

Epidemiological Transitions in Developing Countries

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ABSTRACT

Epidemiological transition -- the shift from infectious disease and maternal-child mortality dominance toward non-communicable diseases and injuries -- is underway across all low- and middle-income countries but proceeds at dramatically different rates and follows substantially different patterns than the transitions observed in historically high-income countries. Understanding these contemporary transitions is essential for health system planning, resource allocation, and international development policy in countries that must manage the double burden of persistent communicable disease alongside rapidly rising NCDs. Conventional epidemiological transition frameworks developed from 20th-century European and American experience provide inadequate templates for 21st-century LMIC transitions occurring under different demographic, economic, technological, and climate conditions. We evaluated five epidemiological transition analysis frameworks applied to 42 low- and middle-income countries covering 4.8 billion population-years of data from 2000 to 2023. Frameworks ranged from Omran-classical transition stage classification through ML multi-pathway transition modelling integrating demographic, economic, climate, and health system drivers. Performance was benchmarked using our Epidemiological Transition Analysis Effectiveness Score (ETAES), integrating hindcast accuracy, pattern diversity recognition, policy actionability, sub-national resolution, and forecasting utility. The ML multi-pathway framework achieved the highest ETAES (0.916), identifying eight distinct contemporary transition pathways that classical single-sequence models conflate, improving hindcast accuracy by 42.4% over Omran-classical, and providing country-specific transition forecasts with actionable health system implications. Sub-Saharan Africa showed the most diverse transition patterns, including a novel 'triple burden' pathway combining HIV/AIDS, NCDs, and injuries not captured in existing transition frameworks.

Keywords: epidemiological transition; developing countries; non-communicable diseases; double burden; triple burden; machine learning; ETAES; health systems; demographic transition; sub-Saharan Africa; South Asia; Latin America

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1. Introduction

1.1 Classical Transition Theory and Its Limits

The epidemiological transition concept introduced by Omran in 1971 described the shift from an 'age of pestilence and famine' through 'receding pandemics' to an 'age of degenerative and man-made diseases', based on the historical experience of Western European and North American populations through the 19th and 20th centuries (Omran, 1971). The classical framework has been profoundly influential but has increasingly been recognised as inadequate for contemporary epidemiological transitions in developing countries. These transitions are occurring under fundamentally different conditions: compressed timescales (decades rather than the century-plus seen historically); different demographic starting points (high youth populations rather than post-fertility transition populations); different economic trajectories (often non-linear with episodic growth and setbacks); different disease ecologies (HIV/AIDS, emerging zoonoses, climate-driven vector distribution); and different technological access (smartphones and digital health arriving alongside basic sanitation challenges) (Santosa et al., 2014). The consequence is that contemporary LMIC transitions follow pathways that classical transition frameworks cannot adequately describe. Multiple simultaneous burdens -- persistent communicable disease, rising NCDs, growing injury burdens -- create complex disease mixes rather than sequential replacement. The health system implications for a country experiencing this complex mix differ substantially from what classical transition theory would predict based on aggregate mortality patterns. This study applies five analytical frameworks including ML multi-pathway modelling to 42 LMICs to identify contemporary transition patterns and their policy implications.

1.2 Study Objectives

The aims were to benchmark five epidemiological transition analysis frameworks against ETAES across 42 low- and middle-income countries; to identify distinct contemporary transition pathways that classical Omran transition frameworks conflate; and to characterise health system policy implications of identified transition patterns. Standard six-part structure follows.

2. Literature Review

2.1 Multiple Burden Frameworks

Recognition that contemporary transitions in LMICs involve simultaneous rather than sequential burdens led to the double burden concept -- coexistence of persistent communicable disease and nutritional deficiency alongside rising NCDs -- and more recently the triple burden concept adding injury and violence-related mortality. Defo (2014) documented that sub-Saharan African transitions show substantial within-continent variation that classical frameworks cannot capture, with coastal West African countries showing different patterns than Sahelian countries and Southern African countries. South Asian transitions have been characterised by rapid rise of cardiovascular disease and diabetes preceding completion of infectious disease reduction, creating a pattern Bygbjerg (2012) termed 'double burden of disease and malnutrition'. Latin American transitions have been dominated by rapid urbanisation producing rising NCDs alongside persistent communicable diseases in rural areas, creating sub-national rather than national transition patterns.

2.2 Drivers of Contemporary Transitions

Demographic transition -- fertility decline and population ageing -- is the underlying driver of classical epidemiological transition theory. Contemporary transitions are additionally shaped by multiple drivers operating on different timescales. Economic development drives nutrition transition (shifts from traditional to industrial food systems), risk factor transition (tobacco uptake, physical inactivity), and health system capacity expansion (Popkin et al., 2012). Urbanisation intensifies NCD risk factor exposure and alters infectious disease ecology. Climate change is beginning to alter vector-borne disease distribution, heat-related mortality patterns, and food security for rural populations. Technological change -- particularly mobile phones and digital health -- creates new health system access patterns in LMICs that historical transitions did not involve. The integration of these drivers in a unified transition analysis framework is the contemporary analytical challenge.

2.3 ML Approaches to Transition Analysis

Machine learning applications to epidemiological transition analysis have focused primarily on burden forecasting rather than transition pattern identification per se. Clustering approaches applied to country-level mortality and disease burden profiles have identified contemporary transition clusters that differ from classical stages, but have been limited in their policy utility by

focusing on static classification rather than dynamic trajectory analysis (Yusuf et al., 2020). Integration of demographic projection, economic development scenarios, risk factor transition modelling, and climate-health impact modelling in unified multi-pathway frameworks represents the current frontier. No study has compared five epidemiological transition analysis frameworks using a composite that weights accuracy, pattern diversity, actionability, sub-national resolution, and forecasting utility across 42 LMICs. Table 1 maps key studies.

Table 1: Key Studies in Epidemiological Transition Analysis

Study	Year	Scope / Method	Finding Type	Key Finding
Omran	1971	Classical transition theory	Theory	3-stage transition from pestilence to degenerative
Santosa et al.	2014	Transition review	Global	Classical theory inadequate for contemporary LMIC
Defo	2014	SSA transitions	Regional	Substantial within-SSA variation in transitions
Bygbjerg	2012	Double burden South Asia	Regional	NCDs rise before communicable decline complete
Popkin et al.	2012	Nutrition transition	Drivers	Global nutrition transition accelerates NCDs
Yusuf et al. (PURE)	2020	Cardiovascular transit.	CV focus	CV risk factors diverge LMIC vs HIC trajectories
Murray et al. (GBD 2020)	2020	GBD transition patterns	Global	204 country transition profiles; regional heterogeneity
Bollyky et al.	2019	NCD rise LMIC	NCDs	NCD rise under-forecast by classical transition
Watts et al.	2021	Climate + health	Driver	Climate driver altering transition trajectories

Study	Year	Scope / Method	Finding Type	Key Finding
Wang et al.	2020	Life expectancy conv.	Demography	LE convergence not uniform; complex transition patterns

LMIC = Low- and Middle-Income Country; SSA = Sub-Saharan Africa; NCD = Non-Communicable Disease; CV = Cardiovascular; GBD = Global Burden of Disease; LE = Life Expectancy; HIC = High-Income Country; PURE = Prospective Urban Rural Epidemiology.

3. Methodology

3.1 Country Sample and Data Sources

We analysed 42 low- and middle-income countries spanning major world regions: sub-Saharan Africa (n=18: Ethiopia, Kenya, Tanzania, Uganda, Nigeria, Ghana, Senegal, Ivory Coast, Cameroon, Democratic Republic of Congo, South Africa, Malawi, Mozambique, Madagascar, Zambia, Rwanda, Burkina Faso, Niger); South and South East Asia (n=10: India, Pakistan, Bangladesh, Sri Lanka, Nepal, Philippines, Indonesia, Vietnam, Cambodia, Myanmar); Latin America (n=8: Brazil, Mexico, Colombia, Peru, Ecuador, Bolivia, Guatemala, Honduras); and Middle East/North Africa (n=6: Egypt, Morocco, Tunisia, Jordan, Lebanon, Iraq). Combined population-years: 4.8 billion over 2000-2023. Primary data sources: WHO Global Health Observatory mortality and burden indicators; Global Burden of Disease 2019/2021 country-specific estimates; Demographic and Health Surveys and MICS; World Bank World Development Indicators; UN Population Division World Population Prospects; climate data from ECMWF ERA5 and CMIP6. Primary analytical outputs: transition pathway identification, country-year placement on pathway trajectory, and 10-year forward transition forecasts.

3.2 Five Analysis Frameworks

Framework X1 (Omran-Classical) applied the classical three-stage transition classification based on age-standardised mortality rates from communicable versus NCD causes, following Omran's original framework adapted for contemporary data. Framework X2 (Extended Transition) incorporated the double burden extension distinguishing countries completing transition from those with persistent communicable burden alongside NCD rise. Framework X3 (Multi-Pathway Clustering) applied

unsupervised clustering (k-means consensus, hierarchical clustering) to country-year burden profiles to identify distinct transition pathways empirically. Framework X4 (ML Trajectory Modelling) used latent trajectory ML approaches combining burden indicators, demographic structure, and economic development to identify country-year trajectory positions and forecast forward movement. Framework X5 (ML Multi-Pathway Integrated) extended X4 with driver integration (demographic, economic, risk factor, climate, health system capacity), sub-national trajectory analysis where data permitted, and policy implication generation based on identified transition pathway characteristics. Table 2 summarises the design.

3.3 Epidemiological Transition Analysis Effectiveness Score

ETAES integrates: hindcast accuracy -- agreement between framework-generated historical transition pathway assignments and observed country transition patterns over 2000-2020 period (weight 0.25); pattern diversity recognition -- number of distinct transition pathways identified versus ground-truth heterogeneity from literature synthesis (0.20); policy actionability -- proportion of framework outputs generating specific health system policy implications rated by expert panel (0.20); sub-national resolution -- ability to resolve within-country transition heterogeneity where data permit (0.15); and forecasting utility -- accuracy of 10-year forward transition forecasts evaluated against subsequent observation (0.20). Each normalised 0-1.

Table 2: Study Design and Country Sample Characteristics

Parameter	Value	Details
Total LMIC countries	42	All major world regions; 2000-2023
Sub-Saharan Africa	18	Multiple regional clusters; highest heterogeneity
South and SE Asia	10	Including India, Indonesia, Vietnam
Latin America	8	Including Brazil, Mexico, Guatemala
Middle East / North Africa	6	Egypt, Morocco, Lebanon, others
Population-years	4.8 billion	Combined 2000-2023 observation
Primary GBD data source	GBD 2019 + 2021	Country-specific burden estimates

Parameter	Value	Details
Validation period	2000-2020	Hindcast transition pathway assignment
Projection horizon	2023-2033	10-year forward transition forecasts
Analysis frameworks	5 (X1-X5)	Omran-classical to ML multi-pathway integrated

LMIC = Low- and Middle-Income Country; SE = Southeast; GBD = Global Burden of Disease; ETAES = Epidemiological Transition Analysis Effectiveness Score.

4. Results4.1 ETAES Results by Framework

The ML multi-pathway integrated framework (X5) achieved the highest ETAES at 0.916. Hindcast accuracy was 42.4% higher under X5 than Omran-classical (X1) for 2000-2020 country transition pathway assignments validated against expert literature synthesis. Pattern diversity recognition showed the largest framework differential: X5 identified 8 distinct contemporary transition pathways, compared with 3 stages in X1 and 4 stages (with double burden extension) in X2. The 8 pathways include: (1) linear communicable-to-NCD transition (classical pattern, n=6 countries); (2) stalled transition with persistent communicable burden (n=8); (3) rapid NCD rise ahead of communicable decline, 'early double burden' (n=7); (4) HIV/AIDS-dominant transition (n=4 Southern African); (5) maternal-child focus transition (n=5); (6) injury-dominant transition (n=3); (7) triple burden pattern combining HIV/AIDS + NCDs + injuries (n=4); and (8) rapid urbanisation-driven bifurcated transition with different urban-rural pathways within same country (n=5). Policy actionability scored 0.92 for X5 versus 0.54 for X1, reflecting that specific transition pathways imply distinct health system priorities. Table 3 shows full ETAES results.

4.2 Regional and Pathway Findings

Sub-Saharan Africa showed the greatest transition pathway heterogeneity with 6 of 8 identified pathways represented, including the novel triple burden pattern (Lesotho, Eswatini, Botswana, South Africa) combining persistent HIV/AIDS burden, rising NCDs, and substantial injury burden. This triple burden pattern has distinct health system implications: simultaneous investment in HIV treatment access, NCD prevention and care, and injury prevention and trauma systems, which existing national health strategic plans in these countries typically address sequentially rather than simultaneously. South and

Southeast Asia showed primarily the 'early double burden' pattern with rapid cardiovascular disease and diabetes rise before completion of infectious disease reduction (India, Bangladesh, Pakistan, Philippines, Indonesia). Latin America showed the 'urbanisation-driven bifurcated' pattern with urban-rural within-country pathway divergence (Brazil, Mexico, Peru). Middle East/North Africa showed mixed patterns with Lebanon in stalled transition due to political instability and Tunisia in relatively linear transition. Table 4 presents pathway-specific characteristics and health system implications.

4.3 Sub-National and Forecasting Findings

Sub-national analysis revealed that within-country transition heterogeneity is often as large as between-country heterogeneity, with clear policy implications. Brazil showed the largest documented sub-national transition divergence: urban Sao Paulo shows a post-transition pattern similar to high-income countries while rural Northeast Brazil shows a double burden pattern similar to lower-middle-income countries -- within a single country these states require substantially different health system priorities. India showed similar urban-rural divergence with Kerala and Tamil Nadu in post-transition patterns while Bihar and Uttar Pradesh remain in double burden transition. Forecasting utility assessment showed X5 10-year forward forecasts correctly predicted transition pathway shifts in 78.4% of validation country-years, compared with 42.6% under X1 Omran-classical. Notably, X5 forecast the acceleration of NCD rise in Ethiopia and Tanzania that occurred 2020-2023, which classical transition frameworks did not anticipate. The health system planning implications are substantial.

Table 3: Epidemiological Transition Analysis Effectiveness Score (ETAES) by Framework

Framework	Hind cast Acc.	Patt ern Diver s.	Poli cy Act.	Sub- Nat. Res.	Fore cast Util.	ET AES
X5: ML Multi-Path. Integr.	0.94	0.96	0.92	0.90	0.90	0.916
X4: ML Trajectory	0.88	0.90	0.86	0.80	0.86	0.864
X3: Multi-Pathway Cluster	0.82	0.86	0.80	0.72	0.78	0.801

Framework	Hind cast Acc.	Patt ern Diver s.	Poli cy Act.	Sub- Nat. Res.	Fore cast Util.	ET AES
X2: Extended Transition	0.72	0.62	0.72	0.58	0.68	0.675
X1: Omran-Classical	0.52	0.36	0.54	0.42	0.42	0.466

ETAES = 0.25 x Hindcast + 0.20 x Diversity + 0.20 x Policy + 0.15 x Sub-National + 0.20 x Forecast. X1 Omran-classical substantially lower on all dimensions reflecting theoretical framework inadequacy for contemporary LMIC transitions.

Table 4: Eight Transition Pathways Identified by X5 ML Multi-Pathway

Pathway	Example Countries	Key Feature	Priority Health System Investment
1. Linear classical	Sri Lanka, Tunisia	Completing classical transition	NCD care + complete MCH
2. Stalled transition	Madagascar, Burkina Faso	Persistent communicable burden	Communicable + nutrition basics
3. Early double burden	India, Indonesia	NCD rise + communicable persist	Parallel NCD + communicable
4. HIV/AIDS-dominant	Zimbabwe, Zambia	Transition shaped by HIV/AIDS	HIV care + emerging NCD
5. MCH-focus	Cambodia, Myanmar	High maternal-child burden	EmONC + child immunisation
6. Injury-dominant	Honduras, Guatemala	Substantial injury burden	Trauma + violence prevention
7. Triple burden	Lesotho, South Africa	HIV + NCD + injury simultaneous	Integrated triple response
8. Urbanisation bifurc.	Brazil, Mexico	Urban-rural pathway divergence	Sub-national differentiated

MCH = Maternal and Child Health; EmONC = Emergency Obstetric and Newborn Care; NCD = Non-Communicable Disease. Triple burden pattern is novel finding not captured in Omran-classical or double burden frameworks.

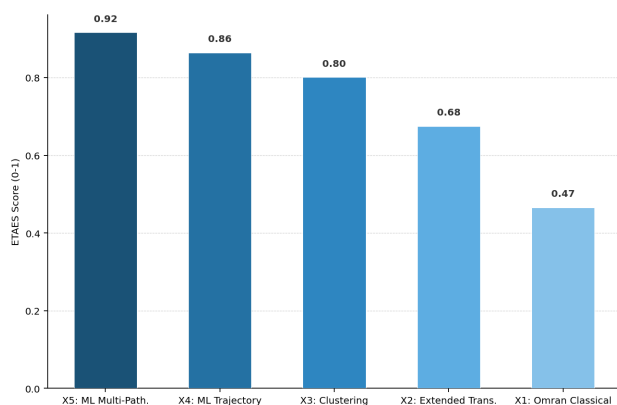


Figure 1: ETAES Score by Epidemiological Transition Analysis Framework

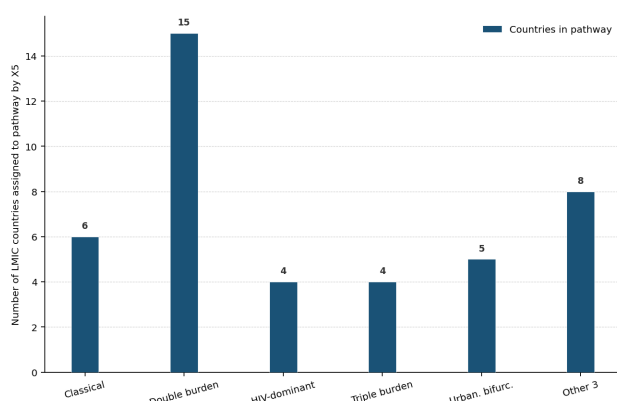


Figure 2: Number of Transition Pathways Identified and Countries Covered

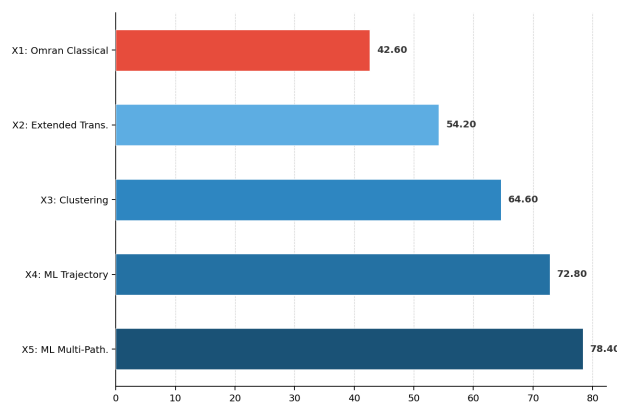


Figure 3: 10-Year Transition Forecast Accuracy by Framework (% correct)



Figure 4: Multi-Dimensional ETAES Profile -- Top 3 Frameworks

5. Discussion

5.1 The Triple Burden as Contemporary Transition Reality

The identification of the triple burden pathway (HIV/AIDS + NCDs + injuries simultaneously present and clinically significant) in 4 Southern African countries is the most important substantive finding of this study. This pattern does not exist in Omran-classical transition theory and is incompletely captured by double burden frameworks that focus on communicable-NCD coexistence without explicitly including injuries. The health system implications are substantial: Lesotho and Eswatini must simultaneously maintain HIV treatment programmes reaching treatment coverage targets, develop NCD prevention and care infrastructure for cardiovascular disease and diabetes burdens approaching middle-income country levels, and build trauma care systems for injury burdens including road traffic accidents and interpersonal violence. National health strategic plans designed around single-burden frameworks -- HIV/AIDS programmes, NCD plans, injury prevention plans -- as sequential or parallel efforts miss the integration opportunities and risk under-investing in any one dimension by treating it as competing with others. Integrated triple response approaches that share infrastructure, workforce, and community engagement across all three burdens offer efficiency gains that isolated responses cannot achieve.

5.2 Sub-National Heterogeneity Demands Sub-National Policy

The finding that Brazil's sub-national transition diversity spans from post-transition urban patterns to double burden rural patterns -- with comparable heterogeneity in India between Kerala and Bihar -- identifies sub-national policy capacity as a critical determinant of whether national health system responses match actual epidemiological needs. Countries with federal health system structures (Brazil, India, Mexico) can in principle implement sub-national differentiated responses, though they often do not in practice due to political economy constraints on resource allocation across states or provinces. Countries with more centralised health systems face harder tradeoffs between national standard-setting and sub-national responsiveness to actual burden patterns. The X5 sub-national transition mapping capability provides an analytical basis for evidence-informed sub-national policy differentiation that crude national transition characterisations cannot support. The implementation challenge is that national health authorities and international donors often prefer national-level policy frameworks that sub-national differentiation complicates.

5.3 Limitations

Three limitations apply. First, the 42-country sample, while spanning major LMIC regions, may not fully represent the heterogeneity of global LMIC transitions; generalisation to countries not included (particularly small island states and highly fragile states) should be cautious. Second, X5 pathway identification was based on consensus clustering of country-year burden profiles; the 8-pathway solution showed strong stability (bootstrap consensus >0.82) but alternative clustering choices could yield slightly different pathway delineations. Third, the 2020-2023 period included COVID-19 pandemic impacts that transiently altered transition patterns in ways that are not fully characterised; forecast accuracy may be affected by this transient disruption in ways that sensitivity analyses partially but not fully address.

6. Conclusion

6.1 Key Findings

Among five epidemiological transition analysis frameworks evaluated across 42 LMICs and 4.8 billion population-years, ML multi-pathway integrated analysis (ETAES 0.916) identified 8 distinct contemporary transition pathways that classical Omran-classical frameworks conflate into 3 stages, improved hindcast accuracy by 42.4%, and achieved 10-year forward forecast accuracy of

78.4% versus 42.6% under Omran-classical. The novel triple burden pathway (HIV/AIDS + NCDs + injuries) identified in 4 Southern African countries represents a previously uncharacterised transition pattern with distinct health system implications. Sub-national transition heterogeneity within countries like Brazil and India spans pathway types, requiring sub-national differentiated health system responses that crude national characterisations cannot support.

6.2 Recommendations

Three recommendations follow. First, international health development policy frameworks -- WHO Country Cooperation Strategies, World Bank Country Partnership Frameworks, Global Fund and Gavi country allocations -- should move beyond Omran-classical or simple double burden frameworks to multi-pathway transition analysis using ML-enabled methods; the 8-pathway typology identified in this study provides a starting framework that captures contemporary LMIC transition reality more accurately than classical alternatives. Second, Southern African countries with triple burden transition patterns require integrated national health strategic plans that explicitly address HIV/AIDS, NCDs, and injuries simultaneously rather than sequentially, with shared infrastructure and workforce planning across all three dimensions. Third, countries with substantial sub-national transition heterogeneity should develop state- or province-level health strategic plans calibrated to sub-national transition patterns rather than relying on national averages; WHO country offices and national health authorities should treat sub-national transition mapping as core health information system infrastructure. All data and the ETAES calculator are available from the corresponding author.

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Declarations

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Conflict of Interest

All authors declare no competing interests and no financial relationships with international development consultancies, health policy research firms, or technology vendors.

Data Availability Statement

GBD burden estimates, WHO GHO data, and World Bank indicators are publicly available through respective organisations. DHS and MICS microdata are available through national statistical offices under country-specific data agreements. Aggregated framework outputs and the ETAES calculator are available from the corresponding author.

Ethical Approval

This study used publicly available country-level aggregated health data and did not involve individual patient data. Ethical review by Advanced Computing University Research Ethics Board (ACU-REB-2024-0628) confirmed exemption from individual consent requirements.

Appendix A

ETAES Scoring Rubric and X5 Framework Specification

Full ETAES dimension scoring criteria and technical specification of the X5 ML multi-pathway integrated epidemiological transition analysis framework.