APCTT
Asian and Pacific Centre for Transfer of Technology
ESCAP

Consolidated Reply



Image generated using AI

Query 11 -

Technologies for Real-Time Public Early Warning for Air Pollution

Community of Practice (CoP) on Climate Technologies

APCTT
COMMUNITY OF PRACTICE
ON CLIMATE TECHNOLOGIES

Community of Practice (CoP) on Climate Technologies

Shared Experiences, Smarter Solutions for Climate Action and Resilience

The Community of Practice (CoP) on Climate Technologies, launched by the Asian and Pacific Centre for Transfer of Technology (APCTT), aims to address climate change challenges in the Asia-Pacific region through technology cooperation and transfer. By leveraging the region's innovation capacities and good practices, the CoP enhances access to critical knowledge on climate technologies, fosters cross-border collaboration, and connects professionals engaged in delivering technological solutions to climate change. The objective of this Community of Practice is to:

- Promote collaborative problem-solving and policy-relevant dialogue
- Support the localization and transfer of innovations aligned with national priorities

Query: Technologies for Real-Time Public Early Warning for Air Pollution

Original Query by: Digvijay Singh Bisht, India

17th July 2026
Posted: 17th June 2026

Across the Asia-Pacific region, air pollution remains a leading cause of premature death, yet many communities still lack access to timely and actionable information about the air they breathe. Advances in IoT sensor networks, satellite remote sensing, AI-based forecasting and mobile alert platforms are creating new opportunities for timely public warnings. However, significant gaps remain in monitoring coverage, data quality, last-mile communication, institutional capacity and public trust.

We invite members to share their direct experiences and tested approaches on the following questions:

1. Which technologies or delivery models have most effectively translated air quality data into warnings that vulnerable communities in Asia-Pacific can understand and act on?

2. How have low-cost sensors, community-based monitoring and official systems been integrated in the current policy and practices, to ensure better governance and long-term sustainability of these arrangements? Which among these have worked best so far?

3. How have early warning systems been tailored for vulnerable groups, and which communication channels have proved most effective for these groups?

Your inputs will inform regional dialogue on inclusive air quality monitoring, technology transfer for early warning and public health resilience across Asia-Pacific and beyond.

Digvijay Singh Bisht
Independent Researcher
India

Contents

1. Summary of Responses 6
2. Relevant Experiences 9
3. Related Resources 9
4. Relevant Organizations/Initiative 23
5. Responses in Full 23

1. Summary of Responses

The query explored three related questions: which technologies and delivery models most effectively translate air-quality data into warnings that vulnerable communities can understand and act on; how low-cost sensors, community-based monitoring, and official systems have been integrated into governance; and how early warning systems have been customized for different vulnerable groups. Eleven members responded, with varying levels of detail.

1. Technologies and delivery models

Effective early warning system (EWS) technologies depend not on any single technology but usually on a decision-support ecosystem consisting of three technology layers, each having its own specific use: satellite observation (regional coverage); ground-based sensor networks (validating local conditions); and forecasting using predictive AI models.

Technological solutions alone are insufficient to ensure effective early warning systems but need to be situated in the context where they are deployed. For example, e.g., India's SAFAR integrates forecast models with multilingual voice-based AQI communication, while Delhi's Graded Response Action Plan (GRAP) mandates calibrated citizen action based on AQI levels. However, evaluations of the implementation of recommended measures of GRAP Stage III and IV reveal a wide range of implementation compliance - from 7% to 99.6%. This suggests that the effectiveness of early warning systems depends not only on generating accurate warnings but also on credible, feasible, and immediate action. The Ahmedabad Heat Action Plan presents an exemplary case of effective implementation. Interventions such as cool roofs, shaded bus stops and SMS alerts - though technologically not very innovative - nevertheless succeeded due to effective community involvement through social media.

The main lesson from the above is that early warning technology is a necessary condition but is not sufficient. The effectiveness of early warning

depends on the full sequence of data collection, prediction, communication, and community action, synced with official action.

2. Low-cost sensors and community monitoring

Despite these strengths, current systems generally show several gaps in spatial coverage of air pollution monitoring, such as uneven coverage, uncertain quality (especially calibration errors) of low-cost sensors, and a lack of a unified communication system across national institutions. These gaps erode public trust and hinder effective implementation of mitigation measures. Uncalibrated sensors, with their existing limitations, need to be urgently replaced and upgraded; one possible way is to co-locate sensors with reference stations, as the Pakistan BlueSky validation example has shown. In general, governance of air pollution monitoring systems is seen to improve when community monitoring supplements official systems. The Appropriate AI–Human-Centred–Application framework also mandates that collaboration is crucial for implementation. Existing success stories of government-citizen systems are Cork City's public dashboard and UNDP–UNICEF platform in Ulaanbaatar. Similarly, citizen monitoring in Buenos Aires and Breathe London are other examples, as is Southeast Asia's SEA-HAZEMON. All these examples show how institutional arrangements can connect community observations with official decision-making. This also brings to the fore the issue of capacity building of Urban Local Bodies to design and implement funding mechanisms for deploying and maintaining EWS - for example, through municipal bonds, used so far in water and sanitation funding but not yet in air pollution.

3. Reaching and differentiating vulnerable groups

No single communication channel can reach all vulnerable groups, necessitating the use of multiple channels such as SMS, mobile applications, radio, community health workers, schools, and religious leaders. Such multi-channel dissemination would be needed to overcome differences in literacy, connectivity and trust among target populations.

To implement the above, it is critical to differentiate between the targets of the communications on early warnings. ASHA workers trusted local networks for slum residents, street vendors, outdoor and informal workers, school-age children, and individuals with existing respiratory or cardiac conditions are audiences each requiring customized communication pathways. SAFAR's multilingual voice-readout system similarly illustrates that accessibility can be incorporated into system design from the outset. WHO's Regional Centre for Environmental Health Action presents a good institutional example of coordinated public-health communication during pollution episodes. Sadly, an important gap in the South Asia region is the absence of an agreement such as the ASEAN Agreement on Transboundary Haze.

A key takeaway from the discussion is that effective communication of EWS depends less on technologies and more on trusted local institutions with the capacity to deliver clear, actionable messages through multiple channels to the target audiences most likely to be affected by air pollution in Asia Pacific.

2. Relevant Experiences

a. Deployed Monitoring and Alert Systems

Country / Programme	Key Programme and Approach	Organisations Involved	Link
China	Over 1,500 monitoring stations feed a four-tier alert system (Blue/Yellow/Orange/Red). When AI-based PM2.5 forecasts exceed threshold values, automated responses trigger: construction shutdowns, traffic restrictions, industrial production limits, and school closure advisories. The Jing-Jin-Ji (Beijing-Tianjin-Hebei) region has piloted 5-day-ahead AI forecasting, demonstrating proactive rather than reactive public health protection.	Ministry of Ecology and Environment (MEE), China; Local Environmental Protection Bureaux (EPBs)	aqicn.org/beijing
Kenya / Nairobi	Nairobi County Government deployed 50 additional low-cost air quality monitors in June 2025 (joining 39 already installed) across 17 constituencies, as part of the Breathe Cities initiative	Nairobi City County Government; Breathe Cities (Clean Air Fund, C40 Cities, Bloomberg	talkafrica.co.ke

Country / Programme	Key Programme and Approach	Organisations Involved	Link
	backed by Clean Air Fund, C40 Cities and Bloomberg Philanthropies. County officers trained in environmental data management translate sensor data into public advisories via an open portal; the programme explicitly targets Nairobi's most vulnerable communities, where air pollution already consumes roughly 10% of the county health budget.	Philanthropies)	
Thailand / Laos / Philippines / Indonesia	An IoT platform of 100+ low-cost Canarin sensor nodes across urban, rural and remote sites, combined with a forest-fire detection model built on PM2.5 and CO readings. When haze episodes are detected, warning messages are sent directly to local forest-fire authorities via Telegram and Line in a 2022 trial, the system detected 367 fire events in a single month at 84%	intERLab, Asian Institute of Technology (AIT); Thailand Research and Education Network Association (ThaiREN); TEIN / Asi@Connect	hazemon.in.th

Country / Programme	Key Programme and Approach	Organisations Involved	Link
	accuracy. Deliberately targets rural communities in the Mekong haze corridor that national monitoring networks do not reach.		
India	India's first integrated air quality and weather early warning system, operational in Delhi, Pune and Mumbai. Combines a ground-based monitoring network with satellite data and AI-driven 24-hour AQI forecasts. Real-time advisories reach the public via digital display boards, SMS, IVRS toll-free lines, and a web portal.	Ministry of Earth Sciences; IITM Pune; India Meteorological Department (IMD)	safar.tropmet.res.in
India / Ahmedabad	Developed in 2016 to complement Ahmedabad's landmark Heat Action Plan — India's first city-level air quality early warning framework. Uses tiered AQI alert thresholds linked to colour-coded health advisories, disseminated through media,	Ahmedabad Municipal Corporation (AMC); IITM Pune; NRDC; Public Health Foundation of India	PMC6068810

Country / Programme	Key Programme and Approach	Organisations Involved	Link
	schools and frontline health workers (ASHA workers). Demonstrates that trusted community health networks, not new parallel systems, are the most effective last-mile channel for vulnerable communities.		
Pakistan	Punjab's Environment Protection Department deployed a province-wide network of automated Air Quality Monitoring Stations, with data flowing through a fully automated chain from analysers to data loggers to a central server to public dashboards. A mobile application delivers live AQI readings, 24-hour forecasts and health advisories, addressing the severe seasonal smog crisis affecting the region October–February.	Environment Protection Department (EPD), Government of Punjab, Pakistan	aqi.punjab.gov.pk

Country / Programme	Key Programme and Approach	Organisations Involved	Link
South Asia / Global	EU-funded, ECMWF-operated service providing freely accessible global daily air quality analyses and 5-day forecasts covering PM2.5, NO2 and ozone across South and Southeast Asia. Tracks major pollution episodes across the Indo-Gangetic plain (Bangladesh, Pakistan, Northern India), with data used by national meteorological services as backbone input for national EWS. In data-sparse developing countries, CAMS provides the only operationally available regional air quality early warning baseline.	ECMWF; European Commission Copernicus Programme; National Meteorological Services across Asia	atmosphere.copernicus.eu

b. Channel Effectiveness and Vulnerable-Group Targeting

Country / Context	Finding and Evidence	Source	Link
India / Ahmedabad	Structured interviews with female outdoor labourers found illiteracy and low phone ownership reduced the heat warnings women received, though community engagement partly compensated; low incomes forced women to keep working during heatwaves regardless. A parallel WEF analysis notes women in South Asia are 41% less likely than men to use mobile internet. Distinct case from the AIR Plan above: this is a critique of the same city's EWS design, not a duplicate.	Trahan, Walshe & Mehta (Int'l J. of Disaster Risk Reduction, 2023); Ahmedabad Municipal Corporation HAP; IIPH-Gandhinagar/NRDC	sciencedirect.com
Bangladesh	76,000+ volunteers (gender-balanced) disseminate warnings via mosque loudspeakers, door-to-door contact and hand flags, reaching households with no mobile coverage in under 15 minutes from warning issuance to	Bangladesh Red Crescent Society (BDRCS); Bangladesh Meteorological Department; Government of	bdrcs.org

Country / Context	Finding and Evidence	Source	Link
	evacuation order. Cyclone mortality fell more than 100-fold over 40 years. Transferable evidence, not an air-pollution system itself, for why human + religious-institution channels reach the rural poor and women where digital alerts cannot.	Bangladesh; IFRC	
United States	Nationally representative survey (n=4,053) found television was the dominant channel for receiving air quality alerts (57.5%), against 30.2% for mobile apps and 26.4% for internet/social media. Adults with respiratory disease were far more likely to receive alerts via their doctor's office (PR 3.10) than the general population evidence that digital channels reach a minority even in a high-connectivity country, and that clinical channels matter disproportionately for medically vulnerable groups.	US Centers for Disease Control and Prevention (ConsumerStyles survey)	PMC8800048

Country / Context	Finding and Evidence	Source	Link
Mexico	A randomised controlled trial found that in a city where 95% of residents already saw pollution as a problem, SMS air-quality alerts and free protective masks had limited effect on actual avoidance behaviour on the specific high-pollution days that mattered; willingness to pay for alerts skewed toward male, younger, higher-income respondents. Shows that pushing raw alerts without behavioural specificity or trusted intermediary support does not reliably translate into correctly-timed protective action, and that a paid-access model can itself be inequitable.	Hanna, Hoffmann, Oliva & Schneider; Inter-American Development Bank (IADB)	iadb.org
United Kingdom / WHO Europe	A randomised trial found messages targeting specificity and psychosocial factors (vs the standard numerical Daily Air Quality Index) increased	WHO Regional Office for Europe	who.int

Country / Context	Finding and Evidence	Source	Link
	intentions to make permanent changes and increased preventer-inhaler use among at-risk groups, though both formats performed similarly for a hypothetical scenario. WHO Europe's 2026 roadmap independently concludes AQIs must be locally adapted and equity-aware, with messages accessible to vulnerable and susceptible groups not just a number on a scale.		
Thailand	Survey of 414 Village Health Volunteers (82% women) in rural Samut Songkhram Province found environmental health literacy was the strongest predictor of PM2.5 preventive behaviour (β=0.619, $p<0.001$), explaining 36.8% of variance stronger than any demographic factor. Evidence that training the human dissemination layer, not just supplying it with	Songsin et al., Suan Sunandha Rajabhat University (preprint, under review at Scientific Reports)	researchsquare.com

Country / Context	Finding and Evidence	Source	Link
	data, is what drives protective action at community level.		
Mongolia / Indonesia	UNICEF's Mongolia project (2018-2023) targeted pregnant women and under-5s in Ulaanbaatar's ger districts (winter PM2.5 up to 687 µg/m³) through community health workers, kindergarten-based air sensors, and mass education its CHW pilot proved effective enough to be expanded nationwide. In contrast, near Indonesia's Mount Merapi, a shift from community radio to WhatsApp volcanic alerts left elderly, non-smartphone residents without warnings; mosque loudspeakers now fill the gap. Paired evidence: one named population success, one digital-only failure.	UNICEF Mongolia; Swiss Agency for Development and Cooperation; Indonesian geological agency (PVMBG); village preparedness teams	unicef.org

3. Related Resources

Resource Title	Authors / Publisher	Key Summary	Link
Air Pollution in Asia and the Pacific: Science-based Solutions	UNEP, 2019	Identifies 25 policy and technological measures that could help 1 billion people breathe cleaner air by 2030 and reduce global warming by a third of a degree Celsius by 2050. Implementing all 25 measures would reduce premature mortality in Asia-Pacific by one third and avoid 2 million premature deaths from indoor air pollution; identifies EWS as integral to the region-wide governance agenda.	unep.org/AirAsiaPac
Development of Ahmedabad's Air Information and Response (AIR) Plan to Protect Public Health	Bherwani et al., Environmental Health Perspectives / PMC, 2018*	Documents the design and implementation of India's first city-level air quality early warning system, combining tiered AQI alert thresholds with community health communication via schools, media and frontline health workers.	PMC6068810

Resource Title	Authors / Publisher	Key Summary	Link
		Cited by CR11 respondent Jagannath Mahanta as evidence that trusted local intermediaries (ASHA workers, ward-level health networks) outperform new parallel communication systems for last-mile EWS delivery.	
Managing Air Quality and its Impacts on Health, Climate Change and Nature in Asia-Pacific	Asian Development Bank (ADB)	Overview of ADB's US$2.5 billion+ investment portfolio in air pollution reduction across Asia-Pacific, documenting results-based lending, clean heating technology financing in Mongolia and China, and financing pathways for scaling monitoring infrastructure and EWS governance in developing member countries.	adb.org (Air Quality)
State of Global Air Report 2024	Health Effects Institute (HEI) / IHME, 2024	Air pollution caused 8.1 million deaths globally in 2021, the second leading risk factor for death worldwide; over 4	stateofglobalair.org

Resource Title	Authors / Publisher	Key Summary	Link
		million of these occurred in Asia-Pacific, including more than 700,000 deaths in children under 5. Provides the country-level PM2.5 and ozone evidence base underpinning demand for early warning systems in the region.	
WHO Global Air Quality Guidelines (2021)	World Health Organization (WHO), 2021	Updated guidelines set the annual PM2.5 limit at 5 µg/m³, halved from the 2005 standard of 10 µg/m³, with Interim Targets (IT-1 to IT-4) guiding progressive improvement. Only 10% of assessed global settlements currently meet WHO standards; these thresholds calibrate AQI alert levels and health advisory messaging in early warning systems across Asia-Pacific.	who.int (AQG)
World Air Quality Report 2024	IQAir, 2024	Annual ranking of PM2.5 pollution across 134 countries; in 2024,	iqair.com/rankings

Resource Title	Authors / Publisher	Key Summary	Link
		19 of the world's 20 most polluted cities were in Asia, with Byrnihat, India recording the highest annual average (128.2 µg/m³). Bangladesh, Pakistan and India remain among the most consistently polluted nations, giving country-level evidence for prioritising EWS investment and identifying the greatest monitoring gaps.	

4. Relevant Organizations/Initiative

Organisation / Initiative	Key Role and Activities	Link
Asian Development Bank (ADB)	Has financed US$2.5 billion+ in air pollution reduction across Asia-Pacific, including monitoring infrastructure, clean technology programmes, and results-based lending for air quality improvement in China, Mongolia, the Philippines and other developing member countries. Supports technical assistance for EWS governance capacity-building in borrower countries.	www.adb.org
Climate and Clean Air Coalition (CCAC) / UNEP	Voluntary partnership of 190+ governments and organizations working to reduce short-lived climate pollutants. Launched the Air Quality Management Exchange (AQMx) Platform in 2024 to support developing countries in meeting WHO AQG targets and support air quality EWS action in 90+ countries through project funding and policy guidance.	www.ccacoalition.org
Copernicus Atmosphere Monitoring Service (CAMS)	EU-funded global atmospheric monitoring service operated by ECMWF. Provides freely accessible daily global air quality analyses and 5-day forecasts including PM2.5,	atmosphere.copernicus.eu

Organisation / Initiative	Key Role and Activities	Link
	NO2 and ozone for South and Southeast Asia, used as backbone input for national EWS in data-sparse developing countries; API and Google Earth Engine integration make the data accessible at no cost.	
IQAir	Swiss environmental technology company operating the world's largest community air quality monitoring platform, with 80,000+ public sensors globally. The AirVisual application provides real-time AQI data and health advisories across Asia-Pacific; publishes the annual World Air Quality Report, the most widely cited PM2.5 pollution ranking.	www.iqair.com/air-quality-community
OpenAQ	Open-source, open-access environmental tech nonprofit aggregating real-time air quality data from 100+ countries, prioritizing low- and middle-income country coverage with 2 billion+ measurements hosted. Operates the Clean Air Community Ambassador Program to build EWS capacity in LMICs and supports community-based monitoring via free API access and data	openaq.org

Organisation / Initiative	Key Role and Activities	Link
	harmonisation tools.	
UNEP — Asia-Pacific Clean Air Partnership	Coordinates the regional clean air agenda through the Asia-Pacific Clean Air Partnership and the 25 Science-based Solutions framework. Publishes flagship air pollution assessments, coordinates cross-border monitoring dialogue, and supports LMIC governments in building institutional capacity for air quality governance, monitoring infrastructure and EWS development.	www.unep.org/regions/asia-and-pacific
World Health Organization (WHO)	Sets global Air Quality Guidelines (2021) and the health-based AQI alert thresholds used in early warning systems worldwide. Maintains the WHO Ambient Air Quality Database covering 6,743 human settlements, and provides technical guidance on health impact assessment, risk communication and advisory design for vulnerable groups.	www.who.int/health-topics/air-pollution

5. Responses in Full

1. Wasswa Shafik, Dig Connectivity Research Laboratory, Canada
2. Zubia Raza, IRMS Risk Manager, Pakistan
3. Monday vian John mary, TIP Fellow, Policy and Market Research, CEO spul foods, Uganda
4. Jagannath Mahanta, Bhubaneshwar, India
5. Rajabu Kasuja
6. Sohail Akhtar, Senior Scientist, PCSIR Lab Complex, Karachi, Pakistan
7. Irum Tariq, Member, Standing Committee on Smog and Climate, LCCI; CEO, Exodus Green Pvt. Ltd., Pakistan
8. APCTT Input 1
9. Paul Gaudencio Abordo, Philippines
10. Dr. Changbeom Choi, Hanbat National University, Republic of Korea
11. Jaykishankumar More, M.Sc. Environmental Sustainability TH Bingen, Air Quality & Pollution Control, PM Research-CSIR–NEERI, Environmental Engineer
12. APCTT Input 2

Responses:

1. Wasswa Shafik, Dig Connectivity Research Laboratory, Canada

Air pollution early warning systems (APEWS) are increasingly recognized as a critical component of climate resilience and public health governance. However, the effectiveness of these systems depends less on the sophistication of sensing technologies and more on their ability to convert environmental data into trusted, actionable, and equitable public intelligence.

The most successful warning systems combine three technological layers:

1. Satellite-based observation for regional coverage,
2. Ground-based sensor networks for localized validation
3. AI-driven predictive analytics for short-term forecasting.

Yet the real innovation lies in translating technical measurements such as PM2.5 concentrations into health-centered advisories that vulnerable populations can immediately understand. Communities rarely respond to numerical pollution indices; they respond to clear messages such as "children should remain indoors," "outdoor work should be reduced," or "wear protective masks between 10 a.m. and 4 p.m."

A persistent challenge across the Asia-Pacific region is the tension between accuracy and accessibility. While regulatory-grade monitoring stations provide highly reliable data, they are often too expensive to achieve dense spatial coverage. Conversely, low-cost IoT sensors democratize monitoring but raise concerns regarding calibration, maintenance, and data credibility. Emerging hybrid governance models-where low-cost sensors are periodically calibrated against reference stations and integrated into national monitoring frameworks-offer a promising pathway toward scalable and trustworthy monitoring systems.

Equally important is the issue of environmental justice. Air pollution exposure is rarely distributed evenly; informal settlements, industrial corridors, and low-income urban neighborhoods often experience disproportionately high pollution burdens while having the least access to monitoring infrastructure. Consequently, future early warning systems should be evaluated not only by technical performance metrics but also by their ability to reduce information inequality and protect the most vulnerable populations.

For vulnerable groups, the communication channel is often more important than the monitoring technology itself. Mobile applications are effective for digitally connected populations, but community radio, SMS alerts, local health workers, schools, religious institutions, and community leaders

remain indispensable in reaching marginalized communities. Multi-channel dissemination strategies consistently outperform technology-centric approaches because they account for disparities in literacy, connectivity, language, and trust.

Looking forward, the next generation of air pollution early warning systems should evolve from monitoring platforms into decision-support ecosystems.

2. Zubia Raza, IRMS Risk Manager, Pakistan

Renewable energy technologies such as solar, hydro, and wind power are leading the way in providing alternatives to fossil fuels, heavy metals (e.g., mercury, lead), nitrogen, and fluorinated gases These technologies aim to reduce carbon, energy consumption, and greenhouse gas emissions.

- **What works**: Successful use of solar energy, electric vehicles, smart farming, and early warning systems.
- **What challenges exist**: High costs, lack of infrastructure, funding gaps, and technical skills shortages.
- **What solutions help**: Government support, investment, training, and technologies adapted to local needs.

The success of climate technologies depends not just on innovation, but on execution. By pooling practical insights and on-the-ground strategies from across the Asia-Pacific, we can evaluate effective models, tackle mutual obstacles, and accelerate the rollout of vital climate solutions for a sustainable tomorrow.

3. Monday vian John mary, TIP Fellow, Policy and Market Research, CEO spul foods, Uganda

Its high time we move forward with skills and knowledge to shelve to global with a smile.

4. Jagannath Mahanta, Bhubaneshwar, India

I think about a lot from the urban governance side.

1. A case that stands out for me is Ahmedabad's Heat Action Plan, India's first one (since 2013). What I find interesting isn't the technology itself it's quite simple, cool roofs, shaded bus stops, SMS heat alerts but how it reached slum dwellers and street vendors, who normally get left out of these rollouts. It worked because it rode on existing trust: ASHA workers and ward-level health networks, not some new parallel system. What nearly broke it was the usual problem funding dried up once the initial push from donors/NGOs faded, and a lot of these plans struggle to stay funded once they're no longer "new."

2. If I had to name one barrier that keeps showing up, it's the gap between where climate finance sits (national/state level) and the actual capacity of Urban Local Bodies to access and use it. ULBs often just don't have the technical bandwidth to build bankable proposals. The thing that's helped, at least partially, is when SHGs or groups like Mahila Housing Trust act as the middle layer they carry the community's trust in a way municipal offices simply don't.

3. On financing Indian cities like Pune and Ghaziabad have tried green municipal bonds, mostly for water and sanitation. They work fine for infrastructure that generates steady revenue, but informal settlements basically get excluded because bond structures need predictable repayment, which slum households can't really offer. If I were designing this again, I'd want concessional/blended finance ring-fenced specifically for last-mile connections, so it's not competing with the commercial logic the bonds run on.

4. What seems to actually determine whether something sticks, in my observation: a trusted local intermediary to handle the trust and troubleshooting side, technology that's simple enough to maintain locally (anything needing outside repair tends to just get abandoned), and real co-

design rather than communities being handed a finished solution. That last one especially "ownership" doesn't happen after the fact, it has to be built in from the start.

5. Rajabu Kasuja

In my view, effective approaches include IoT-based air quality sensors, satellite monitoring, AI-powered forecasting systems, and mobile alert platforms that provide timely and understandable warnings to communities. Community-based monitoring combined with official government systems can improve data quality, public trust, and long-term sustainability. For vulnerable groups, SMS alerts, mobile applications, radio broadcasts, and local community networks are among the most effective communication channels.

I look forward to learning from other members' experiences and sharing further insights on this important topic.

6. Sohail Akhtar, Senior Scientist, PCSIR Lab Complex, Karachi, Pakistan

The research is going on regarding Air Quality Monitoring and risk associated with outdoor living. Significant gaps observed due to lack of real-time public early warning systems for air pollution. The air and atmospheric pollutions are persistently endured by inhabitants from densely populated urban areas. The inflexible gaps in real-time public early warning systems for air pollution are experienced at major crowded and compactly populated cities. Henceforth, persistent gaps in real-time public early warning systems for air pollution have become a critical public affairs issue for major metropolitan regions and also, identified by current modern internet technological progression like Google Weather update and MSN weather. However, discrepancies remain founded in monitoring & coverage for outdoor air quality for the data quality, communication (based on IoT/Bluetooth), institutional capacity, and public trust.

Advances in IoT sensor networks, satellite remote sensing, AI-based forecasting, and mobile alert platforms offer promising solutions. It's being transcripts that IoT sensor networks, satellite remote sensing, AI-based forecasting, and mobile alert from apps platforms offer promising solutions, yet there are significant gaps in effectively translating air quality data into warnings that vulnerable communities can understand and act upon. The most fundamental gap is "geographic inequality" such as rural areas, pollution hotspots near industrial facilities, and major roadways/ bus stations. Satellite remote sensing offers global coverage, from this ground-based monitoring are mostly observed in high-income countries.

Secondly, Data Quality & Data Management gaps are keen to observed and must accomplishing tasks to deal at multiple levels. Low-cost sensors, while essential for expanding coverage, have well-documented accuracy limitations. The adopted low-cost sensors have up to 50% uncertainty for indicative measurements,

The usual low-cost sensors technical obligations include: Sensor drift due to dust and aging, sensors accumulation and environmental degradation, lack of redundancy in many deployments, making malfunction detection difficult, Humidity and temperature interference, problems due to variable air flow. While, Data management gaps, also persevere: insufficient quality assurance/quality control (QA/QC) procedures, lack of standardized operating protocols, and missing data due to equipment failures or communication issues all degrade the reliability of real-time streams.

One another problem is Communication Barriers of warning systems. Effective early warning requires not just detection but giving out audible output such as translation into actionable public messaging or siren. But several communication gaps exist, data accessibility for air quality is fragmented between agencies working for governance cities, districts, states. With out reporting policy, making access consolidated, timely information. Monitoring system design mostly resulting in data products that may not align with clinical or public health communication needs.

Lastly, Alert latency is a global concern for reanalysis of information. It means that by the time multi-day pollution forecasts are available, the predictions are also rendering towards lengthy period, making them operationally irrelevant for proactive public health protection.

All above gaps are not independent, these interact with each other. Limited coverage in low- and middle-income countries means fewer data points to validate data quality; poor data quality undermines public trust, which weaken resource adoption and produces political pressure. The technical work cycle imposed integrated investments in hybrid monitoring networks (reference points, low-cost implementation technology, satellite/IoT, and model for locality) with rigorous quality assurance/quality control.

7. Irum Tariq, Member, Standing Committee on Smog and Climate, LCCI; CEO, Exodus Green Pvt. Ltd., Pakistan

Air pollution continues to be one of the most significant environmental health risks across the Asia-Pacific region. While technological innovations have greatly improved our ability to monitor and forecast air quality, the real measure of success lies in whether this information reaches vulnerable communities in a timely, understandable, and actionable manner. The most successful early warning systems combine multiple technologies rather than relying on a single data source. Satellite observations, ground-based regulatory monitoring stations, low-cost IoT sensors, meteorological forecasting, and Artificial Intelligence (AI)-based prediction models together provide more reliable and localized air quality information.

Mobile applications, SMS alerts, social media platforms, television and radio broadcasts, and community health networks have proven effective communication channels. In rural and underserved areas where smartphone penetration is limited, community volunteers, local government authorities, schools, healthcare facilities, religious institutions, and local FM radio stations remain essential for disseminating warnings.

8. APCTT Input 1

Dear members,

Thank you for your responses so far. To stimulate further discussion, I wish to bring to your notice the following open access papers and blogs on the topic:

Open Access Papers on Air Pollution Early Warning Systems

Wang, J., Niu, T., & Wang, R. (2017). "Research and Application of an Air Quality Early Warning System Based on a Modified Least Squares Support Vector Machine and a Cloud Model." Int. J. Environ. Res. Public Health, 14(3), 249. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5369085

Mo, X., Zhang, L., Li, H., & Qu, Z. (2019). "A Novel Air Quality Early-Warning System Based on Artificial Intelligence." Int. J. Environ. Res. Public Health, 16(19), 3505. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6801950

Shih, D.-H., Wu, T.-W., Liu, W.-X., & Shih, P.-Y. (2019). "An Azure ACES Early Warning System for Air Quality Index Deteriorating." Int. J. Environ. Res. Public Health, 16(23), 4679. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6926579

Yang, R., Hao, X., Zhao, L., Yin, L., Liu, L., Li, X., & Liu, Q. (2022). "Design and implementation of a highly accurate spatiotemporal monitoring and early warning platform for air pollutants based on IPv6." Scientific Reports, 12, 4544. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8930975

Jena, C., Ghude, S.D., Kumar, R., Debnath, S., Govardhan, G., Soni, V.K., Kulkarni, S.H., Beig, G., Nanjundiah, R.S., & Rajeevan, M. (2021). "Performance of high resolution (400 m) PM2.5 forecast over Delhi." Scientific Reports, 11, 4104. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7892871

Masood, A., Hameed, M.M., Srivastava, A., Pham, Q.B., Ahmad, K., Razali, S.F.M., & Baowidan, S.A. (2023). "Improving PM2.5 prediction in New Delhi using a hybrid extreme learning machine coupled with snake optimization algorithm." Scientific Reports, 13, 21057. https://www.nature.com/articles/s41598-023-47492-z

Du, S., Li, T., Yang, Y., & Horng, S.-J. "Deep Air Quality Forecasting Using Hybrid Deep Learning Framework." arXiv:1812.04783. https://arxiv.org/pdf/1812.04783

Jiang, W., Zhu, G., Shen, Y., Xie, Q., Ji, M., & Yu, Y. (2022). "An Empirical Mode Decomposition Fuzzy Forecast Model for Air Quality." Entropy, 24(12), 1803. https://pubmed.ncbi.nlm.nih.gov/36554208

Rana, R., & Kumar, N. (2025). "Air pollution forecasting trends and regional patterns in the Asia Pacific through bibliometric analysis." Discover Environment, 3, 203. https://link.springer.com/article/10.1007/s44274-025-00392-7

"An improved deep learning model for predicting daily PM2.5 concentration" (weighted LSTM extended model), applied to Beijing-Tianjin-Hebei, China. PLOS ONE. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7710732

Blogs on Early Warning Systems in the Asia-Pacific :

UNDP Policy Centre Singapore — "Applications of Low-Cost Air Quality Sensors for Citizen Engagement and Air Pollution Mitigation" https://www.undp.org/policy-centre/singapore/blog/applications-low-cost-air-quality-sensors-citizen-engagement-and-air-pollution-mitigation

AVPN Blog —"Breathing Easier: How Air Quality Can Strengthen Southeast Asia's Climate and Health Resilience" https://avpn.asia/resources/blog/breathing-easier-how-air-quality-can-strengthen-southeast-asias-climate-and-health-resilience

World Resources Institute — "CanAIRy Alert" initiative page https://www.wri.org/initiatives/canairy-alert

World Resources Institute — "Tackling Air Pollution Through Regional Action in Southeast Asia" https://www.wri.org/update/working-together-cleaner-air-southeast-asia-inside-sea-aq-community-practice

WHO EMRO / CEHA News — "Regional expert consultation on establishing an early warning system and communicating health messages during air pollution episodes" https://www.emro.who.int/ceha/ceha-news/regional-expert-consultation-on-establishing-an-early-warning-system-and-communicating-health-messages-during-air-pollution-episodes.html

Asian Development Blog — "Why Regional Cooperation Is Vital for Better Air Quality in Asia and the Pacific" https://blogs.adb.org/blog/why-regional-cooperation-vital-better-air-quality-asia-and-pacific

Asian Development Blog — "Asia's Air Quality Crisis: How Regional Action Can Address Air Pollution" https://blogs.adb.org/blog/asia-s-air-quality-crisis-how-regional-action-can-address-air-pollution

Asian Development Blog — "We Need To Do Whatever it Takes to Improve Air Quality" https://blogs.adb.org/blog/we-need-to-do-whatever-it-takes-to-improve-air-quality

WRI Indonesia — "7 Things to Know About Jakarta's Air Pollution Crisis" https://wri-indonesia.org/en/insights/7-things-know-about-jakartas-air-pollution-crisis

Al Jazeera Opinion — "What New Delhi can learn from China's war on air pollution" https://www.aljazeera.com/opinions/2025/12/12/what-new-delhi-can-learn-from-chinas-war-on-air-pollution

9. Paul Gaudencio Abordo, Philippines

In the Philippines Ai is just booming. not all system integrates it. it should be a new standard for us here.

10. Dr. Changbeom Choi, Hanbat National University, Republic of Korea

Building on the discussion so far, I'd like to add a few points related to real-time air pollution early warning systems.

First, it may be worth considering the role of the "computing continuum" how AI-enabled sensors, edge gateways, and cloud infrastructure work together across different layers rather than in isolation. Edge-level processing allows for faster local alerts, while cloud-level aggregation supports broader forecasting and trend analysis. This could complement the IoT and AI forecasting approaches already mentioned.

Second, rather than focusing solely on high-precision monitoring, there may be value in a "harm reduction" model built on low-cost sensors. Even with lower accuracy, widespread deployment of affordable sensors could expand coverage into underserved and vulnerable communities, providing timely if imperfect warnings that still meaningfully reduce exposure risk.

In designing such systems, the AHA Framework (Appropriate AI, Human-centered, Application-driven), which I presented at the ESCAP General Assembly, offers a useful lens: AI should be "appropriate" to local context and resource constraints rather than maximally sophisticated; design should remain human-centered, prioritizing how communities actually understand and act on alerts; and solutions should be application-driven, built around real operational needs rather than technology for its own sake. Together, these principles could help ensure that early warning systems are not only technically feasible but genuinely trusted and used by the communities they aim to protect.

11. Jaykishankumar More, M.Sc. Environmental Sustainability TH Bingen, Air Quality & Pollution Control, PM Research-CSIR–NEERI, Environmental Engineer

Technologies like IoT sensors, satellite monitoring, and AI can make air pollution warnings more accurate and timelier. However, it is equally important that the information is easy to understand and reaches everyone, especially vulnerable communities, through SMS, mobile apps, local languages, and community awareness programs. I look forward to learning from the experiences shared by other members.

12. APCTT Input 2

Dear members,

The discussion so far has covered the technology categories well. What's missing is specificity: named systems that have been evaluated, the governance mechanics behind sensor integration, and a breakdown of what "vulnerable communities" means in practical design terms. Let me try to add that.

On Q1, technologies/delivery models that have worked

Two systems are worth naming, since most of what's been shared here describes categories rather than deployments. India's SAFAR (System of Air Quality and Weather Forecasting and Research, run by IITM Pune since 2010) puts out colour-coded, multilingual forecasts (English, Hindi, Marathi, Gujarati) with a voice-readout feature across four cities. That is closer to the "decision-support ecosystem" Wasswa Shafik describes than anything else mentioned in this thread. Delhi-NCR's Graded Response Action Plan, run by the Commission for Air Quality Management, converts AQI thresholds directly into mandated public actions: construction bans, school closures, vehicle restrictions. It is a trigger-based EWS, as against the advisory-only systems most of this thread has described.

One caution, though. A review of this winter's GRAP Stage III/IV implementation found compliance gaps ranging from 7% to 99.6% across mandated actions. We thus see that forecasting accuracy and enforcement are two different capacities, and the gap between them sits in governance, not in the technology. A system that predicts correctly but is not acted on is not, in any real sense, an early warning system. It is an announcement.

On Q2, integrating low-cost sensors, community monitoring, and official systems

This is where the thread has stayed most abstract, and there are actual regional examples we could be citing. SEA-HAZEMON, a low-cost sensor network spread across 100+ urban and rural sites in Thailand, Laos, the Philippines, and Indonesia, is a live test of hybrid governance in exactly this geography. In the Philippines, Quezon City's partnership with C40 and Clean Air Asia to build a city air-quality baseline under the Clean Air Cities Declaration is a case of low-cost sensor data feeding straight into a municipal policy commitment. That is the "sustainability beyond the pilot" Jagannath Mahanta flagged as the usual failure point once donor funding dries up, and it is worth asking of every pilot mentioned in this thread: what happens to it after year two?

On calibration, since that came up earlier: a recent validation of low-cost BlueSky sensors against reference beta-attenuation monitors in Pakistan found error rates in the single digits (NRMSE around 4%, NMAE around 3%), as against the roughly 50% uncertainty figure people keep citing for uncalibrated deployments. Co-location and periodic correction against a reference monitor is not an optional add-on to a low-cost sensor network. It is the difference between the two figures above.

On Q3, tailoring for vulnerable groups

The thread has mostly treated "vulnerable communities" as a single category. It is worth separating out who actually needs different design, and why. Outdoor and informal workers, construction, street vending, traffic policing,

need occupation-specific advisories tied to shift timing, because a general AQI number does not do much for someone standing at a traffic signal for eight hours. School-age children need trigger-linked protocols, automatic suspension of outdoor PE or playground time, rather than a blanket "stay indoors" message that assumes someone at home is watching the news. People with existing respiratory or cardiac conditions are usually better reached through their clinic or pharmacy than through an app they may never open. SAFAR's voice-readout, multilingual design is one of the few examples here that was actually built for low-literacy access, not retrofitted for it later, and that distinction matters more than any technical spec.

One regional gap worth naming directly

A lot of Asia-Pacific's worst pollution episodes cross borders. The Indonesia-Malaysia-Singapore haze is the clearest case, and it has not come up yet in this thread. The ASEAN Specialised Meteorological Centre, based in Singapore, already runs a three-tier regional early-warning advisory for transboundary haze under the ASEAN Agreement on Transboundary Haze Pollution. It is a working example of multi-country EWS governance, and directly relevant to APCTT's interest in technology transfer across the region.

A few concrete points for the regional dialogue

1. Prioritize named, evaluated systems over technology categories. SAFAR, GRAP, and SEA-HAZEMON are transferable because their implementation detail is documented, not because the category "AQI forecasting" or "low-cost sensor network" exists.

2. Budget calibration as core infrastructure, not an afterthought. Any technology-transfer effort should fund co-location and periodic correction of low-cost sensors against a reference monitor from day one.

3. Assess enforcement capacity alongside forecasting capacity. GRAP's compliance gap is a reminder that a warning system is only as good as the institutional machinery that acts on it.

4. Design communication for low-literacy and shift-work realities from the outset. SAFAR's voice-readout should be the starting point for new systems, not a feature added after the fact.

5. Give transboundary mechanisms like ASMC the same attention as national systems in this dialogue. The region's worst episodes do not respect borders, and neither should the governance conversation.

Happy to go deeper on any of this if it is useful for the regional dialogue.

Sources referenced above:

- [SAFAR — India (IITM, Pune) - https://safar.tropmet.res.in/

- [Graded Response Action Plan (GRAP) — CAQM] - https://caqm.nic.in/

- [Delhi GRAP implementation gap review] – The Print - https://theprint.in/environment/delhi-brought-grap-reactively-after-aqi-crossed-limit-13-out-of-17-times-this-winter/2855807/

- [ASEAN Specialised Meteorological Centre — Haze Early Warning - https://asmc.asean.org/asmc-about/

- [ASEAN Agreement on Transboundary Haze - https://asean.org/wp-content/uploads/2021/01/ASEANAgreementonTransboundaryHazePollution-1.pdf

- [4 ways cities are using low-cost sensors — Clean Air Fund (SEA-HAZEMON, Quezon City)] - https://www.cleanairfund.org/news-item/4-ways-cities-are-using-low-cost-sensors-to-improve-air-quality/)

- [Low-cost sensors for effective air quality monitoring — ScienceDirect] - https://www.sciencedirect.com/science/article/pii/S0160412025002727/pdfft?md5=981c701625e69b15d6aa184c348585c4&pid=1-s2.0-S0160412025002727-main.pdf

Many thanks to all who contributed to this query!

This Consolidated Reply is a systematic compilation of all responses received, and additional desk research compiled by CoP Moderating Team at APCTT. If you have further information to share on this topic, please send it at apctt.cop@un.org.

Disclaimer

The views expressed in this document do not reflect the views of the Asian and Pacific Centre for Transfer of Technology (APCTT) of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). The designations employed and the presentation of the materials do not imply the expression of opinion of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities. This publication follows the United Nations' practice in reference to countries. Where there are space constraints, some country names have been abbreviated. Mention of a commercial company or product in this publication does not imply endorsement by ESCAP-APCTT. The Links contained in this publication are provided for the convenience of the reader and are correct at the time of issue.

No use may be made of this publication for resale or any other commercial purpose whatsoever without prior permission.

APCTT
Asian and Pacific Centre
for Transfer of Technology
ESCAP

Asian and Pacific Centre for Transfer of Technology (APCTT)

APCTT Building,
C2, Qutab Institutional Area, New Delhi - 110016, India
apctt@un.org, +91-11-69013700

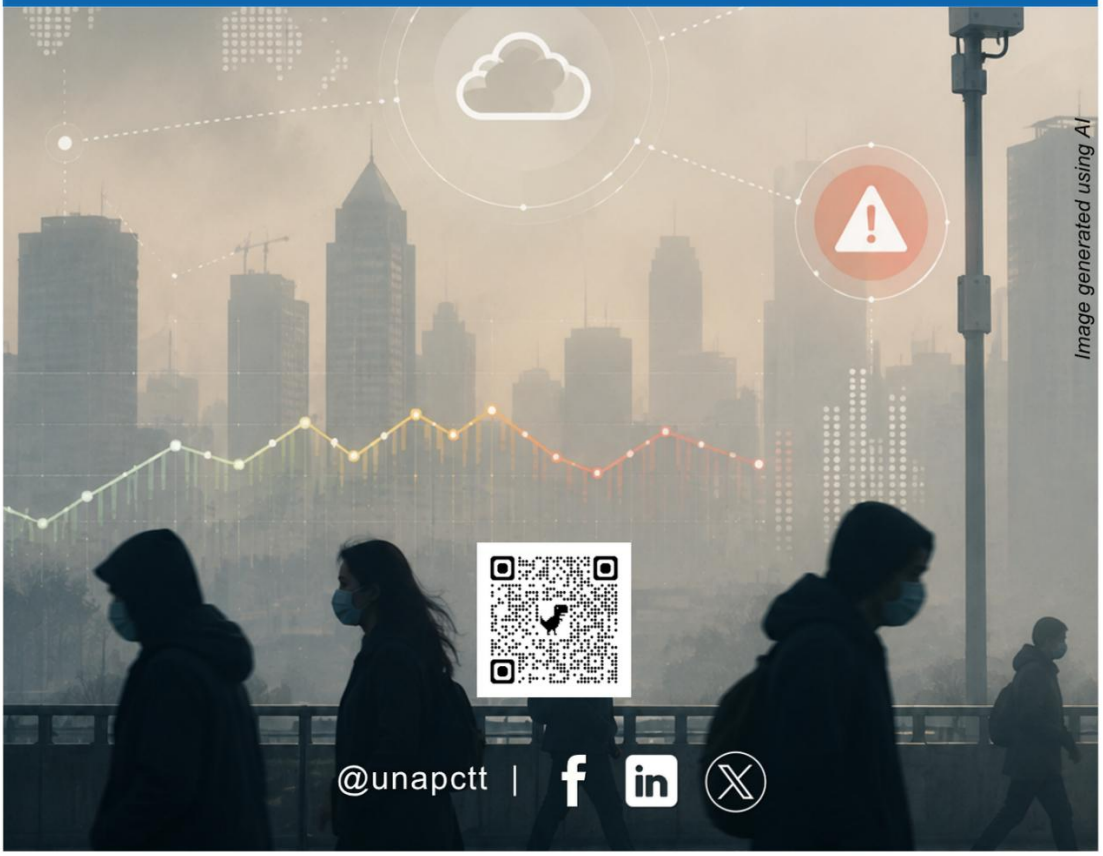


Image generated using AI

@unapctt |