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The relationship between water quality measurements and the prevalence of kidney dysfunction among HTI employees in Banyuasin, Indonesia

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ABSTRACT

Chronic Kidney Disease (CKD) is a global health challenge with a worldwide prevalence of 13,4%. (Riskesdas, 2018). In. Indonesia, while the national prevalence among the productive-age population is 0,38%, Industrial Forest Plantation or Hutan Tanaman Industri (HTI) employees in Banyuasin are at increased risk due to exposure to substandard drinking water with acidic pH (mean 5.8 ± 0.4), heavy metals (Fe 0.45 mg/L), Total Dissolved Solids (TDS) of 420 mg/L, and extreme occupational heat stress (38.2 °C). This study aimed to analyze the relationship between water quality parameters and kidney dysfunction among HTI employees and to identify occupational risk factors that exacerbate renal health in industrial settings. This narrative review, conducted in April 2026, synthesized evidence from 10 studies published between 2018 and 2026. A systematic literature search was performed via PubMed, Scopus, Sinta, and Google Scholar using keywords such as "water quality," "pH nephrotoxicity," and "occupational CKD," occupational CKD. This review focused on the correlation between water quality parameters (pH, TDS, and contaminants) and clinical renal dysfunction indicators (estimated Glomerular Filtration Rate (eGFR) and creatinine) among industrial workers based on medical check-up data, with a focus on the implications for HTI Banyuasin, Indonesia. The literature synthesis demonstrated that contamination of drinking water by Perfluorooctanoic Acid (PFOA) and heavy metals is significantly associated with a decline in the eGFR. Furthermore, chronic dehydration resulting from heat stress in tropical environments induces recurrent Acute Kidney Injury (AKI), which contributes to the development of Chronic Kidney Disease of unknown (CDKu) etiology. Poor water quality and inadequate hydration management are major risk factors for kidney disorders among HTI employees. Strengthening workplace Water, Sanitation, and Hygiene (WASH) standards is essential for the early prevention and long-term protection of worker health.

Keywords: chronic kidney disease; water quality; HTI employees; heat stress; PFOA

1. INTRODUCTION

Chronic Kidney Disease (CKD) represents a significant global health challenge, affecting approximately 850 million individuals worldwide. In Indonesia, while the national prevalence among the productive-age population is reported to be 0.38%, localized industrial regions, particularly within the Industrial Forest Plantation or Hutan Tanaman Industri (HTI) sector, face unique environmental and occupational pressures that may substantially elevate these figures. Despite well-established traditional risk factors such as hypertension and diabetes, emerging evidence, often referred to as Chronic Kidney Disease of unknown (CKDu) etiology, suggests that non-traditional factors, specifically environmental nephrotoxicity and occupational heat stress, are critical drivers of renal function decline in the industrial workforce.

In the HTI sector of Banyuasin, Palembang, employees operate under extreme conditions characterized by high solar exposure and reliance on local, non-standardized water sources. Preliminary environmental assessments in this region have identified water quality concerns, including acidic pH levels (mean 5.8 ± 0.4), elevated heavy metal concentrations (e.g., Fe 0.45 mg/L), and high Total Dissolved Solids (TDS) of 420 mg/L. While existing occupational health literature extensively documents the impact of heat stress on renal health in agricultural communities, there remains a distinct research gap regarding the synergistic impact of poor water quality and occupational stressors, specifically in the Banyuasin HTI environment.

The relationship between water quality and renal function is supported by population-based research identifying associations between water attributes, such as zinc, ammonia, Chemical Oxygen Demand (COD), and Dissolved Oxygen (DO), and the prevalence of CKD. Furthermore, contamination by agrochemicals and industrial pollutants, such as Perfluorooctanoic Acid (PFOA), has been linked to toxic nephropathy in various epidemiological studies. Although the World Health Organization (WHO) emphasizes that Water, Sanitation, and Hygiene (WASH) are foundational to the prevention of noncommunicable diseases, these standards are often overlooked in industrial work environments where workers rely on vulnerable local water sources.

Current occupational CKD studies often focus exclusively on either agrochemical exposure or heat-related physiological stress. This narrative review distinguishes itself by integrating these variables to provide a comprehensive analysis of the "multiple hit" hypothesis, whereby chronic chemical exposure through drinking water interacts with heat-induced dehydration to accelerate the decline in the estimated Glomerular Filtration Rate (eGFR). By synthesizing clinical and environmental data from 2018 to 2026, this study clarifies the relationship between specific water quality parameters and kidney dysfunction among HTI employees. Ultimately, this review provides a targeted scientific basis for developing workplace-specific WASH interventions, offering an applied contribution to Indonesian occupational health policy that existing global reviews do not address.

2. METHOD

This descriptive narrative review was conducted in April 2026 to synthesize the evidence on the relationship between water quality parameters and kidney dysfunction among industrial workers, specifically focusing on HTI Banyuasin employees. A systematic literature search was performed across PubMed, Scopus, Sinta, and Google Scholar using the following keywords: “water quality,” “pH nephrotoxicity,” “occupational CKD,” “arsenic kidney,” and “heat stress eGFR” heat stress eGFR. This descriptive narrative review was conducted in April 2026. A systematic literature search was performed via PubMed, Public Health Science and Research, Scopus, Sinta, and Google Scholar using the keywords “water quality,” “pH nephrotoxicity,” “occupational CKD,” “arsenic kidney,” and “heat stress eGFR.” We synthesized narrative evidence from 10 studies (2018–2026) regarding the relationship between water quality parameters (pH, TDS, contaminants) and the prevalence of kidney disorders (urea, creatinine, eGFR) among industrial workers, based on Medical Check-Up (MCU) results, with a specific focus on the implications for employees of HTI Banyuasin.

The literature search aimed to identify original research and review articles published between 2018 and 2026 that evaluated the synergy between environmental stressors and renal health. The screening process involved three stages. First, identification and initial database screening of titles and abstracts were based on defined keywords. Second, full-text articles were screened using strict inclusion and exclusion criteria to ensure relevance to tropical industrial work environments. Third, ten high-quality studies were selected for the final synthesis. These studies were chosen for their clinical data (eGFR, creatinine) and environmental data (pH, heavy metals, osmolarity) in populations exposed to heat stress and nephrotoxic chemicals comparable to the HTI Banyuasin population.

Inclusion Criteria: (1) articles published in Indonesian or English between 2018 and 2026 were included; (2) original research or peer-reviewed reviews focusing on physical (temperature and pH) and chemical (heavy metals, PFOA, and agrochemicals) water quality parameters; (3) studies reporting objective clinical renal function data, specifically eGFR, blood creatinine, or urinalysis, in worker populations; and (4) research addressing occupational renal risks related to heat stress, dehydration, or particulate matter exposure. Exclusion Criteria: (1) studies unavailable in full-text format or limited to conference abstracts and (2) animal-based (in vivo) studies that lack direct applicability to human occupational health.

3. RESULTS AND DISCUSSION

3.1. Article Profile and Occupational Relevance

The articles synthesized in this study represent data from various countries; 70% originated from outside Indonesia (Spain, Italy, Guatemala, Taiwan, Sweden, South Korea, and the United States), and 30% were from Indonesia. The included study designs ranged from large-scale prospective cohort studies in Spain, Italy, and Sweden to case-control studies and occupational reports from Indonesia.

The profiles of the articles cover agricultural and industrial worker populations that share characteristics with HTI employees in Palembang, particularly regarding exposure to extreme physical environments and the risk of chemical exposure. By utilizing data from tens of thousands of samples across various journals, this review establishes a robust statistical foundation indicating that non-traditional environmental factors play a significant role in the decline of renal function (eGFR). The research profile data are presented in the following Table 1.

Table 1. Profile of Reviewed Articles

No.	Researchers	Country of Origin	Sample Size (n)	Study Design	Instruments	Measurement Focus
1.	Suban and Widani (2024)	Indonesia	50 Respondents	Descriptive Analytic (Cross-sectional)	Structured questionnaire and medical observation record	Mineral water consumption patterns, energy drink consumption history, and renal failure status
2.	Paz-Graniel et al. (2024)	Spain	5.671	Prospective Cohort (PREDIMED-Plus intervention)	143-item Food Frequency Questionnaire (FFQ) and blood/urine biochemical analysis	Total water intake (glasses/day) and changes in eGFR over 1 year
3.	Cirillo et al. (2022)	Italia	4.554	Mixed: Cross-sectional and Longitudinal (15 years)	Self-reported fluid intake questionnaire and clinical 24-hour urine collection	Association between fluid intake and renal outcomes (dialysis/transplantation) and changes in eGFR
4.	Butler-Dawson et al. (2025)	Guatemala	134 female workers	Observational Cohort (pre- and post-shift)	Wet Bulb Globe Temperature (WBGT) sensors,	Heat exposure (heat stress), particulate matter

					questionnaires, and urine creatinine analysis	(dust), and renal damage biomarkers
5.	Chang et al. (2018)	Taiwan	22,011 (water samples & medical records)	Ecological Population-based Study (Cross-sectional)	Big Data Integration: National Water Quality Database and Health Insurance Database	61 physical/chemical water quality parameters (including pH) and CKD prevalence
6.	Ilyas and Kresna (2021)	Indonesia	Case Review (7-step occupational assessment)	Evidence-Based Case Report (EBCR) using a 7-step occupational assessment	PICO strategy, Bradford Hill criteria, and systematic literature review	Causal relationship between workplace PFOA exposure and kidney disease.
7.	Fitria et al. (2020)	Indonesia	102 Respondents	Case-Control Study	Interview questionnaires, environmental temperature measurement tools, and urine/blood biomarker tests	Environmental (pesticides) and occupational (workload/heat) risk factors in farmers
8.	Edlund et al. (2024)	Swedia	224,633 Workers	Prospective Cohort (National registry-based)	Job Exposure Matrix (JEM) for particulates and national health registry data (ICD-10)	Occupational particulate exposure (inorganic dust/metal) and risk of CKD incidence
9.	Park and Kang (2025)	Korea Selatan	Literature Review	Comprehensive Narrative Review	Secondary data analysis from medical databases (PubMed, Cochrane, Embase)	Comprehensive synthesis of occupational risk factors (chemical, physical, and psychosocial).
10.	Wilke et al. (2019)	USA	23,360 Patients	Retrospective Study (clinical and environmental data)	Electronic Medical Records (EMR) and secondary environmental data (EPA & USGS)	Interaction between geo-environmental (water/air) and agro-environmental (pesticides) factors

Source: Authors' Analysis (2025)

3.2. Methodological Comparison: Cohort vs. Cross-Sectional Studies

Strength of Evidence: Large-scale cohort studies, such as those conducted by Edlund et al. (2024) and Paz-Graniel et al. (2024), provide robust longitudinal evidence of the long-term effects of environmental exposure on eGFR. Conversely, cross-sectional studies, such as that by Suban and Widani (2024), offer valuable prevalence snapshots but remain constrained by limitations in establishing the temporal sequence between exposures (e.g., nephrotoxic beverage consumption) and clinical outcomes (e.g., renal impairment).

Contextual differences utilized large-scale ecological data from Taiwan, enabling the analysis of 61 distinct water-quality parameters. However, these findings may not be entirely generalizable to the HTI Banyuasin context because of disparities in water infrastructure and specific pollutant profiles prevalent in tropical plantation environments (Chang et al, 2018).

3.3. Analysis of Water Quality Parameters and Chemical Contamination Risk

Conflicting Evidence and Exposure Variability PFOA Causality vs. Environmental Confounders: Ilyas and Kresna (2021) proposed a potential causal link between PFOA and CKD; however, methodological challenges persist in isolating PFOA effects from confounding factors such as pesticides or heat stress. This aligns with Wilke et al. (2019), who demonstrated that decoupling the impacts of water chemistry from climatic factors in agricultural communities remains inherently difficult.

Heat Stress Exposure Variability: Butler-Dawson et al. (2025) provides compelling evidence that heat stress induces acute changes in urine creatinine levels. The heavy physical workload was incorporated as a factor, demonstrating that renal vulnerability is not solely attributable to ambient temperature but rather to the synergy between physical exertion and dehydration, which is further exacerbated by poor water quality (Fitria et al., 2020).

Water quality is a key environmental determinant of renal health. Based on the literature synthesis, water quality parameters in industrial regions are not limited to physical properties, such as pH and turbidity, but also encompass nephrotoxic chemical contaminants such as heavy metals. Exposure to PFOA and other synthetic substances indicates that industrial workers consuming water contaminated with PFOA are at a high risk of developing CKD. PFOA has a long biological half-life and is resistant to metabolism, leading to its accumulation within the renal tubules, which triggers progressive cellular damage.

In HTI areas, the use of herbicides and chemical fertilizers can contaminate groundwater with heavy metals and agrochemical residues. It was identified that water pollutants, including heavy metals, were significantly correlated with the incidence of CKD. These chemical elements induce oxidative stress in the nephrons, which are the functional units of the kidney. Global WASH standards emphasize that access to safe water and sanitation is the cornerstone of noncommunicable disease prevention. For field-based HTI employees, the lack of standardized water sources often forces them to rely on local water, the chemical parameters of which may not be safe for renal health. The following Table 2 summarizes the interventions and research findings of the studies (Chang et al., 2018).

Table 2. Summary of Interventions and Research Findings

No.	Researchers	Treatment/Exposure	Comparison	Duration	Key Research Findings
1.	Suban and Widani (2024)	Consumption of nephrotoxic beverages (energy/soda drinks) and insufficient mineral water intake	Adequate mineral water consumption (>2 L/day)	Long-term (Chronic)	Significant association between insufficient mineral water intake, energy drink consumption, and the incidence of Chronic Kidney Failure.
2.	Paz-Graniel et al. (2024)	Low total water intake (lowest quartile)	High total water intake (highest quartile)	1 Year (365 days)	Higher water intake is associated with protection against eGFR decline in populations with high cardiovascular risk. .
3.	Cirillo et al. (2022)	High fluid intake (>2,000 mL/day from various beverages)	Low fluid intake (<1,000 mL/day)	15 Years (5,475 days)	High mineral water intake was independently associated with improved urine flow and lower osmolarity.
4.	Butler-Dawson et al. (2025)	Heat stress exposure (high WBGT) and dust particulate exposure during working hours.	Resting conditions (off-duty/holidays)	Per Work Shift (Daily)	Heat and dust exposure significantly increased renal damage biomarkers (creatinine) and the risk of severe dehydration in the workers.

5.	Chang et al. (2018)	Exposure to poor water quality parameters (heavy metals, imbalanced pH)	Water meeting national quality standards	Historical Data (Annual)	61 water quality attributes correlated with CKD prevalence; chemical pollutants in water are significant environmental risk factors in Taiwan.
6.	Ilyas and Kresna (2021)	Occupational exposure to PFOA	Workers not exposed to PFOA	Chronic (Employment tenure)	PFOA has a causal link to CKD because of its long biological half-life and direct toxic effects on renal tubular cells.
7.	Fitria et al. (2020)	Pesticide exposure, high temperatures (>31.7°C), and heavy physical workload	Non-farmers or farmers with minimal exposure	Growing Season (Daily/Chronic)	The combination of heat stress, dehydration, and pesticide exposure increases the risk of CKDu.
8.	Edlund et al. (2024)	Occupational particulate exposure (inorganic dust, metal smoke, silica)	Workers without significant particulate exposure	Median 21 Years	Chronic exposure to organic dust and metal smoke is associated with an increased risk of end-stage renal disease (ESRD).
9.	Park and Kang (2025)	Occupational risk factors (heat stress, night shifts, chemical agents)	Standard working conditions (no extreme exposure)	Comprehensive Review	Non-traditional occupational factors (primarily heat and industrial chemicals) are major contributors to kidney disease in workers.
10.	Wilke et al. (2019)	Agro-environmental (fertilizers, herbicides) and geo-environmental (temperature/water) exposure	Regions with low agricultural chemical usage	Retrospective Data	Patients in agricultural communities have a higher risk of toxic nephropathy due to interactions between

Source: Authors' Analysis (2025)

3.4. Mechanisms of Heat Stress and Occupational Dehydration

The geographical conditions of Palembang, characterized by high solar exposure, impose extreme heat loads on the field workers. This is associated with the onset of recurrent Acute Kidney Injury (AKI). indicated that workers exposed to high temperatures without adequate hydration are at risk of developing subclinical AKI (Butler-Dawson et al., 2025). In HTI environments, chronic dehydration leads to renal hypoperfusion (reduced blood flow to the kidneys). When this occurs repeatedly, the condition may progress to CKDu. Furthermore, dehydration activates the vasopressin pathway, in which the body increases vasopressin secretion to conserve water. However, chronically high vasopressin levels are deleterious to renal interstitial tissue. This condition is further exacerbated if the worker's urine specific gravity consistently remains above 1.020 (Fitria et al., 2020).

3.5. Fluid Consumption Patterns and the Impact of Hydration on eGFR

The quantity and quality of fluids consumed by employees determine the prevalence of impaired renal function. Regarding the substitution of mineral water with nephrotoxic beverages, Suban and Widani (2024) identified a strong correlation between energy drink consumption and the incidence of chronic kidney failure. Many industrial workers consume energy drinks or sweetened beverages to combat fatigue, despite the fact that their artificial sweeteners and additives increase the renal filtration load. Conversely, Paz-Graniel et al. (2024) demonstrated that adequate mineral water intake (a minimum of 2 L/day) significantly protects the eGFR. Mineral water facilitates detoxification and prevents the formation of urinary crystals, which can trigger kidney stones and chronic Urinary Tract Infections (UTIs).

3.6. Synergy of Risk Factors: The "Multiple Hit" Hypothesis in HTI Employees

This study suggests that the prevalence of kidney impairment among HTI employees in Palembang is likely multifactorial, resulting from a combination of several simultaneous factors, a concept known as the "multiple hit" hypothesis. According to the principles of toxicology and occupational health, exposure to multiple hazardous substances or dual particulates triggers synergistic effects, exponentially increasing health risks compared to single exposures. In addition to water quality, exposure to industrial dust and metal fumes in the workplace contributes to systemic inflammation, accelerating the progression of renal fibrosis. This hypothesis is particularly relevant for workers in high-risk industries such as HTI, where employees are exposed to a combination of extreme heat, toxic chemicals, and physical stress, which collectively exacerbate renal injury. These factors include: (1) chemical factors, the presence of pollutants (e.g., PFOA/heavy metals) in local water sources (Ilyas & Kresna, 2021); (2) physical factors, heat stress resulting from prolonged outdoor work; (3) behavioral factors, insufficient intake of pure mineral water and high consumption of supplements or sweetened beverages; and (4) additional environmental factors, exposure to industrial dust particulates that trigger systemic inflammation (Edlund et al., 2024) (see Table 3).

Table 3. Synthesis of Risk Factor Findings

Analytical Variable	Primary Findings from References	Clinical Impact on the Kidneys
Water Chemical Quality	PFOA & Heavy Metal Contamination	Renal tubular cell damage & progressive eGFR decline
Work Climate	Heat Stress (Temperature >31.7°C)	Renal hypoperfusion & risk of recurrent AKI
Hydration Patterns	Insufficient Mineral Water (<2 L/day)	Concentrated urine, crystalluria, & vasopressin activation
Lifestyle	Energy Drink Consumption	Hyperfiltration & acute toxic nephropathy

Source: Synthesis of Analysis (2025)

3.7. Water Quality and Environmental Contaminants

Limitations in establishing causality although there is a consensus regarding the association between water quality and renal function, most studies exhibit variations in "dose" exposure. Cirillo et al. (2022) indicated that a fluid intake of >2,000 ml/day provides a protective effect independent of beverage type. However, other studies suggest that if the water source is contaminated with heavy metals, increased fluid intake may inadvertently heighten the toxic load. This highlights that water quality cannot be evaluated in isolation from the quantity of intake in occupational health analyses.

The quality of drinking water is a critical factor affecting renal health. Research conducted in Taiwan has demonstrated an association between 61 water quality attributes and the prevalence of CKD, where specific contaminants in water can accelerate the decline in kidney function. Contaminants such as heavy metals (e.g., arsenic) and synthetic chemicals such as PFOA have been identified as nephrotoxic agents in the work environment. PFOA, which has a long biological half-life, has been linked to an increased risk of CKD in workers who are chronically exposed. Furthermore, within agricultural communities, the use of fertilizers, herbicides, and pesticides can contaminate groundwater sources, subsequently increasing the risk of toxic nephropathy among workers.

Methodologically, the current literature remains heavily reliant on secondary data and questionnaire-based surveys, particularly in developing regions. Inconsistencies in exposure measurement, such as the variance between WBGT monitoring and questionnaire-based temperature reporting, constitute a primary reason for exercising caution when drawing causal inferences. The "multiple hit" hypothesis, supported by Park and Kang (2025), represents the most relevant framework for future investigations in HTI Banyuasin, given that workers in this sector are simultaneously exposed to physical (heat) and chemical (heavy metals/PFOA) stressors.

3.8. Policy Analysis and Practical Interventions

To mitigate the identified risks and improve the long-term health outcomes of industrial workers, the following policy-oriented framework is proposed: First, Integrated Occupational Health Surveillance. Industrial stakeholders should implement a formal surveillance system that incorporates baseline and periodic serum creatinine and eGFR monitoring into annual MCU protocols. This system must prioritize high-risk groups, particularly field workers exposed to chronic heat stress. Second, WASH compliance should be strengthened. WASH standards must be elevated from basic hygiene practices to mandatory industrial safety KPIs. Organizations should transition from relying on non-standardized local water sources to providing certified mineralized drinking water at all fieldwork sites. Third, Workplace Environmental Monitoring is required. Implementing real-time environmental monitoring, such as the WBGT index, is essential for regulating labor intensity during peak heat hours. This management mechanism is crucial for mitigating physiological dehydration, which increases renal vulnerability. Fourth, Incentivizing Industrial Compliance. Indonesian occupational health regulations should be updated to mandate environmental water quality assessments that specifically screen for industry-related pollutants, such as PFOA and heavy metals, rather than limiting testing to standard bacteriological parameters. Fifth, Preventive Hydration Protocols should be implemented. Occupational health policies should formally prohibit the use of high-caffeine or high-sugar beverages as fatigue-management tools, instead institutionalizing hydration protocols that emphasize the intake of mineralized water to maintain urine flow and prevent the formation of renal calculi and concentrated urine.

4. CONCLUSION

This narrative review highlights the association between poor-quality drinking water and an elevated risk of renal dysfunction among employees in the HTI sector. Our findings suggest that renal impairment within this workforce is likely multifactorial, stemming from the synergistic "multiple hit" effect of chemical exposure, specifically PFOA and heavy metals, and occupational heat stress, which collectively exacerbate the physiological strain on the kidneys. However, owing to the inherent diversity in study designs and reliance on secondary literature, these findings should be interpreted as indicative associations rather than definitive causal relationships. Consequently, these results provide a robust scientific foundation for future hypothesis testing and underscore the urgent need for site-specific, prospective clinical studies to evaluate the renal health status of the HTI workforce in Banyuasin, Indonesia. Detailed practical recommendations, including integrated occupational health surveillance and strengthened WASH compliance, are provided in the preceding section to guide immediate industrial safety interventions.

Ethical Approval

Ethical approval was not required for this study because it employed a descriptive narrative review design and did not involve the direct participation of human subjects, animal subjects, clinical intervention, experimental procedures, or the collection of identifiable personal data. This study synthesized evidence from publicly available scientific articles, review papers, and secondary sources related to water quality, occupational kidney disease, heat stress, and renal health among industrial workers. All sources were used responsibly and cited properly, in accordance with academic research ethics.

Informed Consent Statement

Informed consent was not applicable because this study did not involve human participants, interviews, surveys, clinical examinations, or the collection of individual-level medical data. This review was based entirely on previously published literature and publicly accessible secondary sources.

Authors' Contributions

SN contributed to the conceptualization of the study, development of the review framework, literature search, article screening, synthesis of findings, interpretation of occupational and environmental health evidence and preparation of the original manuscript draft. MI contributed to the methodological supervision, validation of the review process, critical interpretation of public health implications, manuscript review, editing, and refinement of the discussion and conclusion. Both authors have read and approved the final version of the manuscript.

Disclosure Statement

The authors declare that they have no competing interests or conflicts of interest related to this study. No financial, personal, professional, or institutional relationships influenced the design, analysis, interpretation, or reporting of the results.

Data Availability Statement

The data supporting the findings of this study were derived from publicly available scientific articles, review papers, and secondary sources cited in this manuscript. No new empirical datasets were generated or analyzed in this study. Further information regarding the reviewed sources may be made available by the corresponding author upon reasonable requests.

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