

Architecture for Real-Time Air Quality Monitoring and Personalized Health Recommendations in Bogotá

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Abstract

Air pollution is a critical public health challenge in Bogotá. This work presents a **production-ready architecture** for real-time air quality monitoring that integrates heterogeneous data sources (AQICN, Google Air Quality API, IQAir) into a unified PostgreSQL schema with **sub-150ms query latencies** and personalized health recommendations.

Key achievements:

- 3NF database schema (8 entities)
- 85,000+ readings processed
- 216 readings/hour ingestion rate
- EPA/WHO compliant recommendations

Problem Statement

Bogotá residents lack access to integrated air quality data across multiple monitoring sources. Current systems are:

- **Fragmented:** Multiple platforms with inconsistent formats
- **Not personalized:** No health guidance for vulnerable groups
- **Technical:** Complex indicators (PM_{2.5}, AQI, NO₂)
- **Quota-limited:** API restrictions complicate monitoring
- **Delayed:** Hourly aggregations miss rapid events

Impact: 8 million residents exposed to PM_{2.5} levels exceeding WHO guidelines (13.1 vs 5 µg/m³).

Key Objectives

Primary Goal: Design a centralized platform integrating multi-source air quality data with personalized recommendations.

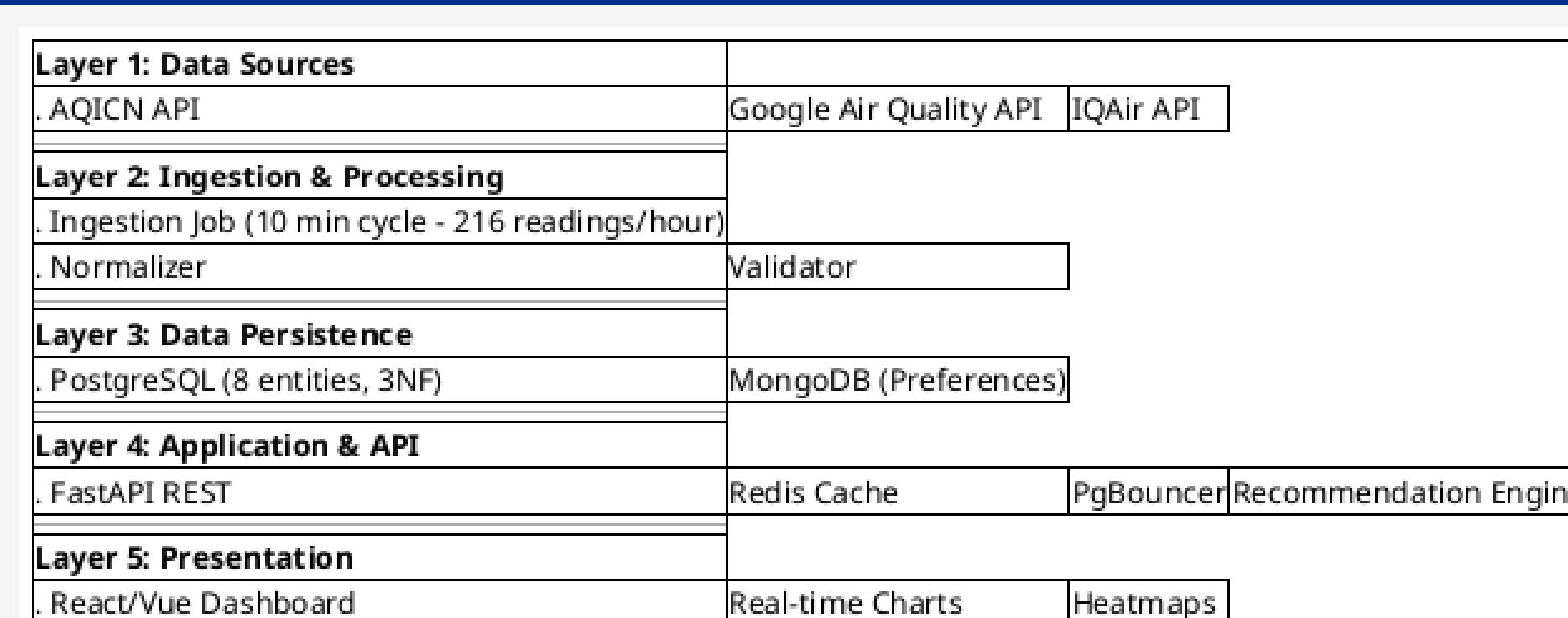
Specific Objectives:

- **O1:** Scalable PostgreSQL architecture with temporal partitioning
- **O2:** Unified ingestion pipeline (10-min cycle)
- **O3:** Sub-200ms query performance
- **O4:** Rule-based recommendation engine
- **O5:** REST API with pagination support
- **O6:** Performance validation & benchmarking

Database Schema (3NF)

Database Schema - 8 Entities (3NF)		
Geospatial & Monitoring		
Station	Pollutant	Provider
AirQualityReading	AirQualityDailyStats	
Users & Access		
AppUser	Alert	Recommendation
Key Features:		

System Architecture (5 Layers)



Layer 1 – Data Sources:

- AQICN, Google Air Quality API, IQAir

Layer 2 – Ingestion:

- APScheduler (10-min cycle)
- 216 readings/hour (6 stations × 6 pollutants)
- JSON validation & normalization

Layer 3 – Persistence:

- PostgreSQL (3NF, 8 entities)
- MongoDB (user preferences)

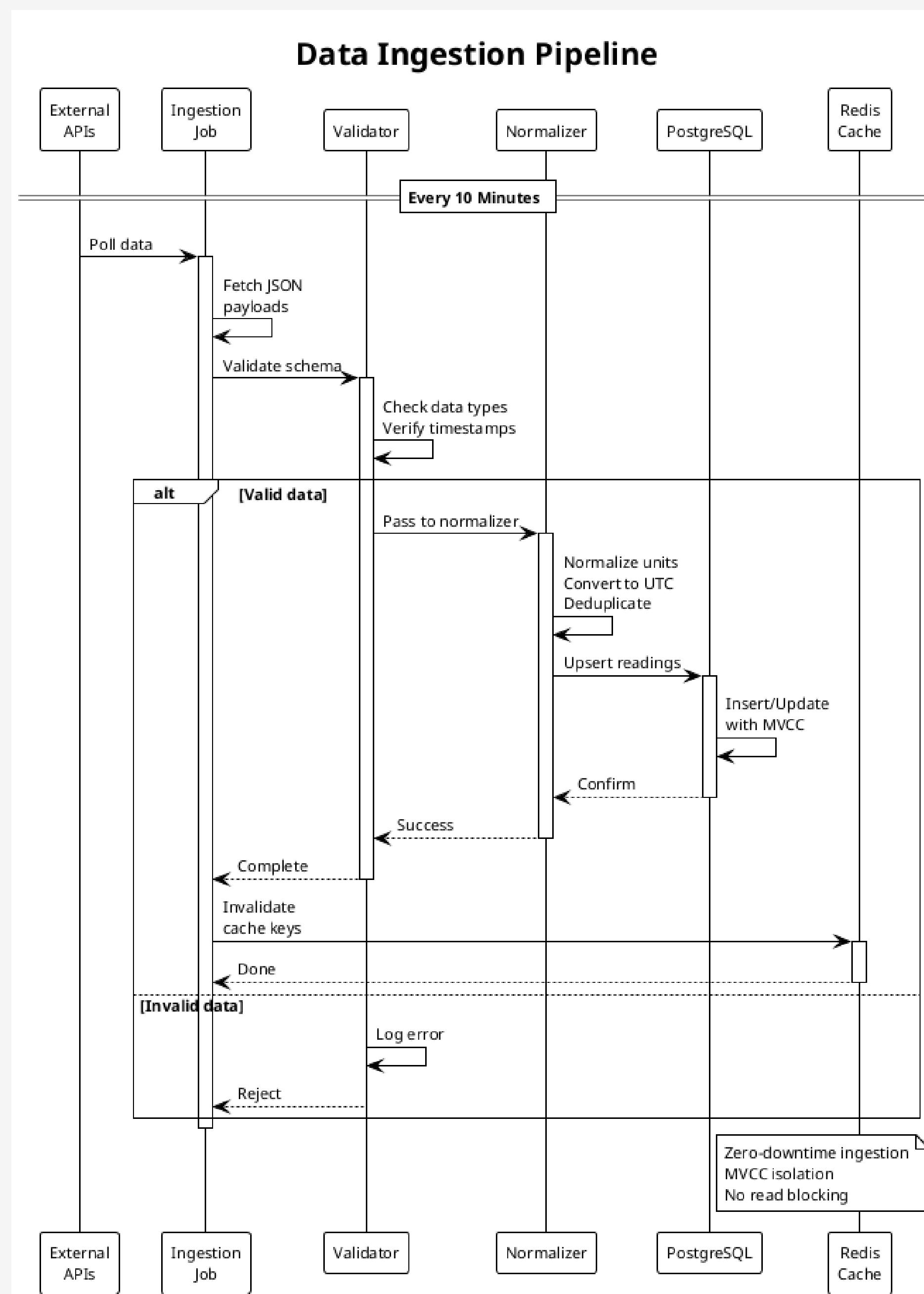
Layer 4 – Application:

- FastAPI REST endpoints
- Redis cache (5-10 min TTL)
- PgBouncer connection pooling
- Rule-based recommendation engine

Layer 5 – Presentation:

- React/Vue.js dashboard
- Real-time charts & heatmaps

Data Ingestion Pipeline



Pipeline Features:

- **Validation:** Pydantic schema validation
- **Normalization:** UTC timestamps, canonical units
- **Deduplication:** Identifies identical readings

Query Performance Results

Query Performance (85,000 readings)		
Q1: Latest Readings	42.8 ms	✓
Q2: Monthly Averages	127.3 ms	✓
Q3: Active Alerts	143.6 ms	✓
Q4: Data Completeness	87.5 ms	✓
Q5: Recommendations	73.9 ms	✓

Optimization Techniques:

- Composite B-tree indexes
- Temporal partitioning (30.2% improvement)
- Materialized views (35× row reduction)
- Redis caching (5-10 min TTL)

Performance on 85,000 readings:

Query	Latency	Status
Q1: Latest readings	42.8 ms	✓
Q2: Monthly averages	127.3 ms	✓
Q3: Active alerts	143.6 ms	✓
Q4: Data completeness	87.5 ms	✓
Q5: Recommendations	73.9 ms	✓

All queries ; 150ms validated with EXPLAIN ANALYZE

Scalability & Performance

Scalability & Performance		
Current Performance:		
50-100 concurrent users		
70-75% CPU usage		
Sub-150ms latency		
140 req/sec throughput		
Scaling Strategies:		
Vertical: 8+ vCPUs → 1,000+ users		
Horizontal: Read replicas + Load balancer		
Partitioning: Monthly tables (78% improvement)		
10-Year Projection:		
525M+ readings		
Partition pruning		
Consistent sub-200ms latency		

Current Capacity:

- 50–100 concurrent users
- 70–75 % CPU usage
- Sub-150ms latency
- 140 requests/second throughput

Scaling Strategies:

- **Vertical:** 8+ vCPUs → 1,000+ users
- **Horizontal:** Read replicas + load balancer
- **Partitioning:** 78 % latency improvement

10-Year Projection:

- 525M+ readings supported
- Partition pruning maintains performance
- Consistent sub-200ms latency