Exposome-Driven Precision Medicine: Integrating Environmental and Health Data into Digital Healthcare Frameworks in Pakistan
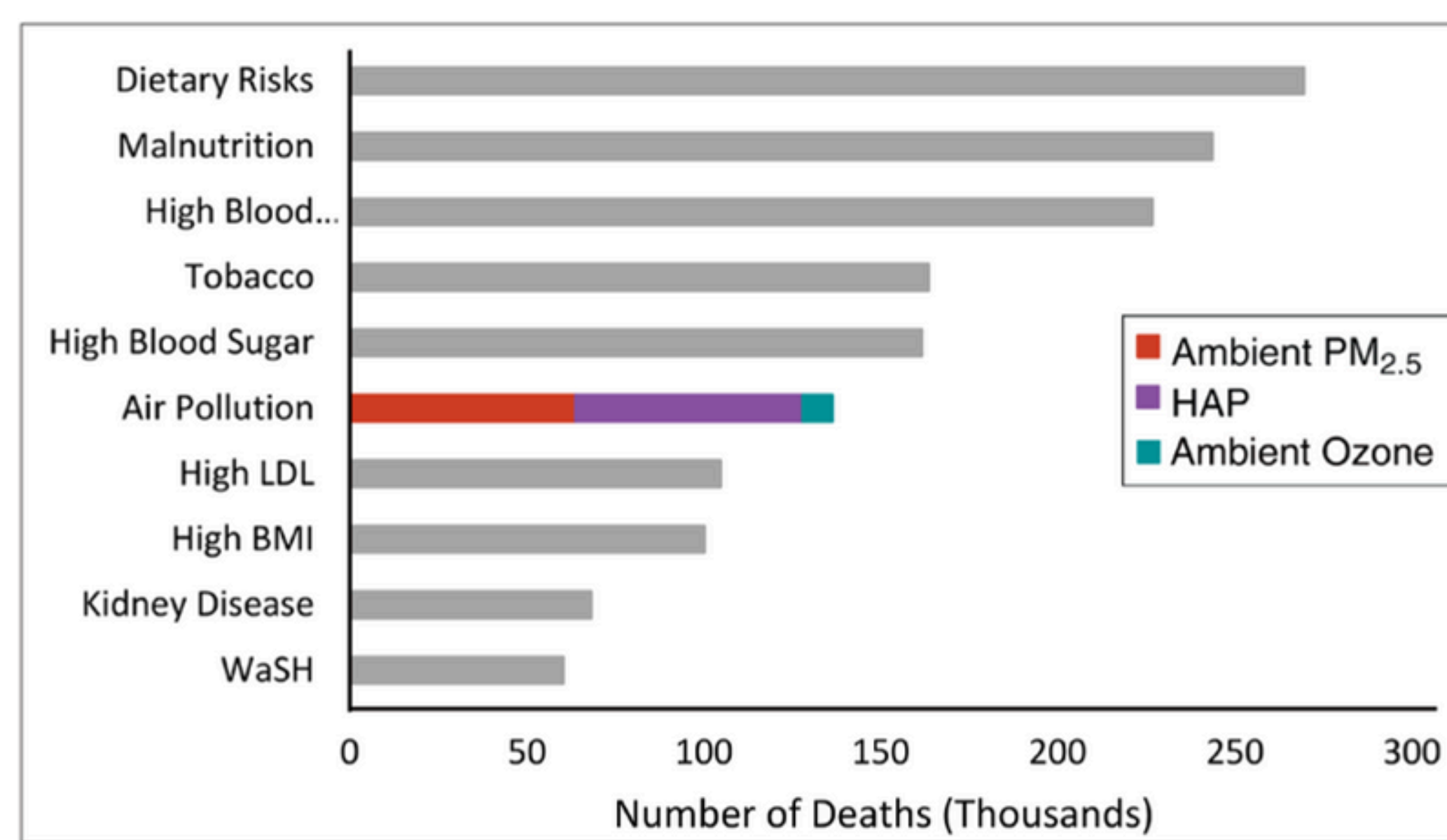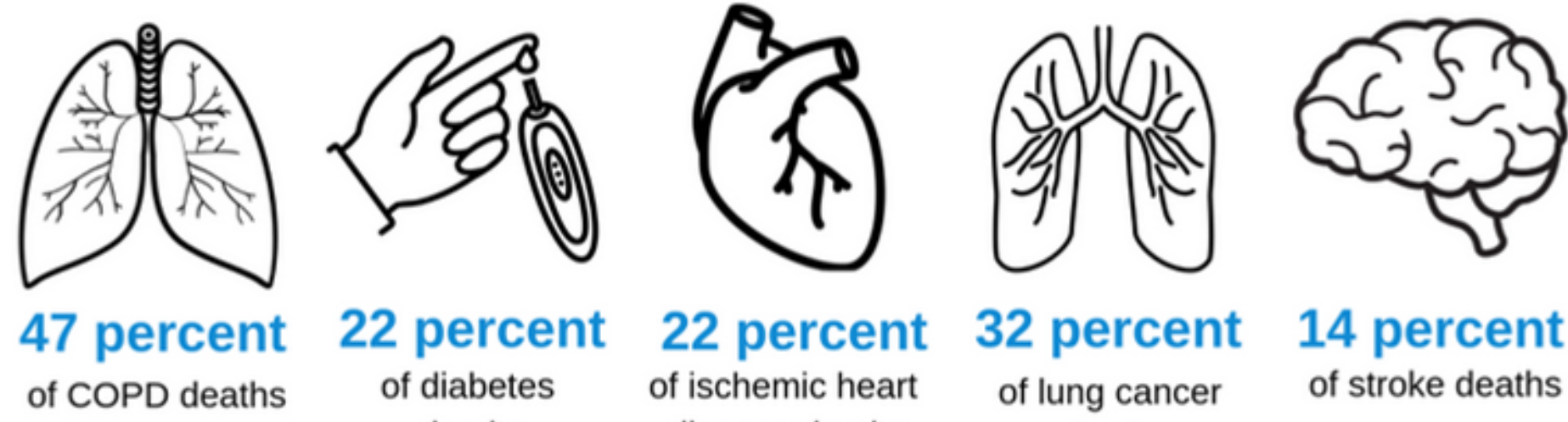
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Introduction

Environmental exposures, such as air pollution, water contamination, and occupational hazards, contribute significantly to non-communicable diseases (NCDs) in Pakistan, accounting for 58% of deaths. Air pollution alone causes 128,000 premature deaths annually, with exposure to particulate matter (PM2.5) and household air pollution linked to increased hospitalizations, cardiovascular diseases, and respiratory conditions (WHO, 2024). Despite this, environmental data remains underutilized in clinical decision-making, limiting the potential of precision medicine (Fig. 1). Integrating real-time environmental data with patient health records is essential for improving disease prediction, personalized care, and early intervention in Pakistan's healthcare system (State of Global Air, 2019).

Percentage of deaths by cause attributed to air pollution in Pakistan.

47 percent of COPD deaths
22 percent of diabetes deaths
22 percent of ischemic heart disease deaths
32 percent of lung cancer deaths
14 percent of stroke deaths

Leading risk factors for death and disability in Pakistan in 2017 (State of Global Air, 2019).

Legend: Ambient PM2.5, HAP, Ambient Ozone

X-axis: Number of Deaths (Thousands), 0 to 300
Categories: Dietary Risks, Malnutrition, High Blood..., Tobacco, High Blood Sugar, Air Pollution, High LDL, High BMI, Kidney Disease, WaSH
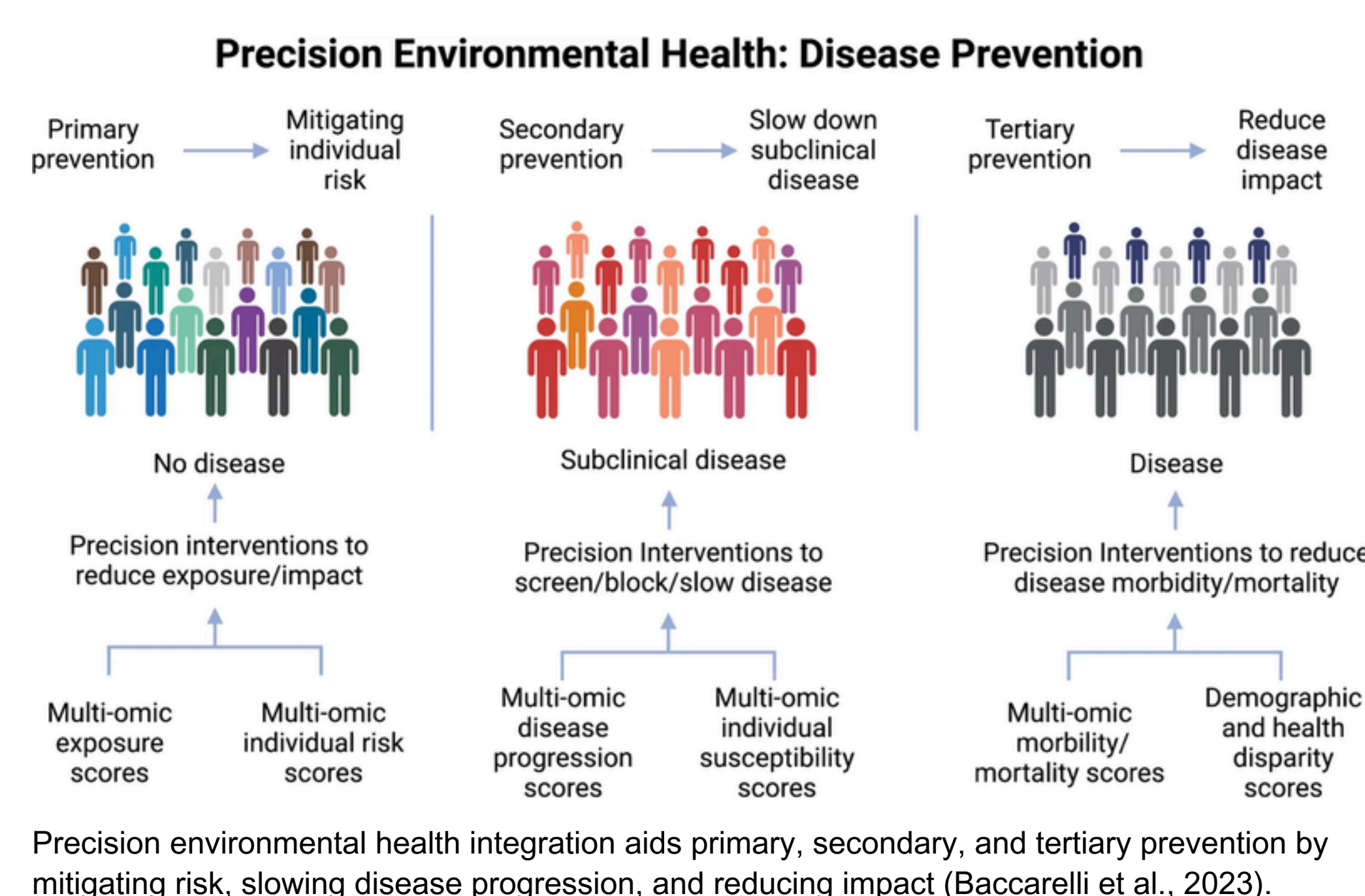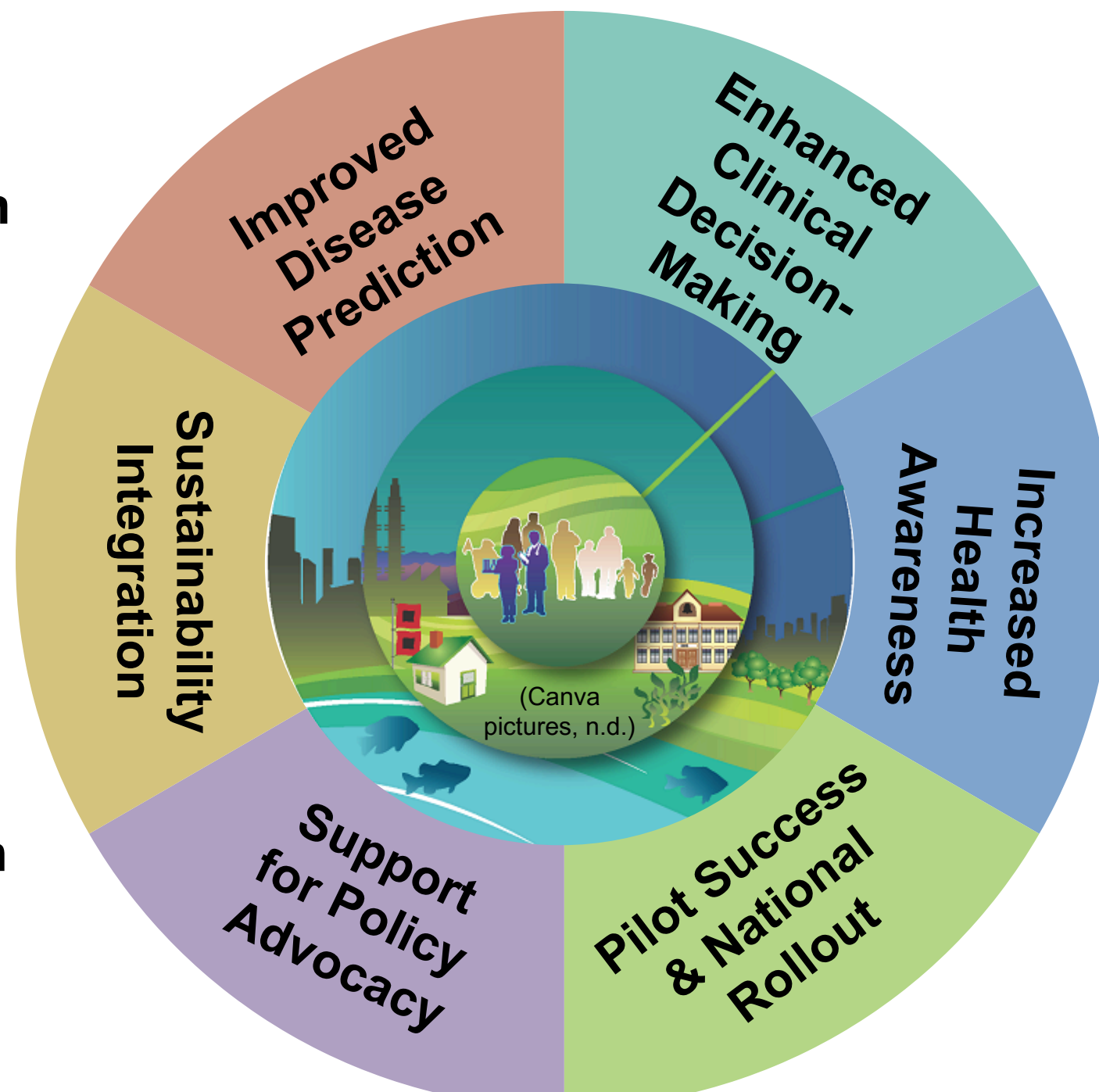
Aim

This project aims to develop a framework for the Pakistan Exposome Dashboard, integrating real-time environmental data (e.g., air quality, water contaminants) with health data in Pakistan's healthcare system. It will improve disease prediction, risk stratification, and clinical decision-making, while supporting health awareness and policy advocacy to enhance precision medicine and chronic disease prevention.

Results

The Pakistan Exposome Dashboard framework:

- Integrates real-time environmental data with health records, enhancing disease prediction, clinical decision-making, and health awareness.
- Proposes pilot testing at Aga Khan University Hospital to demonstrate effective interventions for high-risk patients.
- Supports policy advocacy, aligns with national health strategies, and ensures long-term sustainability.

(Canva pictures, n.d.)

Wheel: Improved Disease Prediction, Enhanced Clinical Decision-Making, Increased Health Awareness, Pilot Success & National Rollout, Support for Policy Advocacy, Sustainability Integration

Precision Environmental Health: Disease Prevention

Primary prevention → Mitigating individual risk — No disease
Precision interventions to reduce exposure/impact
Multi-omic exposure scores, Multi-omic individual risk scores

Secondary prevention → Slow down subclinical disease — Subclinical disease
Precision Interventions to screen/block/slow disease
Multi-omic disease progression scores, Multi-omic individual susceptibility scores

Tertiary prevention → Reduce disease impact — Disease
Precision Interventions to reduce disease morbidity/mortality
Multi-omic morbidity/mortality scores, Demographic and health disparity scores

Precision environmental health integration aids primary, secondary, and tertiary prevention by mitigating risk, slowing disease progression, and reducing impact (Baccarelli et al., 2023).

Methods

The Exposome-Driven Precision Medicine framework for integrating environmental and health data into Pakistan's healthcare system follows a multi-phase approach, ensuring realistic implementation, feasibility, and scalability. This methodology is designed to integrate real-time environmental data with patient health data to improve disease prediction, clinical decision-making, and health outcomes.

Phase 01:
Key Players:
- Healthcare Providers, Environmental Health Specialists, IT/EHR System Providers, Policymakers, CHWs.

Actions:
- Identify and secure sources of environmental exposure data from relevant agencies like EPA, WHO, and UNICEF.
- Stakeholder Engagement: Assess environmental data integration into EHR.
- Feasibility Study: Evaluate infrastructure and data compatibility.
- Funding: Secure support from WHO, UNICEF, and national agencies.

Phase 02:
Actions:
- Develop Dashboard: Integrate environmental data (e.g., PM2.5, NO$_2$, SO$_2$) with patient health data.
- Development of risk assessment documents based on the environmental factors feeding into the dashboard.
- Development of clinical interpretation and application standards per exposure-disease interaction/risk.

Dashboard Features:
- Real-Time Integration: Visualize air quality, water contaminants, and hazards.
- User Interface: Simple, actionable design.
- Data Visualization: Clear graphs and alerts.
- Technology: Web-based, mobile-friendly, EHR integration.

Phase 03:
Actions:
- Expand: Deploy to 5-7 hospitals in high-risk areas.
- Refine: Improve interface and data integration based on feedback.
- Engage Community Health Workers: Involve CHWs in data collection and education.

System Refinements:
- Optimize: Enhance dashboard usability.
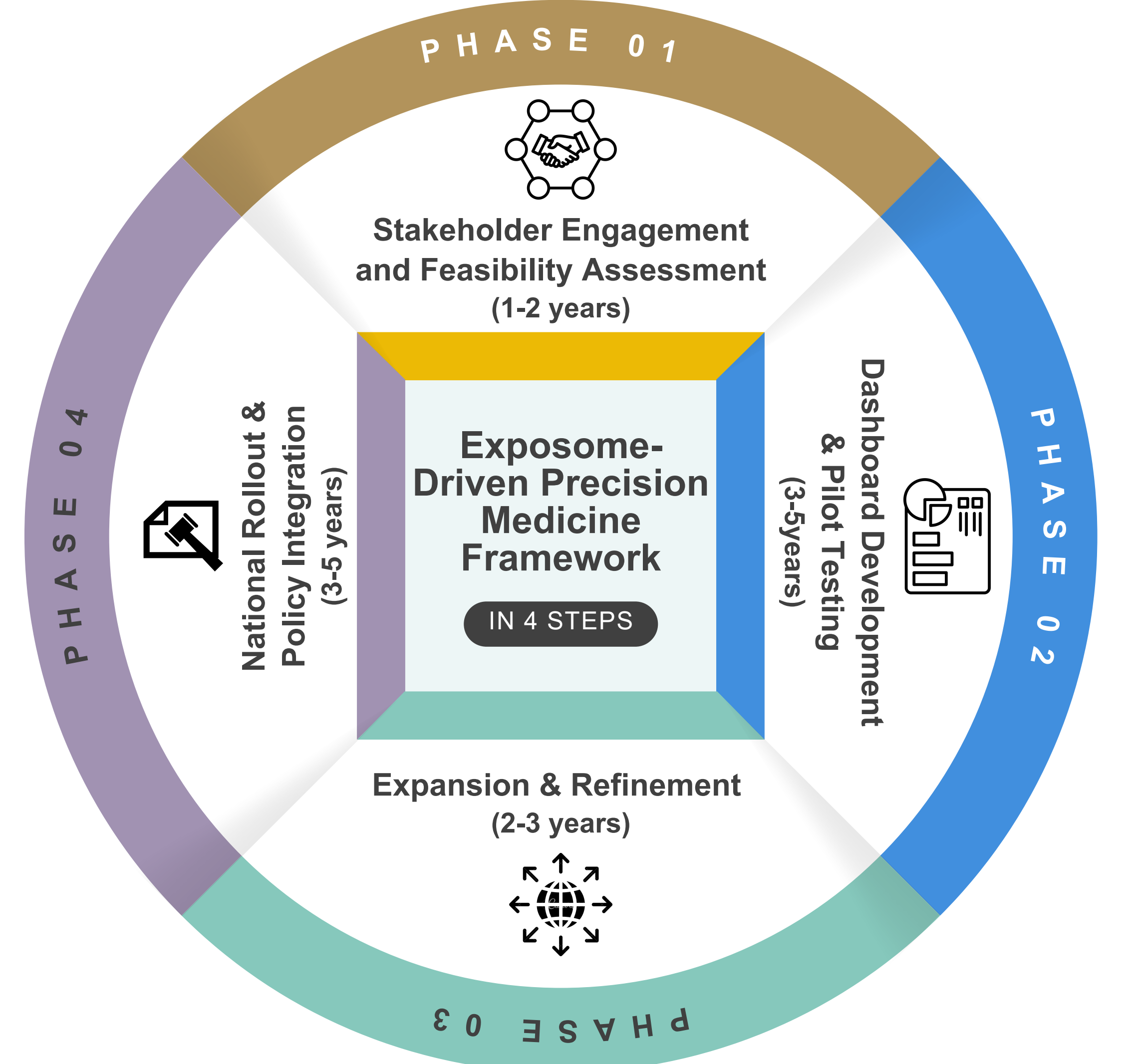- Enhance Integration: Improve data accuracy for better disease prediction and intervention.

Phase 04:
Actions:
- Scale Nationwide: Deploy to hospitals in urban and rural areas.
- Integrate with National Policies: Align with health strategies for long-term integration.
- Ensure Sustainability: Ongoing training, updates, and technical support.

Sustainability Plan:
- Develop a long-term plan for data accuracy and system maintenance.
- Integrate the dashboard into public health strategies for lasting impact.

PHASE 01 — Stakeholder Engagement and Feasibility Assessment (1-2 years)
PHASE 02 — Dashboard Development & Pilot Testing (3-5 years)
PHASE 03 — Expansion & Refinement (2-3 years)
PHASE 04 — National Rollout & Policy Integration (3-5 years)

Exposome-Driven Precision Medicine Framework IN 4 STEPS

(Medical Advantage, n.d.)

(Canva pictures, n.d.)

Dashboard Overview
- Air Quality Indices: Visualize PM2.5, NO$_2$, and SO$_2$ levels with color-coded risk indicators for quick assessment.
- Water Contaminants: Display contamination levels for arsenic and microbial contaminants by region.
- Health Data Integration: Correlate environmental exposures with patient outcomes (e.g., asthma exacerbations, cardiovascular events).
- guidance for therapeutic or intervention decisions based on exposure-health interactions.

Conclusion

- The framework for a Pakistan Exposome-Driven Precision Medicine dashboard integrates environmental data with health records to enhance disease prediction, clinical decision-making, and personalized care plans.
- Pilot testing at Aga Khan University Hospital will demonstrate the system's effectiveness in urban and rural settings, improving health awareness and supporting policy advocacy.
- By aligning with national health policies, the project will ensure long-term sustainability and scalability, transforming chronic disease management and healthcare delivery across Pakistan.

Fig. 1
(Vrijheid, 2014)
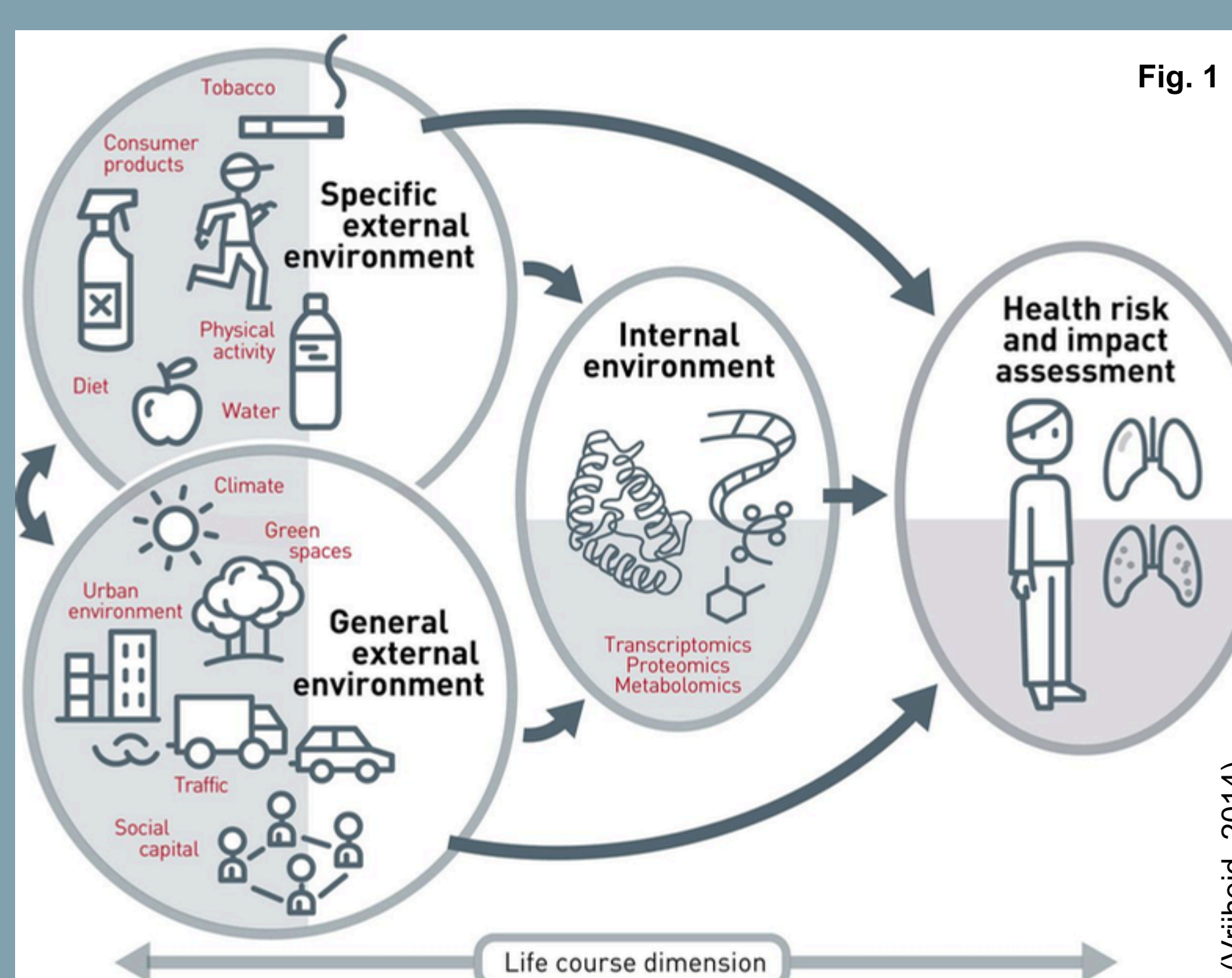
For More Information:

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Acknowledgement and References

1. Baccarelli, A., Dolinoy, D. C., & Walker, C. L. (2023). A precision environmental health approach to prevention of human disease. Nature communications, 14(1), 2449. https://doi.org/10.1038/s41467-023-37626-2
2. State of Global Air. (2019). Pakistan: Air pollution is the 6th leading risk factor for mortality. State of Global Air. https://www.stateofglobalair.org/sites/default/files/soga_2019_pakistan.pdf
3. Vrijheid M. (2014). The exposome: a new paradigm to study the impact of environment on health. Thorax, 69(9), 876–878. https://doi.org/10.1136/thoraxjnl-2013-204949
4. World Health Organization. (2024). Air quality and health. WHO. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health