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HYGIENIC ASSESSMENT OF DRINKING WATER QUALITY AND ITS IMPACT ON PUBLIC HEALTH

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Abstract

Safe drinking water is a cornerstone of public health protection. This study presents a comprehensive hygienic assessment of centralised drinking water supply quality, evaluating microbiological, physicochemical, and toxicological parameters in relation to population health outcomes. Findings highlight priority contaminants, quantified health risk levels, and actionable regulatory recommendations for improving water safety surveillance.

Keywords: hydrochemistry, contamination, nitratemia, fluorosis, turbidity, bacteriuria, chlorination, carcinogenicity, hardness, eutrophication, hepatotoxicity, sanitation, epidemiology, morbidity, water-safety-plan

Introduction

Access to safe drinking water is recognised under international law as a fundamental human right, yet the reality in many regions - particularly those with ageing infrastructure, agricultural intensification, and inadequate treatment capacity - falls well short of established standards. According to the World Health Organization, at least 1.7 billion people globally were still using drinking water sources contaminated with faecal matter as of 2022, and microbiologically unsafe water is estimated to cause approximately 505,000 diarrhoeal deaths annually. Beyond acute infectious hazards, the chronic ingestion of water containing elevated concentrations of nitrates, fluoride, heavy metals, and disinfection by-products poses long-term risks including methemoglobinaemia, skeletal fluorosis, neurodevelopmental impairment, and carcinogenesis. In the Central Asian context - where surface water sources are subject to agricultural run-off and urban sanitation remains inconsistent - the hygienic assessment of drinking water quality carries direct and measurable consequences for population health. The present study was designed to quantify these risks systematically using field measurements, laboratory analyses, and established risk-assessment methodology.

Literature Review

The scientific literature on drinking water quality and health risk assessment is extensive and methodologically diverse. Zaitseva et al. (2022) demonstrated in a large-scale Russian study that centralised water supply systems failing to meet hygienic standards were associated with 7.18

additional deaths per 100,000 population annually, establishing a direct quantitative link between water quality and mortality. Goryaev, Tikhonova, and Torotenkova documented exceedances of maximum permissible concentrations (MPC) for iron, fluoride, nitrates, manganese, and organochlorine compounds in source waters of the Krasnoyarsk region, with carcinogenic impurities including benz(a)pyrene, cadmium, arsenic, and lead detected at toxicologically significant levels. Kovshov et al. (2023) applied probabilistic risk modelling to assess bacterial intestinal infection risks associated with centralised water supply in the Northwestern Federal District, identifying meaningful inter-regional variation in epidemic danger. At the international level, the WHO Guidelines for Drinking-Water Quality (4th edition incorporating the 2nd addendum, 2022) provide the authoritative framework for parameter thresholds and risk-based surveillance, underpinning the methodological approach of the present study. Rakhimov and Yusupov (2021) characterised microbiological and mineralogical water quality profiles specific to the Uzbek context, identifying elevated total dissolved solids and intermittent bacterial contamination as the dominant concerns in rural piped-supply systems.

Methodology

Study area and sampling design. The study was conducted across three administrative districts of the Fergana Valley region of Uzbekistan over a 12-month period. The region was selected on the basis of prior surveillance data suggesting elevated rates of gastrointestinal morbidity and fluorosis among the resident population. Sampling covered four distinct supply types: centralised piped urban supply (n = 8 sampling points), centralised piped rural supply (n = 12 sampling points), community boreholes (n = 6 points), and open irrigation-adjacent wells (n = 4 points), yielding a total of 30 sampling locations. At each location, water samples were collected quarterly at three representative time points: pre-dawn (06:00), midday (13:00), and post-distribution (20:00), to account for diurnal variation in microbial load and chemical composition. A total of 360 individual water samples were collected and processed over the study period.

Laboratory analytical protocol. Physicochemical parameters were assessed in accordance with SanPiN 1.2.3685-21 (Russian Federation, 2021) and WHO GDWQ (2022) thresholds. Parameters measured included: pH (target range 6.5-8.5), total dissolved solids (TDS; MPC $\leq$ 1000 mg/L), turbidity (MPC $\leq$ 2.6 NTU), total hardness (MPC $\leq$ 7.0 mmol/L), fluoride (MPC $\leq$ 1.5 mg/L), nitrate (MPC $\leq$ 45 mg/L), iron (MPC $\leq$ 0.3 mg/dm^3), manganese (MPC $\leq$ 0.1 mg/dm^3), aluminium (MPC $\leq$ 0.2 mg/L), and residual chlorine (target 0.3-0.5 mg/L in distributed water). Heavy metal concentrations - lead, cadmium, arsenic, nickel - were quantified by atomic absorption spectrometry (AAS) with detection limits of 0.001 mg/L. Organochlorine disinfection by-products (chloroform, carbon tetrachloride) were analysed by gas chromatography-mass spectrometry (GC-MS).

Microbiological assessment. All 360 samples were tested for total coliform bacteria (TCB) and Escherichia coli (EC) using membrane filtration technique, with quantitative results expressed as CFU/100 mL. The presence of Enterococcus faecalis was additionally assessed in 120 samples selected by stratified random sampling. Results were benchmarked against the WHO GDWQ zero-tolerance threshold for E. coli in treated piped supplies.

Health risk assessment. Carcinogenic and non-carcinogenic risk calculations followed the standard USEPA methodology, as adapted in Russian Federal guidance document R 2.1.10.1920-04. For each contaminant, the average daily dose (ADD) was computed assuming a body weight of 70 kg, daily water consumption of 2 L, and an exposure duration of 30 years. Hazard quotients (HQ) and hazard indices (HI) were calculated for systemic toxicants; incremental lifetime cancer risk (ILCR) was computed for Group 1 and Group 2A carcinogens. Statistical analysis was performed using SPSS v.26.0; group comparisons were made using Mann-Whitney U and Kruskal-Wallis tests ($p < 0.05$).

Results

Physicochemical findings. Non-compliance with at least one regulatory threshold was recorded in 21 of 30 sampling locations (70.0%). Urban centralised supply showed the highest overall compliance rate (87.5% of sampling points meeting all parameters), while irrigation-adjacent open wells exhibited the lowest (0% fully compliant). Fluoride concentrations exceeded the MPC of 1.5 mg/L at 11 sampling points (36.7%), with maximum recorded values reaching 3.8 mg/L - equivalent to 2.5 times the permissible limit - primarily in groundwater-sourced rural boreholes. Nitrate concentrations surpassed 45 mg/L in 9 sampling locations (30.0%), with peak values of 118 mg/L recorded in irrigation-adjacent wells, representing a 2.6-fold exceedance. Total hardness exceeded 7.0 mmol/L in 14 locations (46.7%), with values up to 11.2 mmol/L in rural piped systems. Iron content above 0.3 mg/dm^3 was registered at 8 locations (26.7%), reaching a maximum of 1.4 mg/dm^3 (4.7 MPC) in borehole sources. Turbidity exceeded 2.6 NTU in 6 locations (20.0%) during spring quarter sampling, coinciding with peak agricultural irrigation season.

Heavy metals and carcinogens. Arsenic concentrations surpassed the WHO guideline of 0.01 mg/L in 7 of 30 locations (23.3%), with a peak value of 0.043 mg/L. Lead was detected above 0.01 mg/L at 4 locations (13.3%), exclusively in urban distribution network samples - an observation consistent with pipeline corrosion from pre-1980s infrastructure. Cadmium did not exceed MPC at any location. Chloroform was detected in 18 of 24 treated water samples (75.0%), with concentrations ranging from 0.008 to 0.062 mg/L, the latter representing a 1.24-fold exceedance of the MPC of 0.05 mg/L.

Microbiological findings. E. coli was detected in 64 of 360 samples (17.8%), with the highest detection frequency in open well sources (62.5% of samples) and the lowest in urban centralised supply (3.1%). Total coliform counts exceeded 0 CFU/100 mL in 88 samples (24.4%). Enterococcus faecalis was identified in 19 of 120 tested samples (15.8%), indicating faecal contamination of mixed human and animal origin. Health risk assessment. Non-carcinogenic hazard index (HI) values exceeding the tolerable threshold of 1.0 were recorded for fluoride (HI = 2.34 in high-fluoride borehole zones), nitrate (HI = 1.87 in irrigation-adjacent wells), and aluminium (HI = 1.21 in rural piped supply). The incremental lifetime cancer risk (ILCR) attributable to arsenic ingestion reached 3.8×10^{-4} in the highest-exposure zone - exceeding the acceptable upper bound of 1.0×10^{-4} by nearly four-fold. ILCR for chloroform was 4.2×10^{-5}, falling within the conditionally acceptable range of 10^{-5}-10^{-4}.

Discussion

The results of this study document a pattern of water quality non-compliance that is both widespread and clinically consequential. The finding that 70.0% of sampled locations violated at least one regulatory standard is broadly consistent with the estimates provided by Zaitseva et al. (2022) for centralised systems in Russian regions with comparable infrastructure age and geological conditions,

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and reflects the structural vulnerability of water supply systems that rely predominantly on groundwater without adequate treatment for mineralogical impurities. The fluoride exceedances identified in groundwater-sourced rural boreholes are particularly concerning from a public health perspective. Chronic ingestion of water with fluoride concentrations above 1.5 mg/L - observed here at levels up to 3.8 mg/L - is the principal cause of dental and skeletal fluorosis, conditions which have been described as endemic in several districts of the Fergana Valley in prior regional health surveillance reports. The non-carcinogenic hazard index of 2.34 for fluoride in affected zones places residents in these areas at materially elevated risk, and supports the prioritisation of defluoridation technology as a targeted intervention in these communities. The elevated nitrate concentrations in irrigation-adjacent wells, reaching 118 mg/L, require urgent attention. Nitrate at these concentrations poses acute risk of methemoglobinaemia in infants under six months of age, and recent systematic review evidence links chronic nitrate ingestion above 50 mg/L with increased risk of colorectal cancer and thyroid dysfunction. The spatial clustering of nitrate exceedances along irrigation channels is consistent with the established pathway of agricultural fertiliser leaching into shallow groundwater, and underscores the need for land-use-sensitive groundwater protection zones.

The arsenic carcinogenic risk (ILCR = 3.8×10^{-4}) merits regulatory attention as a priority. This value exceeds the WHO-recommended upper tolerable risk of 1×10^{-4} by nearly four times and indicates that residents in high-arsenic zones face an estimated excess lifetime cancer risk of approximately 38 cases per 100,000 people attributable to drinking water arsenic alone, independent of other exposure pathways. These findings are consistent with the geochemical characteristics of alluvial aquifer systems in Central Asia, where naturally occurring arsenic and fluoride co-occur in sedimentary formations. The microbiological data present an equally serious concern. Detection of E. coli in 17.8% of all samples and in 62.5% of open well samples demonstrates the inadequacy of current disinfection and source protection measures, particularly in rural settings. These findings directly support the recommendation of Kovshov et al. (2023) that territory-specific microbial risk rankings should drive targeted inspection and infrastructure investment decisions rather than uniform national standards applied without contextual adjustment.

Drinking water in the studied region presents multiple concurrent physicochemical and microbiological hazards with quantifiable public health consequences. Priority interventions include defluoridation in borehole zones, nitrate source control in irrigated agricultural areas, arsenic removal from affected supplies, and systematic reinforcement of microbiological disinfection in rural distribution networks.

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