For example, if evaluation finds repeated medicine stock-outs, the response may involve forecasting, procurement, inventory management and redistribution rather than simply instructing health workers to improve performance. Similarly, if coverage is low in remote areas, outreach schedules, transport and community partnerships may be more relevant than additional classroom training.

12. Discussion

Primary-care evaluation is most useful when it combines a health-system perspective with the everyday reality of service delivery. The WHO framework provides a structured way to connect

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

system capacity and service delivery with health outcomes while keeping quality, equity and resilience visible. [1,2]

The 2024 WHO primer on implementing PHC emphasizes that strengthening primary care requires attention to governance, financing, human resources, medicines, infrastructure and digital health, alongside service delivery. [3] This supports an important evaluation principle: programme performance should be interpreted in the context of the system that is expected to deliver it.

Recent evaluation work on WHO's Special Programme on Primary Health Care also illustrates the value of examining relevance, coherence, effectiveness, efficiency, added value, sustainability and equity rather than relying on a single outcome measure. [4] At national and district levels, the same logic can help decision-makers move from reporting activity to learning about implementation.

13. Recommendations

- Define a small, balanced set of indicators before implementation and align them with programme objectives.
- Combine routine quantitative data with facility observation, record review and community or patient feedback.
- Disaggregate important indicators to identify geographic and social inequalities.
- Use standard indicator definitions and strengthen data-quality checks at facility and district levels.
- Review results regularly with frontline teams and use findings to make practical corrective actions.
- Evaluate quality, equity, resilience and user experience alongside service coverage.
- Build evaluation into routine programme management instead of treating it as a one-time event.
- Protect confidentiality and use data ethically, especially when collecting information about vulnerable groups.

14. Conclusion

Evaluating a national health programme at the primary care level is not simply an exercise in counting services. It is a way of understanding whether national intentions are being translated into accessible, equitable, high-quality care for real communities. A strong evaluation examines resources, implementation, coverage, quality, outcomes, user experience and the distribution of benefits. It also asks why results differ between places and groups.

The most useful evaluation is practical and continuous. When data are reliable, indicators are balanced, communities are heard and findings are linked to decisions, evaluation becomes a tool for learning rather than judgement alone. In this way, primary-care evaluation can help national

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

programmes become more responsive, sustainable and capable of moving health systems closer to universal health coverage.

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ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

ANTIBIOTIC RESISTANCE AS AN EMERGING ENVIRONMENTAL HEALTH PROBLEM

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Abstract

Antibiotic resistance is usually discussed as a clinical problem, but resistant bacteria and resistance genes also move through water, soil, food systems, wastewater, healthcare waste and industrial pollution. This environmental dimension is increasingly recognized as an important part of the One Health response to antimicrobial resistance (AMR). Antibiotic residues and resistant microorganisms can enter the environment through human excreta, animal production, pharmaceutical manufacturing, agricultural runoff and inadequately treated waste. Environmental settings can then provide opportunities for resistant organisms and resistance genes to persist, mix and spread. The United Nations Environment Programme describes pollution as an important driver and pathway of AMR, while the World Health Organization has emphasized the need to control antibiotic manufacturing waste and strengthen surveillance. This narrative review examines the relationship between antibiotic resistance and environmental health, focusing on wastewater, pharmaceutical pollution, agriculture, animal production, solid waste and environmental transmission. It also discusses surveillance, stewardship, sanitation and the One Health approach. The review argues that protecting antibiotics cannot be achieved by clinical prescribing policies alone. Environmental management must become part of routine AMR prevention, with stronger monitoring, safer waste systems, responsible antimicrobial use and cooperation among health, environmental, agricultural and industrial sectors.

Keywords: antibiotic resistance; antimicrobial resistance; environmental health; One Health; wastewater; pharmaceutical pollution; antibiotic residues; resistant bacteria; antimicrobial stewardship; environmental surveillance.

1. Introduction

Antibiotics transformed modern medicine. They made bacterial infections treatable, reduced complications from surgery and helped make cancer therapy, transplantation and other complex care

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

safer. Their effectiveness, however, is not permanent. Bacteria can acquire or select resistance mechanisms that reduce the ability of antibiotics to control them. The result is antimicrobial resistance, one of the major threats to public health recognized internationally.

The environmental side of this problem is sometimes less visible. A resistant bacterium does not remain inside a hospital or a farm simply because that is where it first emerged. Bacteria, resistance genes and antibiotic residues can enter wastewater, rivers, soil and other environmental compartments. The 2023 UNEP assessment concluded that the environment plays a key role in the development, transmission and spread of AMR and emphasized that pollution prevention is part of the solution. □cite□turn0search4□turn0search10□

This perspective changes the question from 'How do we treat resistant infections?' to a broader public-health question: 'How do we reduce the environmental conditions that allow resistance to develop and circulate?' This narrative review explores that question and considers why environmental health should be treated as a central part of antibiotic-resistance prevention.

2. Why Antibiotic Resistance Is an Environmental Health Issue

Environmental health is concerned with how physical, chemical and biological conditions influence human wellbeing. Antibiotic resistance fits naturally within this field because environmental contamination can affect both the survival of resistant organisms and human exposure to them. Wastewater treatment plants, healthcare facilities, pharmaceutical manufacturing areas, livestock settings, agricultural soils and contaminated water bodies can all become points where antibiotic residues, bacteria and resistance genes meet.

The environmental dimension does not mean that every resistant infection comes directly from a river or soil. Human-to-human transmission remains critically important. Instead, the environment should be viewed as one interconnected part of a larger system. The One Health approach recognizes that human, animal, plant and ecosystem health are linked, making AMR too complex for any single sector to manage alone. □cite□turn0search0□turn0search6□

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Figure 1. Environmental pathways that connect antibiotic use with resistance

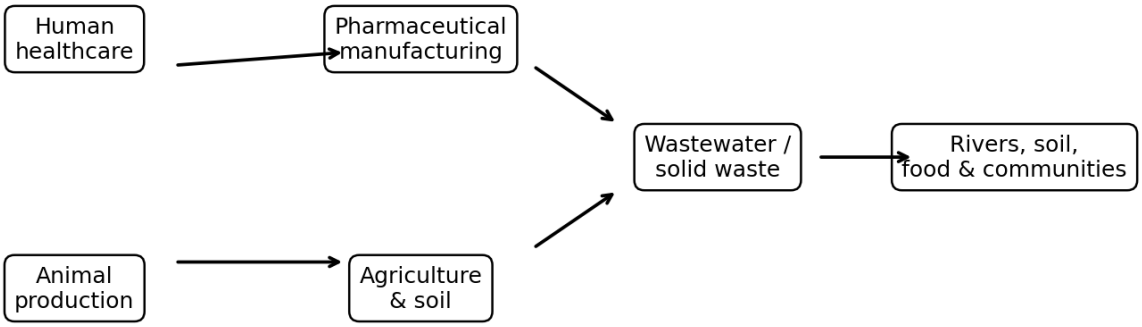


Figure 1. Conceptual pathways linking antibiotic use, waste and environmental dissemination of resistance. This is a synthesis diagram, not a quantitative transmission model.

3. The Scale of the Problem

The clinical consequences of antibiotic resistance provide the reason environmental prevention matters. A landmark global analysis estimated that bacterial AMR was directly attributable to about 1.27 million deaths in 2019 and was associated with approximately 4.95 million deaths. These estimates demonstrate that resistance is not a theoretical future problem; it already contributes substantially to mortality. □cite□turn0search18□

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Figure 2. Global burden context for bacterial antimicrobial resistance

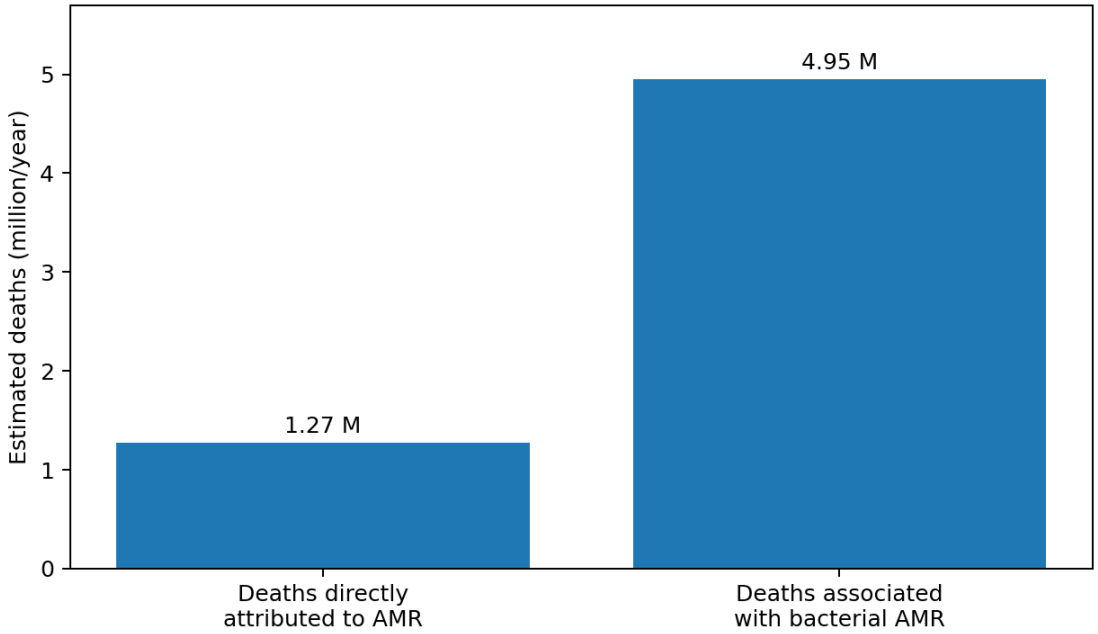


Figure 2. Global burden context based on the 2019 global bacterial AMR analysis. The values are published estimates and are shown for context rather than as annual current surveillance figures.

More recent WHO surveillance confirms the continuing scale of resistance. The 2025 Global antibiotic resistance surveillance report analyzed more than 23 million bacteriologically confirmed cases reported by countries and tracks resistance trends across multiple pathogen–antibiotic combinations. The report reinforces the importance of surveillance, while also showing that global data remain uneven across settings. □cite□turn0search1□

4. Wastewater: A Meeting Place for Antibiotics and Resistance

Wastewater is one of the clearest connections between human activity and environmental AMR. After antibiotics are used, a proportion of many medicines or their metabolites can leave the body and enter sewage. Wastewater can also contain bacteria from humans, hospitals and other sources. If treatment is incomplete, antibiotic residues, resistant organisms and resistance genes may reach receiving waters.

The concern is not simply that a river becomes contaminated. Wastewater contains a mixture of biological and chemical materials, and microbial communities in these settings can create opportunities for resistance genes to move between bacteria. The environmental risk therefore depends on concentration, persistence, microbial ecology, wastewater treatment and local conditions.

WHO has specifically issued guidance on wastewater and solid-waste management for antibiotic manufacturing, noting that high levels of antibiotics downstream of manufacturing sites have been

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

documented and that pollution from manufacturing can contribute to resistance. □cite□turn0search16□

5. Pharmaceutical Manufacturing and Antibiotic Pollution

Antibiotic production can create environmental risks when manufacturing wastewater is not adequately controlled. This issue is especially important because very high concentrations of active antibiotic compounds may occur near production sites. Such concentrations can create strong selective pressure in environmental microbial communities, potentially favouring resistant organisms.

The problem is partly regulatory. Environmental standards for pharmaceutical manufacturing have not historically been as comprehensive as the standards used for product quality or worker safety. WHO's 2024 guidance therefore calls for better wastewater and solid-waste management, risk-based controls, auditing and transparency across the antibiotic manufacturing chain. □cite□turn0search16□

This is an important reminder that antibiotic stewardship is not limited to doctors and patients. Manufacturers, regulators, procurement systems and waste-management services also influence whether antibiotic pollution enters the environment.

6. Agriculture, Livestock and Food Systems

Antibiotics are also used in animal health and, in some settings, agriculture. Manure and animal waste can contain antibiotic residues and resistant bacteria. When waste is applied to land, resistance-related material may enter soil and potentially move through runoff into surface water. Food systems can therefore connect antibiotic use in animals with environmental exposure and, under some circumstances, human exposure.

The goal is not to treat all agricultural antimicrobial use as inappropriate. Antibiotics remain important medicines for animals as they are for people. The public-health challenge is ensuring that treatment is justified, appropriately targeted and accompanied by good infection prevention, animal husbandry, vaccination and waste management. UNEP emphasizes responsible antimicrobial use in agriculture and stronger environmental controls as part of a One Health response. □cite□turn0search6□

7. Healthcare Waste and Community Sources

Hospitals generate wastewater and solid waste containing microorganisms, pharmaceutical residues and other biological materials. Healthcare facilities therefore require effective infection prevention, pharmaceutical-waste management and wastewater control. At the community level, unnecessary antibiotic use, inappropriate disposal of medicines and poorly managed sanitation can also contribute to environmental loading.

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These pathways illustrate why public awareness and infrastructure matter. A person may think of antibiotic resistance as something that happens inside a patient after repeated antibiotic exposure, but resistance is also shaped by what happens to antibiotics and bacteria after they leave the body. Safe sanitation and waste management are therefore part of antimicrobial stewardship.

8. Environmental Factors and Their Potential Role

Environmental source	What may enter the environment	Potential AMR concern	Priority response
Municipal wastewater	Antibiotic residues, bacteria, resistance genes	Environmental mixing and downstream exposure	Improve sanitation and wastewater treatment; monitor hotspots.
Hospitals	Resistant organisms, pharmaceuticals, clinical waste	Release of clinically important organisms and residues	Strengthen infection control and healthcare waste management.
Pharmaceutical manufacturing	High concentrations of active antibiotics	Strong selective pressure near discharge points	Set discharge controls, auditing and transparent monitoring.
Livestock and manure	Antibiotic residues, resistant bacteria, genes	Soil and water contamination	Responsible veterinary use and safer manure management.
Agricultural runoff	Microorganisms, residues and genes	Transport to surface waters	Reduce contamination at source and manage runoff.
Solid waste / medicine disposal	Unused medicines and contaminated material	Persistent residues and microbial exposure	Safe collection and disposal systems.

9. How Resistance Can Persist and Spread in the Environment

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Resistance can arise through natural bacterial evolution and selection, but environmental contamination can increase the opportunity for resistant organisms and resistance genes to persist and interact. Antibiotic residues can exert selective pressure, while dense microbial communities create opportunities for genetic exchange. Mobile genetic elements such as plasmids can carry resistance genes between bacteria, although the importance of individual pathways varies by organism and environment.

Environmental conditions are also dynamic. Rainfall can move contaminants from land to water, wastewater discharge can alter microbial communities, and sediments may act as reservoirs where bacteria and resistance genes persist. Climate-related changes in temperature, flooding and water availability may further alter exposure pathways. UNEP therefore describes environmental AMR as a multifaceted problem involving pollution, climate change, biodiversity and ecosystem health. □cite□turn0search6□

10. One Health: Bringing the Pieces Together

The strongest response to environmental AMR is not a separate 'environmental programme' operating alongside healthcare. It is an integrated One Health strategy. Doctors, pharmacists, veterinarians, farmers, microbiologists, environmental scientists, engineers, wastewater professionals, regulators and communities all influence different parts of the resistance cycle.

WHO's GLASS system provides a standardized framework for AMR surveillance and increasingly supports broader surveillance approaches, including antimicrobial use and the potential incorporation of food-chain and environmental information. As of December 2024, 141 countries, territories and areas had committed to contribute data to GLASS on AMR and/or antimicrobial use. □cite□turn0search13□

Environmental surveillance can add information that clinical surveillance cannot provide on its own. Monitoring wastewater and environmental sites may help identify resistance trends, pollution sources and emerging threats earlier, particularly when surveillance is linked to laboratory capacity and public-health decision-making.

11. Prevention and Control Priorities

Priority	Why it matters	Examples of action
Reduce unnecessary antibiotic use	Less antibiotic pressure means fewer opportunities for selection and pollution	Antimicrobial stewardship; appropriate prescribing; veterinary stewardship.

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Control pharmaceutical pollution	High environmental antibiotic concentrations can favour resistance	Manufacturing discharge standards, monitoring and auditing.
Improve wastewater and sanitation	Reduces release and movement of bacteria, genes and residues	Treatment upgrades, sanitation coverage, hotspot surveillance.
Strengthen healthcare waste management	Limits release of resistant organisms and medicines	Segregation, safe disposal, infection prevention.
Improve agricultural practices	Reduces contamination from animal waste and runoff	Vaccination, hygiene, responsible treatment and manure management.
Build integrated surveillance	Connects clinical, use and environmental information	One Health data platforms and laboratory networks.
Support public awareness	People influence antibiotic demand and disposal	Education on appropriate use and safe medicine disposal.

12. Challenges and Research Gaps

Several gaps make environmental AMR difficult to manage. First, the presence of a resistance gene in an environmental sample does not automatically mean that it will cause human disease. Risk depends on the organism, gene, mobility, concentration, exposure route and ability to reach susceptible people. Second, methods for environmental AMR surveillance are not yet as standardized globally as clinical surveillance. Third, low-resource settings may face simultaneous challenges in sanitation, laboratory capacity, regulation and access to antibiotics.

Research should therefore move toward harmonized environmental monitoring, better risk assessment and studies that connect environmental measurements with human and animal outcomes. More evidence is also needed to determine which wastewater interventions provide the greatest AMR benefit and how environmental controls can be implemented without compromising equitable access to essential antibiotics.

13. A Humanized Public-Health Perspective

Antibiotic resistance can feel like a problem belonging to laboratories and hospitals, but the environmental perspective makes it much more relatable. The medicines used in clinics, the

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

antibiotics used to protect animal health, the wastewater leaving a community and the water flowing downstream are parts of the same system. What happens in one place can influence another.

A humanized response does not mean placing blame on individual patients, farmers or healthcare workers. Antibiotic use is shaped by access to healthcare, diagnostic uncertainty, prescribing practices, animal-health needs, pharmaceutical supply chains and environmental infrastructure. Effective prevention therefore requires supportive systems that make the responsible choice easier.

The goal is not to create fear around antibiotics. It is to protect their value. Antibiotics remain essential medicines, and the environmental health approach asks society to preserve them while reducing the pollution and transmission pathways that make resistance more likely.

14. Conclusion

Antibiotic resistance is an emerging environmental health problem as well as a clinical one. Resistant bacteria, resistance genes and antibiotic residues can move through wastewater, healthcare waste, pharmaceutical manufacturing, livestock systems, agricultural soils and surface waters. These pathways connect human, animal and ecosystem health and demonstrate why a One Health response is necessary.

The environmental component of AMR should be addressed through prevention at the source, responsible antimicrobial use, stronger sanitation and wastewater management, control of pharmaceutical pollution, safer agricultural practices and integrated surveillance. WHO and UNEP both emphasize that environmental action is an important part of protecting the effectiveness of antibiotics. □cite□turn0search10□turn0search16□

Ultimately, the fight against antibiotic resistance is not only about developing new medicines. It is also about managing the environments in which bacteria live, move and exchange genetic information. Protecting water, soil and ecosystems is therefore also a way of protecting future patients.

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ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

HOSPITAL AND HEALTHCARE-ASSOCIATED INFECTIONS: IMPORTANCE OF HYGIENE

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Abstract

Hospital and healthcare-associated infections (HAIs) remain one of the most persistent challenges to safe patient care. Patients enter hospitals to receive treatment, yet exposure to microorganisms can sometimes lead to infections that were not present or incubating when care began. These infections increase suffering, prolong hospital stays, raise costs, complicate treatment, and can contribute to antimicrobial resistance. Although modern hospitals use sophisticated diagnostic and therapeutic technologies, basic hygiene remains one of the most dependable foundations of infection prevention. Hand hygiene, environmental cleaning, safe use of personal protective equipment, appropriate reprocessing of reusable equipment, respiratory hygiene, safe injection practices, linen and waste management, and reliable water, sanitation and hygiene services work together rather than in isolation. This narrative review discusses how hygiene interrupts transmission, why healthcare workers and patients share responsibility, and how hospitals can turn hygiene from a routine task into a visible culture of safety. Current guidance from the World Health Organization (WHO) and Centers for Disease Control and Prevention (CDC) emphasizes that infection prevention and control (IPC) is an essential part of quality healthcare and that many HAIs are preventable when evidence-based measures are consistently implemented.

Keywords: healthcare-associated infections; hospital-acquired infections; hygiene; hand hygiene; infection prevention and control; environmental cleaning; personal protective equipment; patient safety; antimicrobial resistance; WASH.

1. Introduction

Healthcare is built around trust. A patient expects that a hospital will make them safer, not expose them to another illness. HAIs challenge that expectation because healthcare environments contain many conditions that can favor transmission: vulnerable patients, invasive procedures, frequent contact between people, shared equipment, high patient turnover, and microorganisms that may be resistant to several antibiotics. WHO describes IPC as a practical, evidence-based approach that protects patients and health workers from avoidable infections and notes that it is relevant to every

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

healthcare interaction. HAIs are not limited to major outbreaks; they can occur during ordinary care in hospitals, clinics, dialysis units, long-term care facilities and other settings.

The importance of hygiene is therefore broader than simply keeping a ward visibly clean. Hygiene is a coordinated set of behaviors and systems designed to break the chain by which microorganisms move from a source to a susceptible person. Good hygiene does not mean that every microorganism must be eliminated. Instead, it reduces unnecessary microbial exposure at the moments when transmission is most likely. This distinction is important because effective infection prevention depends on consistent, risk-based practices rather than appearance alone.

2. Burden and Significance of HAIs

HAIs are among the most common adverse events associated with healthcare delivery. WHO's 2024 global IPC report reports that, on average, about 7 of every 100 patients in acute-care hospitals in high-income countries and 15 of every 100 patients in low- and middle-income countries acquire at least one HAI during a hospital stay. These figures illustrate an important equity issue: infection prevention is needed everywhere, but resource constraints can make reliable IPC and WASH services more difficult to maintain. HAIs can result in additional treatment, longer admission, loss of productivity, emotional stress for families, and increased pressure on already busy health systems.

The clinical burden also intersects with antimicrobial resistance. An infection that is preventable may become more difficult to manage when the causative organism is resistant to commonly used medicines. Consequently, hygiene is not merely a housekeeping concern. It is part of antimicrobial stewardship and patient safety because preventing an infection avoids the need for some antibiotic exposure in the first place.

3. How Hygiene Breaks the Chain of Transmission

Microorganisms can move through direct contact, contaminated hands, shared equipment, environmental surfaces, respiratory particles, contaminated food or water, and unsafe procedures. In a busy ward, one missed opportunity for hand hygiene can be followed by many contacts. Likewise, a poorly cleaned high-touch surface can become a link between patients and staff. CDC guidance emphasizes that hand hygiene and environmental cleaning are complementary: contaminated surfaces can contribute to transmission, while hands and gloves can carry organisms from the environment to patients and back again.

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Figure 2. Simplified chain of transmission and points for hygiene intervention

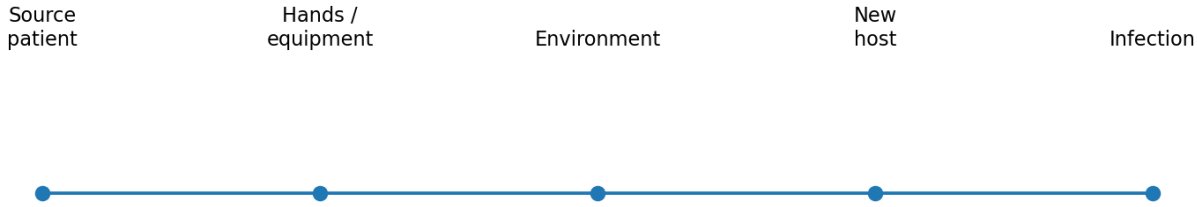


Figure 2. Simplified chain of transmission and hygiene points that can interrupt spread. Conceptual illustration based on IPC principles; not a measured epidemiological model.

4. Hand Hygiene: The First Line of Defense

Among all routine hygiene behaviors, hand hygiene is especially visible because hands connect people, equipment and surfaces. Healthcare workers may touch a patient, adjust a device, handle a bedside object and then approach another patient within a short period. Without appropriate hand hygiene, microorganisms can travel along that sequence. CDC identifies hand hygiene as a core component of Standard Precautions and recommends cleaning hands at key clinical moments, including before patient contact, before aseptic tasks, after contact with the patient or the patient's environment, after exposure to body fluids, and after glove removal.

Alcohol-based hand rub is generally preferred when hands are not visibly soiled because it is convenient and supports rapid access to hand hygiene. Soap and water remain important when hands are visibly dirty and in situations specified by local infection-control guidance. Importantly, gloves do not replace hand hygiene. Gloves can become contaminated, and their removal can transfer organisms if hands are not cleaned afterward.

Improving hand hygiene is not simply a matter of telling staff to wash their hands more often. Hospitals need accessible sinks or hand-rub dispensers, adequate supplies, training, reminders, observation, feedback and supportive leadership. A respectful culture also matters: staff should be able to remind one another about hand hygiene without embarrassment or blame.

5. Environmental Cleaning and Disinfection

A clean-looking room is not necessarily a microbiologically safe room. High-touch surfaces such as bed rails, bedside tables, call buttons, door handles and frequently handled equipment may receive repeated contact. CDC guidance describes environmental cleaning as a fundamental IPC intervention

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and recommends structured programs with trained personnel, appropriate supplies, standardized procedures, monitoring and feedback.

Cleaning removes dirt and organic material and can reduce microbial contamination; disinfection is used when indicated by the risk and the surface or equipment involved. The process should follow the product manufacturer's instructions, including correct dilution and contact time. High-touch areas and rooms used by vulnerable patients generally require greater attention than low-touch surfaces.

Environmental services staff should be recognized as members of the infection-prevention team. Their work is often less visible than clinical procedures, but it directly supports safe care. Clear schedules, adequate staffing, training, checklists and feedback can make cleaning more reliable and reduce variation between shifts.

Figure 1. Illustrative hygiene-related prevention priorities

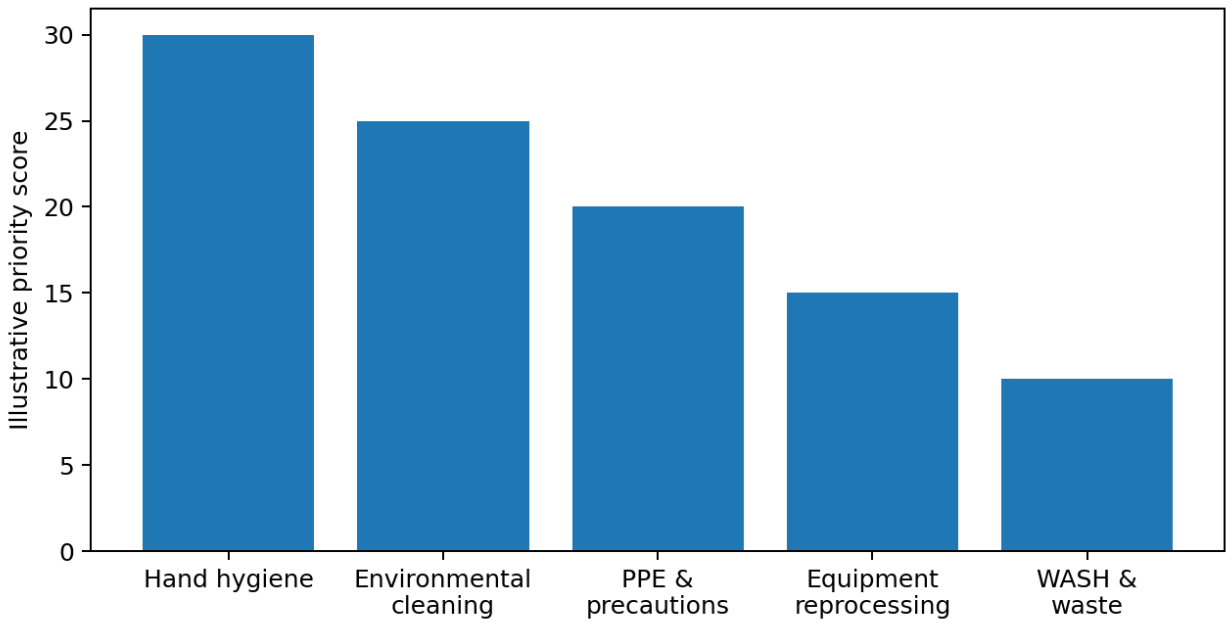


Figure 1. Illustrative hierarchy of hygiene-related prevention priorities. Values are a conceptual scoring device for presentation, not measured estimates of HAI reduction.

6. Other Essential Hygiene Measures

Measure	Why it matters	Practical focus
Personal protective equipment (PPE)	Reduces exposure to blood, body fluids and infectious material when indicated.	Choose correctly, put on/remove safely, and avoid unnecessary reuse.

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Reusable equipment	Shared devices can carry organisms between patients.	Clean, disinfect or sterilize according to the item's risk and manufacturer guidance.
Respiratory hygiene	Coughing and respiratory secretions can spread infection.	Provide tissues/masks when appropriate, encourage covering coughs, and separate symptomatic patients when indicated.
Safe injections	Unsafe injection practices can transmit bloodborne pathogens.	Use aseptic technique and single-use items as required.
Linen and waste	Improper handling can spread contamination to people and surfaces.	Segregate, transport and process materials using facility procedures.
Water, sanitation and hygiene (WASH)	Reliable water and sanitation enable hand hygiene, cleaning and safe care.	Maintain infrastructure, supplies, drainage and waste systems.

7. Hygiene as a Team Responsibility

Infection prevention cannot be assigned to one department. Nurses, physicians, cleaners, laboratory personnel, technicians, students, patients, caregivers, administrators and visitors all influence the infection risk of a healthcare environment. The most successful programs therefore make hygiene part of everyday work rather than a special activity performed only during outbreaks.

Leadership is particularly important. If supplies are frequently unavailable, staffing is inadequate, or staff are punished for reporting problems, compliance is unlikely to improve sustainably. By contrast, visible leadership, realistic workloads, reliable supplies, training and feedback can turn hygiene expectations into habits. Patients can also participate by asking whether hands have been cleaned before a procedure or contact, provided that such conversations are encouraged respectfully and do not place responsibility for infection prevention on patients.

8. Common Barriers to Effective Hygiene

Several barriers repeatedly weaken IPC. These include overcrowding, high workload, staff shortages, lack of sinks or hand-rub dispensers, shortages of gloves or cleaning supplies, inadequate training,

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inconsistent supervision, unclear responsibilities and weak feedback systems. In some settings, infection prevention may be viewed as an additional task rather than a core part of clinical care. Another challenge is that compliance can fall when staff are tired or when workflow is poorly designed.

These problems should be approached as system problems rather than simply blaming individuals. If a dispenser is empty, the correct response is not only to remind workers to clean their hands; the hospital must also examine supply chains, placement, maintenance and accountability. A human-centered approach asks what makes the safe action easy, visible and realistic during a busy shift.

9. Monitoring, Feedback and Quality Improvement

Measurement helps hospitals understand whether their IPC systems work in practice. Useful indicators can include availability of hand hygiene products, observed hand hygiene opportunities, environmental cleaning performance, healthcare-associated infection rates, device-associated infection measures, and completion of staff training. However, measurement should lead to improvement rather than punishment.

Feedback is most useful when it is timely, specific and constructive. A ward that receives information showing where hand hygiene opportunities are being missed can test small changes, such as moving dispensers closer to the point of care, improving signage or changing workflow. Repeated measurement then shows whether the change made a difference. This quality-improvement cycle is more sustainable than one-time campaigns.

10. Practical Hygiene Checklist for Healthcare Facilities

Area	Minimum expectation	Monitoring idea	Common failure point
Hand hygiene	Products available at points of care; staff follow clinical indications.	Routine observation and supply checks.	Empty dispensers or poor placement.
Environmental cleaning	Written schedules and risk-based cleaning of high-touch areas.	Checklist/audit with feedback.	Incomplete cleaning during busy periods.
Equipment	Reusable equipment reprocessed	Spot checks and documentation.	Unclear responsibility.

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	between patients as required.		
PPE	Correct PPE available and used when indicated.	Training and observation.	Incorrect selection or removal.
WASH	Safe water, sanitation and waste systems functioning.	Facility rounds and maintenance logs.	Infrastructure interruptions.
Education	Regular orientation and refresher IPC training.	Training completion and competency checks.	Training treated as a one-time activity.

11. Discussion

The central lesson is that hygiene works best as a system. Hand hygiene alone cannot compensate for contaminated equipment, inadequate cleaning, unsafe injections or unreliable water. Conversely, excellent environmental cleaning cannot fully protect patients if hands repeatedly transfer microorganisms between care activities. WHO's global IPC strategy places IPC at the center of patient safety, health emergency preparedness and efforts to address antimicrobial resistance. This integrated view reflects the reality of modern healthcare: prevention measures overlap and reinforce one another.

Another important lesson is that the human side of hygiene matters. People are more likely to follow practices that are convenient, understood and supported by their workplace. Staff need time, supplies, training and psychological safety to speak up about risks. Patients and families need clear information without being frightened. Cleaners need recognition and training. Managers need reliable data rather than assumptions. When these pieces align, hygiene becomes part of the identity of the organization.

12. Conclusion

Hospital and healthcare-associated infections remain a major patient-safety concern, but they are not an unavoidable price of modern healthcare. A substantial proportion of infection risk can be reduced through consistent infection prevention and control practices supported by good hygiene and WASH services. Hand hygiene is central, yet it is only one component of a broader safety system that includes environmental cleaning, appropriate PPE, safe equipment reprocessing, respiratory hygiene, injection safety, linen and waste management, and strong organizational leadership.

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The most practical way forward is to make the safe behavior the easy behavior: provide supplies where care occurs, train staff repeatedly, monitor performance, give constructive feedback, maintain the environment, and treat every member of the healthcare team as part of infection prevention. Ultimately, hygiene is not simply about cleanliness. It is about protecting people at their most vulnerable and making every healthcare interaction safer.

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ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

VACCINE-PREVENTABLE DISEASE ELIMINATION

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Abstract

Vaccine-preventable diseases have changed the history of public health. Diseases that once caused repeated childhood deaths, disability and fear can now be controlled, eliminated, and in the case of smallpox, eradicated through vaccination combined with strong surveillance and public-health systems. Yet elimination is not automatic. It depends on consistently high immunization coverage, equitable access, reliable disease surveillance, rapid outbreak response, public trust, strong supply chains and the ability of health systems to reach children who are missed by routine services. This narrative review examines the meaning of control, elimination and eradication; the role of routine immunization; lessons from polio, measles and rubella; barriers such as missed vaccinations, conflict, geographic access and vaccine confidence; and practical strategies for sustaining progress. Current WHO and UNICEF estimates show that global childhood vaccination has improved but remains below the level needed to achieve several elimination goals. In 2025, global DTP3 coverage was 85%, while approximately 13.5 million children received no routine vaccine dose. Measles-containing vaccine coverage also remained below the approximately 95% level generally needed to prevent sustained transmission. The review emphasizes that elimination is not simply a vaccine-delivery target: it is a long-term social and health-system achievement requiring every community to be reached and every outbreak to be detected quickly.

Keywords: vaccine-preventable diseases; immunization; disease elimination; eradication; measles; polio; rubella; vaccination coverage; surveillance; vaccine confidence; public health; primary healthcare.

1. Introduction

Vaccination is one of the clearest examples of prevention working before illness begins. Instead of waiting for a child to become seriously sick, immunization prepares the immune system in advance. Over decades, vaccination has reduced illness, disability and death from many infectious diseases

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

and has become a foundation of primary healthcare. WHO reports that immunization prevents millions of deaths every year and is central to global health security and outbreak prevention.

The phrase vaccine-preventable disease elimination can sound simple, but elimination is a demanding public-health goal. It means reducing transmission of a disease to zero in a defined geographic area through deliberate efforts, while continued measures may still be required to prevent re-establishment. Eradication is a still higher standard: permanent reduction of worldwide transmission to zero, after which routine interventions may no longer be needed. Smallpox remains the classic example of eradication. Polio is the major current eradication effort, while measles and rubella are prominent elimination goals.

The central lesson is that vaccines are necessary but not sufficient on their own. A country may have an effective vaccine but still experience outbreaks if children miss doses, communities are difficult to reach, surveillance is weak, or confidence in vaccination falls. Elimination therefore requires a complete system: vaccines, trained workers, cold-chain capacity, community engagement, laboratories, data, political commitment and rapid response.

2. Understanding Control, Elimination and Eradication

Term	Meaning	Example
Control	Reducing disease incidence or impact to an acceptable level through ongoing measures.	Long-term reduction of many vaccine-preventable infections through routine immunization.
Elimination	Reducing transmission or disease occurrence to zero in a defined geographic area, with continued measures needed to prevent reintroduction.	Measles or rubella elimination goals in specific regions.
Eradication	Permanent worldwide reduction of disease transmission to zero, making routine control measures unnecessary.	Smallpox eradication; global polio eradication remains an ongoing goal.

3. Why High Vaccination Coverage Matters

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Population immunity is the bridge between individual vaccination and community protection. When a large proportion of people are immune, an infectious agent has fewer opportunities to move from one person to another. The exact coverage needed depends on how contagious the disease is and how well the vaccine protects against infection and transmission. Measles is particularly demanding because it spreads extremely efficiently; WHO's Immunization Agenda 2030 notes that around 95% coverage with two timely doses of measles-containing vaccine is needed to prevent sustained spread.

Current global figures show why elimination remains unfinished. WHO and UNICEF estimated that in 2025 about 90% of infants received at least one DTP-containing vaccine dose and 85% received the third dose. Approximately 13.5 million children were zero-dose children. UNICEF also reports that first-dose measles-containing vaccine coverage reached 86%, leaving millions of children without this protection. These are global averages, and averages can hide much lower coverage in particular communities or districts.

Figure 1. Selected global routine immunization coverage, 2025

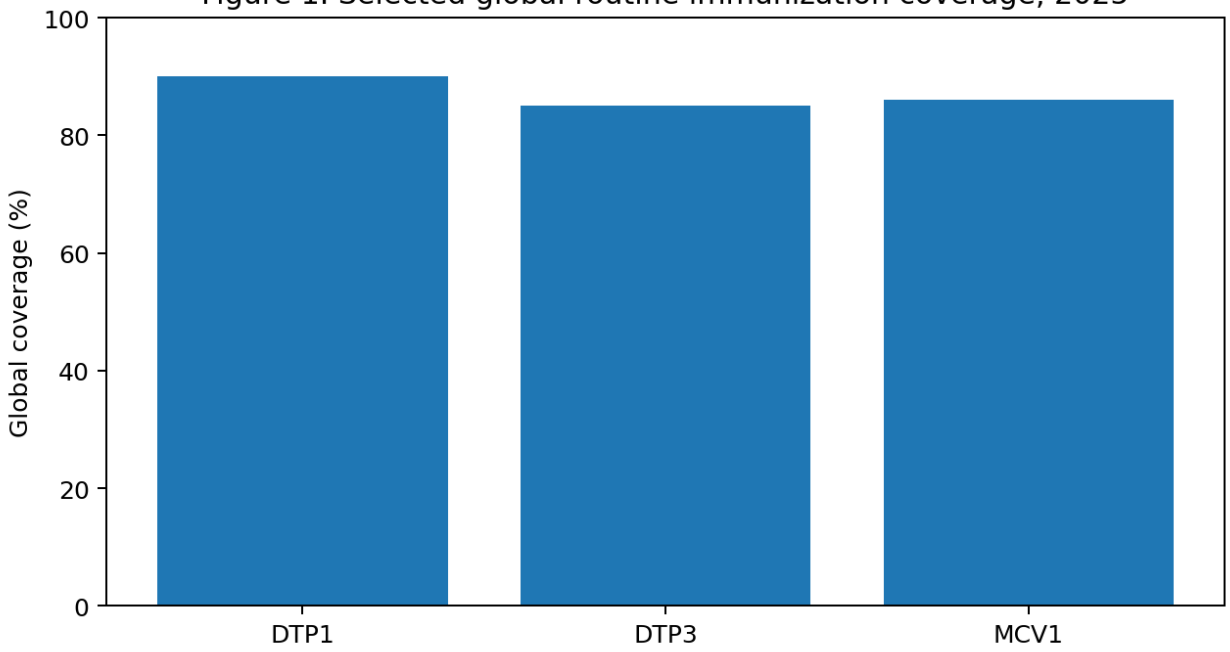


Figure 1. Selected global routine immunization coverage in 2025. Values are WHO/UNICEF estimates: DTP1 90%, DTP3 85%, and MCV1 86%.

4. The Role of Routine Immunization Systems

Elimination programs are strongest when they are built on reliable routine immunization rather than depending only on occasional campaigns. Routine services create repeated opportunities to vaccinate children at the recommended ages and to identify families who have missed appointments. They also

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connect vaccination with other primary-healthcare services such as growth monitoring, nutrition support and health education.

A strong routine program requires more than vaccines arriving at a national warehouse. Doses must remain potent through the cold chain, health workers need appropriate training, vaccination sessions need to be convenient, records must be accurate, and communities need confidence that services are safe and respectful. WHO's Essential Programme on Immunization now supports vaccination across the life course, reflecting the fact that immunization is not only a childhood issue.

Equity is especially important. Children who are easiest to reach may already be well protected, while zero-dose and under-vaccinated children are often concentrated in remote, poor, displaced, conflict-affected or otherwise underserved communities. Elimination strategies must therefore ask not only 'What is the national coverage?' but also 'Who is still missing?'

5. Measles and Rubella: Lessons for Elimination

Measles is a useful indicator of the strength of an immunization system because its high transmissibility rapidly exposes immunity gaps. When coverage falls, outbreaks can occur even after years of progress. Rubella presents a different but equally important concern because infection during pregnancy can cause congenital rubella syndrome and severe birth defects. Preventing rubella transmission is therefore connected not only to childhood vaccination but also to protecting future pregnancies.

WHO reports that by January 2025, 179 of 194 countries had introduced rubella-containing vaccine, while global coverage was estimated at 73%. Although reported rubella cases have fallen dramatically since 2000, progress is uneven. For measles, regional elimination has also stalled in several settings. These experiences show that elimination cannot be declared and then forgotten. High coverage has to be sustained year after year, and imported infections must be detected and contained quickly.

A practical lesson is that elimination programs should treat every outbreak as information about the system. An outbreak can reveal a geographic pocket of low coverage, delayed vaccination, poor data quality, vaccine-access barriers or communication problems. Investigating these causes is more valuable than simply counting cases.

6. Polio and the Challenge of Eradication

Polio demonstrates both the power of vaccination and the difficulty of finishing an eradication effort. Decades of immunization have reduced poliovirus transmission enormously, but the final stage is demanding because any remaining transmission can threaten communities and allow spread across borders. WHO's 2025 mid-term review of Immunization Agenda 2030 noted that wild poliovirus

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

type 1 remained endemic in Afghanistan and Pakistan and that variant poliovirus transmission continued in several countries.

The polio experience highlights the importance of surveillance, laboratory capacity, rapid vaccination responses and community trust. Children who are repeatedly missed by vaccination teams are not simply statistics; they often represent practical barriers such as mobility, insecurity, inaccessible locations, misinformation, or gaps between health services and communities. Successful eradication therefore requires social and operational solutions as well as biological tools.

7. Barriers to Vaccine-Preventable Disease Elimination

The barriers to elimination are rarely caused by one factor. Access problems can occur when health facilities are distant, transport is difficult, vaccination sessions are irregular, or families cannot easily return for follow-up doses. Conflict and displacement can interrupt services and destroy health infrastructure. Outbreaks can also follow the disruption of routine programs after emergencies.

Vaccine confidence is another important component. People may have questions about safety, side effects, effectiveness or the need for vaccination when a disease becomes less visible. The most effective response is not ridicule or pressure. Health workers should listen to concerns, communicate clearly, explain benefits and risks honestly, and use trusted local voices. Confidence grows when people experience respectful care and consistent information.

Health-system barriers can be equally important. Stock-outs, inadequate cold-chain equipment, staff shortages, weak data systems and poor follow-up of missed children can reduce coverage even when communities are willing to vaccinate. This is why elimination is fundamentally a health-system strengthening challenge.

8. Surveillance and Outbreak Response

Vaccination coverage tells us how many people have received a vaccine; surveillance tells us what is happening with disease. Elimination requires both. Sensitive surveillance should identify suspected cases quickly, collect appropriate specimens, confirm diagnoses through reliable laboratories, map transmission and guide response.

Rapid response matters because vaccine-preventable infections can spread before a health system realizes that an outbreak has begun. Once an outbreak is detected, response may include case investigation, contact and community assessment, targeted vaccination, risk communication and strengthened routine services. The exact response depends on the disease, local epidemiology and national guidance.

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Digital records and data systems can improve identification of children who miss doses, but technology is only useful when information is accurate and frontline workers can act on it. Data should be used to find gaps and improve services rather than simply to produce reports.

9. Community Engagement and Human Factors

Elimination is ultimately a community achievement. Health workers may deliver vaccines, but families decide whether and when to attend, community leaders influence trust, and local organizations can help identify children who are being missed. Programs that understand local routines, languages and concerns are more likely to reach people effectively.

A humanized approach recognizes that vaccine decisions are often shaped by real experiences. Parents may be balancing work, transport, childcare, previous experiences with healthcare and information from family or social networks. Listening before advising can make communication more effective. Respectful conversations also reduce the risk that people feel judged when they have questions.

The same principle applies to health workers. Staff need manageable workloads, adequate supplies, training and supportive supervision. If an immunization program expects excellent performance but does not provide the tools needed to achieve it, the gap is a system failure rather than simply an individual failure.

10. Strategies to Accelerate Elimination

Priority	Practical strategy	Expected benefit
Reach zero-dose children	Use local data to identify underserved settlements and provide convenient outreach or mobile services.	Improves equity and closes immunity gaps.
Strengthen routine services	Maintain vaccine supply, cold chain, trained staff and reliable session schedules.	Makes protection sustainable between campaigns.
Improve surveillance	Link community detection, laboratories and rapid reporting.	Finds outbreaks earlier and supports targeted action.
Build vaccine confidence	Listen to concerns and communicate with clear,	Supports informed acceptance and trust.

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	respectful, evidence-based messages.	
Use outbreak response strategically	Investigate cases, map transmission and vaccinate according to national guidance.	Limits spread and reveals weaknesses.
Maintain political commitment	Fund immunization, surveillance and workforce capacity over the long term.	Prevents short-term gains from being lost.

Figure 2. Conceptual pathway from strong immunization systems to disease elimination

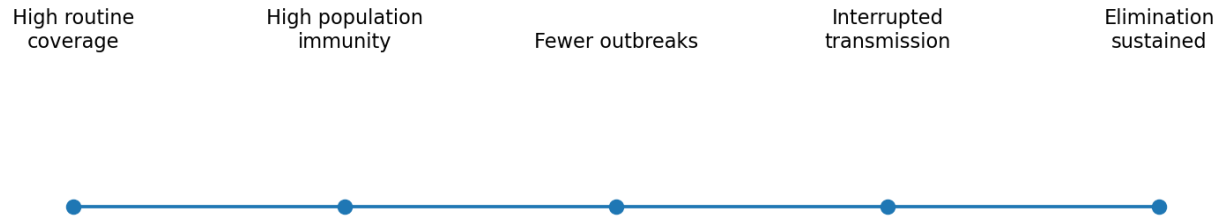


Figure 2. Conceptual pathway showing how sustained high coverage, population immunity, surveillance and rapid response support elimination. This is a conceptual model, not quantitative data.

11. Elimination, Equity and Primary Healthcare

Elimination programs can strengthen primary healthcare when they are designed to leave useful systems behind. Cold-chain improvements, trained vaccinators, disease surveillance, laboratory networks and better community outreach can support many other health programs. Conversely, an immunization campaign that operates completely separately from routine services may produce short-term coverage gains without fixing the underlying access problem.

Equity should therefore be treated as an outcome, not just a principle. National averages can improve while specific communities remain vulnerable. Disaggregated data by geography and other relevant factors can help programs locate these gaps. The goal is not merely to achieve a high national percentage; it is to ensure that protection reaches people who are most likely to be missed.

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12. Discussion

The evidence and experience of global immunization programs point to a consistent conclusion: elimination is possible, but it is fragile. WHO's mid-term review of Immunization Agenda 2030 reported that the world was off track for several elimination and eradication goals and that large disruptive outbreaks of vaccine-preventable diseases remained frequent in 2024. At the same time, the continued expansion of vaccination programs and the large number of deaths prevented each year demonstrate that progress is achievable.

The most important shift is to view elimination as continuous prevention rather than a one-time finish line. High coverage must be maintained even when disease becomes rare. Surveillance must continue even when no cases are detected. Communities must remain engaged even after an outbreak ends. Health systems must be prepared to identify imported infections and respond before local transmission becomes established.

This perspective also makes the topic more human. Behind every percentage are children, parents, health workers and communities. A missed vaccine can mean an avoidable illness; a timely vaccine can mean that illness never happens. Elimination is therefore not only an epidemiological ambition but a commitment to protect people who may never know that prevention worked.

13. Conclusion

Vaccine-preventable disease elimination is one of public health's most ambitious and worthwhile goals. Vaccines provide the biological foundation, but elimination depends on much more: equitable access, strong routine immunization, reliable cold chains, trained health workers, accurate records, sensitive surveillance, laboratory confirmation, rapid outbreak response and sustained public trust.

Current global data show both progress and unfinished work. In 2025, global DTP3 coverage reached 85%, yet millions of children remained unvaccinated or incompletely vaccinated, and measles coverage remained below the level needed to reliably prevent transmission. These gaps remind us that elimination cannot be achieved by national averages alone. The hardest-to-reach communities must be reached deliberately and respectfully.

Ultimately, successful elimination is built through consistency. Vaccinate every eligible child, identify those who are missed, listen to communities, investigate every suspected outbreak, strengthen routine services and keep political commitment strong. When these actions continue for long enough, diseases that once seemed inevitable can become rare, then disappear from communities, and potentially disappear from the world.

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ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

BEYOND RECOVERY: MATERNAL HYGIENE AND MENTAL HEALTH DURING THE POSTPARTUM PERIOD

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Abstract

The postpartum period is often described as a time of recovery, but recovery is much more than the healing of the body after childbirth. It is a period in which a woman or other person who has given birth is simultaneously healing from pregnancy and birth, adapting to new responsibilities, learning infant care, coping with disrupted sleep, and adjusting emotionally and socially. Maternal hygiene is an important part of this process because clean hands, appropriate perineal and wound care, safe breast care, clean clothing and surroundings, and timely recognition of infection can reduce preventable complications. Mental health is equally important. Postpartum depression and anxiety can affect emotional well-being, relationships, sleep, functioning and the ability to enjoy early parenthood. The World Health Organization (WHO) recommends screening for postpartum depression and anxiety with validated tools accompanied by diagnostic and management services, while also recommending psychosocial and psychological interventions during the antenatal and postnatal periods. This narrative review explores the relationship between maternal hygiene and mental health, practical barriers to self-care, the role of family and healthcare workers, and the importance of continuous, person-centred postnatal care. The central message is simple: postpartum care should not ask mothers to choose between physical cleanliness and emotional well-being. Both are parts of the same recovery journey.

Keywords: postpartum period; maternal hygiene; maternal mental health; postpartum depression; postpartum anxiety; postnatal care; infection prevention; self-care; breastfeeding; psychosocial support; maternal well-being.

1. Introduction

The birth of a baby is commonly portrayed as the end of pregnancy and the beginning of a joyful new chapter. In reality, the weeks after birth can be physically demanding and emotionally complicated. The body is recovering from pregnancy and childbirth while the new parent is learning

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

an entirely new routine. Feeding, changing, comforting and responding to a newborn can occupy much of the day and night, leaving little uninterrupted time for eating, bathing, sleeping or simply sitting quietly.

The World Health Organization describes a positive postnatal experience as one in which women, newborns, partners, parents, caregivers and families receive consistent information, reassurance and support from motivated health workers, within a health system that recognizes their needs and cultural context. This approach is important because postpartum health cannot be reduced to a single check-up. It is a continuing process that includes physical, psychological and social well-being.

Maternal hygiene belongs within this broader picture. Hygiene after childbirth is not about achieving perfection or following an endless list of rules. It is about reducing infection risk, supporting comfort and dignity, and helping the recovering body heal. Mental health care is similarly practical: recognizing distress, providing support, encouraging rest, screening when appropriate and ensuring access to professional care when symptoms are significant. When these areas are addressed together, postpartum care becomes more humane and more realistic.

2. The Postpartum Period as a Whole-Person Recovery Phase

The first six weeks after birth are often emphasized in clinical guidance, but the transition to ongoing health does not end at six weeks. ACOG describes postpartum care as an ongoing process rather than a single encounter and recommends attention to physical recovery, mood, emotional well-being, sleep and fatigue, infant feeding, contraception, chronic conditions and health maintenance. WHO similarly recommends a continuum of postnatal contacts and care tailored to individual needs.

This matters because some difficulties are obvious while others are hidden. A fever or wound problem may be visible to a clinician, whereas persistent sadness, anxiety, guilt, loneliness or exhaustion may be dismissed as simply part of becoming a parent. Good postpartum care creates space for both types of concerns.

A humanized approach also recognizes that postpartum experiences vary widely. A person recovering from an uncomplicated vaginal birth may have different needs from someone recovering from a caesarean birth, significant blood loss, a complicated pregnancy or a difficult birth experience. Social circumstances matter too. Someone with reliable family support may have opportunities to rest that another person does not. Postpartum care should therefore be individualized rather than based on a single idealized experience.

3. Maternal Hygiene After Childbirth

Hygiene after childbirth has a clear purpose: protecting healing tissues and reducing exposure to infection. Hand hygiene is central, particularly before and after touching a wound, changing sanitary

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materials, caring for the baby, preparing food or performing other close-contact tasks. Clean water and appropriate facilities make these behaviors easier, which is why water, sanitation and hygiene services are part of quality postnatal care.

After vaginal birth, the perineal area may be tender and swollen, while postpartum bleeding is expected to change over time. After caesarean birth, an abdominal incision requires observation and appropriate care according to the clinician's instructions. The exact care plan should be individualized, especially if there were complications. General advice should never replace professional assessment when there are concerning symptoms.

Breast and nipple hygiene should also be approached sensibly. Routine gentle cleanliness is usually sufficient; aggressive scrubbing or harsh products can irritate sensitive skin. Hand hygiene before feeding or expressing milk is more useful than trying to make the breast 'sterile.' The goal is comfortable, practical hygiene that can be sustained while caring for a newborn.

Clothing, bedding, toilets and frequently touched household surfaces should be kept reasonably clean, but postpartum care should not become a demand for constant cleaning. Excessive cleaning can increase workload and anxiety without providing proportional health benefits. The better goal is a safe and manageable environment.

4. Mental Health During the Postpartum Period

Emotional changes after birth are common, but persistent or severe symptoms deserve attention. The postpartum period can involve sleep disruption, physical discomfort, changing hormones, feeding challenges, uncertainty and major changes in identity and routine. These experiences can contribute to emotional distress, particularly when combined with previous mental health difficulties, limited support, financial stress, relationship problems or a difficult birth experience.

Postpartum depression can involve persistent low mood, loss of interest or pleasure, guilt, hopelessness, anxiety, changes in sleep or appetite, difficulty concentrating and feeling unable to cope. Postpartum anxiety may present as excessive worry, tension, restlessness or persistent fear. These conditions are not a sign of weakness and are not evidence that someone is a bad parent.

WHO recommends screening for postpartum depression and anxiety with a validated instrument when screening is accompanied by appropriate diagnostic and management services. WHO also recommends psychosocial and psychological interventions during the antenatal and postnatal period to help prevent depression and anxiety. ACOG likewise emphasizes assessment of mood and emotional well-being as a routine component of postpartum care.

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Mental health screening should therefore be treated as ordinary healthcare rather than as a test that a parent can 'fail.' Asking about mood can open a door to support. It also gives healthcare workers an opportunity to identify people who may need more focused assessment or referral.

5. How Hygiene and Mental Health Interact

Physical and mental health are often discussed separately, but postpartum life makes their connection obvious. Pain, infection, wound discomfort, urinary problems or breast complications can make sleep and daily functioning harder. Poor sleep can then increase emotional vulnerability. In the other direction, depression or severe anxiety can reduce motivation and energy for routine self-care. The result can be a cycle in which physical discomfort and emotional distress reinforce each other.

Figure 1. Interconnected domains of postpartum recovery

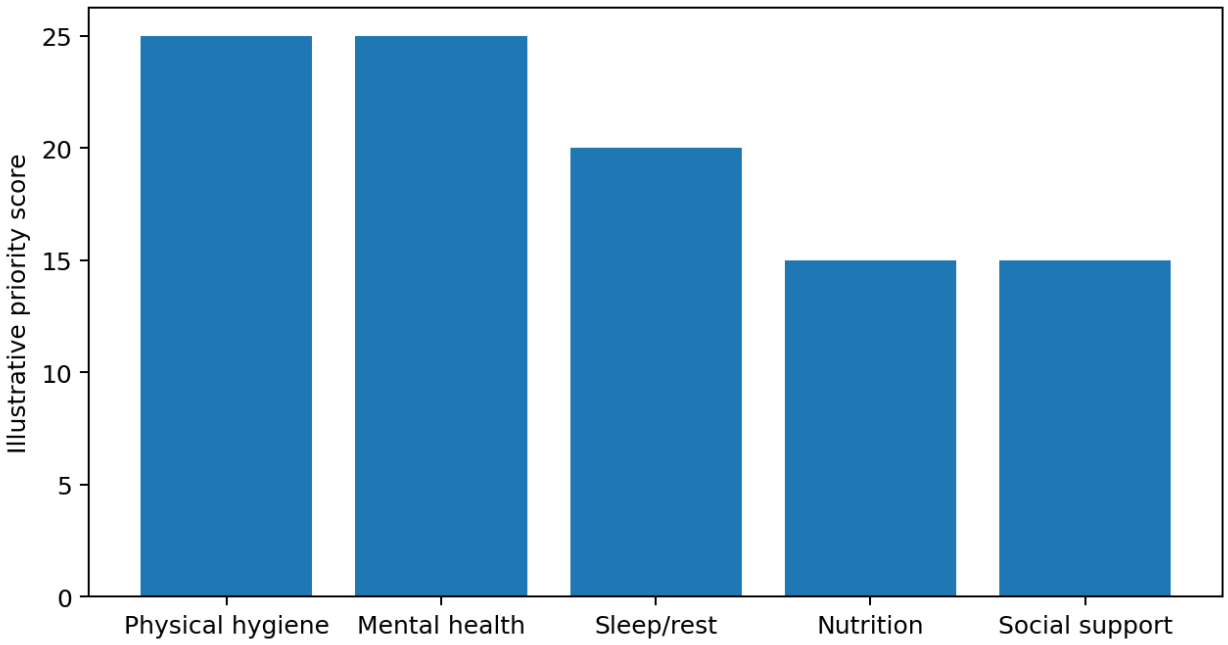


Figure 1. Interconnected domains of postpartum recovery. The values are illustrative priority scores for presentation, not clinical measurements.

The practical implication is that healthcare workers should not treat hygiene as a purely physical task. If a new mother says she is too exhausted to manage basic self-care, the response should include curiosity about sleep, pain, emotional state, support at home and other barriers. Similarly, someone presenting with low mood may also need assessment of physical recovery, feeding difficulties or untreated pain.

This integrated approach is particularly important because postpartum care can become fragmented. Different professionals may focus on the baby, the delivery wound, feeding or mental health without

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seeing the complete picture. A coordinated approach makes it easier to recognize how one problem can influence another.

6. Sleep, Fatigue and Self-Care

Sleep is one of the most difficult resources to protect after childbirth. Newborns often wake frequently, and feeding responsibilities can make uninterrupted sleep difficult. Fatigue can affect concentration, mood, patience and the ability to complete routine tasks. A person may know that hygiene and nutrition matter but still struggle to find the time and energy to care for themselves.

This is where practical support becomes more valuable than advice alone. Family members or trusted helpers can assist with meals, household work, laundry, errands and infant care so that the recovering parent can rest. Where available, healthcare services can reinforce realistic strategies for rest and shared caregiving.

Self-care should also be reframed. It is not a luxury or a reward for finishing all household duties. Basic hygiene, adequate food and fluids, appropriate rest, emotional support and medical follow-up are part of the work of recovery.

7. Family, Community and Healthcare Support

Support area	Helpful action	Why it matters
Practical help	Share meals, laundry, household tasks and infant care.	Creates protected time for rest and personal care.
Emotional support	Listen without judgment and check in regularly.	Reduces isolation and makes it easier to discuss distress.
Healthcare follow-up	Attend scheduled postnatal contacts and raise physical or emotional concerns.	Allows early recognition and management of complications.
Hygiene support	Keep water, clean materials and basic supplies accessible.	Makes safe hygiene practical during fatigue.
Partner involvement	Participate in infant care and appointments where appropriate.	Shares responsibility and can strengthen confidence.

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Community support	Use trusted family, community or peer networks when welcomed by the parent.	Builds a wider safety net beyond the clinic.

8. Barriers to Maternal Hygiene and Mental Well-Being

Postpartum self-care is influenced by more than motivation. Lack of privacy, limited water access, financial constraints, crowded housing, inadequate sanitation, distance from healthcare, lack of family support and cultural expectations can all affect recovery. A parent may also feel pressure to appear happy and grateful, making it harder to admit that they are struggling.

Healthcare systems can unintentionally add to this problem when postpartum care is organized around one scheduled visit rather than a continuing process. WHO recommends additional postnatal contacts, including early contacts in the first days after birth and later follow-up, with additional care when risks are identified. ACOG similarly recommends early contact and ongoing care rather than waiting for a single traditional postpartum appointment.

Another barrier is stigma. Mental health symptoms may be interpreted as a failure to cope, while hygiene difficulties may be interpreted as laziness or poor parenting. Such judgments are counterproductive. Supportive care asks what is making recovery difficult and what resources could make it easier.

9. Recognizing When Professional Help Is Needed

Routine emotional ups and downs can occur after birth, but symptoms that are persistent, severe, worsening or interfering with daily functioning should be discussed with a healthcare professional. Screening tools can help identify people who need further assessment, but screening is only useful when a pathway to evaluation and treatment exists.

Physical warning signs also require timely medical assessment. These may include fever, worsening pain, foul-smelling discharge, heavy or concerning bleeding, problems with a surgical wound, breast symptoms accompanied by significant illness, or other symptoms that feel unusual or severe. The exact threshold for evaluation depends on the clinical situation.

Mental health concerns deserve the same seriousness as physical concerns. A parent should not be expected to simply 'push through' significant depression or anxiety. Professional assessment can help determine the appropriate support, which may include counseling, psychological therapy, social support, medical treatment when indicated, or urgent care depending on severity.

10. Practical Postpartum Hygiene and Mental Health Checklist

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Domain	Practical focus	Who can help	When to escalate
Hand and personal hygiene	Regular hand hygiene; gentle routine washing; clean clothing and surroundings.	Parent, partner, family.	Difficulty maintaining basic care because of illness, pain or severe distress.
Perineal/wound care	Follow clinician-specific instructions; keep area appropriately clean and observe for changes.	Parent and healthcare worker.	Fever, worsening pain, concerning wound changes or other abnormal symptoms.
Breast care	Gentle hygiene and attention to comfort; seek advice for significant feeding problems.	Parent, lactation/health professional.	Significant pain, fever or worsening breast symptoms.
Mental health	Talk about mood, anxiety, sleep and coping; use validated screening when appropriate.	Healthcare worker, partner, family.	Persistent/worsening symptoms or impaired functioning.
Rest and nutrition	Protect opportunities for sleep, meals and fluids; share household tasks.	Family/community.	Severe exhaustion, inability to eat/drink or concerning physical symptoms.
Follow-up	Keep postnatal contacts and ask questions without embarrassment.	Healthcare team.	Any symptom that feels urgent or unsafe.

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Figure 2. Conceptual postpartum support pathway

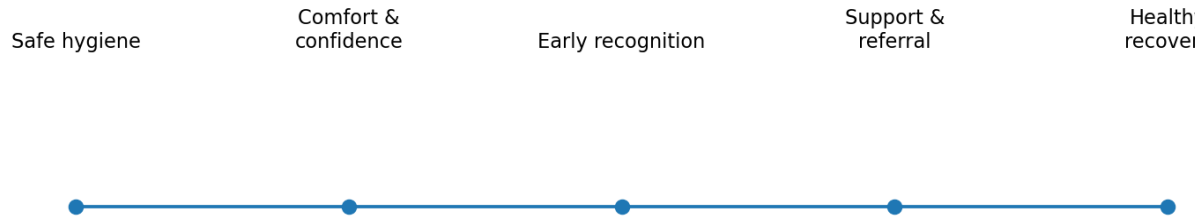


Figure 2. Conceptual postpartum support pathway showing how hygiene, comfort, early recognition and social/clinical support can work together. This is a conceptual model, not a clinical prediction tool.

11. Discussion

The postpartum period is sometimes treated as a short bridge between childbirth and the return to ordinary life. It is better understood as a major life transition in its own right. WHO's postnatal guidance places the experience of the mother and newborn at the center of care and emphasizes information, reassurance, support and person-centred services. This perspective helps move postpartum care away from a narrow focus on checking whether the body has healed.

Maternal hygiene and mental health are especially suitable for an integrated approach because they are influenced by the same underlying conditions: sleep, support, pain, access to services, household resources, confidence and the quality of communication with healthcare workers. A person who feels supported is more likely to have opportunities for self-care, while someone whose physical recovery is comfortable may find it easier to cope emotionally. Neither relationship is automatic, but both show why whole-person care matters.

The humanized goal is not to create a perfect postpartum routine. New parents will have difficult days, interrupted sleep and moments when the laundry remains unfinished. Good care should reduce unnecessary pressure rather than add to it. The priority is safety, dignity, support and early recognition of problems.

12. Recommendations for Better Postnatal Care

• Treat postpartum care as an ongoing process rather than a single appointment.

• Include physical recovery, hygiene, sleep, nutrition, mood and social circumstances in routine assessments.

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• Use validated screening for postpartum depression and anxiety when diagnostic and management pathways are available.

• Provide clear, culturally respectful education about hygiene, warning signs and when to seek care.

• Encourage partners, family members and trusted support networks to share practical responsibilities.

• Make essential hygiene supplies and clean water accessible in facilities and, where possible, through community-based support.

• Train healthcare workers to communicate without judgment and to recognize both physical and psychological needs.

• Use follow-up systems to identify people who miss care or who need additional support.

• Ensure that people with significant mental health symptoms or physical complications can access appropriate professional assessment and treatment.

13. Conclusion

Postpartum recovery is not simply the process of a body returning to its pre-pregnancy state. It is a period of physical healing, emotional adjustment, learning, relationship change and adaptation to a new rhythm of life. Maternal hygiene helps protect physical recovery, but it must be practical and compassionate rather than demanding. Mental health deserves the same level of attention, because depression and anxiety can affect well-being, functioning and the experience of early parenthood.

The strongest postpartum care combines prevention, early recognition and support. Clean water and hand hygiene, appropriate wound and perineal care, comfortable living conditions, adequate rest, respectful communication, social support and mental health screening are not separate tasks. They are interconnected pieces of a safe recovery.

Ultimately, beyond recovery means recognizing the person behind the patient. A new mother or parent should not have to prove strength by suffering silently. Postnatal care is most effective when it offers information without judgment, practical help without blame, and professional care when it is needed. A healthy postpartum period is not defined by perfection; it is defined by safety, dignity, support and the opportunity to heal.

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TECHNICAL SCIENCE RESEARCH IN UZBEKISTAN
ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

ДИФФЕРЕНЦИАЛ ҲИСОБЛАШЛАРДАН ФОЙДАЛАНИБ ИҚТИСОДИЙ МАСАЛАЛАРНИ ЕЧИШ УСУЛЛАРИ

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Термиз муҳандислик ва агротехнологиялар университети

Ўқитиш услубиятидан унумли фойдаланиш ўз ўрнида қуйидагиларни ўз ичига олади, яъни: иқтисодий ўзгарувчилар ва объектларни ажратиб олиш, ҳамда асосийси улар орасидаги боғлиқликни расмий ифодалашни ўргатиш.

Бундан ташқари аниқ шаклланган, берилган маълумотлар ва нисбатлардан дедукция усуллари билан шу ўрганилаётган объектнинг ўзига мос келувчи якуний хулосага келиш лозим бўлади.

Замоновий услубиятда иқтисодий масалаларни ечишда математика ва статистика усулларини қўллаб индуктив йўл билан объект ҳақида янги ахборотлар олишга ва юқори кузатиш натижаларига мос келувчи ўзгарувчиларининг боғланиш шаклларини ва унинг параметрларини баҳолаш керак бўлади.

Бу усулдан фойдалнишнинг яна бир зарурий томони шуки, математика тилидан фойдаланиш иқтисодий назариянинг асосларини аниқ ифодалашга ,ҳамда барча тушунча ва хулосаларини тушунарли ҳолга келтиришга имконият яратади.

Биз ушбу илмий изланишда дифференциал ҳисоблашлардан иқтисодий масалаларни ечиш ва таҳлил қилишда фойлаланиш услубиятларини кўриб чиқамиз.

Юқорида келтирганимиздек иқтисодий кўрсаткичларнинг боғланишларини ўргатиш иқтисодий таҳлилнинг асосий вазифаси ҳисобланади. Масалан, агар солиқлар ортса ёки импортга бож тўлаш киритилса, давлат даромадлари қайси йўналишга ўзгаришини, Фирмалар тушумлари ортиши ёки камайиши унинг маҳсулотлари баҳоси кўтаришишига боғлиқлигини

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аниқлашда дифференциал ҳисоблашлар усулидан фойдаланиб бундай иқтисодий масалаларни ечишда улар орасидаги боғланишларда иштирок этувчи ўзгарувчиларни аниқлаб берадиган функция зарурлиги ўргатилади.

Маълумки иқтисодий кўрсаткичларни аниқлашда оптималлаш усулларидан фойдаланиш мақсадга мувафиқдир. Қайсики, кўрсаткичнинг оптимал қийматини топиш бир ва бир неча ўзгарувчили функциянинг экстремумини топишга келтирилади.

Дастлабки таълим беришда иқтисодий кўрсаткич Y-ни бошқа кўрсаткич X нинг фукцияси сифатида максималлаш ёки минималлаш зарур бўлса масалан айтайлик максимал фойда олишда ишлаб чиқариш ҳажми кўрсаткичига боғлиқ функцияни танлаш зарурлигини ва оптимал нуқта яъни максимал нуқта сифатида X аргументнинг ортишига тўғри келадиган Y функциянинг лимити нолга интилиши кераклигини тушунтириш керак бўлади. Иқтисодиётнинг бир қатор масалалари максималлаштириш масалаларини ўз ичига олади ва чегаравий шартлардан ташкил топади.

Чегаравий масалалар математик дастурлаш масалалари бўлиб, уларни ечишда дифференциал ҳисоблашларга асосланган компьютерларда дастурий таъминотлар мавжуд.

Биз ушбу илмий изланишда юқоридаги хулосалардан келиб чиққан ҳолда талаб функциясининг ўзаро боғлиқлигини математик таҳлил қилиш масаласини услубий ёритиб беришга харакат қиламиз. Бунда энг содда иқтисодий боғланиш қандай саволларга жавоб бериши кераклиги тушунтирилади, масалан қуйидаги жавоблар изланади:

1. Ўрганилаётган иқтисодий кўрсаткичларни қандай омиллар аниқлайди?
2. Ишоралар қанақа?
3. Боғланишнинг даражаси қанақа?
4. Боғланишнинг сонлардаги ёки миқдорий ифодаси қанақа?

Иқтисодий назариядан маълумки, талаб функцияси маҳсулотга бўлган талаб миқдори– q^D,унинг нархи p, истеъмолчиларнинг даромадлари I, бошқа тўлдирувчи товарлар нархи p^C

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ёки ўрнини босувчи p^S товарлар нархи, кутилаётган нархлар ва кутилаётган даромадларга боғлиқ.

Талаб функциясининг кўринишини қуйидагича ёзамиз(2):

$q^D = f(p, I, T, p^C, p^S, p^e, I^e, \ldots)$

Боғланиш Y=f(x) кучли ёки кучсиз эканлиги аниқлашнинг икки йўли бор, яъни:

Орттирма бўйича ёндошиш $(\Delta x \Rightarrow \Delta y)$,

Омилни ортиши $\Rightarrow$ изланаётган кўрсаткичнинг ортиши

(х ни ўзгариши) $\Rightarrow$(у ни ўзгариши)

Абсалют ўзгаришни ёки сезгирлик ўлчавини функциянинг ўзгариш тезлиги яъни ўзгаришлар нисбати каби ёзиш мумкин :

$$\frac{\Delta Y}{\Delta X} \to \lim_{\Delta x \to 0} \frac{\Delta Y}{\Delta X} \equiv \frac{\partial y}{\partial x} \equiv f'(x)$$

Темпли ёндошишни эса $(\%\Delta x \Rightarrow \%\Delta y)$ каби ёзилади.

Демак қандайдир ўзгарувчининг фоиздаги ўзгариши деганда бу ўзгарувчининг ўзгарган қийматини унинг дастлабки қийматига нисбати каби ёзиш мумкин яъни:

$\%\Delta x = \frac{\Delta x}{x} = \frac{x_2 - x_1}{x_1}$ Бунга мисол қилиб масалан, бир дона ноннинг нархи 500 сўмдан 1000 сўмга ортса, нархнинг фоиздаги ўзгаришини қуйидагича ёзамиз: $\%\Delta x = \frac{1000 - 500}{500} = 100\%$

Ўзгаришнинг сезгирлик ўлчови функциянинг эластиклиги чегаравий ҳолатни ёки дифференциални ифодалайди:

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$$\frac{\%y}{\%x} \to \lim_{\%x \to 0} \frac{\%y}{\%x} \equiv \lim_{\Delta x \to 0} \frac{\Delta y / y}{\Delta x / x} \equiv \frac{dy}{dx} * \frac{x}{y} \equiv \frac{f'(x)x}{y}$$

Бу функционал боғланишни гарафикли ёки жадвал кўринишдаги ифодасини кўрсатиш учун ўрганилаётган объектнинг функционал формулаларини тузуш керак бўлади.

Демак назарий моделларни аниқлаш учун эконометрик изланишлар олиб бориб эмпирик формулалар ёрдамида ҳосил қилишимиз мумкин.

Юқоридаги талаб функциясини қуйидаги формула билан аниқлаш мумкин:

$$q^D = q_0 - \alpha * p - \beta * p^c + \gamma * p^s$$

Бу моделнинг кўринишидан аниқлаш мумкинки унинг графиги тўғри чизиқни ифодалайди. Демак бу моделга асосланиб қарорлар қобул қилиш мумкин(3).

Айтайлик монополист бозорда маркетинг изланишлар олиб бориб, ўз маҳсулотига бўлган талаб фукнциясини аниқлаб олган бўлсин ва қанча маҳсулот ишлаб чиқариш керак ҳамда қандай нарҳларда сотиш ҳақида қарор қобул қилиши керак бўлсин. Агар у жуда юқори нарҳ белгиласа, истеъмолчилар маълум бир даврда ундан кўпроқ маҳсулот харид қилмай қолишади. Агар у кўпроқ маҳсулот ишлаб чиқарса, маълум бир даврда барча маҳсулотларини сотиб бўлиши учун нарҳни пасайтиришга тўғри келади. Бундай ҳолда нима юз беради, албатта умумий тушум ёки даромад сотиш ҳажмининг ортиши ҳисобига ортади яъни ютуқга эришиши мумкин ва бир вақтнинг ўзида нарҳнинг пасайиши ҳисобига даромад камайиши мумкин.

Демак натижа қайси бир кўрсаткич катта бўлишига боғлиқ бўлади. Монополист қандай қилиб оптимал ишлаб чиқариш ҳажмини аниқлайди деган жўяли савол пойда бўлади. Уни аниқлаш учун эса монополист умумий тушумни(даромад) ишлаб чиқариш ҳажмига қандай боғланганлигини аниқлаб олиши керак бўлади. Буни модел орқали ифодалаймиз(4):

$$p(q) = R(q) - C(q) = p(q)q - C(q)$$

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Бу модел орқали монополист қандай ишлаб чиқариш ҳажмида максимал фойда олишини аниқлаб олиши керак бўлади, аблатта уни аниқлаш учун танланган функциянинг экстремум нуқталари мавжудлиги текшириб кўрилади. Ферма теоремасига кўра зарурий ва етарлилик шартлари текшириб кўрилади. Масалан етарлилик шарти иккита яъни аниқланган функциянинг изланаётган соҳада ўзлуксизлиги бўлса иккинчиси танланган функция аниқланган бўлса у шу нуқтада икки марта дифференциалланса, унда $p'(q_0)=0$ ва $p''(q_0)\neq 0$ бўлса, унда q_0 нуқтада $p(q)$ функция максимумга эришади, агар $p''(q_0)\prec 0$ бўлса ва агар $p''(q_0)\succ 0$ бўлса минумумга эришади.

Демак ўқув жараёнида ўқувчиларни экстремал масалаларга кўникмалар ҳосил қилиш учун ва иқтисодий масалаларни ечишда дифференциал ҳисоблашлардан фойдалнишни ўргатиш мумкин бўлади. Бунинг учун оптималлаштириш масалаларини ҳамда чегаравий самарадорлик кўрсаткичларини оптимал ишлаб чиқариш ҳажмларини аниқлашда фойдаланиш мумкин.

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ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

ANXIETY AND DEPRESSION IN YOUNG ADULTS

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Abstract

Anxiety and depression have become one of the defining health concerns for people in their late teens and twenties. This narrative review pulls together recent survey data, global estimates and research reviews to describe how common these conditions are among young adults, what may be behind the rise, and why so many people go without care. In the United States, about one in three adults aged 18 to 25 had a mental illness in 2024, the highest share of any adult age group, and young adults were far more likely than older adults to report serious thoughts of suicide. Global estimates suggest that depression and anxiety rose by more than a quarter in 2020, with younger people affected more than older ones. Research on social media points to small-to-moderate associations rather than proven causes. There is some encouraging news, because national data show declines among young adults between 2021 and 2025, but nearly half of adults with a mental illness still receive no treatment. Early recognition, easier access to care and realistic expectations about technology are the most practical ways forward.

Keywords: *anxiety; depression; young adults; mental health; social media; COVID-19; treatment gap; prevention*

1. Introduction

Picture a 22-year-old in the final year of a degree. Grades are fine, friends are around, nothing dramatic has happened. Yet mornings feel heavy, sleep is patchy, and a vague dread follows every message left unanswered. This person is a composite, not a real case, but many readers will recognise the picture. It is the everyday face of anxiety and depression in young adulthood: often quiet, often hidden, and easy to dismiss as “just stress.”

Headlines say that anxiety and depression are now common in young adults, and the numbers support the claim, although the full story is more mixed than the headlines suggest. This article looks at how widespread these conditions really are, what the research says about possible causes, why many

ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

young people are never treated, and what appears to help. Most of the detailed data come from the United States, where national surveys are large and regular, and global figures are used where they exist. The review is narrative rather than systematic, so the sources were chosen for their quality and relevance and not through an exhaustive search.

2. How Common Is It, Really?

The best recent numbers come from the National Survey on Drug Use and Health (NSDUH), a large annual US survey. In 2024, about one third of adults aged 18 to 25 (33.2%, or 11.6 million people) had experienced a mental illness in the past year, compared with 23.4% of all adults (SAMHSA, 2025). Averaged over 2022 to 2024, the pattern by age is striking: roughly 34% of 18- to 25-year-olds, 30% of those aged 26 to 49 and 14% of people over 50 (Figure 1; SAMHSA, 2025b). Mental illness, in this survey, covers any diagnosable mental, behavioural or emotional disorder, so it is wider than anxiety and depression alone, but these two conditions make up a large part of it.

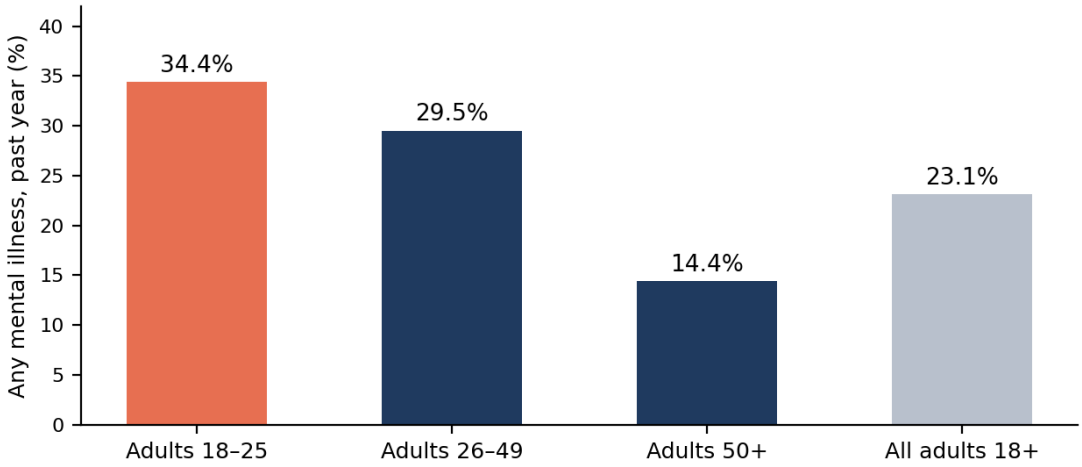


Figure 1. Share of US adults with any mental illness in the past year, by age group (2022–2024 annual averages). Source: SAMHSA (2025b).

Depression shows the same age gradient. In the 2021 survey, 18.6% of adults aged 18 to 25 had a major depressive episode in the past year, more than double the 8.3% seen among all adults (NIMH, 2023). Suicidal thoughts follow suit: 12.8% of young adults reported serious thoughts of suicide in the past year, against 5.2% of adults overall, and after adjustment for other factors the odds were about 5.5 times higher than for people aged 50 or older (SAMHSA, 2025b). Table 1 gathers the main figures.

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Table 1. Key mental-health figures for young adults (US, NSDUH)

Indicator	Young adults 18–25	Comparison
Any mental illness, past year (2024)	33.2% (11.6 million)	23.4% of all adults
Serious mental illness, past year (2024)	9.4% (3.3 million)	12.0% in 2021
Major depressive episode (2021)	18.6%	8.3% of all adults
Serious thoughts of suicide (2022–2024)	12.8%	5.2% of all adults
Adults with any mental illness who received treatment (2024)	—	52.1% (all adults)

Now for the part that rarely makes the headlines. Serious mental illness among young adults fell from 12.0% in 2021 to 9.4% in 2024, and among adolescents the rate of major depressive episodes dropped from 20.8% to 15.4% over the same period (SAMHSA, 2025a). The 2025 survey, released in July 2026, reported further declines among 18- to 25-year-olds in depressive episodes, any mental illness and serious mental illness (SAMHSA, 2026). So the fairest summary is that anxiety and depression are common, were unusually high in the early 2020s, and may now be easing. Even so, a rate of one in three is not a reason to relax.

3. What Might Be Driving the Rise?

No single cause explains it, and anyone offering one should be treated with caution. The evidence is strongest for the pandemic. A global analysis covering 204 countries estimated that in 2020 cases of major depression rose by 27.6% (an extra 53.2 million) and anxiety disorders by 25.6% (an extra 76.2 million), with women and younger people affected more than men and older groups (COVID-19 Mental Disorders Collaborators, 2021). Closed schools and campuses, lost jobs and weeks of isolation hit people at an age when friendships, study and first jobs are being built (Figure 2A).

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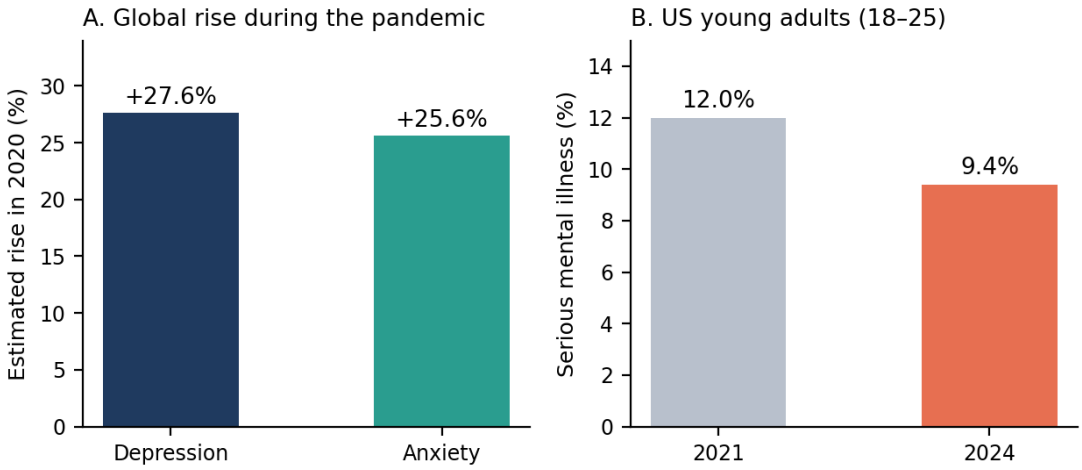


Figure 2. (A) Estimated global rise in depression and anxiety in 2020 due to the pandemic (COVID-19 Mental Disorders Collaborators, 2021). (B) Serious mental illness among US adults aged 18–25 (SAMHSA, 2025a).

Social media is the most debated suspect. Large reviews do find links. A meta-analysis of 98 studies found small but significant associations between social media use and both depression and anxiety, and "problematic" use, the compulsive, can't-put-it-down kind, was also tied to poorer sleep (Ahmed et al., 2024). Another analysis of 18 studies put the correlation for problematic use at about 0.27 for depression and 0.35 for anxiety (Shannon et al., 2022). Yet a scoping review of 140 studies noted that almost all examined association rather than cause, and that depression may itself lead to more social media use, not just the reverse. Shorter, purposeful use appeared to go with better mood (Hilty et al., 2023). In other words, the screen may be part of the picture without being the whole picture.

Other pressures are widely discussed, including money worries, an unpredictable job market, loneliness and the strain of life transitions, although they are harder to measure and fewer large studies isolate their effect. Substance use also travels with poor mental health: in 2021, 13.5% of young adults had both a substance use disorder and a mental illness (SAMHSA, 2022). Table 2 summarises how strong the evidence looks for each factor.

Table 2. Possible contributors and how strong the evidence looks

Factor	What the research shows	Strength of evidence
Pandemic disruption	Global rise of about 26–28% in depression and anxiety in 2020; younger people more affected	Strong for a short-term rise

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Factor	What the research shows	Strength of evidence
Social media use	Small associations overall; stronger for problematic use; direction of cause unclear	Mixed, mostly correlational
Poor sleep	Linked with problematic social media use and with worse mood	Moderate, associational
Substance use	13.5% of young adults had both a substance use disorder and a mental illness (2021)	Strong association
Money, work and loneliness	Frequently discussed pressures of early adulthood	Plausible; less directly measured

4. Telling Stress From Something More

Everyone feels low or tense sometimes. The difference lies in how long it lasts and how much it gets in the way. Surveys such as the NSDUH describe a major depressive episode as a period of at least two weeks with a persistent low mood or loss of interest, together with problems such as disrupted sleep, appetite or concentration (NIMH, 2023). Anxiety tends to show up as constant worry, restlessness or physical symptoms. The two often overlap, which is part of why they are so often discussed together. Table 3 lists some common signs.

Table 3. Common signs of depression and anxiety

More typical of depression	More typical of anxiety	Often seen in both
Persistent low or empty mood	Constant, hard-to-control worry	Trouble sleeping
Loss of interest in usual activities	Racing heart, tight chest, shaking	Difficulty concentrating

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More typical of depression	More typical of anxiety	Often seen in both
Feelings of worthlessness or guilt	Avoiding situations that cause fear	Tiredness and low energy
Changes in appetite or weight	Feeling on edge or unable to relax	Pulling away from friends

If any of these signs last for weeks, get worse, or include thoughts of self-harm, it is time to talk to a doctor, counsellor or someone trusted. Anyone in immediate danger should contact local emergency services or a crisis line in their country right away.

5. The Treatment Gap

Recognising a problem is only the first step, and the second is often the harder one. In 2024, 52.1% of US adults with a mental illness received any treatment in the past year, which means almost half did not (SAMHSA, 2025a). The 2025 figure was similar at 50.9% (SAMHSA, 2026). Young adults have historically been among the least likely to get care: the 2021 survey found that, despite having the highest rate of serious mental illness, people aged 18 to 25 had the lowest treatment rate of any adult age group (SAMHSA, 2022).

The reasons are easy to guess and familiar from everyday life: cost, long waiting lists, stigma, not knowing where to start, and the sense that “it’s not bad enough yet.” Young adults also sit in an awkward gap between child and adult services, and many are moving between cities, universities and jobs, which makes continuity of care difficult.

6. What Seems to Help

The good news is that both conditions are treatable. Talking therapies such as cognitive behavioural therapy and, where appropriate, medication are established first-line options, and many people recover or manage symptoms well (NIMH, 2023). In the NSDUH, two thirds of adults who considered themselves to have had a mental health issue said they were in recovery or had recovered (SAMHSA, 2025a).

Beyond formal treatment, several practical steps are reasonable. Protecting sleep, staying physically active and keeping real-world friendships going all support mood. On the digital side, the research hints that shorter and more purposeful use is better than long, passive scrolling (Hilty et al., 2023),

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though no one should pretend that a simple screen-time limit is a cure. At the system level, universities, employers and primary-care clinics can make it easier to ask for help by offering quick screening, short waiting times and low-cost counselling. Friends and family matter too: asking "how are you really?" and listening without rushing to fix things costs nothing.

7. Limits of the Evidence

A few cautions apply. Most figures here are from the United States, and the picture may differ elsewhere. The surveys rely on self-report, and definitions change between studies, so numbers are not always comparable. The NIMH has noted that more than half of the selected 2021 NSDUH sample did not complete the interview, and people with depression may be over-represented among those who did not (NIMH, 2023). And because most social media research is correlational, it cannot say whether screens cause distress, distress drives screen use, or both.

8. Conclusion

Anxiety and depression are common among young adults, and the data confirm it: about one in three US adults aged 18 to 25 had a mental illness in 2024, and global estimates show a sharp pandemic-era jump. At the same time, recent surveys offer cautious hope, with several indicators for young adults moving downward since 2021. The causes are layered, and the evidence points to a mix of pandemic disruption, sleep, substance use, social pressures and possibly technology rather than any single culprit. What is clear is the gap between need and care. Closing it will take earlier recognition, easier and cheaper access, and a willingness among all of us to treat mental health as seriously as we treat a broken bone.

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ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

THE HIDDEN PLASTIC PATHWAY: MICROPLASTIC MIGRATION FROM ENTERAL AND PARENTERAL NUTRITION SYSTEMS IN INTENSIVE CARE

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Abstract

Enteral and parenteral nutrition are essential for critically ill patients who cannot meet their nutritional needs by ordinary eating. Both routes bring nutrient solutions into contact with containers, connectors, syringes, filters and tubing, many of which contain polymers. These materials may be sources of microscopic plastic particles or chemical constituents that migrate into fluids. This narrative review examines potential pathways of microplastic exposure through nutrition systems in intensive care, summarizes emerging evidence, and identifies practical and research priorities. A study published in 2024 detected microplastics in 43% of 30 tested enteral nutrition formula samples from nine brands; this finding is important but should not be generalized to every product or clinical setting. Research on infusion systems has also highlighted potential particle transfer and major limitations in current detection methods. However, the amount reaching individual patients and the clinical consequences of nutrition-system exposure remain uncertain. Particle shedding must be distinguished from chemical leaching, as each requires different tests. The appropriate response is neither alarm nor dismissal: life-sustaining nutrition should not be delayed, while standardized testing, transparent material information and carefully designed clinical research are needed.

Keywords: microplastics; nanoplastics; enteral nutrition; parenteral nutrition; intensive care; infusion systems; medical devices; contamination; patient safety

1. Introduction

Nutrition is an active part of critical care, supporting recovery, tissue repair and the maintenance of lean body mass. When oral intake is unsafe or inadequate, enteral nutrition (EN) can deliver formula through a feeding tube. When the gastrointestinal route is unsuitable or cannot meet requirements, parenteral nutrition (PN) provides nutrients intravenously. Both approaches depend on a chain of manufactured products, including bags, bottles, connectors, syringes and tubing, that may contain plastic polymers.

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Plastic components have made healthcare more accessible and practical: they are lightweight, flexible, inexpensive and can be manufactured for single use. The relevant question is not whether plastic should simply be removed from clinical care. It is whether microscopic particles or chemical additives can migrate from nutrition products and administration equipment into the fluid, what dose may reach the patient, and whether that exposure has clinical consequences. These questions require separate evidence.

Microplastics are often defined as plastic particles smaller than 5 mm, while the term nanoplastics is used for still smaller particles, although definitions vary. Results across studies can be difficult to compare because laboratories use different sample preparation procedures, lower size limits, polymer-identification techniques and contamination controls. The World Health Organization has emphasized uncertainties in exposure measurement and health-risk assessment [1]. These issues are especially relevant in intensive care, where nutrition may be delivered continuously and patients may already have substantial physiological stress.

2. Review approach

This article is a narrative review of selected peer-reviewed studies and authoritative reports concerning microplastics, enteral formulas, infusion systems, medical-device materials and human-health evidence. It is not a systematic review or meta-analysis, and no new patient data were collected. Numerical findings are attributed to the studies that reported them; no pooled estimate of exposure has been calculated. Because the field is evolving, readers should verify the latest literature before using this review for clinical policy or publication.

3. How might particles enter the pathway?

Potential sources can be considered at three stages: before a product reaches the ward, during preparation, and while the fluid moves through the administration circuit. For EN, contact points may include the formula container, cap, transfer set, feeding bag, syringe, connector and feeding tube. For PN, the pathway can include the nutrient container, compounding equipment, transfer devices, administration set, pump segment, filter and vascular catheter. A plastic component does not automatically release particles; migration may depend on polymer type, manufacturing quality, storage, fluid chemistry, mechanical stress, temperature and contact time.

Two processes should be distinguished. Particle shedding is the release of solid fragments or fibres. Chemical leaching is the transfer of substances such as plasticizers or stabilizers from a material into a fluid. They may occur together, but require different analytical methods. Detecting a chemical additive does not prove that microplastic particles are present, and counting particles does not establish the dose of chemical additives.

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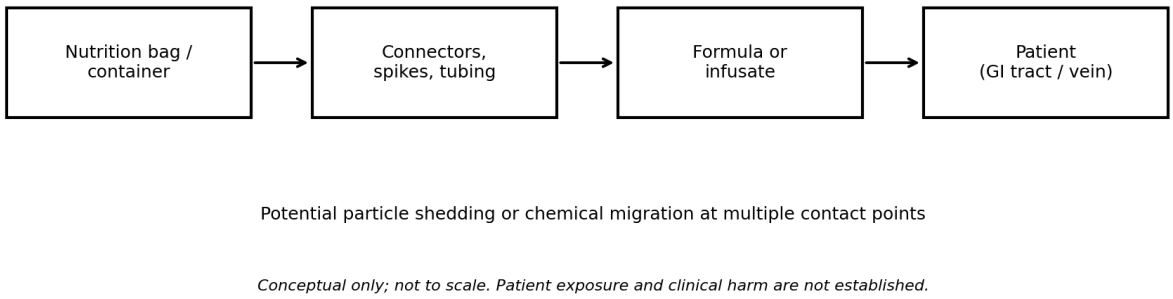


Figure 1. Conceptual pathway for potential particle or chemical migration during nutrition delivery. This schematic is illustrative and does not represent measured exposure.

4. Evidence from enteral nutrition

One directly relevant study by Başaran and colleagues examined 30 samples from nine brands of enteral nutrition formulas. Microplastics were reported in 43% of the tested samples, with polymethyl methacrylate identified as the dominant polymer [2]. The authors also calculated estimated daily intake using their findings and assumed consumption. This study is notable because it investigated a clinical nutrition product rather than relying only on environmental samples.

The result should nevertheless be interpreted in context. Thirty samples cannot represent every formula, production batch, package type, country or handling practice. Particles may potentially be introduced during manufacture, packaging, storage, sampling or laboratory processing, so procedural blanks and appropriate controls are essential. The 43% finding is a result from this particular sample set, not evidence that 43% of all enteral nutrition products worldwide are contaminated.

The administration circuit creates further questions. Bags, connectors and tubing could contribute particles, but evidence tracing a particle from a specific component through the full circuit and into a patient remains limited. EN also differs from ordinary food ingestion: it may be delivered continuously, bypasses oral exposure and passes through a tube whose material varies between products. The additional exposure attributable specifically to bedside equipment is not yet well quantified.

5. Evidence from parenteral nutrition and infusion systems

PN deserves separate attention because the solution enters the bloodstream and bypasses the gastrointestinal barrier. Medical containers and devices have long been studied for chemical leaching, including plasticizers from certain polyvinyl chloride (PVC) materials. The degree of migration depends on the material and fluid; lipid-containing solutions may interact with materials differently

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from aqueous solutions. Chemical leaching is related to, but distinct from, the newer question of microplastic particle transfer [3].

A 2026 review of infusion therapy identifies medical devices and pharmaceutical containers as a potentially overlooked route of particle exposure and highlights weaknesses in testing methods, source attribution and clinical risk assessment [4]. Laboratory experiments can demonstrate particle transfer under selected conditions, but findings depend on circuit design, solution, flow rate, duration, filter, particle-size threshold and analytical method. Experimental transfer does not establish the dose received by every ICU patient or prove a particular clinical outcome.

In-line filters may retain some particles, but performance varies with pore size, particle properties, filter design and compatibility with the prescribed formulation. Filters should be used only in line with product instructions and local protocols. They are not a universal solution, and changes to PN administration must account for nutrient delivery, emulsion stability and device compatibility. Pharmacy, nutrition-support and infection-prevention teams should assess proposed changes together.

6. Potential biological significance

Researchers are studying possible effects of microplastics through cell experiments, animal models, environmental studies and analyses of human samples. Proposed mechanisms include oxidative stress, inflammatory signalling, physical interactions with tissues and effects related to additives or contaminants carried on particle surfaces. A plausible mechanism, however, is not the same as a demonstrated clinical outcome. Dose, size, shape, polymer, surface chemistry and exposure duration may all influence biological behaviour.

It is reasonable to ask whether direct vascular exposure differs from ingestion, since the intestine acts as a partial barrier. Yet the amount and size distribution of particles that may pass through nutrition circuits, their fate in blood and their relationship to outcomes such as inflammation, organ dysfunction or thrombosis have not been adequately established. WHO has likewise highlighted substantial uncertainty in the broader evidence linking microplastic exposure to human health effects [1]. Clinicians should not state that nutrition-system microplastics are known to cause a specific ICU complication.

Table 1. Potential sources, pathways and evidence gaps

Stage / component	Possible concern	Current evidence	Key uncertainty

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Formula or nutrient container	Particles or additives may migrate during manufacture or storage	Direct formula testing exists; one study found particles in 43% of tested EN samples [2]	Representativeness across products, batches and methods
Bags, connectors, syringes and tubing	Shedding from contact surfaces or handling	Plausible; evidence varies by device and test conditions	Contribution of each component during real-world use
PN infusion set and vascular access	Direct delivery of particles or leached chemicals	Infusion-device research is emerging [3,4]	Patient-level dose and clinical significance
Filters and handling	Filters may retain some particles; handling may introduce contamination	Performance is product- and method-dependent	Validated practices that reduce particles without disrupting therapy

7. Current evidence at a glance

The evidence can be viewed in three layers. First, microplastics are widely documented in environmental samples and have been reported in some food, water and biological samples. Second, direct but limited evidence indicates that particles can be present in some enteral formulas and that medical infusion pathways warrant investigation. Third, evidence that exposure specifically attributable to EN or PN systems causes measurable harm in ICU patients remains insufficient. This distinction matters: absence of proof of harm does not establish zero risk, but neither does particle detection prove clinical injury.

Question	Evidence status	Clinical interpretation
Are microplastics present in environmental samples?	Well documented, although measured counts vary by method	Exposure is plausible; comparisons need standardized testing.
Have particles been reported in EN formulas?	Yes, in a limited direct study [2]	A signal for further testing, not a universal prevalence estimate.

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Can medical-device materials release particles or chemicals?	Chemical leaching is established for some materials; particle evidence is developing [3,4]	Material choice and fluid compatibility matter.
Do nutrition-system particles cause specific ICU outcomes?	Not established	Do not delay or withhold clinically indicated nutrition on this evidence alone.

8. Practical clinical and system-level steps

A proportionate response should protect patients without interrupting essential treatment. During procurement, hospitals can request information on polymer composition, extractables and leachables testing, particle testing where available, and compatibility with the intended formula or infusate. Transparent, comparable manufacturer data would be more useful than broad assurances that a product is simply 'medical grade.'

At the bedside, staff should follow established preparation and administration procedures. Avoid unnecessary transfers, avoidable manipulation, damaged equipment and nonvalidated substitutions. Clean handling is also important for research because airborne fibres from clothing, air and work surfaces can contaminate samples. Studies should use procedural blanks, appropriate controls, validated sampling tools and polymer confirmation.

Nutrition delivery must remain central to clinical decisions. Any change to tubing, filters, bags or connectors should consider sterility, infection risk, flow, adsorption of nutrients or medicines, emulsion stability and device instructions. No patient should have clinically indicated EN or PN withheld because of an unquantified microplastic concern. If a facility wishes to review this issue, the first step is a multidisciplinary review involving pharmacy, clinical engineering, infection prevention and nutrition support.

9. Research priorities

The most informative studies would test the entire delivery pathway rather than a formula or device in isolation. Researchers could compare fluid before and after passage through specified components, use unused-device and procedural blanks, identify polymers with spectroscopy, and report particle size and morphology. Test conditions should reflect real flow rates, temperatures, storage periods and administration durations. Particle counts and chemical migration should be reported separately.

Clinical studies should investigate whether measured exposure correlates with biomarkers or patient-centred outcomes while accounting for illness severity, medication use, transfusions and other exposure sources. Neonates and other vulnerable groups deserve attention, with rigorous ethical

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safeguards and contamination-resistant methods. Shared reporting standards and independent replication are necessary before studies can be compared reliably or clinically meaningful thresholds proposed.

10. Conclusion

Enteral and parenteral nutrition are indispensable in intensive care, yet they create repeated contact between nutrient fluids and polymer-based containers and devices. A 2024 study reported microplastics in some tested enteral formula samples, while recent infusion-system literature highlights a need for stronger measurement and risk assessment. The typical dose delivered to ICU patients and any clinical harm specifically caused by these pathways remain uncertain. The appropriate response is neither complacency nor alarm: improve standardized testing, seek transparent device information, maintain careful handling practices and conduct patient-relevant research, while preserving timely access to life-sustaining nutrition.

Limitations

This is a narrative review of selected literature rather than a systematic review with duplicate screening and formal risk-of-bias assessment. Studies use heterogeneous methods and are not directly comparable. Findings may change as further research becomes available.

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UDK 620.197.3:547.992.3:66.094.94

MAHALLIY XOMASHYOLAR ASOSIDA KALSIY LIGNOSULFONATNING KORROZIYAGA BARDOSH MATERIALLAR OLISH TEXNOLOGIYASIGA BOG‘LIQLIGI

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Annotatsiya. Maqolada mahalliy lignosellyulozali xomashyolardan kalsiy lignosulfonat olish va undan korroziyaga bardosh materiallar ishlab chiqarishda foydalanishning ilmiy-texnologik asoslari tahlil qilinadi. G‘o‘zapoya va boshqa o‘simlik qoldiqlaridan ligninni ajratish, sulfonatlash, kalsiy birikmalari bilan neytrallash va hosil bo‘lgan polimer-elektrolitni qoplama matritsasiga kiritish bosqichlari ko‘rib chiqilgan. Kalsiy lignosulfonat molekulasidagi sulfonat, gidroksil, karboksil va aromatik guruhlarning metall yuzasida adsorbsiyalanishi, passiv qatlamni barqarorlashtirishi va pitting korroziyasini susaytirishi tahlil qilingan. Ilmiy manbalarda Q235 po‘latda 7200 soatlik sinovdan keyin ham 93 foizdan yuqori ingibirlash samaradorligi qayd etilgani, shuningdek pH 7–12,5 oralig‘ida CLSning adsorbsiya va passivatsiya mexanizmlari o‘zgarishi ko‘rsatilgan. Mahalliy xomashyo uchun ligninni ajratish–sulfonatlash–Ca(OH)2 bilan neytrallash–tozalash–kompozitsiyalash ketma-ketligiga asoslangan texnologik sxema taklif etilgan.

Kalit so‘zlar: kalsiy lignosulfonat, lignin, mahalliy xomashyo, korroziya, po‘lat, antikorrozion material, adsorbsiya, passivatsiya, qoplama.

Аннотация. В статье анализируются научно-технологические основы получения лигносульфоната кальция из местного лигноцеллюлозного сырья и его применения при разработке коррозионностойких материалов. Рассматриваются стадии выделения лигнина из стеблей хлопчатника и других растительных отходов, сульфирования, нейтрализации соединениями кальция и введения полученного полиэлектролита в защитную матрицу. Проанализированы адсорбция сульфонатных, гидроксильных, карбоксильных и

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ароматических групп на поверхности металла, стабилизация пассивной пленки и подавление питтинговой коррозии. Согласно литературным данным, лигносульфонат кальция сохраняет эффективность ингибирования выше 93% даже после 7200 ч испытаний, а в диапазоне pH 7–12,5 механизм защиты изменяется от преимущественной адсорбции к совместному действию адсорбционной и пассивной пленок. Для местного сырья предложена технологическая схема: выделение лигнина – сульфирование – нейтрализация Ca(OH)2 – очистка – компаундирование.

Ключевые слова: лигносульфонат кальция, лигнин, местное сырье, коррозия, сталь, антикоррозионный материал, адсорбция, пассивация, покрытие.

Abstract. This article analyzes the scientific and technological basis for producing calcium lignosulfonate from local lignocellulosic feedstocks and applying it in corrosion-resistant materials. The technological route includes lignin isolation from cotton stalk and other plant residues, sulfonation, neutralization with calcium compounds, purification, and incorporation of the resulting polyelectrolyte into protective matrices. The roles of sulfonate, hydroxyl, carboxyl, and aromatic groups in metal-surface adsorption, passive-film stabilization, and suppression of pitting corrosion are discussed. Published studies report inhibition efficiencies above 93% even after 7200 h exposure and show that within pH 7–12.5 the protection mechanism evolves from dominant adsorption to a combined adsorption/passivation process. A local-feedstock route based on lignin extraction, sulfonation, Ca(OH)2 neutralization, purification, and composite formulation is proposed.

Keywords: calcium lignosulfonate, lignin, local feedstock, corrosion, steel, anticorrosion material, adsorption, passivation, coating.

1. KIRISH

Korroziya metall konstruksiyalar, temir-beton armaturalari, quvur tarmoqlari, issiqlik almashinish uskunalari va texnologik apparatlarning xizmat muddatini qisqartiradigan asosiy omillardan biridir. Xlorid ionlari mavjud muhitlarda po‘latning himoya passiv qatlami lokal buzilib, pitting korroziyasi tezlashadi. Shu sababli korroziya ingibitorlari va himoya qoplamalariga qo‘yiladigan talab nafaqat yuqori samaradorlik, balki toksikligi past, biologik parchalanadigan va iqtisodiy jihatdan maqbul xomashyo bilan ham belgilanmoqda.

Kalsiy lignosulfonat (CLS) ligninning sulfonatlangan kalsiy tuzi bo‘lib, odatda sulfit usulidagi sellyuloza ishlab chiqarish oqimlaridan yoki alohida sulfonatlash orqali olinishi mumkin. Uning tarkibida aromatik halqa, sulfonat, fenolik va alifatik gidroksil hamda karboksil guruhlar mavjud. Shu funksional markazlar metall yuzasi, Ca2+ ionlari va oksid-gidroksid passiv qatlam bilan o‘zaro ta’sirlashib, himoya plyonkasi hosil qiladi.

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Kalsiy lignosulfonatning ayniqsa temir-beton armaturalari korroziyasini kamaytirishdagi xususiyati ilmiy adabiyotlarda qayd etilgan. Wang va boshqalar Q235 uglerodli po‘latda CLSning umumiy va pitting korroziyasiga qarshi samarali ekanini, uzoq muddatli sinovda 7200 soatdan keyin ham ingibirlash darajasi 93 foizdan yuqori bo‘lib qolganini ko‘rsatgan (Wang et al., 2017). Bu holat kalsiy lignosulfonatni oddiy dispersant yoki plastifikator emas, balki funksional antikorrozion komponent sifatida ko‘rish imkonini beradi.

O‘zbekiston uchun mazkur yo‘nalishning amaliy qiymati mahalliy lignosellyulozali xomashyo bazasi bilan bog‘liq. G‘o‘zapoya, paxta tozalash chiqindilari, don somoni va boshqa qishloq xo‘jaligi qoldiqlari lignin manbai bo‘la oladi. G‘o‘zapoyadan lignin ajratish bo‘yicha tadqiqotlarda ion suyuqlik va ultratovush yordamidagi ion suyuqlik usullarida mos ravishda 93,60 va 94,01 foizlik ajratish darajalari olingan (Hasan et al., 2022). Bu ko‘rsatkichlar g‘o‘zapoyaning yuqori qo‘shilgan qiymatli lignin hosilalarini olish uchun real xomashyo ekanini ko‘rsatadi.

Maqolaning maqsadi mahalliy lignosellyulozali xomashyodan kalsiy lignosulfonat olishning texnologik ketma-ketligini asoslash, uning antikorrozion ta’sir mexanizmini tahlil qilish va korroziyaga bardosh kompozit materiallar yaratishda asosiy boshqariladigan parametrlarni aniqlashdan iborat.

2. METODOLOGIYA VA ADABIYOTLAR TAHLILI

Tadqiqot adabiyotlarni tizimli-qiyosiy tahlil qilish, texnologik modellashtirish va funksional guruhlar–korroziya mexanizmi o‘rtasidagi bog‘liqlikni umumlashtirish usullariga tayandi. Asosiy ilmiy baza sifatida kalsiy lignosulfonatning Q235 po‘latdagi adsorbsiyasi, pitting korroziyasiga ta’siri va pHga bog‘liq himoya mexanizmini o‘rgangan ishlar tanlandi. Mahalliy xomashyo qismi uchun g‘o‘zapoya ligninini ajratish bo‘yicha tadqiqotlar hamda lignosellyulozali chiqindilarni delignifikatsiya qilish bo‘yicha zamonaviy natijalar hisobga olindi.

Kalsiy lignosulfonatning himoya mexanizmi muhit pHiga kuchli bog‘liq. Wang, Zuo, Zhao va Zha (2016) 0,1 mol/L NaCl + Ca(OH)2 muhitida pH 7–12,5 diapazonini o‘rganib, pH 7–9,5 oralig‘ida po‘lat faol holatda bo‘lishini va 0,001 mol/L CLS anod hamda katod reaksiyalarini bir vaqtda susaytirishini ko‘rsatgan. Bu sharoitda sulfonat guruhlari va aromatik halqalarning metall yuzasiga adsorbsiyasi asosiy himoya omili bo‘lgan.

pH 9,5–10,5 dan yuqori sharoitda po‘lat yuzasida Fe2O3, FeOOH, FeO va CaO/Ca(OH)2 komponentlarini o‘z ichiga olgan passiv qatlam shakllanishi kuchayadi. CLS ushbu passiv holatni mustahkamlaydi va pitting korroziya potensialini musbat tomonga siljitadi. pH taxminan 10,5 bo‘lganda lignosulfonatning –SO3− guruhlari va passiv qatlam tashqi qismidagi Ca2+ komponentlari o‘rtasida Ca–O–S ko-adsorbsiya strukturasining shakllanishi ehtimoli yuqori deb talqin qilingan.

2017-yildagi uzoq muddatli tadqiqotda kalsiy lignosulfonat simulyatsiya qilingan beton g‘ovak eritmasida po‘latning ham umumiy, ham pitting korroziyasini susaytirgani qayd etilgan.

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Mikroskopik infraqizil tasvirlar dastlab CLS korroziyaga moyil faol nuqtalar atrofida selektiv adsorbsiyalanishini, vaqt o‘tishi bilan esa yaxlit adsorbsion himoya qatlami shakllanishini ko‘rsatgan. Molekulyar modellashtirish sinapil spirt fragmentlarini elektron qabul qilishga moyil faol markaz sifatida ajratgan.

Mahalliy xomashyo texnologiyasida birinchi kritik bosqich ligninni ajratishdir. G‘o‘zapoya lignini G–S tipidagi lignin bo‘lib, strukturaviy tadqiqotlarda guayatsil birliklari taxminan 59%, siringil birliklari 40% va p-gidroksifenil birliklari qariyb 1% ulushda aniqlangan (Kang et al., 2012). Ushbu aromatik tuzilish keyingi sulfonatlash va metall yuzasiga adsorbsiyalanish uchun zarur bo‘lgan reaktiv markazlarni beradi.

Ikkinchi kritik bosqich sulfonatlash va kalsiy tuziga o‘tkazishdir. Lignin sulfonatlangach, suvda eruvchan polielektrolitga aylanadi. Keyingi Ca(OH)2 yoki boshqa kalsiy asosli neytrallash orqali kalsiy lignosulfonat olinadi. Antikorrozion maqsad uchun mahsulotning kul miqdori, sulfonatlanish darajasi, molekulyar massa taqsimoti, pH va suvda eruvchanligi qat’iy nazorat qilinishi kerak.

1-jadval. Kalsiy lignosulfonatning antikorrozion xususiyatlarini belgilovchi asosiy omillar

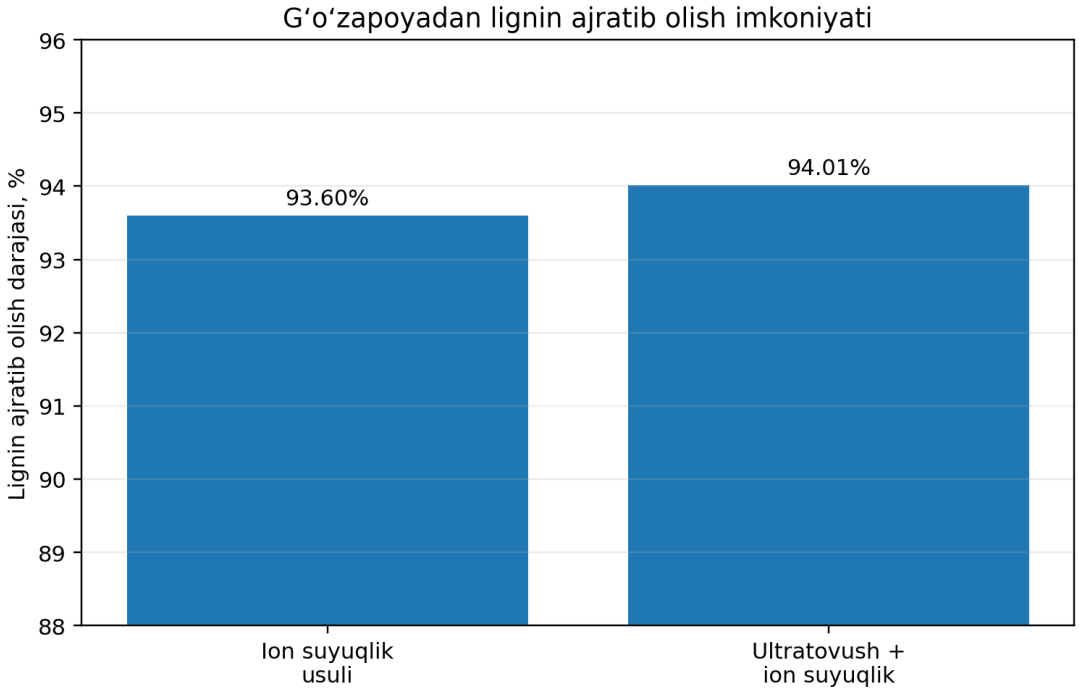
Omil	**Texnologik boshqariladigan parametr**	**Korroziyaga ta’siri**
Sulfonatlanish darajasi	Sulfonatlovchi reagent miqdori va reaksiya vaqti	Suvda eruvchanlik va metall yuzasiga ionik adsorbsiyani kuchaytiradi
Molekulyar massa	Ajratish va fraksiyalash rejimi	Himoya plyonkasi zichligi va diffuziya xususiyatini belgilaydi
Ca2+ miqdori	Neytrallash darajasi	Ca–O–S ko-adsorbsiyasi va passiv qatlam bilan o‘zaro ta’sirga ta’sir qiladi
Fenolik/OH guruhlar	Lignin manbai va modifikatsiya	Metall sirtidagi faol markazlar bilan bog‘lanishni kuchaytiradi
Kul va tuz qoldiqlari	Yuvish va membranali/tozalash bosqichi	Qoplama bir xilligi va elektrokimyoviy barqarorlikka ta’sir qiladi
pH	Mahsulotni standartlashtirish	Adsorbsiya–passivatsiya mexanizmi nisbatini o‘zgartiradi

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3. NATIJALAR

Adabiyot ma’lumotlari mahalliy xomashyo asosida CLS olishning xomashyo bosqichi texnologik jihatdan real ekanini ko‘rsatadi. Hasan va boshqalar (2022) g‘o‘zapoyadan ligninni ion suyuqlik usulida 93,60%, ultratovush yordamidagi ion suyuqlik usulida esa 94,01% darajada ajratgan. Bu natija xomashyoning asosiy aromatik polimer komponentini yuqori darajada ajratib olish mumkinligini ko‘rsatadi. Biroq sanoat texnologiyasida ion suyuqlik narxi va regeneratsiya xarajati hisobga olinishi kerak; amaliy sharoitda ishqoriy, gidrotermal yoki kombinatsiyalangan variantlar iqtisodiy jihatdan maqbulroq bo‘lishi mumkin.

2023-yildagi EnZolv tadqiqotida g‘o‘zapoyadan ligninni olib tashlash darajasi optimallashtirilgan sharoitda 78,68% ga yetgan. Bu biologik-fermentativ yondashuv yuqori tozalash talab qilinmaydigan, ekologik yumshoq texnologiya uchun muqobil yo‘l ekanini ko‘rsatadi. Demak, CLS ishlab chiqarishda xomashyo ajratish texnologiyasi faqat maksimal chiqim bo‘yicha emas, reagent sarfi, chiqindi suv va ligninning keyingi sulfonatlanishga yaroqliligi bo‘yicha tanlanishi lozim.



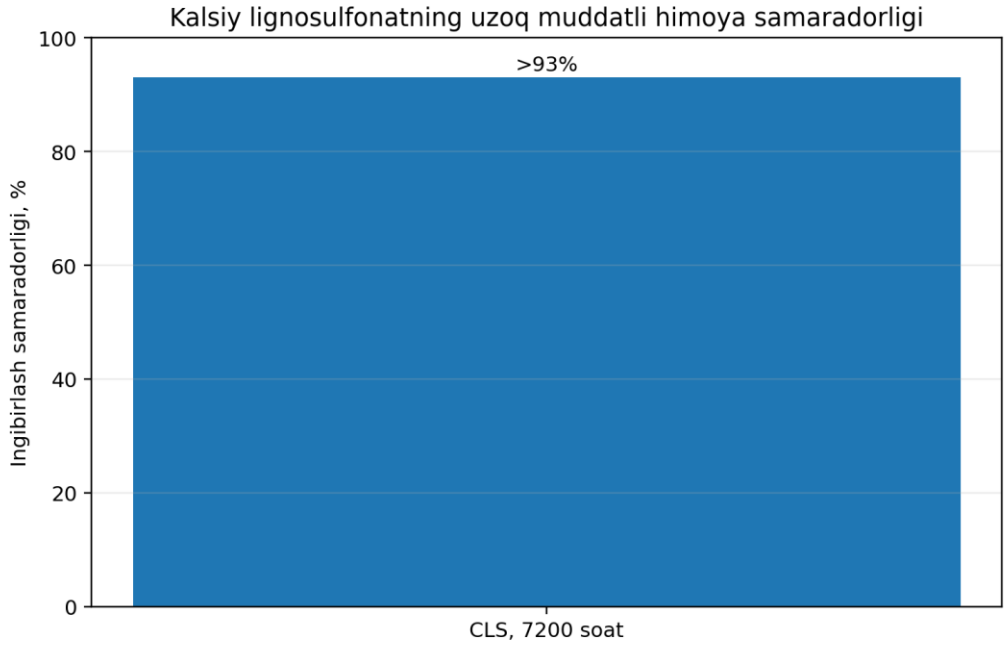
1-rasm. G‘o‘zapoyadan lignin ajratish darajasi. Hasan va boshqalar (2022) ma’lumotlari asosida.

Kalsiy lignosulfonatning korroziyaga qarshi samaradorligi uzoq muddatda ham saqlanishi alohida ahamiyatga ega. Wang va boshqalar (2017) simulyatsiya qilingan beton g‘ovak eritmasida 7200 soatlik immersiondan keyin ham ingibirlash samaradorligi 93% dan yuqori ekanini qayd etgan.

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Ushbu natija CLSning faqat dastlabki adsorbsiya bilan emas, balki vaqt o‘tishi bilan sirtni qayta tashkil qiluvchi barqaror adsorbsion qatlam bilan bog‘liq ekanini ko‘rsatadi.

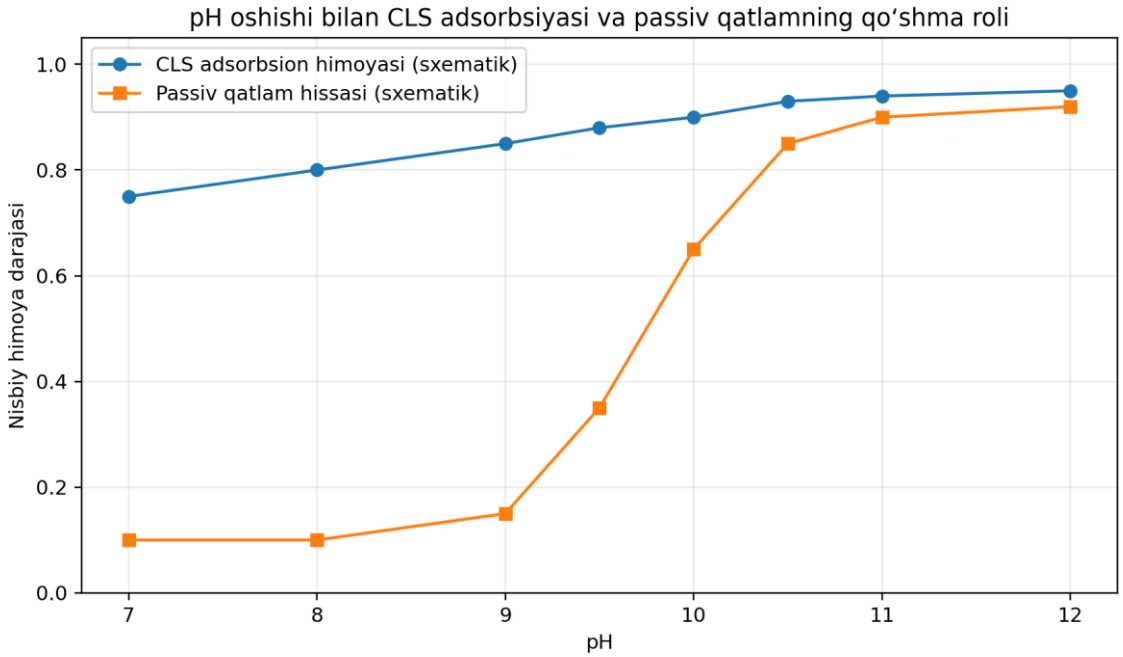
CLSning texnologik afzalligi uning bir vaqtning o‘zida ikki vazifani bajarishidadir: faol metall yuzasida adsorbsion inhibitor sifatida ishlaydi va ishqoriy muhitda mavjud passiv oksid-gidroksid qatlamni barqarorlashtiradi. Bu ayniqsa temir-beton armaturasi, sement asosli qoplamalar va xlorid ta’siriga uchraydigan po‘lat konstruksiyalar uchun muhim.



2-rasm. CLSning 7200 soatlik immersiondan keyingi ingibirlash samaradorligi. Wang va boshqalar (2017) ma’lumotlari asosida.

pHga bog‘liq mexanizm ham mahsulotni qaysi matritsaga qo‘shishni tanlashda hal qiluvchi omildir. Neytralga yaqin muhitda asosiy himoya sulfonat guruhlari va aromatik fragmentlarning metall yuzasiga adsorbsiyasi bilan ta’minlanadi. Ishqoriylik ortgani sari CaO/Ca(OH)2 va temir oksid-gidroksidlaridan iborat passiv qatlamning hissasi ortadi, CLS esa ushbu qatlamni zichlashtiradi. Shu sababli kalsiy lignosulfonat sementli va fosfatli tizimlarda oddiy suvli muhitga nisbatan boshqa doza va molekulyar xususiyatlarni talab qilishi mumkin.

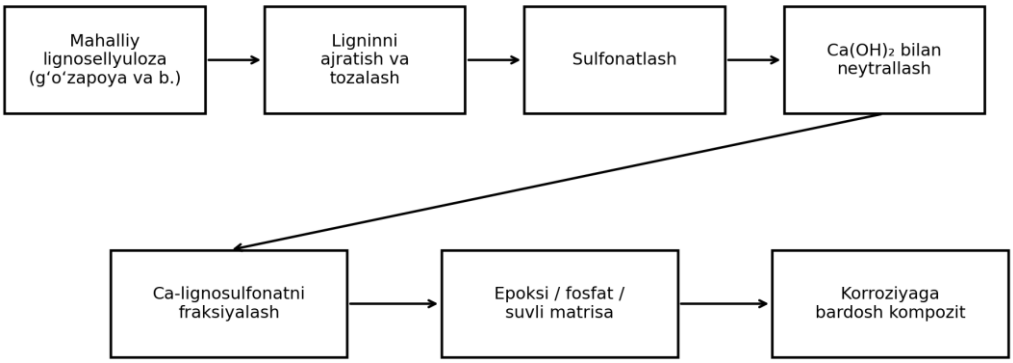
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3-rasm. pH oshishi bilan adsorbsion va passivatsion himoya ulushining sxematik o‘zgarishi. Wang et al. (2016) mexanizmi asosida muallif ishlanmasi.

Mahalliy xomashyo uchun taklif etilayotgan texnologik ketma-ketlik quyidagicha: lignosellyulozali biomassani maydalash va ekstraktiv moddalardan tozalash; ligninni ajratish; ligninni sulfonatlash; Ca(OH)2 bilan neytrallash; ortiqcha noorganik tuz va past molekulyar birikmalarni ajratish; kalsiy lignosulfonatni konsentrlash yoki quritish; tayyor CLSni epoksi, sement-polimer, fosfat yoki suvli himoya tizimiga maqsadli dozada kiritish. Bu yondashuvda mahsulotni to‘liq quritish shart emas: suvli qoplama yoki beton qo‘shimchasi uchun konsentrlangan eritma shakli energiya sarfini kamaytirishi mumkin.

Mahalliy xomashyo asosida kalsiy lignosulfonatli antikorrozion material olishning taklif etilayotgan texnologik sxemasi



4-rasm. Mahalliy xomashyo asosida kalsiy lignosulfonatli korroziyaga bardosh material olishning taklif etilayotgan texnologik sxemasi.

2-jadval. Mahalliy CLS asosida korroziyaga bardosh material yaratishda tavsiya etiladigan sinovlar

Sinov	**O‘lchanadigan ko‘rsatkich**	**Texnologik qaror**
FTIR	–SO3−, –OH, aromatik guruhlar	Sulfonatlash va kimyoviy tuzilmani tasdiqlash
GPC/SEC	Molekulyar massa taqsimoti	Fraksiya va plyonka hosil qilish xususiyatini tanlash
Potentiodinamik qutblanish	Icorr, Ecorr	Optimal CLS dozasi va inhibitor turini baholash
EIS	Rct, Cdl, qoplama qarshiligi	Uzoq muddatli himoya va qoplama barqarorligini baholash
SEM/EDS	Sirt morfologiyasi va element tarkibi	Passiv/adsorbsion plyonka yaxlitligini tekshirish
Tuzli tuman testi	Nuqson va zang tarqalishi	Real qoplama formulatsiyasini tanlash

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Yopishish sinovi	Adgeziya mustahkamligi	CLSning matrisa bilan mosligini tekshirish

4. MUHOKAMA

Olingan tahlil kalsiy lignosulfonatning antikorrozion material yaratishdagi roli uning faqat kimyoviy tabiatiga emas, balki ishlab chiqarish texnologiyasiga bevosita bog‘liqligini ko‘rsatadi. Xomashyo tarkibi, ligninning ajratish usuli, sulfonatlanish darajasi va Ca2+ miqdori o‘zgarsa, tayyor CLSning molekulyar massasi va sirt faolligi ham o‘zgaradi. Natijada bir xil nominal dozada turli partiyalar turlicha korroziya himoyasi berishi mumkin.

Shu sababli mahalliy ishlab chiqarish uchun eng katta xato — lignosulfonatni faqat yon mahsulot sifatida qabul qilib, uning funksional tarkibini standartlashtirmaslikdir. Antikorrozion maqsadli CLS uchun kamida sulfonat guruhlari miqdori, quruq modda, Ca2+ ulushi, kul, pH, molekulyar massa va eruvchanlik bo‘yicha texnik spetsifikatsiya ishlab chiqilishi kerak.

Ikkinchi muhim masala matrisa tanlashidir. CLS suvda yaxshi eriydi va gidrofil xususiyatga ega. Shu bois epoksi qoplamaga yuqori miqdorda bevosita kiritish suv yutishni oshirib, to‘siq xususiyatini yomonlashtirishi mumkin. Bunday tizimlarda kapsullash, ion almashuvchi tashuvchilarga yuklash yoki sirt modifikatsiyasi maqsadga muvofiq. Sementli va fosfatli muhitda esa CLSning Ca2+ komponenti hamda sulfonat guruhlari passiv qatlam bilan sinergik ishlashi mumkin.

2026-yildagi zamonaviy tadqiqotlar CLSning qattiq qoplamada yarim immobilizatsiya qilingan shaklda ham foydali ekanini ko‘rsatadi. Masalan, kalsiy lignosulfonat, PVDF va uglerod qora asosidagi gidrofob qoplama rux anod yuzasida suv va sulfat ionlarini cheklab, eritmadan ajraluvchi Ca2+ hamda lignosulfonat anionlari hisobiga dinamik himoya yaratgan. Mazkur ish an’anaviy po‘lat korroziyasi bo‘lmasa-da, CLSni polimer matritsada boshqariladigan tarzda ushlab turish materialning uzoq muddatli interfeys barqarorligini oshirishi mumkinligini ko‘rsatadi (Li et al., 2026).

Uchinchi masala iqtisodiy va ekologik balansdir. G‘o‘zapoyadan lignin olish yuqori chiqim berishi mumkin, biroq qimmat ion suyuqlik yoki murakkab regeneratsiya jarayoni mahalliy texnologiyaning tannarxini oshiradi. Shu sababli sanoat miqyosida eng yuqori ekstraksiya foizini emas, balki lignin sifati, reagent qayta ishlanishi, suv sarfi va keyingi sulfonatlash bilan moslikni birgalikda optimallashtirish kerak.

To‘rtinchi masala mahalliy sinovlar yetishmasligidir. Kalsiy lignosulfonatning xalqaro adabiyotlarda yaxshi korroziya himoyasi ko‘rsatgani mahalliy xomashyodan olingan CLS ham avtomatik ravishda shu natijani beradi degani emas. G‘o‘zapoya ligninining strukturasi, kul tarkibi va molekulyar massa taqsimoti yog‘och ligninidan farq qilishi mumkin. Shu sababli mahalliy

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mahsulot uchun Q235 yoki St3 po‘latda NaCl, Ca(OH)2 + NaCl va qoplama ichidagi elektrokimyoviy sinovlar majburiy bo‘lishi kerak.

5. XULOSA

Kalsiy lignosulfonat mahalliy lignosellyulozali xomashyolar asosida olinishi mumkin bo‘lgan istiqbolli ekologik antikorrozion komponentdir. Uning himoya xususiyati sulfonat, gidroksil va aromatik guruhlarning metall yuzasiga adsorbsiyasi, Ca2+ bilan ko-adsorbsiya va ishqoriy muhitda passiv qatlamni barqarorlashtirish mexanizmlariga tayangan.

Ilmiy manbalar CLSning simulyatsiya qilingan beton g‘ovak eritmasida uzoq muddatli samaradorligi yuqori ekanini ko‘rsatadi: 7200 soatlik sinovdan keyin ham ingibirlash darajasi 93 foizdan yuqori saqlangan. pH 7–9,5 oralig‘ida adsorbsion himoya ustun bo‘lsa, pH 10 atrofidan boshlab passiv oksid-gidroksid qatlam bilan sinergik mexanizm kuchayadi.

Mahalliy xomashyo sifatida g‘o‘zapoya ligninga boy va texnologik jihatdan istiqbolli. Tadqiqotlarda undan ligninni 93–94 foizgacha ajratish imkoniyati ko‘rsatilgan. Shu asosda ligninni ajratish, sulfonatlash, Ca(OH)2 bilan neytrallash, tozalash va qoplama matritsasiga kiritishdan iborat texnologik sxema taklif etildi.

Kelgusida asosiy e’tibor mahalliy CLS uchun standart sifat ko‘rsatkichlarini ishlab chiqish, optimal sulfonatlanish va Ca2+ darajasini aniqlash, po‘lat yuzasida EIS va potentiodinamik sinovlarni o‘tkazish hamda epoksi, fosfat va sement-polimer tizimlarida uzoq muddatli korroziya sinovlarini bajarishga qaratilishi lozim. Ana shunda mahalliy qishloq xo‘jaligi chiqindilarini yuqori qo‘shilgan qiymatli, import o‘rnini bosuvchi korroziyaga bardosh materiallarga aylantirish uchun ilmiy asos yaratiladi.

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ISSN (E): 2992-9148 SJIF 2024 = 5.333 ResearchBib Impact Factor: 10.77 / 2025 VOLUME-4, ISSUE-10

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ISSN (E): 2992-9148
ResearchBib Impact Factor: 9.576 / 2024
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