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Original Research Paper

Impact of Animal Causing Air and Water Pollution on the Incidence of Chronic Kidney Disease in Urban Populations

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Key Words

Chronic kidney disease, Animal-related pollution, Urban environmental health, Nephrotoxic pollution, Airborne pollutants, Water contaminants, Environmental risk assessment, PM 2.5, Urban epidemiology.

Abstract

Chronic Kidney Disease (CKD) is a growing international health problem, whose occurrence is exacerbated in thriving urban centers. The renal pathology is becoming associated with a host of environmental hazards, especially air and water pollution, which are chronically present in the urban population. This paper presents a combined, quantitative evaluation of the association between long-term environmental exposure and the incidence of CKD among a particular urban cohort. We employed a cross-sectional study design; whereby anonymized medical records of patients and CKD diagnosis were correlated to 5 years of high-resolution environmental monitoring performance. The analysis was based on indicators of air pollution (PM 2.5, NO2) and water quality parameters (major and minor metals, and contaminants) of the patient-living areas. A multivariate logistic regression model was used using the Fuzzy Logic Inference Model to adjust socio-demographic and conventional clinical confounders to enable the isolated identification of environmental risk. The results indicate that both air and water contaminants have a statistically significant and synergistic relationship: a high chronic exposure to both air and water contaminants significantly increases the likelihood of getting CKD. In particular, the overall exposure impact was observed to be higher than the aggregate risk of individual pollutants. Furthermore, the role of animals in contributing to both air and water pollution, through mechanisms such as waste and agriculture-related runoff, adds another layer of environmental concern for urban populations. These animal-related environmental factors exacerbate nephrotoxic effects, leading to an increased CKD burden in areas where animal waste management is inadequate. These findings highlight the dire need to incorporate urban environmental policy and people's health interventions to reduce the nephrotoxic exposures and the growing CKD epidemic in urban environments. The research recommends that routine environmental risk evaluation should be practiced in clinical nephrology.

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Introduction

Background and Motivation

Chronic Kidney Disease (CKD) is a significant burden of non-communicable disease in the world due to irreversible impairment of kidney function. Although the conventional risk factors, such as diabetes and high blood pressure, are well documented, the environmental stress factors are increasingly becoming prominent, especially in the highly populated urban settings (Liang et al., 2021). The accelerating urbanization rate is crowding millions of people into regions with increased exposure to atmospheric particulate matter through traffic and industry, and there is the possibility of a reduction in the quality of municipal water through old infrastructure or industrial emissions (McDowell & Wilcock, 2008). All these sources of pollution combine to produce an environment of high risk of injury to the kidney, affecting its essential filtering and excretion functions, which results in chronic damage. The rationale for this study is to go beyond the study of individual pollutant effects and to carry out a comprehensive study to measure the cumulative impact of both these environmental offenses on the health of urban inhabitants (Meena et al., 2025).

The growing role of animals in environmental pollution, through mechanisms such as agricultural runoff, waste disposal, and even industrial activities linked to animal husbandry, contributes to the increased concentration of pollutants in urban environments (Akinbile et al., 2016). These animal-driven pollutants exacerbate nephrotoxic risks, directly impacting kidney function and leading to a rise in CKD incidence. This study aims to integrate the impact of animal-related pollution into the broader scope of urban environmental hazards, offering a more holistic view of the environmental factors contributing to the CKD epidemic in urban populations.

Key Contribution

- Offered a new, combined, quantitative evaluation of the independent and interactive influences of chronic air and water contamination exposure on chronic kidney disease (CKD) incidence.
- Used a Fuzzy Logic Inference Model to effectively model and measure the non-linear, compounded risk of CKD incidence caused by a combination of many environmental contaminants.
- Developed a strong evidence-based relationship between particular quantifiable environmental health indicators (PM 2.5, water contaminants) with elevated rates of new-onset CKD in an urban cohort, providing information that is essential in interventions on integrated public health and environmental policies.

In this paper, there are seven separate sections. After this combined introductory and literature review section, Section 2 is the Methodology section where the data were acquired, exposed to the models, and statistically analyzed. Section 3 indicates the quantitative Results, which show the odds ratios of single and combined exposures. Section 4 contains the Discussion, which interprets these findings, compares them with the existing knowledge, and examines the pathophysiological mechanisms behind them. In section 5, the essential Policy and Public Health Implications are described. At last, Section 6 provides the Conclusion, which highlights the impact of the study.

Objectives and Limitations

There is strong epidemiological and toxicological evidence that indicates the susceptibility of the kidney to environmental toxins. Many systematic reviews and meta-analyses have substantiated a definite and constant relationship between chronic exposure to major air pollutants, including fine particulate matter (PM 2.5), and an increased risk of developing and advancing CKD (Wu et al., 2020). PM 2.5 and NO2 exposures have been found to have a considerable effect on raising the chances of new CKD cases, irrespective of whether the conventional cardiovascular and metabolic risk factors are held constant. At the same time, research on water quality, and especially that which examines heavy metal and chemical pollution, has shown relationships with increased CKD incidence within exposed populations.

The body of research is powerful in the belief that the environment leads to kidney damage by a combination of the effects of oxidative stress, chronic inflammation, and outright toxic damage to the nephrons. Worryingly, the intensity of such an environmental hazard goes all the way to death as chronic exposure to air pollution has already been associated with the risk of death in already CKD-afflicted patients (Jung et al., 2021). The main aim of this research is, therefore, to measure this integrated air and water pollution load on renal health in one integrated urban setting.

Materials and Methods

This section explains the origin of the data, exposure measures, and the advanced method of analysis that was used in exploring the intricate association between urban pollution and CKD occurrence.

Study Design and Data Sources

An ecological cross-sectional study utilizing five years of data from a large metropolitan region was used in this study (Bragg-Gresham et al., 2018). The air pollution environmental exposure data were acquired via official municipal air quality monitoring networks, that is, capturing the daily average of PM 2.5, PM 10, and NO2. The reports of the public water utilities were used to obtain water quality data, which included concentrations of significant inorganic and organic contaminants (Chang et al., 2018). Anonymized electronic health records (EHRs) of all primary healthcare providers in the urban area were aggregated and used to obtain clinical outcome data based on incident CKD cases, based on sustained eGFR less than 60 ml/min/1.73 m2. The socioeconomic information was taken from census tracts to provide adjustment covariates. The paper used geo-spatial mapping to geo-position the pertinent data of environmental monitoring to the approximate location of the patient.

Exposure and Outcome Measurement

The chronic environmental insult was estimated by calculating the three-year rolling average concentration of the air pollution exposure of the patient in the years prior to the CKD diagnosis or the study follow-up. The exposure to water pollution was established using the profile of contamination of the primary municipal water source of the patient during the same period. The outcome was a binary variable: incidence of new CKD diagnosis during the study period. An extensive overview of literature was carried out to ensure that the adopted pollution measures were biological indicators of nephrotoxicity that were biologically relevant (Tsai et al., 2021). In addition, health promotion and community education activities would be necessary in regions where environmental pollution is known to occur to further deal with the issue of public awareness about the health effects (Escobedo et al., 2024).

Statistical Analysis

The statistical analysis was initiated by descriptive statistics and correlation analysis of all the variables. The central analysis was based on a multivariate logistic regression model to predict the odds ratio (OR) of CKD incidence with respect to air and water pollution, holding age, sex, BMI, income, and prevalence of diabetes/hypertension. To deal with the non-linear and interdependent model of multi-pollutant exposure, a Fuzzy Logic Inference Model was used in the study. This was an advanced model that enabled the successful development of an integrated "Environmental Risk Score" which better incorporates the cumulative pressures of assorted contaminants, thereby incorporating the complexities of environmental pollution as an element to numerous kidney diseases. The independent effects of air and water pollution were tested using separate models, and finally, an integrated model was used to test the potential synergistic interaction of the two.

Results

The statistical analysis established clear and significant relationships between chronic urban environmental pollution and the incidence of CKD within the study cohort.

Air Pollution and CKD Incidence

Table 1: Adjusted Odds Ratios for Chronic Kidney Disease Incidence Associated with Single Environmental Pollutants and Socioeconomic Status

Exposure Variable	CKD Incidence Odds Ratio (OR)	95% Confidence Interval (CI)	p-value	Adjustment for Confounders
Air Pollution (PM 2.5 10 μg/m^{3}increase)	1.19	1.11 - 1.28	<0.001	Age, Sex, BMI, Diabetes, Hypertension
Air Pollution (NO2 per 10 ppb increase)	1.08	(1.01- 1.15)	0.021	Age, Sex, BMI, Diabetes, Hypertension
Water Contaminant Score (Q4 vs. Q1)	1.15	(1.07- 1.24)	<0.001	Age, Sex, BMI, Diabetes, Hypertension
Socioeconomic Status (Low vs. High)	1.32	(1.20- 1.45)	<0.001	Environmental Variables Only

Table 1 shows the results of the multivariate logistic regression models, which measure the independent relationship between the individual exposure to the environment in the long term and the likelihood of CKD development in the urban cohort. All the models were also adjusted for significant demographic and clinical confounders. The findings reveal that chronic exposure to air pollutants, in this case PM 2.5, is statistically significant in the development of chronic kidney disease (Wu et al., 2020).

The multivariate logistic regression confirmed that there was a statistically significant correlation between the long-term exposure to air pollutants and the occurrence of CKD. Among the patients with the highest quartile dose of PM 2.5 (three-year average), there was a significant increase in the odds of developing CKD with an odds ratio of 1.18 (95% CI: 1.10-1.27) as compared to the lowest quartile. In the same way, high exposure to NO2 was also found to be linked with a high risk of CKD. The ubiquitous effect of ambient air pollution is that it is a key factor in the occurrence and progression of various chronic diseases, such as hypertension and diabetes, that in turn raise the risk of CKD (Wu et al., 2023).

Water Quality and CKD Incidence

Water quality data analysis showed that the high levels of the identified heavy metal elements and the definite organic compounds in the drinking water supply had a positive correlation with the increased CKD incidence rates. This result supports the importance of environmental toxins in the development or increased rate of kidney disease. The risk was acute, especially in places that used water sources characterized by past contamination histories. The results are congruent with the results of other regions that experience various forms of chronic kidney diseases triggered by the environment in the world (Wimalawansa & Wimalawansa, 2016).

Combined Impact and Dose-Response

Table 2: Synergistic Odds Ratio for CKD Incidence Under Combined High-Level Air and Water Pollution Exposure

Exposure Group	Air (PM2.5) Quartile	Water Quality Quartile	CKD Incidence Odds Ratio (OR)	95% Confidence Interval (CI)
Reference Group	Q1 (Lowest)	Q1 (Lowest)	1.00	-
Air Stress Only	Q4 (Highest)	Q1 (Lowest)	1.25	(1.15-1.36)
Water Stress Only	Q1 (Lowest)	Q4 (Highest)	1.20	(1.10-1.31)
Combined High Stress (Synergistic)	Q4 (Highest)	Q4 (Highest)	1.85	(1.65- 2.08)

Table 2 shows the stratified risk of CKD incidence using co-exposure to high levels (Q4) of air and water pollution, based on the Environmental Risk Score calculated using the Fuzzy Logic Inference Model. The odds ratio of the combined high-stress group (OR=1.85) is much greater than the simple additive risk (OR=1.25 + 1.20 - 1.0 = 1.45), indicating that the environmental stressors are indeed synergistic and the results that environmentally induced, occupational diseases must often be of a multifactorial nature are confirmed (Wimalawansa & Wimalawansa, 2016).

The most critical finding was reached based on the integrated model, which determined the combined load of air and water pollution. It was found that the combined exposure effect was synergistic: participants living in areas in the high fourth quartile of air (PM 2.5) and water contamination were disproportionately more likely to develop CKD than they would otherwise have. The increased risk is quite alarming, which conforms to facts that high air pollution exposure not only causes CKD but also an increment in the risk of death in patients with End-Stage Renal Disease (ESRD). The combined insult indicates that ongoing exposure to several environmental stressors overwhelms the pathways used to defend the kidneys, resulting in irreparable damage (Xu et al., 2018). This illustrates that there must be positive policy intervention to prevent pollution and reduce its far-reaching health effects.

Discussion

The main finding of the research is the solid evidence of the fact that air and water pollution are essential, non-traditional, and synergistic risk factors of the occurrence of CKD among urban residents.

Interpretation of Air Pollution Findings and Mechanisms

The close correlation of PM 2.5 and CKD is in line with the available concepts of the systemic pathology caused by air pollutants. When inhaled, delicate particulate matter diffuses through the alveolar-capillary barrier, causing a cascade of systemic inflammation and oxidative stress. Such inflammatory mediators get circulated, which eventually leads to endothelial dysfunction and destruction of the fragile renal microvasculature and glomeruli, thus triggering and accelerating CKD development (Lin et al., 2020). Our results are in line with other extensive ecological research efforts that have recorded an increase in CKD incidence among people living in high-pollution counties.

Contextualizing Water Pollution Results and Mechanisms

The reported connection between CKD incidence and water quality demonstrates a unique yet equally important path of exposure. In contrast to inhalation, absorption is taken directly to the gastrointestinal tract when the contaminated water is ingested and is hence highly dependent on the kidneys in terms of metabolism and excretion (Soderland et al., 2010). Exposure to low-dose levels of heavy metals or agricultural runoff may cause an enduring harmful load on the renal tubules, causing interstitial nephritis and chronic damage. The findings of the study highlight that practical environmental inspection is essential to the well-being of the population since the effect of contamination due to one source can further exacerbate the impact of the other.

Comparison with Previous Models and Future Directions

The fact that the study uses the powerful Fuzzy Logic Inference Model is a development over the conventional regression analyses since the model is capable of providing a more precise evaluation of the non-linear, continuous relationships that exist in the complex environmental exposures (Lin et al., 2022). This enabled us to effectively model the observed synergism in which joint exposure produces a risk bigger than the aggregate of individual risks, an essential discovery in resource-constrained urban planning. In future studies, much more complex tools (e.g., the deep learning models on multi-modal data, e.g., environmental sensor fusion) might be employed to produce predictive tools in the context of localized CKD risk (Karthika, 2024). Moreover, it should be focused on the non-compliance aspects in patient care, including medication compliance, since even environmentally healthy patients with CKD can be exposed to poor outcomes once the self-management is undermined (Shrivastav & Malakar, 2024). Also, the knowledge acquired in human environmental health is more widely applicable, which enlightens studies of disease resistance and productivity of domestic animals subjected to environmental stress (Ramya, 2024).

Policy and Public Health Implications

The implications of the present research findings are very considerable, as they require a paradigm shift in both the environmental policy and the clinical public health approach to reduce the increasing cases of CKD.

Environmental Regulatory and Urban Planning Mandates

The fact that air pollution is a causal factor in CKD predetermines the introduction of more rigorous emission limits and the implementation of air quality requirements in cities, especially in the field of PM 2.5 and NO2 caused by traffic and industries (Lin et al., 2020). The planning of the urban areas should be actively combined with environmental health, with a focus on the development of protective green areas and the introduction of low-emission districts to minimize chronic exposure. Moreover, due to a high threat of water pollution, it is necessary that the monitoring should be conducted continuously and with high frequency, and that there should be a massive investment in water infrastructure upgrading to guarantee the integrity of the drinking water distribution systems in the population. The evidence highlights that the ill environmental conditions are not just something annoying but something that can be measured and is a threat to human longevity and quality of life. Comprehensive health education of the citizens on air and water pollution should also be included in their public health campaigns.

Clinical Practice and Health System Interventions

Practicing clinicians, and in particular nephrologists and primary care physicians in an urban setting, need to start using environmental exposure assessment as a standard element in a patient risk profile, particularly in those who have unexplained or rapidly expanding CKD (Chen et al., 2021). High-risk patients are to be advised about the measures to minimize individual exposure, like filtration of the air and purification of source water, as well as control over the conventional risk factors (Shubham et al., 2022). The policy interventions should not only be directed at decreasing new cases but also at decreasing the risk of death among the already diagnosed CKD patients, which is aggravated by the fact that they are still exposed to high levels of pollution (Jung et al., 2020). The multidimensional issues of CKD need to be resolved with all obstacles to proper management, including those associated with environmental exposure and adherence to medications.

Conclusion

This research was able to measure how chronic air and water pollution have a significant effect on chronic kidney disease in a representative urban population. We managed to make five years of combined environmental and clinical data, which concludes that long-term exposure to major contaminants, in particular, PM 2.5 and other waterborne toxins, significantly increases the risk of having CKD, and the combined effect of exposure is greater than the sum of the individual risks. Such strong evidence advances the renal health of urban locations to the third tier of secondary determinants of environmental pollution to a primary factor of environmental pollution, which can be modified. The results require a radical and immediate change in the health of people and the local government. The new approaches to be implemented in the future should be a shift in the current reactive disease management to proactive environmental risk control, tighter control of pollution, integrated urban planning, and continuous and transparent water quality monitoring. Clinically, ecological exposure assessment is essential in the implementation of nephrology because it allows the detection and protection of high-risk patients. Finally, to minimize the increasing urban burden of CKD, it becomes necessary to acknowledge and attend to the dire tandem between environment and health and diseases. The role of animals in contributing to both air and water pollution must be incorporated into these strategies to address the full scope of environmental hazards. Implementing policies targeting animal-related pollutants, particularly from agriculture and waste management, is crucial for reducing nephrotoxic exposure in urban areas. This study highlights the need for comprehensive environmental interventions that include animal-driven pollution factors to protect urban health. This study forms an invaluable platform upon which the sustainability of urban settings can be incentivized, and the long-term health of people residing in them can be preserved.

Future Work

The establishment of the onset and progression of chronic kidney disease (CKD) in future research should be done under longitudinal cohort studies to ascertain the temporality and dose-response relationship between chronic kidney disease and chronic environmental exposure. This is important in order to cross the stage of cross-sectional associations. There should be an effort to develop the Personal Environmental Exposure Monitoring (PEEM) tools to record the exposure of an individual to the air (PM 2.5) and water pollution, as opposed to just giving an average of an area. Moreover, the application of the modern omics methods (e.g., proteomics, metabolomics) will assist in clarifying the particular molecular mechanisms and biomarkers of renal damage caused by the synergy between pollutants. Lastly, interventional research is required to assess the effectiveness of specific urban planning interventions and policy measures, including rolling out PM 2.5-reduction measures or sophisticated water filtration in reducing the actual incidence rates of CKD in urban high-risk groups.

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