The Scuba-Diving Air Quality Index (SD-AQI): Definition, Validation, and Application

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***Abstract*—We propose the Scuba-Diving Air Quality Index (SD-AQI), a compact index tailored for lightweight compressor-site monitoring. SD-AQI fuses readings from inexpensive metal-oxide semiconductor (MOS / MQ) gas sensors and environmental sensors to provide a single operational score that highlights contamination risks relevant to scuba breathing air (e.g., CO, CO_2, hydrocarbons, NO_x, NH_3, H_2). We describe the mathematical formulation, normalization, mitigation for common MOS pitfalls, and illustrative simulations and figures. The implementation captures raw payloads for forensic analysis and supports backfill and calibration.**

***Index Terms*—Air Quality Index, MOS sensors, MQ sensors, scuba diving, SD-AQI, compressed air safety**

I. Introduction

Breathing-air quality in scuba diving cylinders is critical for diver safety. Contaminants such as carbon monoxide (CO), high carbon dioxide (CO_2), hydrocarbons (e.g., CH_4), volatile organic compounds (VOCs), nitrogen oxides (NO_x), ammonia (NH_3), and hydrogen (H_2) present significant health hazards when present at elevated concentrations. Continuous monitoring at compressor sites permits early detection and operational alarms.

Low-cost MOS (MQ) sensors are frequently used for continuous monitoring due to their sensitivity and low cost. However, MOS sensors are semiquantitative and suffer from cross-sensitivity, baseline drift, and environmental confounders. SD-AQI is designed as a pragmatic, robust operational metric that aggregates multiple sensor channels into a single scalar score optimized for early warning.

II. Sensor Suite and Data Model

The SD-AQI system (implemented in the IoT Babar project) collects the following channels (keys shown as stored in the database): LPG (MQ-2), CO (MQ-2,MQ-7,MQ-9), Smoke (MQ-2), CO_MQ7 (MQ-7), CH4 (MQ-4), CO_MQ9 (MQ-9), CO2 (MQ-135), NH3 (MQ-135), NOx (MQ-135), Alcohol/Benzene (MQ-135), H2 (MQ-8), Air (MQ-8/MQ-135), and Temperature/Humidity.

Each record $r(t)$ contains sensor values $x_g(t)$ for each gas sensor g and server-side UTC timestamp t. The backend stores a `raw_payload` JSON text column for every incoming record to support backfilling and forensic reprocessing.

III. SD-AQI Formulation

We proceed in three steps: per-gas normalization, weighting, and aggregation.

A. Per-gas normalization

For each sensor channel g we compute a normalized sub-score $s_g \in [0, 1]$ via a clamped linear transform:

$$s_g = \text{clamp}\left(\frac{x_g - b_g}{u_g - b_g}, 0, 1\right) \tag{1}$$

where b_g is a baseline (clean air) reference and u_g an upper-concern threshold. The clamp function ensures s_g remains in $[0, 1]$. Calibration determines b_g and u_g (manufacturer guidance or local reference measurements).

B. Weighting and aggregation

Assign a weight $w_g \geq 0$ for each gas reflecting toxicity and operational importance. SD-AQI is then a weighted sum scaled to a convenient range:

$$\text{SD-AQI} = C \sum_g w_g \, s_g \tag{2}$$

where constant C sets the numerical range (e.g., $C = 6$ in the prototype). Example weights (heuristic) used in the IoT Babar implementation:

$$w_{CO} = 0.05, \quad w_{CO\_MQ7} = 0.1, \quad w_{CO\_MQ9} = 0.1,$$
$$w_{CH4} = 0.1, \quad w_{H2} = 0.05,$$
$$w_{CO2} = 0.5, \quad w_{NOx} = 0.1, \quad w_{Air} = 0.05.$$

When multiple sensors provide redundant information for the same gas (e.g., CO reported by MQ-2, MQ-7, MQ-9), we apply a robust fusion step: compute normalized sub-scores for each sensor and combine them via median or trimmed mean before applying a single gas-level weight. This reduces single-sensor noise influence.

IV. Handling Sensor Pitfalls

MOS sensors exhibit several non-ideal behaviors:

- **Warm-up:** sensors require heating; ignore or down-weight first N minutes after power-on.
- **Baseline drift:** use a rolling baseline estimator (percentile-based or exponential smoothing) to adapt b_g.
- **Humidity and temperature sensitivity:** apply compensation using measured T/H or conditional thresholds.
- **Cross-sensitivity:** use redundancy and statistical methods (PCA/ICA) or down-weight correlated channels.

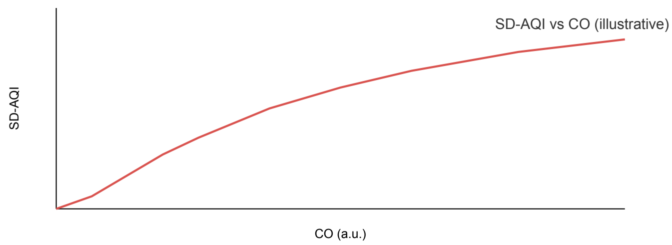

Fig. 1. Illustrative SD-AQI response as CO increases (synthetic).

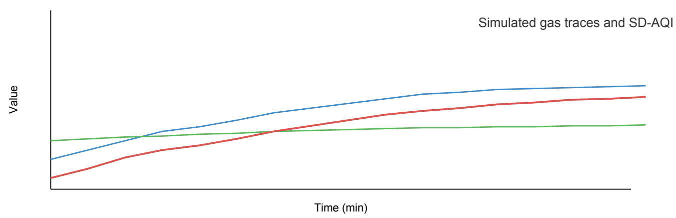

Fig. 2. Simulated time series of gas channels and the resulting SD-AQI (synthetic).

V. Illustrative Simulations

We provide two illustrative plots: (1) SD-AQI response to increasing CO and (2) a simulated time-series of multiple channels and resulting SD-AQI. The prototype Python snippet (included in the project) demonstrates parameter choices and produces the figures.

Figure 1 shows the SD-AQI as CO increases under linear normalization and the weights above. Figure 2 shows a 30-minute synthetic trace.

VI. Thresholds, Interpretation and Alarms

SD-AQI is an operational indicator. Example conservative thresholds (subject to local calibration):

- SD-AQI < 3.0: Normal
- $3.0 \leq$ SD-AQI < 6.0: Advisory — increase inspection frequency
- $6.0 \leq$ SD-AQI < 12.0: Warning — consider stopping fills
- SD-AQI ≥ 12.0: Critical — stop filling and investigate immediately

Thresholds must be validated against reference analyzers and local safety standards. Because MOS sensors do not measure absolute concentration reliably without calibration, pair SD-AQI alarms with confirmatory measurements.

VII. Limitations and Future Work

This work is exploratory. Limitations include the semiquantitative nature of MOS sensors and the necessity of local calibration. Future directions:

- Formal calibration studies against laboratory-grade gas analyzers to map raw sensor units to concentration and set u_g thresholds.
- Machine-learning-based compensation for cross-sensitivity and environmental confounders.
- Incorporating particulate measurements (PM2.5) in alarm logic and integrating with human factors for actionable alarms.
- Publishing reproducible notebooks and adding automated backfill utilities that extract and re-process `raw_payload` to populate new DB columns.

VIII. Conclusion

SD-AQI provides a compact, actionable index for compressor-site monitoring. By combining multiple MOS channels with normalization, robust fusion, and weighting tuned for diving hazards, SD-AQI supports continuous monitoring and operational alarms. The approach is low-cost and enables distributed monitoring, but must be validated with reference instrumentation before use in life-critical decisions.

Acknowledgment

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References

[1] U.S. EPA, "Air Quality Index (AQI) Basics".
[2] MQ series datasheets (MQ-2, MQ-4, MQ-7, MQ-8, MQ-9, MQ-135).