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Sexual-Reproductive Dysfunction in Men Residing in Environmentally Degraded Areas: A Clinical-Functional Analysis Using the ICF Framework

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Abstract

Male reproductive health is increasingly affected by environmental pollution, yet most studies focus on semen quality alone, overlooking sexual function as a relevant functional outcome. The main objective of our study is to evaluate the combined effect of the environment on men's sexual and reproductive functions by an integrated clinical-functional approach based on the International Classification of Functioning, Disability and Health (ICF). A cross-sectional study was conducted on 216 men aged 25-45 years who had lived in the areas of the Kyrgyz Republic with different environmental conditions for at least 5 years: environmentally favorable areas (control) and areas mainly exposed to pesticides, heavy metals, or radionuclides. Sexual function was assessed by the International Index of Erectile Function (IIEF), and reproductive function was determined by the integration of semen parameters assessed according to WHO guidelines. Results were explained within the ICF concept. The male inhabitants of the polluted localities exhibited markedly reduced erectile and orgasmic functions compared with the control group ($p < 0.05$). All the exposure groups displayed a considerable decline in semen quality, such as reduction in sperm concentration, defective progressive motility, decreased velocity, abnormal morphology, and an increased number of immature germ cells.The pesticide and heavy metal-exposed groups reflected the highest level of dysfunction. Sexual dysfunction, when interpreted through the ICF framework, might be a feature that is functionally relevant and that appears at an early stage of environmentally induced reproductive damage. This study thus points to the necessity of incorporating functional outcomes in environmental health risk assessments.

Keywords: Sexual health, Kyrgyzstan, Reproductive health, Environmental pollution, Health equity

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Introduction

Male reproductive health is increasingly recognized as a sensitive indicator of population health in the context of growing environmental pollution. Over recent decades, the global prevalence of infertility has risen to approximately 10–15% of couples, with male factors contributing to nearly half of all cases (Mascarenhas *et al*., 2012; Agarwal *et al*., 2015). Concurrently, large-scale epidemiological studies have reported a marked decline in semen quality, including reductions in sperm concentration, motility, and morphological normality, particularly in industrialized and environmentally burdened regions (Carlsen *et al*., 1992; Swan *et al*., 1997).

A growing body of evidence implicates chronic exposure to environmental pollutants as a major contributor to these adverse trends. Pesticides, heavy metals, persistent organic pollutants, plasticizers, and air contaminants are widely distributed in modern ecosystems and may enter the human body through inhalation, ingestion, occupational exposure, and trophic chains. Population-based studies have demonstrated associations between air pollution, pesticide exposure, and impaired semen quality in exposed men (Hauser *et al*., 2005; Radwan *et al*., 2014; Nassan *et al*., 2019; Chen *et al*., 2022; Razhaeva et al., 2022). Experimental and epidemiological studies consistently demonstrate associations between environmental toxicants and impaired spermatogenesis, increased prevalence of abnormal sperm forms, reduced motility, and higher risk of male infertility (Jeng, 2014; Skakkebaek *et al*., 2016; Buck Louis *et al*., 2018; Skakkebaek *et al*., 2022; Rodprasert *et al*., 2023). Many of these substances exhibit endocrine-disrupting properties, affecting the testicular microenvironment and regulatory pathways even at low or environmentally relevant doses (Jeng, 2014; Hu *et al*., 2020).

In environmental and occupational health research, male reproductive toxicity is most often assessed using semen parameters as primary outcome measures. While semen analysis provides essential information on reproductive capacity, it does not fully reflect the functional consequences of environmental exposure. Sexual function, encompassing erectile and orgasmic domains, is closely linked to neurovascular regulation, reproductive system integrity, and overall health status (Alhussain *et al*., 2022; Balaji *et al*., 2022; Delcea *et al*., 2024; Essah *et al*., 2024; Frost *et al*., 2024; Ribeiro *et al*., 2024; Rosellini *et al*., 2024; Uneno *et al*., 2024; Umarova *et al*., 2024). Importantly, disturbances in sexual function frequently coexist with impaired semen quality and may serve as early or subclinical indicators of reproductive system dysfunction (Aitken, 2020; Pozdeeva *et al*., 2021). Nevertheless, sexual function remains underrepresented in studies addressing environmental determinants of male fertility.

A key limitation of existing research is the lack of integrative approaches that simultaneously consider sexual function and reproductive outcomes in environmentally exposed populations. Most investigations focus either on laboratory-based semen characteristics or on infertility prevalence, without accounting for functional aspects that directly influence reproductive behavior, participation, and quality of life. This fragmented approach may underestimate the broader health impact of environmental pollution on male populations and limit the interpretation of clinical relevance in public health contexts (Constantin *et al*., 2022; Mojsak *et al*., 2022; Sugimori *et al*., 2022; Kajanova & Badrov, 2024; Lee & Ferreira, 2024).

The International Classification of Functioning, Disability and Health (ICF) provides a comprehensive framework for integrating environmental exposures with biological and functional outcomes (World Health Organization, 2013). Within the ICF model, environmental pollutants are conceptualized as environmental factors (domain *e*) that contribute to impairments of body functions (*b*) and structures (*s*), ultimately leading to limitations in activity and participation (*d*), including sexual activity and reproductive performance. Application of the ICF framework enables sexual and reproductive dysfunctions to be interpreted as interconnected consequences of environmentally mediated impairments in functioning rather than isolated clinical conditions.

Against this background, the present study aims to assess sexual and reproductive dysfunctions in men residing in environmentally unfavorable conditions using a clinical–functional approach grounded in the ICF framework. Such an approach may improve understanding of the population-level health effects of environmental exposure and support the development of more comprehensive strategies for prevention and environmental health risk assessment.

Materials and Methods

Study Design and Participants

Data collection was performed continuously during the study period using a unified protocol to assess sexual and reproductive functioning in men residing in regions with different environmental conditions in the Kyrgyz Republic. The study included 216 men of reproductive age (25–45 years) who had been permanently living in their respective regions for at least five years.

Participants were divided into four groups according to the predominant environmental exposure in their area of residence: a control group from environmentally favorable regions (n = 62), a pesticide exposure group from agricultural areas with intensive agrochemical use (n = 54), a heavy metals exposure group from industrial regions (n = 52), and a radionuclide exposure group from areas affected by radioactive contamination (n = 48).

Inclusion criteria were male sex, age between 25 and 45 years, permanent residence in the study region for at least five years, and provision of written informed consent. Exclusion criteria included acute inflammatory diseases of the urogenital system, confirmed genetic causes of infertility, oncological diseases, and severe decompensated somatic pathology.

Assessment of Sexual Function

Sexual function was assessed using the International Index of Erectile Function (IIEF), a validated multidimensional self-administered questionnaire widely applied in clinical and epidemiological studies. In accordance with the objectives of the present analysis, two domains were evaluated: erectile function and orgasmic function. Domain scores were calculated using standard scoring algorithms, with lower scores indicating greater impairment of sexual functioning.

Assessment of Reproductive Function

Reproductive function was evaluated by semen analysis performed in accordance with World Health Organization recommendations. Only aggregated semen parameters were included in the analysis in order to maintain a focused analytical approach in line with the objectives of this study. These factors included the percentage of morphologically normal spermatozoa, sperm concentration, and increasing sperm motility.

In addition, the presence of pathological semen findings (pathospermia) was recorded as a dichotomous variable (yes/no). Detailed semen characteristics, including viscosity, liquefaction time, agglutination, leukocyte count, immunological tests, and extended classifications of sperm abnormalities, were not included in the present analysis.

Functional Analysis within the ICF Framework

Study findings were interpreted using the conceptual framework of the International Classification of Functioning, Disability and Health (ICF). Environmental exposures were considered environmental factors (domain *e*), while alterations in sexual and semen parameters were interpreted as impairments of body functions and structures (domains *b*and *s*), leading to limitations in activity and participation related to sexual life and reproduction (domain *d*). The ICF was applied as an analytical framework without formal coding (Adeleke, 2022; Sri *et al*., 2022; Guzek *et al*., 2023; Simonyan *et al*., 2023; Tsiganock *et al*., 2023; Sanlier & Yasan, 2024).

Statistical Analysis

Statistical analysis was performed using non-parametric methods. Quantitative variables were compared between groups using the Mann–Whitney U test, while categorical variables were analyzed using the chi-square (χ^2) test. Differences were considered statistically significant at $p < 0.05$.

Ethical Considerations

The study was conducted in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to inclusion in the study (Razhaeva *et al*., 2022; Rojas *et al*., 2022; Al Abadie *et al*., 2023; Lee *et al*., 2023; Ncube *et al*., 2023; Oran & Azer, 2023).

Results and Discussion

Sexual Function

Table 1. Sexual function parameters assessed by the International Index of Erectile Function (IIEF) in men residing in regions with different environmental conditions **Table 1**.

IIEF domain	Control group (n = 62)	Pesticide exposure (n = 54)	Heavy metals exposure (n = 52)	Radionuclide exposure (n = 48)
Orgasmic function score	7.7 ± 0.8	5.7 ± 0.6*	5.2 ± 0.3*	5.8 ± 0.3*
Erectile function score	16.2 ± 1.3	10.8 ± 1.6*	12.7 ± 1.9*	11.2 ± 2.3*

Data are presented as mean ± standard error (M ± m). * $p < 0.05$ compared with the control group (Mann–Whitney U test).

Assessment of sexual function using the International Index of Erectile Function revealed significant differences between men residing in environmentally favorable areas and those exposed to adverse environmental factors. Both erectile and orgasmic function scores were significantly lower in all exposure groups compared with the control group ($p < 0.05$) **(Table 1)**.

Overall, sexual dysfunction was markedly more prevalent in environmentally exposed populations, with the most severe impairments observed in men residing in areas contaminated by pesticides and heavy metals.

Reproductive Function

Semen analysis revealed a marked deterioration of reproductive parameters in men exposed to environmental pollutants. All exposure groups demonstrated significantly reduced sperm concentration, impaired progressive motility, decreased sperm velocity, and a lower proportion of morphologically normal spermatozoa compared with the control group ($p < 0.05$).

In parallel, the proportion of immature germ cells was increased two- to threefold in environmentally exposed men, indicating disruption of spermatogenic maturation. The most pronounced alterations were observed in men residing in areas contaminated by pesticides and heavy metals **(Table 2)**.

Table 2. Aggregated semen parameters in men residing in regions with different environmental conditions **Table 2**.

Semen parameter	Control group (n = 62)	Pesticide exposure (n = 54)	Heavy metals exposure (n = 52)	Radionuclide exposure (n = 48)
Sperm concentration (million/mL)	65.4 ± 11.3	42.5 ± 14.4*	48.3 ± 10.5*	35.2 ± 8.4*
Progressive motility (%)	66.2 ± 5.4	44.6 ± 6.1*	48.3 ± 6.0*	53.2 ± 4.4*
Sperm velocity (mm/min)	2.98 ± 0.14	2.01 ± 0.27*	2.29 ± 0.16*	2.34 ± 0.21*
Morphologically normal forms (%)	7.2 ± 0.3	3.2 ± 0.8*	2.4 ± 0.6*	2.8 ± 0.5*
Immature germ cells (%)	1.2 ± 0.2	2.6 ± 0.5*	3.3 ± 0.4*	2.8 ± 0.9*

Data are presented as mean ± standard error (M ± m). * $p < 0.05$ compared with the control group (Mann–Whitney U test).

Association between Sexual and Reproductive Dysfunction

Analysis of sexual and reproductive parameters revealed a consistent convergence of functional impairments. Groups with the most pronounced deterioration of semen quality—characterized by reduced sperm concentration, impaired motility, and abnormal morphology—also demonstrated the lowest scores for erectile and orgasmic function. Disorders of erection and ejaculation were among the most frequent clinical forms of infertility in environmentally exposed groups and were significantly more prevalent than in the control group. This parallel deterioration suggests that sexual dysfunction may represent a functional correlate of impaired spermatogenesis rather than an isolated clinical condition. The concordance of these impairments supports the interpretation of sexual dysfunction as an early and functionally relevant manifestation of environmentally mediated reproductive damage.

Interpretation within the ICF Framework

From the perspective of the International Classification of Functioning, Disability and Health, the observed findings can be conceptualized as a sequential pathway. Chronic exposure to adverse environmental factors—pesticides, heavy metals, and radionuclides—acts as an environmental determinant (domain *e*), contributing to impairments of body functions and structures related to the reproductive system (domains *b* and *s*). These impairments manifest clinically as reduced semen quality and sexual dysfunction, ultimately leading to limitations in activity and participation (domain *d*), particularly in sexual life and reproductive capacity.

This functional interpretation highlights the integrated nature of sexual and reproductive dysfunctions as interconnected outcomes of environmental exposure rather than independent clinical entities.

Principal Findings

The present study demonstrates that environmental disadvantage is associated with a dual impairment of male reproductive health, affecting both sexual function and spermatogenesis. These findings are consistent with international data indicating declining male reproductive capacity in environmentally burdened populations (Skakkebaek *et al*., 2016; Skakkebaek *et al*., 2022). Men residing in environmentally contaminated regions exhibited significantly reduced erectile and orgasmic function alongside marked deterioration of semen quality, including decreased sperm concentration, impaired motility, and abnormal morphology. Importantly, these impairments occurred in parallel across exposure groups, with the most pronounced alterations observed in populations exposed to pesticides and heavy metals.

The convergence of sexual and reproductive dysfunctions suggests that these outcomes represent interconnected manifestations of environmentally mediated reproductive damage rather than independent clinical entities. From a public health perspective, this dual impairment highlights the broader functional consequences of environmental exposure on male reproductive capacity and quality of life.

Pathophysiological Mechanisms

Although the present study did not directly assess molecular or hormonal pathways, several biologically plausible mechanisms may underlie the observed associations. Environmental toxicants such as pesticides, heavy metals, and radionuclides are known to induce oxidative stress, leading to excessive generation of reactive oxygen species and subsequent damage to sperm membranes and DNA (Skakkebaek *et al*., 2006; Rodprasert *et al*., 2020; Skakkebaek *et al*., 2021). Such oxidative injury is widely recognized as a key contributor to reduced sperm motility, viability, and morphological integrity.

Chronic low-grade inflammation of the male reproductive tract has also been implicated in environmentally mediated reproductive dysfunction (Chen *et al*., 2017). The elevated prevalence of inflammatory semen characteristics in environmentally exposed groups suggests that inflammatory processes may exacerbate functional impairment of spermatogenesis. Finally, regulatory disturbances affecting neurovascular and cellular signaling pathways—without direct hormonal assessment—may contribute to sexual dysfunction, particularly erectile and orgasmic disturbances, as part of a broader functional dysregulation associated with environmental exposure (Pozdeeva *et al*., 2021; Assidi, 2022).

Comparison with Existing Literature

The findings of this study are consistent with reports from international organizations and previous epidemiological and experimental studies. Reports by the World Health Organization and the United Nations Environment Programme emphasize that environmental pollutants, including pesticides and heavy metals, are associated with adverse reproductive outcomes and declining semen quality in exposed populations (Sharpe & Skakkebaek, 1993; Sweeney *et al*., 2015). Numerous andrology studies have similarly documented reduced sperm concentration, motility, and increased prevalence of abnormal sperm morphology in environmentally burdened regions (Skakkebaek *et al*., 2016; Skakkebaek *et al*., 2020; Rodprasert & Toppari, 2021; Rodprasert *et al*., 2023).

Moreover, emerging evidence suggests that sexual dysfunction may coexist with impaired reproductive parameters in men exposed to environmental stressors, although this aspect has received limited attention in environmental health research (World Health Organization, 2001; Pozdeeva *et al*., 2021). The present study adds to the literature by demonstrating a consistent alignment between sexual and reproductive dysfunctions within environmentally exposed populations.

Implications of the ICF Framework

A key strength of this study lies in the application of the International Classification of Functioning, Disability and Health as an interpretative framework. The ICF enables environmental exposure to be conceptualized as an environmental determinant (domain *e*) that contributes to impairments of body functions and structures (domains *b* and *s*), ultimately resulting in limitations in activity and participation (domain *d*), including sexual life and reproductive capacity (World Health Organization & United Nations Environment Programme, 2013).

This functional perspective allows a shift from isolated laboratory measurements toward a more integrated understanding of how environmental factors influence real-life functioning (Jurewicz *et al*., 2018). Such an approach is particularly relevant for environmental health research, where the ultimate concern extends beyond biological alterations to include functional capacity and participation

Study Limitations

Several limitations should be acknowledged. First, the cross-sectional design precludes causal inference and limits the ability to assess temporal relationships between environmental exposure and reproductive dysfunction. Second, the absence of hormonal and molecular assessments restricts direct evaluation of endocrine and mechanistic pathways underlying the observed impairments. Finally, exposure assessment was based on area of residence rather than individual-level exposure quantification, which may introduce exposure misclassification (Buck Louis *et al*., 2018; Oralbekova *et al*., 2021; Wójcik *et al*., 2022).

Conclusion

Men residing in environmentally unfavorable conditions demonstrate a consistent pattern of reduced sexual function and impaired spermatogenesis. These alterations occur concurrently and appear to reflect a shared functional response to chronic environmental exposure rather than isolated clinical abnormalities. The application of the ICF framework enables integration of

clinical and functional findings, highlighting sexual dysfunction as a potentially early and functionally relevant marker of environmentally mediated reproductive impairment. Incorporating functional outcomes into environmental health research may improve risk assessment and support more comprehensive strategies for prevention and population-level reproductive health protection.

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