An Environmental-AI Integrated Recommender System for Parkinson's Rehabilitation: A Prototype Study in Taiwan

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ABSTRACT

This study presents a prototype Environmental-AI recommender system for Parkinson's disease rehabilitation. Using Taiwan as a testbed, the system integrates real-time environmental data—including air quality, meteorological conditions, and satellite-derived indices —with individual health data such as symptom logs and wearable outputs. A rule-based engine interprets environmental conditions, while a generative AI model converts combined inputs into plain-language daily recommendations. The system supports both diagnosed Parkinson's disease patients and high-risk individuals, offering symptom-aware or preventive lifestyle guidance. Simulated user profiles demonstrate how recommendations adapt to varying environmental and personal contexts. Results show the suggestions align with Parkinson's disease care guidelines and environmental health principles. While promising, the system requires further validation, particularly to address AI hallucination risks and real-world clinical effectiveness. This approach illustrates the potential of combining environmental informatics and generative AI to support personalized chronic disease management.

Key words: Taiwan, Parkinson's, Environment, AI

Introduction

Parkinson's disease (PD), the second most common neurodegenerative disorder after Alzheimer's, poses a growing challenge in aging societies like Taiwan. With over 77,000 diagnosed cases as of 2022 and 1–2% of adults over 65 affected, Taiwan is rapidly becoming a "super-aged society," with those aged 65+ projected to exceed 20% by 2025 (Lin et al., 2024). This demographic shift underscores the urgent need for effective PD management and prevention strategies. Environmental factors are increasingly recognized as critical contributors to PD onset and progression. Studies have linked chronic exposure to pesticides, industrial chemicals, and air pollutants with elevated PD risk (De Miranda et al., 2022; Murata et al., 2022). Fine particulate matter ($PM_{2.5}$), in particular, is believed to accelerate neurodegeneration through inflammation and oxidative stress (Murata et al., 2022). Additionally, toxic metals such as manganese and arsenic may induce epigenetic modifications that are implicated in PD pathogenesis (Newell et al., 2025). As such, environmental exposure is now considered a key element in understanding PD alongside genetic factors (Aravindan et al., 2024; Jacobs et al., 2020). Environmental conditions also influence symptom management and quality of life for PD patients. Age-friendly features like green space, clean air, and low noise levels are associated with better physical and mental health among older adults (Zhou et al., 2022; Enssle & Kabisch, 2020). Conversely, environmental stressors such as noise pollution and urban congestion have been linked to depression and lower life satisfaction in seniors (Tsimpida & Tsakiridi, 2025; Xie et al., 2025). While effects can vary by context (Liu et al., 2019), overall, the environment plays a significant role in chronic disease care.

Despite this, current PD rehabilitation programs seldom adapt to real-time environmental conditions. Standard care focuses on fixed advice and clinical monitoring but rarely considers factors like daily air quality, humidity, or noise levels that may affect symptom severity. Patients and caregivers are often left to interpret environmental risks themselves, highlighting a gap in adaptive, personalized support. Emerging technologies offer a way forward. With the growth of wearable devices, environmental sensors, and generative AI, it is now feasible to integrate live data into personalized health recommendations. Some digital health tools for PD have shown promise in tracking symptoms and promoting exercise (Alves et al., 2024), yet few incorporate environmental context into their logic. The combination of environmental sensing with AI-generated, personalized coaching remains an untapped area in PD care.

This study presents a prototype system that integrates environmental sensing with AI to deliver personalized daily health recommendations for individuals with Parkinson's disease (PD) or those at high risk. The Environmental-AI integrated recommender system collects data on environmental conditions (e.g., weather, air quality, satellite imagery) and user health status (e.g., symptom reports, wearable data). It combines rule-based logic with a generative AI model (Gemini) to generate plain-language, personalized guidance. The system operates via a dual-path approach: one tailored to confirmed PD patients, focusing on symptom management and activity adaptation, and another aimed at high-risk individuals to encourage preventive behaviors. Developed in the context of Taiwan, the system utilizes rich local environmental datasets and is demonstrated using simulated patient profiles. This prototype highlights the potential of integrating environmental data and AI for personalized care, while identifying future needs such as validation, system refinement, and potential application to other health contexts.

Literature Review

Environmental Factors in Parkinson's Disease and Aging Health

A substantial body of literature has established that environmental exposures play a significant role in the etiology of Parkinson's disease. In particular, long-term exposure to certain toxic chemicals and pollutants has been associated with an increased risk of developing PD. Pesticides are among the most consistently implicated toxicants – many epidemiological studies have observed higher PD incidence in populations with occupational or residential exposure to agricultural pesticides (De Miranda et al., 2022; Aravindan et al., 2024). For example, a comprehensive environmental health agenda for PD prevention noted strong links between pesticide exposure (such as in farming communities) and PD, urging greater regulation and safer handling of these chemicals (De Miranda et al., 2022). Industrial chemicals and solvents have similarly been cited as risk factors. Beyond specific chemicals, broad indicators of pollution correlate with PD patterns: PD prevalence tends to be elevated in urbanized or industrial areas with poor air quality compared to rural areas (De Miranda et al., 2022). Air pollution, especially airborne particulate matter and traffic-related pollutants, has been scrutinized as a potential contributor to neurodegeneration. In a recent review, Murata et al. (2022) conclude that chronic inhalation of polluted air can affect the brain by inducing systemic inflammation and oxidative stress, as well as by direct entry of ultrafine particles through the olfactory pathway. Such mechanisms may promote α-synuclein aggregation and dopaminergic neuron injury, accelerating the pathogenesis of PD (Murata et al., 2022). These findings are supported by animal and cellular studies that show exposure to diesel exhaust, particulate matter, or ozone can trigger neuroinflammatory processes. While causation in humans is difficult to prove conclusively, the epidemiological evidence is increasingly pointing to air pollution as an emerging risk factor for PD that might compound other risk factors (Murata et al., 2022).

Heavy metals and other environmental toxins have also been linked to PD through both epidemiological and molecular research. A systematic review by Newell et al. (2025) examined how environmental toxicants might drive epigenetic changes associated with neurodegenerative diseases. The review found that four toxic metals – mercury, manganese, cadmium, and arsenic – have reported associations with PD, Alzheimer’s disease, and ALS, potentially through altering DNA methylation or histone acetylation patterns in genes relevant to neuronal survival (Newell et al., 2025). For instance, manganese exposure was shown to cause hypoacetylation of certain histone proteins in experimental settings, a change that has been observed in PD patients' neural tissue (Newell et al., 2025). Additionally, chronic exposure to high levels of airborne fine particulates ($PM_{2.5}$ above World Health Organization guidelines) has been associated with epigenetic modifications (such as methylation changes) that could impair cellular functions and are also found in patients with neurodegeneration (Newell et al., 2025). These insights suggest that environmental factors do not just influence PD risk in a superficial way, but can lead to biological changes at the molecular level that predispose individuals to neurodegenerative processes.

Given the multifactorial nature of PD, there is growing interest in integrating environmental risk factors with genetic susceptibility to improve risk prediction. Jacobs et al. (2020) analyzed data from the UK Biobank (a large longitudinal cohort) to assess PD determinants, and they constructed Polygenic Risk Scores (PRS) for PD for each individual. When combining the PRS (which captures genetic predisposition) with various environmental and lifestyle factors, they found that prediction of PD status improved (Jacobs et al., 2020). In their analysis, factors such as family history of PD, history of depression, daytime sleepiness, and even non-neurological conditions like migraine or epilepsy were associated with higher PD risk (Jacobs et al., 2020). Many of these factors can be thought of as either environmental exposures or downstream effects of environmental and lifestyle influences. The conclusion was that both innate (genetic) and external (environmental) factors contribute to PD, and considering them together yields a more complete risk profile (Jacobs et al., 2020). This underlines an important point for our work: a personalized approach to PD care or prevention should ideally account for the individual's environment (external risk and protective factors) in addition to their personal health history or genetic background.

While the negative impacts of environmental toxicants are a key concern for PD prevention, there is another side to the environment–health relationship: positive or protective environmental features that can enhance well-being, especially in older adults managing chronic conditions. The concept of "age-friendly environments" encompasses factors like green space availability, walkability, low crime and pollution, social infrastructure, and accessibility – all of which contribute to the physical and mental well-being of seniors (Zhou et al., 2022). Zhou et al. (2022) conducted a meta-analysis of studies on age-friendly environments and found a modest but significant positive correlation between overall environment quality ratings and older adults' well-being outcomes. Specifically, combined environmental factors had a correlation coefficient of $r \approx 0.07$ with physical well-being and $r \approx 0.16$ with mental well-being in the elderly (Zhou et al., 2022). Although these effect sizes are relatively small, they reinforce that better environments (cleaner, greener, safer, more accessible) tend to support healthier aging.

Green space is one environmental feature that has received considerable attention. Contact with nature and urban green spaces has been associated with stress reduction, improved mood, and increased opportunities for physical activity and social interaction for older people. A study by Enssle and Kabisch (2020) in Berlin found that older adults who frequently visited urban green spaces (parks, community gardens, etc.) reported higher levels of social integration (they were more likely to have recently met friends or neighbors) and better self-rated health than those who seldom visited such spaces. Green spaces can serve as venues for exercise (walking, tai chi, etc.) which is beneficial for PD patients, and they may also provide a calming environment that reduces anxiety and depression symptoms that often accompany PD. However, not all environmental attributes are beneficial unconditionally. For example, Liu et al. (2019) explored green space in relation to various health outcomes across Chinese provinces and found nuanced effects: while increased green coverage was linked to lower incidence of some infectious diseases (e.g., dysentery, likely due to improved sanitation or cooler microclimates), it was paradoxically associated with higher incidence of others like malaria and tuberculosis (Liu et al., 2019). This was likely due to complex ecological reasons (e.g., more mosquito habitats in green areas, or socio-economic confounders). The takeaway is that environmental factors can have diverse impacts on health, and interventions should be evidence-based and context-specific. In designing an environmental health recommender, it is important to incorporate established beneficial factors (like promoting exposure to green nature when possible) while also guarding against exposures known to be harmful (air pollution, extreme weather, etc.).

For individuals with PD, daily fluctuations in the environment can influence symptom severity and safety. For instance, high ambient heat and humidity can worsen fatigue or dizziness in PD patients (who may have autonomic dysfunction), whereas extremely cold weather can increase rigidity. Poor air quality or high pollution days might aggravate breathing or cardiovascular stress. High noise levels can increase agitation or interfere with concentration and sleep. Light pollution at night could also disrupt sleep patterns, which is relevant because many PD patients suffer from sleep disorders. These links, while sometimes subtle, suggest that a truly personalized PD management plan would benefit from dynamic adjustments based on environmental conditions. Yet, traditional healthcare delivery has not been able to offer such granular, personalized advice on a continuous basis.

AI and Personalized Recommendation Systems in Healthcare

The advent of artificial intelligence in healthcare has opened new possibilities for personalized interventions. Recommender systems driven by AI can analyze large amounts of data and deliver customized suggestions or decision support. In the context of chronic disease management like PD, researchers have begun exploring digital solutions that act as personal health coaches. Alves et al. (2024) describe the development of *MoveONParkinson*, an AI-powered mobile application aimed at encouraging physical activity and exercise in people with PD. The system includes a conversational agent that interacts with patients, provides motivational cues, answers questions about exercise routines, and tracks the users' progress (Alves et al., 2024). Importantly, the design of that app was informed by behavioral change theories and current clinical guidelines which emphasize regular aerobic and balance training for PD patients (Alves et al., 2024). In their pilot study, Alves et al. found high user acceptance for the app, indicating that PD patients and their physiotherapists were willing to incorporate such technology into exercise programs. This demonstrates the feasibility of AI-assisted, personalized recommendations in PD care. However, MoveONParkinson and similar apps largely focus on internal factors (exercise regimens, symptom tracking) without integrating external environmental data. More generally, mobile health (mHealth) applications for PD and other chronic diseases are on the rise. Many apps provide medication reminders, symptom diaries, or educational content. Some utilize data from wearables (e.g., detecting tremor or gait changes via smartwatch) to alert patients or clinicians about fluctuations in condition. Yet, few if any current systems bring in environmental context when making recommendations. For example, an app might tell a patient to "take a walk for 30 minutes today" because exercise is beneficial – but it would not ordinarily check if today's air quality or weather makes that walk advisable or if it should suggest an indoor alternative. Likewise, an app might not recognize that a patient in a densely built, noisy city center might benefit from being directed to the nearest park for that walk to reduce stress and noise exposure. These kinds of contextual adaptations are precisely what an environment-informed AI system could provide.

Another frontier is the use of large language models (LLMs) like GPT-4 or Google's Gemini in generating health advice. LLMs are capable of understanding and producing human-like text, which makes them potentially useful for translating complex data inputs into accessible advice. They can be prompted with specific instructions and data, and then generate narrative outputs (e.g., a friendly paragraph of health advice). This natural language output can make recommendations feel more like personalized coaching rather than rigid instructions. However, using LLMs in healthcare also raises issues – primarily the accuracy and reliability of the generated content. LLMs are prone to “hallucinations,” meaning they may produce plausible-sounding statements that are factually incorrect or not evidence-based. In a medical context, this could be harmful if not carefully controlled. Ensuring that an AI’s suggestions are medically valid is a critical challenge. Some current research is exploring how to keep LLMs grounded in verified medical knowledge, such as by feeding them with trusted reference information or by having their outputs reviewed by clinicians or rule-based checks.

In summary, existing literature shows a gap that our work attempts to fill. While environmental factors are known to be important in PD and older adult health, and while AI-driven personalized recommendation systems are emerging in healthcare, these two areas have not been fully integrated. No prior study (to our knowledge) has combined real-time environmental sensing with a generative AI to produce tailored daily health recommendations for PD patients. Our approach builds upon the environmental health findings (incorporating both risk factor mitigation and healthy environment promotion) and the technological trend of AI personalization, to create an innovative system. The following sections describe the methodology of developing this system, the data sources and architecture, and demonstrate its function through simulated use cases.

Methodology and Data

System Architecture

The system uses a multi-layer architecture to integrate environmental data with personalized health recommendations. It consists of four components: data ingestion, logic processing, AI generation, and user output.

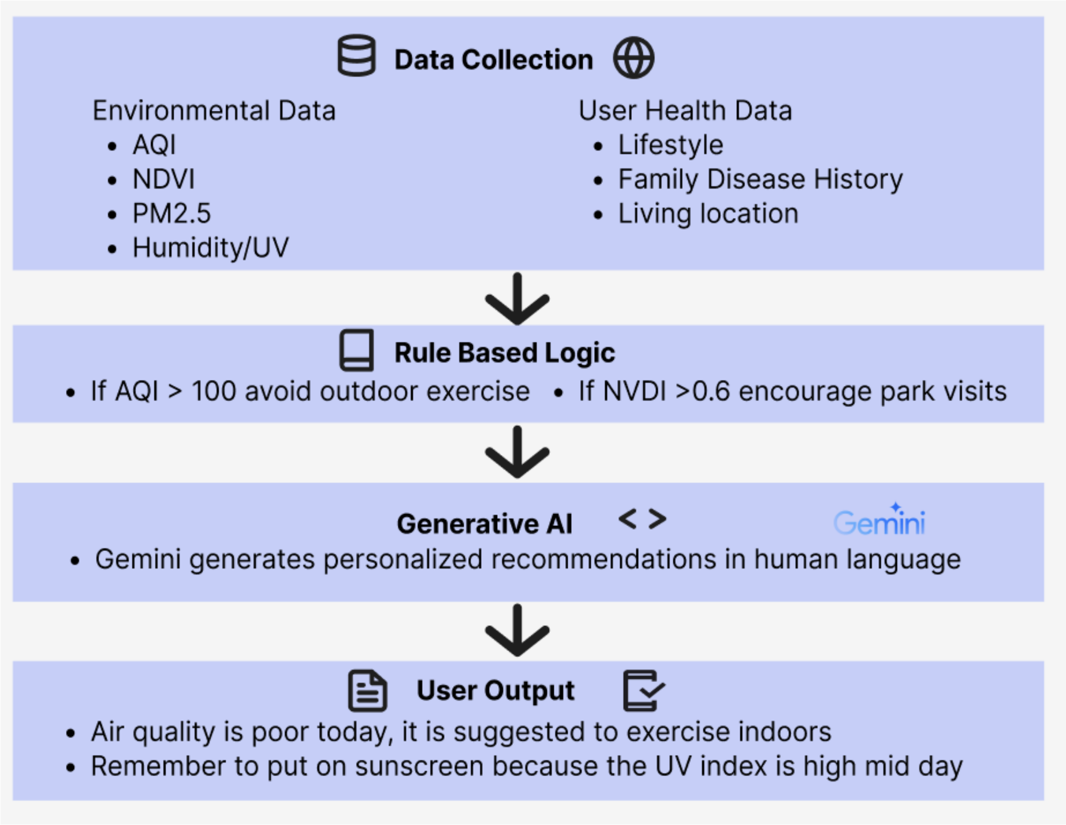

Figure 1 *System Architecture*

Data Ingestion Layer: This backend gathers real-time environmental data through APIs and satellite sources. From Taiwan's EPA and Central Weather Bureau, we collected air quality (AQI, $PM_{2.5}$), temperature, humidity, and UV index. Remote sensing tools like Sentinel-2 and Google Earth Engine provided NDVI and NDBI to assess green space and urban density. VIIRS nightlight imagery was used as a proxy for light pollution. Noise data was either user-estimated or inferred from urban density due to limited API access. These data streams are updated regularly (hourly or daily) and stored for processing.

Logic and Processing Layer: This layer applies a ruleset based on health guidelines to interpret environmental conditions. Each factor has thresholds that trigger specific suggestions. For instance, AQI over 100 prompts users to avoid outdoor exercise, while high NDVI encourages park visits.

Other examples include hydration advice on humid days, sleep tips in high light-pollution zones, and noise-related stress reduction suggestions. The rules work in combination to produce daily recommendation points based on the user's environment.

AI Generation Layer: Gemini AI transforms the structured recommendations into plain-language advice. The system builds a prompt with the user's profile (e.g., age, symptoms, PD status) and environmental summary (e.g., "AQI=120, humid, urban noise high"), then instructs the model to generate a concise and encouraging daily tip. The AI's role is to "humanize" the advice, making it understandable and relevant. For example, it may suggest indoor stretching on polluted days or remind users to wear sun protection if UV levels are high.

User Output Layer: Recommendations are delivered through a user interface, such as an app or dashboard. Advice updates daily and is accompanied by relevant environmental data. Users can give feedback on suggestions, helping the system refine future outputs. While our prototype was tested with simulated profiles, this layer could support real-time personalization in future deployments.

Overall, the system connects environmental data with AI-driven coaching through a structured, modular design. Each layer supports customization, making the platform adaptable and scalable for real-world health support.

Data Sources

This prototype uses two main data categories: simulated patient profiles and environmental data specific to Taiwan.

Simulated Patient Profiles: We created representative user profiles to test the system's dual-path logic for both diagnosed PD patients and individuals at high risk. Each profile included demographic details, symptom history (e.g., tremors, constipation, REM sleep issues), lifestyle habits (e.g., sleep patterns, exercise), and baseline wearable data such as daily step counts and sleep duration. For example, one profile represents a 62-year-old sedentary male with family history and prodromal symptoms, while another depicts a 68-year-old woman with early-stage PD who stays active but has disrupted sleep. A third profile shows an older adult without PD but exposed to environmental stressors like high humidity. These profiles were grounded in PD research to reflect common risk patterns and used to simulate inputs a real system might receive.

Environmental Data Sources: Taiwan offers robust open data infrastructure ideal for this study. Air quality readings (AQI, $PM_{2.5}$) were obtained from the Taiwan Air Quality Monitoring Network. Weather conditions, including temperature, humidity, and UV index, were pulled from the Central Weather Administration. Satellite-derived indices—NDVI and NDBI—were calculated from Sentinel-2 imagery via Google Earth Engine to estimate vegetation and urban density. Nighttime light pollution was estimated using VIIRS satellite data, while noise levels were approximated using land-use data and urban density due to limited public noise datasets.

Environmental and patient data were time-aligned and location-specific. Each simulated case was tested using real environmental snapshots from different regions in Taiwan (e.g., high-pollution days in Hsinchu or high-UV periods in Taipei), allowing us to observe how the system adapted its recommendations under varied real-world conditions.

Recommender Engine Design

At the core of the system is the recommender engine, which blends rule-based logic with AI-generated content to deliver personalized advice. It operates in two distinct modes based on user type:

Mode A – PD Patient Path: For diagnosed Parkinson's patients, the engine emphasizes symptom management, daily routines, and environmental safety. It adjusts suggestions based on personal logs—for instance, recommending longer warm-ups if stiffness is reported, or indoor balance exercises if outdoor conditions are slippery. The system also considers environmental triggers such as pollution or heat that might worsen symptoms.

Mode B – High-Risk Individual Path: For users not diagnosed but with PD risk factors, the system focuses on preventive lifestyle coaching. It promotes physical activity, hydration, sleep regularity, and outdoor engagement when conditions are favorable. For example, on clear days, the AI might suggest a walk in green space or tai chi in the park to support both fitness and social interaction.

Both modes use the same environmental rules but apply different emphasis and language. We crafted two prompt templates for Gemini: one centered on PD symptom support ("to help with your Parkinson's symptoms...") and another for general wellness ("to stay healthy and reduce your risk..."). Personal rules include simple health logic—for instance, low step count triggers exercise encouragement, or insomnia logs prompt sleep tips. Prompts also include specific safeguards, instructing the AI to avoid discussing medication and focus only on lifestyle advice.

Here's a typical prompt structure:

User: 68F, early-stage PD, walks ~4500 steps/day, poor sleep. Environment: AQI 50, UV high, green space nearby. Generate 2–3 wellness suggestions considering her profile and today's conditions.

The AI then produces accessible, empathetic language tailored to the user's context. Outputs are validated against standard PD guidance, and hallucination risks are minimized through tight prompt controls. Finally, the system supports bilingual output. While development was in English, rule templates can localize into Chinese, making the platform accessible to Taiwan-based users. Overall, this hybrid engine balances scientific accuracy with personalized communication, helping users receive relevant and understandable daily guidance.

Results

To evaluate the system, we conducted a simulation using three distinct user profiles (as described in the Methodology) and generated daily recommendations for each under representative environmental conditions. These case studies illustrate how the integrated system personalizes advice and how it differs for each scenario.

User A – High-Risk Individual in Urban/High-Pollution Environment: User A is a 62-year-old male with no formal PD diagnosis but significant risk factors. He lives in Hsinchu City's busy downtown, an area characterized by dense buildings and traffic (poor air quality and noise). He has a family history of PD (his father had the disease) and reports prodromal symptoms like REM sleep behavior disorder and chronic constipation. His lifestyle is fairly sedentary and he often stays up late at night. On the chosen day for simulation, the environmental data for his location showed high air pollution (AQI around 130, $PM_{2.5}$ levels above 50 μg/m³, which is unhealthy), hot and humid conditions (afternoon temperature 32°C, humidity ~75%), and moderate UV index (~7 at noon). There is some green space near his residence (a small park, NDVI about 0.4) but also considerable noise from traffic (estimated >65 dB).

The system generated the following recommendation for User A: *"It's recommended that you take a gentle walk early in the morning to stay active and help with your sleep cycle. Morning hours have slightly better air quality and cooler temperatures. Given today's air pollution is high, if you go out later, try to avoid main roads with heavy traffic – perhaps walk along quieter, tree-lined streets or in* *the park to get some fresh air and shade. Make sure to wear a mask outdoors today, as the* $PM_{2.5}$ *levels are elevated. Also, stay hydrated because of the heat and humidity; drinking water regularly can help with your constipation and prevent dehydration. In the evening, keep your bedroom dark and quiet (close the windows to block city noise and use curtains) to improve your sleep. By adjusting your routine to the environment, you can stay healthier and manage stress better."*

In plain terms, the system advised User A to exercise at an optimal time (morning) to regulate his circadian rhythm and avoid the worst pollution of the day. It gave context-specific tips like choosing shaded routes away from traffic due to high $PM_{2.5}$ and noise. It also linked a personal health issue (constipation) with an actionable suggestion (hydration, moderate exercise can help bowel motility). These recommendations address both preventive goals (for a high-risk person, increasing activity and avoiding pollution might reduce risk) and immediate comfort/symptom relief (coping with heat and constipation). Notably, without the environmental integration, a generic advice might have simply been "exercise more and drink water" – our system made it more specific: "exercise in the morning in a less polluted, shaded area and drink water because it's hot and you have constipation issues."

User B – Parkinson's Patient in Green, Low-Pollution Environment: User B is a 68-year-old female living in the Beitou district of Taipei, which is known for its greenery (near hot spring parks) and relatively clean air for a city. She has early-stage PD, chiefly experiencing mild motor symptoms and some sleep irregularity. She enjoys gardening and currently averages about 4,500 steps a day walking, which is good but below general recommendations for older adults. She does not have severe symptoms, but her sleep is inconsistent (sometimes up late, sometimes up early). On the simulated day, air quality was good (AQI ~30), green space density around her home was high (NDVI ~0.6, as she lives near a large park), and weather was warm but not extreme (28°C midday, moderate humidity 60%). Noise levels were typical of a residential area (not too high).

The system's recommendation for User B was as follows: *"Today is a great day to be active! The air quality is good, and you have plenty of green space nearby. Consider taking a 30-minute morning walk in the park – the greenery and fresh air can boost your mood and balance. Since you're currently walking about 4,500 steps a day, let's aim a bit higher – try to reach ~7,000 steps today if you feel up to it. You might split this into a morning and late afternoon walk. Also, you mentioned enjoying gardening; that's wonderful exercise too, just remember to wear a hat or sunscreen because the UV index is high around midday. In addition to walking, you could add some light Tai Chi or stretching exercises in your routine (perhaps in the park with a group, if available). Tai Chi is known to help with balance and coordination in PD. Finally, since your sleep has been irregular, sticking to a consistent bedtime and doing some relaxing activity (like gentle stretches or reading) before bed tonight could improve your rest. Keep up the great work staying active!"*

For User B, the advice leveraged the positive environmental conditions: encouraging more outdoor time in the park, which is feasible because of low pollution. The recommendation specifically suggested increasing her step count towards 7,000 – a personalized goal above her current baseline – and even recommended Tai Chi, which is an exercise often beneficial for PD patients (improving balance and flexibility). It also accounted for the high UV by cautioning sun protection during gardening. The tone is supportive, congratulating her on her gardening and walking habit and nudging her to do a bit more. This reflects how the system can adapt to someone who is already moderately active by providing an appropriate challenge (whereas for User A, who was sedentary, the system started with just a gentle walk advice). By referencing Tai Chi and group activities, the AI tapped into known PD-friendly exercises and also subtly encouraged social interaction (joining a group in the park), which is good for mental health. All these elements were derived from the context: good environment allowed for these recommendations, and her personal profile (enjoys gardening, etc.) guided the AI to mention related activities.

User C – High-Risk Individual in Humid Climate, Rural Setting: User C is a 74-year-old male residing in the East District of Tainan City. He has no diagnosed neurological conditions and no family history of PD, so he might be considered a general older adult with potentially lower PD risk, but we included him to test the system's preventive angle in an environment with other challenges. He has a routine of taking a morning walk every day and is relatively healthy, though he tends to nap often and may not drink enough fluids. The environmental scenario for his day was very high humidity (around 85% in early morning climbing to 90% later, common in southern Taiwan), warm temperature (~29°C), and since he lives in a less urbanized area, lower pollution (AQI ~40) and low light pollution at night. There is moderate green space around (some fields or parks, NDVI ~0.5). Essentially, the key environmental issue for him was the tropical climate (hot and humid) and the risk of dehydration or heat stress it brings.

The system's recommendation for User C was: *"It's quite humid today, so for your daily walk, try to go earlier in the morning when it's a bit cooler and the humidity is slightly lower. Walking is a fantastic habit – keep it up daily. Just be mindful of the heat: carry a bottle of water with you and take small sips regularly during your walk to stay hydrated. High humidity can make you feel tired faster, so listen to your body and rest in the shade if you feel overheated. Since you often take naps, ensure they're not too late in the day so as not to disrupt your nighttime sleep. The air quality is good, which is great – you can breathe easy outdoors. Also, even on warm days, doing some light stretching or balance exercises indoors (maybe during the hotter afternoon) can complement your morning walks. Remember to drink water not just when outside but throughout the day – perhaps have a glass with each meal and one in between. Staying well-hydrated will help you feel more energetic and is good for your overall health."*

For User C, the advice was focused on preventing dehydration and heat-related fatigue, reflecting the very humid environment. The system suggested adjusting the timing of exercise (earlier to avoid peak humidity/heat) and reinforced the habit of daily walking. It emphasized hydration multiple times, which ties to his personal tendency to nap (possibly indicating fatigue that could be partly due to not enough fluid intake or the draining effect of humidity). It also gave a generic but useful tip about not napping too late to preserve nighttime sleep – showing that it remembers to address sleep hygiene even though the environmental triggers for sleep here (like light pollution or noise) were minimal for him. The recommendation to do some indoor exercises in the hot afternoon is an example of adapting to environment constraints: recognizing that afternoons might be too uncomfortable outside, the system still encourages physical activity by suggesting an indoor alternative at that time. Overall, User C's guidance is more general wellness-focused (he is not a PD patient or strongly high-risk), but it demonstrates the system's value even for healthy older adults: it functions as a context-aware health coach that can adapt advice to daily weather.

Parkinson’s Advice

Exercise early in the day
UV index = 8

Stay hydrated
Humidity 75%

Spend time outdoors
Air quality good (AQI=10)

Figure 2. Interface of this Mobile App

The results indicate that the Environmental-AI integrated recommender system can effectively generate personalized daily health recommendations for Parkinson’s patients and individuals at risk. These recommendations (a) adapt to environmental conditions, (b) are tailored to the individual’s health profile, and (c) align with established health guidelines. While the findings are based on simulated data, they provide a compelling proof of concept that the system can operate as intended. As illustrated in Figure 2, the recommendations can be delivered directly to users’ mobile devices, enabling more informed health decisions. The following section discusses the implications of these findings, the potential practical benefits of such a system, and the challenges and limitations that warrant further attention.

Discussion

One of the key strengths of the recommendation system lies in its ability to personalize advice based on the user's surrounding environment. Rather than offering static, one-size-fits-all recommendations, the system dynamically adjusts its guidance based on real-time environmental data—including air pollution (e.g., $PM_{2.5}$, AQI), humidity, UV index, and green space availability. For example, on days with high air pollution, the system may suggest indoor exercises or wearing a mask outdoors, while on days with good air quality and strong greenery, it may encourage outdoor walking or tai chi. This location- and time-sensitive design ensures that the advice is not only medically sound but also practically relevant.

In addition to environmental exposure, the system considers personal lifestyle and background information, such as daily activity levels, sleep routines, and family history of Parkinson's disease. These data points allow the recommendations to remain within the user's physical abilities and reflect their existing habits. For instance, a sedentary older adult with prodromal PD symptoms might receive gentle activity suggestions, while an early-stage patient already engaged in daily walking may be encouraged to increase intensity or vary routines. By integrating these two dimensions—external context and internal profile—the system delivers recommendations that are both feasible and meaningful for individual users. This level of personalization is particularly important for Parkinson's disease, where environmental triggers (e.g., heat, noise, air quality) can exacerbate symptoms, and where patients often have varying levels of mobility and cognitive function.

The use of Gemini AI further enhances the system's adaptability and communication effectiveness. Rather than presenting raw rule-based outputs, the AI transforms these inputs into natural language suggestions that feel supportive and conversational. For instance, instead of saying "AQI > 100: avoid outdoor activity," Gemini might generate "The air quality is not great today, so it's better to exercise indoors or wear a mask if going outside." This shift in tone—from directive to empathic—can be especially important for elderly users, who may respond better to recommendations that feel like human coaching rather than automated alerts. Moreover, the AI's ability to rephrase technical information into everyday language reduces cognitive barriers and improves accessibility.

Nonetheless, several challenges remain. One major limitation is the need to validate AI-generated advice across diverse patient scenarios. The current prototype has only been tested using simulated profiles; future clinical trials involving real users will be essential to evaluate its effectiveness and safety. Urban–rural disparities may also affect the system's applicability. Recommendations suitable for individuals in high-density urban areas may not translate well to those in rural regions, where environmental exposures differ significantly. In addition, the ethical implications of using AI in healthcare should be carefully considered. Large language models like Gemini carry a known risk of generating plausible-sounding yet scientifically unsupported content. To mitigate this, AI-generated recommendations should undergo rigorous review to ensure they are consistent with current medical evidence and clinical guidelines.

Conclusion

We developed and tested a personalized Environmental-AI integrated recommender system for Parkinson's rehabilitation. The system combines environmental data—sourced from the Taiwan Air Quality Monitoring Network, the Central Weather Agency, and Google Earth Engine—with personal health information such as family disease history, lifestyle habits, and Parkinson's disease status to construct a tailored prompt. This prompt is submitted to Gemini AI to generate daily health recommendations. The prototype system includes several key components: collecting real-time environmental data, applying rule-based health guidelines to interpret environmental conditions, and generating structured advice through AI.

While environmental factors have long been recognized as influencing Parkinson's disease, and AI-driven recommendation systems are increasingly applied in healthcare, the integration of environmental data with AI remains largely unexplored. This system addresses that gap by providing real-time, environment-aware recommendations, offering a novel tool for personalized support in managing chronic Parkinson's disease. Nevertheless, the system has limitations and requires further development for broader application. At present, it has only been tested with simulated data; future clinical trials will be necessary to evaluate its robustness and medical validity. Additional enhancements may include incorporating user feedback, improving the reliability of AI-generated advice, and making the recommendations more adaptive over time.

The system shows strong potential for scalability and practical use in clinics, homes, and elderly care centers. By generating personalized profiles and real-time recommendations, it may also assist in preventive care for high-risk individuals in senior living environments. Although challenges remain—particularly in validating AI-generated recommendations—these can be mitigated through alignment with established scientific evidence. In the future, similar systems could be adapted to support the management and prevention of other chronic conditions such as Alzheimer's disease, asthma, and beyond.

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