International Journal of Ecology and Environmental Sciences
www.ecologyjournal.in
Online ISSN: 2664-7133, Print ISSN: 2664-7125
Received: 24-09-2025, Accepted: 23-10-2025, Published: 08-10-2025
Volume 7, Issue 4, 2025, Page No. 117-119

Estimating drinking-water ingestion requirements under hot climate conditions: The case of N'Djamena (Chad)

Jean-Paul Vicat, Jean-Claude Doumnang Mbaigané
University of N'Djamena, Faculty of Exact and Applied Sciences, Laboratory of Geology, Geomorphology, and Remote Sensing, N'Djamena, Republic of Chad

Abstract
This study presents an estimation of daily drinking-water ingestion rates for adults and children under the climatic and lifestyle conditions of N'Djamena. Water ingestion rates were estimated using both a segmented linear temperature–intake relationship and a multivariate equation, based on the mean annual and mean daily maximum temperatures. The results indicate average values of approximately 4 $L \cdot day^{-1}$ for adults and 2 $L \cdot day^{-1}$ for children, which are more representative of Sahelian populations than the default rates commonly applied in temperate regions. These values are recommended for use in local human health risk assessments.

Keywords: Drinking-water ingestion, Water turnover, Heat exposure, Sahelian climate, N'Djamena (Chad)

Introduction
The chemical composition of drinking water can pose health risks to consumers, depending not only on contaminant concentrations but also on the daily volume of water ingested. The amount of water consumed varies substantially with environmental, physiological, and lifestyle factors, including temperature, humidity, physical activity level, and diet.

For health risk assessment purposes, baseline drinking-water ingestion rates of 2.0 $L.day^{-1}$ for adults and 1.0 $L.day^{-1}$ for children are typically adopted under temperate conditions (≈ 20 °C), following guidance from the U.S. Environmental Protection Agency (USEPA, 2011) [1] and the U.S. National Academies of Sciences, Engineering, and Medicine (NASEM, 2005) [2]. However, these standard values may underestimate actual exposure in hot or arid environments, where water requirements are substantially higher.

In warm climates, increased requirements arise primarily from enhanced sweat losses. The sweat rate increases sharply with air temperature, physical workload, humidity, and acclimatization status (Gisolfi, 1993) [3]. Public health authorities, including the World Health Organization, recommend higher intakes—typically 2–3 $L \cdot day^{-1}$ for sedentary adults during hot periods, and considerably more for those performing physical labor (WHO, 2023) [4].

Recent studies conducted in sub-Saharan Africa and other hot or semi-arid regions have consistently reported a strong relationship between air temperature, heat exposure, and daily water consumption. Both self-reported and measured data indicate that water intake rises substantially with increasing ambient temperature, particularly in populations exposed to prolonged outdoor activity or limited access to cooling (Stringer *et al.*, 2021 ; Buchwald *et al.*, 2022 ; Mkaddem and Mahjoubi, 2022; Timotewos *et al.*, 2022; Mounirou *et al.*, 2023) [5, 6, 7, 8, 9]. These findings highlight the need to adjust ingestion estimates to local climatic and lifestyle conditions when performing health risk assessments related to drinking-water exposure.

In this study, we estimate realistic daily drinking-water ingestion rates for adults and children in N'Djamena (Chad), under typical Sahelian temperature regimes, based on empirical temperature–ingestion relationships and predictive models of human water turnover. The objective is to provide locally adapted exposure parameters for future human health risk assessments of water contamination in N'Djamena.

Methods
To estimate daily drinking-water ingestion as a function of ambient temperature, we first applied a segmented linear approximation proposed by the NASEM (2005) [2], and then the multivariate equation of Yamada *et al.*, (2022) [10].

Linear Temperature–Intake Relationship
The empirical linear relationship assumes that water intake doubles at 30 °C and triples at 40 °C compared to the reference condition (20 °C):

$I(T)= I_o$ for $T \leq 20°C$

$I(T)=I_o (1+0.1(T-20))$ for $20°C \leq T \leq 30°C$

$I(T)=I_o (2+0.1(T-30))$ for $30°C \leq T \leq 40°C$

$I(T)=I_o \times 3$ for $T>40°C$

where I_0 is the baseline ingestion rate at 20 °C:

- $I_0 = 2.0\ L.day^{-1}$ for adults
- $I_0 = 1.0\ L.day^{-1}$ for children

For 20–40 °C, a compact form $I(T) \approx I_0 \times (0.1T-1)$ was used for calculation.

Multivariate equation of Yamada
The multivariate equation proposed by Yamada *et al.* (2022) estimates water turnover (WT, $mL.day^{-1}$) as:

$$WT = 1076 \times PAL + 14.34 \times \text{Bodyweight (kg)} + 374.9 \times \text{Sex} + 5.823 \times \text{Humidity \%} + 1070 \times \text{Athlete status} + 104.6 \times HDI + 0.4726 \times \text{Altitude (m)} - 0.3529 \times Age^2 + 24.78 \times \text{Age (y)} + 1.865 \times Temperature^2 - 19.66 \times \text{Temperature °C} - 713.1$$

Where
- *PAL* = Physical Activity Level (total energy expenditure / basal metabolic rate)
- *Sex*: 1 = male, 0 = female
- *Athlete*: 1 = trained athlete, 0 = non-athlete
- *HDI = Human Developpemet Index (*0 = high-HDI countries, 1 = medium, 2 = low-HDI countries)

Daily drinking-water ingestion was estimated from total water turnover (WT) by applying a proportional factor representing the share of total water intake obtained from beverages.

Results

Linear Temperature–Intake Relationship

The calculations were performed using an average annual air temperature of 28.70 °C for N'Djamena, as reported by long-term climatological data from Nambatingar Ngaram (2015) [11], Mahamat Nour (2019) [12] and WeatherSpark (2025) [13].

Because mean daily temperature includes both daytime and nighttime values, it may underestimate exposure to daytime heat. Therefore, calculations were also performed using the average daytime high temperature of 35.08 °C (WeatherSpark data, 2025) [13].

Based on these two temperature conditions (28.70–35.08 °C), estimated drinking-water ingestion rates ranged from 3.74–5.02 L.day^{-1} for adults and 1.87–2.51 L.day^{-1} for children (Table 1).

Table 1: Estimated drinking-water ingestion rates (L.day^{-1}) and water turnover (L.day^{-1}) according to temperature and model type. DWIR : drinking-water ingestion rate; WT : water turnover

Temperature	Linear relation		Yamada equation							
			Male				Female			
	adult	child	adult	adult	child	child	adult	adult	child	child
	DWIR	DWIR	WT	DWIR	WT	DWIR	WT	DWIR	WT	DWIR
28.70° C	3.74	1.87	4.81	3.85	3.03	2.42	4.44	3.55	2.65	2.12
35.08° C	5.02	2.51	5.44	4.35	3.65	2.92	5.06	4.05	3.28	2.62
Average	4.38	2.19	5.13	4.10	3.34	2.67	4.75	3.80	2.97	2.37

Multivariate equation of Yamada

The Yamada-based calculations were performed for adults (30 y, 70 kg) and children (3 y, 15 kg), using the following parameters: Athlete = 0, HDI = 2, humidity = 43 %, and altitude = 295 m.

Results are highly sensitive to PAL (Physical Activity Level), whose typical values after FAO/WHO/UNU (2001) [14], Black *et al*., (2013) [15] and Yamada *et al*., (2022) [10] are summarized in Table 2.

Table 2: Typical PAL values

Population	Description of activity level	Typical PAL
Child (3–10 y)	Spontaneous play, light walking	1.4–1.55
Adolescent (10–18 y)	Moderate school/sport activity	1.6–1.75
Sedentary adult	Office work, low mobility	1.5–1.6
Moderately active adult	Frequent walking, temperate climate	1.7–1.8
Active / field worker	Agricultural or manual labor, hot climate	1.9–2.0
Heavy labor / hot climate	Sustained physical effort, heat exposure	2.1–2.3
Trained athlete	Daily intensive training	2.4–2.6

Given the harsh living and working conditions in N'Djamena, a PAL of 2.0 was considered appropriate for adults, while a value of 1.4 was adopted for children, reflecting very low levels of physical activity. With these values, the water turnover is estimated at 4.81–5.44 L·day^{-1} for male adults, 3.03–3.65 L·day^{-1} for male children, 4.44–5.06 L·day^{-1} for female adults, and 2.65–3.28 L·day^{-1} for female children at 28.7–35 °C, respectively (Table 1). The fraction of water turnover attributable to drinking water, often assumed at 30–40 %, likely underestimates actual intake because local diets are largely composed of compact cereal meals (e.g., millet porridge) and meat or fish, with limited soups, fruits, or high-moisture foods. Consequently, the proportion of drinking water in total water turnover is much higher and can been estimated at 80% (NHMRC, 2006) [16]. Using these assumptions, estimated drinking-water ingestion rates were 3.85–4.35 L·day^{-1} for male adults, 2.42–2.92 L·day^{-1} for male children, 3.55–4.05 L·day^{-1} for female adults, and 2.12–2.62 L·day^{-1} for female children at 28.7 and 35 °C, respectively (Table 1).

Discussion

The close agreement between the empirical linear model and the Yamada multivariate equation supports the robustness of our results. The linear approach provides a simple temperature-dependent approximation, whereas the Yamada model integrates physiological and environmental variables, among which the physical activity level (PAL) exerts a major influence. Under N'Djamena's environmental conditions, the convergence of both models toward similar ingestion ranges (Table 1) suggests that temperature and physical activity are the dominant drivers of water needs, outweighing smaller effects of altitude or humidity.

Average drinking-water ingestion rates derived from the Yamada equation are similar for males and females (Table 1), but slightly lower for females (3.80 L·day^{-1} for adults; 2.37 L·day^{-1} for children) than for males (4.10 and 2.67 L·day^{-1}, respectively), due to the "Sex" parameter being set to zero in the Yamada formula. In the local context, however, women's total daily energy expenditure is likely to exceed that of men, as they perform most physically demanding domestic tasks (e.g., collecting water and fuel for cooking, manual washing, and food preparation). Similar gender disparities in energy expenditure have been reported across sub-Saharan Africa (FAO/WHO/UNU, 2001; Black *et al*, 2013; Graham *et al*., 2016; Yeyemi *et al*., 2017; Russel *et al*., 2020) [14, 15, 17, 18, 19]. Consequently, the actual drinking-water needs of women may be slightly higher than those estimated with a PAL of 2.0.

Overall, our findings confirm that drinking-water requirements in N'Djamena are substantially higher than default ingestion rates used for temperate regions. Based on Table 1, we propose single, sex-independent intake values of 4.17 L·day^{-1} for adults and 2.36 L·day^{-1} for children, corresponding to the arithmetic means between the temperature–intake linear estimates and the Yamada model outputs. For local health risk assessments, these values can be rounded to 4 $L \cdot day^{-1}$ for adults and 2 $L \cdot day^{-1}$ for children. These estimates are consistent with empirical observations from other Sahelian and semi-arid regions, where similar levels of daily water use have been reported (e.g., Buchwald *et al*., 2022; Timotewos *et al*., 2022; Mounirou *et al*., 2023) [6, 8, 9]. They also align with operational experience from the Department of Geology of the University of N'Djamena, which recommends a minimum provision of 4 L $person^{-1}$ day^{-1} and a safety margin of 6 L day^{-1} for field missions in the region.

Although the present estimates provide a realistic baseline, several sources of uncertainty remain. In particular, the linear approximation assumes a uniform increase of 10 % per °C between 20 °C and 40 °C, which may not fully capture nonlinear physiological responses under extreme heat conditions. Moreover, the Yamada equation was calibrated primarily on populations in Asia and North America, whose anthropometry, acclimatization, and hydration behavior may differ from those of Sahelian populations.

Conclusion

This study provides a first quantitative estimation of drinking-water ingestion rates adapted to the climatic and lifestyle conditions of N'Djamena (Chad). Both the empirical temperature–intake relationship and the Yamada multivariate model yielded consistent results, indicating robust estimates. The proposed ingestion rates, 4 $L \cdot day^{-1}$ for adults and 2 $L \cdot day^{-1}$ for children, are substantially higher than default values used for temperate climates, reflecting greater heat exposure, higher physical activity levels, and dry dietary habits typical of Sahelian populations.

These results highlight the need for context-specific ingestion parameters in exposure and health risk assessments for hot and arid environments. Future studies should include continuous monitoring of actual water consumption by socioeconomic group and season, and take into account gender differences and occupational exposure. Such data would refine local drinking-water ingestion estimates and improve the accuracy of health risk evaluations.

References

1. USEPA. Exposure Factors Handbook: 2011 Edition. U.S. Environmental Protection Agency, 2011:EPA/600/R-09/052F.
2. National Academies of Sciences, Engineering, and Medicine. Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate. The National Academies Press, 2005. https://doi.org/10.17226/10925
3. Gisolfi CV. Water requirements during exercise in the heat. In Marriott BM, editor, Nutritional Needs in Hot Environments: Applications for Military Personnel in Field Operations. National Academies Press,1993:87-96.
4. WHO. Staying hydrated in the heat: what the public can learn from professional athletes. World Health Organization, 2023.
5. Stringer LC, Mirzabaev A, Benjaminsen TA, Harris RMB, Jafari M, Lissner TK, *et al*. Climate change impacts on water security in global drylands. One Earth, 2021:4(6):851-864.
6. Buchwald RR, Gitau MW, Mahagamage MGYL, Wallace RM. Heat, hydration, and health: Drinking-water consumption and challenges under rising temperatures in low- and middle-income countries. International Journal of Environmental Research and Public Health,2022:19(11):6822.
7. Mkaddem C, Mahjoubi S. Climate change and its impact on water consumption in Tunisia: Evidence from an ARDL approach. Munich Personal RePEc Archive,2022:115658.
8. Timotewos MT, Barjenbruch M, Behailu BM. The assessment of climate variables and geographical distribution on residential drinking water demand in Ethiopia. Water,2022:14(11):1722.
9. Mounirou LA, Sawadogo B, Yanogo H, Yonaba R, Zorom M, Faye MD, *et al*. Estimation of the actual specific consumption in drinking water supply systems in Burkina Faso (West Africa): Potential implications for infrastructure sizing. Water, 2023:15(19):3423.
10. Yamada Y, Zhang X, Henderson M, Sagayama H, Pontzer H, Watanabe D, *et al*. Variation in human water turnover associated with environmental and lifestyle factors. Science,2022:378(6622):909-915.
11. Nambatingar N. Contribution à l'étude analytique des polluants (en particulier de type métaux lourds) dans les eaux du fleuve Chari lors de sa traversée de la ville de N'Djamena. Thèse, Université Claude Bernard - Lyon I, 2011.
12. Mahamat Nour A. Fonctionnement hydrologique, chimique et isotopique du principal affluent du lac Tchad: le système Chari-Logone. Thèse, Université Aix-Marseille, 2019.
13. WeatherSpark. Average weather in N'Djamena, Chad. Cedar Lake Ventures, Inc., 2025.
14. FAO/WHO/UNU. Human energy requirements: Report of a Joint FAO/WHO/UNU Expert Consultation. FAO Food and Nutrition Technical Report,2001:Series 1.
15. Black AE, Coward WA, Cole TJ, Prentice AM. Human energy expenditure in affluent societies: An analysis of 574 doubly-labelled water measurements. European Journal of Clinical Nutrition,1996,50:72-92.
16. NHMRC. Nutrient Reference Values for Australia and New Zealand: Water. National Health and Medical Research Council, 2006.
17. Graham JP, Hirai M, Kim SS. An analysis of water collection labor among women and children in 24 sub-Saharan African countries. PLOS ONE, 2016:11(6):e0155981.
18. Yeyemi AY, Jajimaji F, Oyeyemi AL, Jabbo AA. Cardiovascular responses to millet pounding activity among women in a rural community in Northeastern Nigeria. Annals of African Medicine,2017:16(1):24-29.
19. Russel KC, Buman MP, Davis J, Haskell WL. Estimating energy expenditure of head-hauling water and grain grinding from heart rate monitor measurements in northern Mozambique. Public Health Nutrition, 2020:23(16):2886-2897.