Supplementary information for

Capillary Flow-Driven Paper-Based Microfluidic Sensor for NDMA Detection in Water

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Movie S1. Working mechanism of the sensor

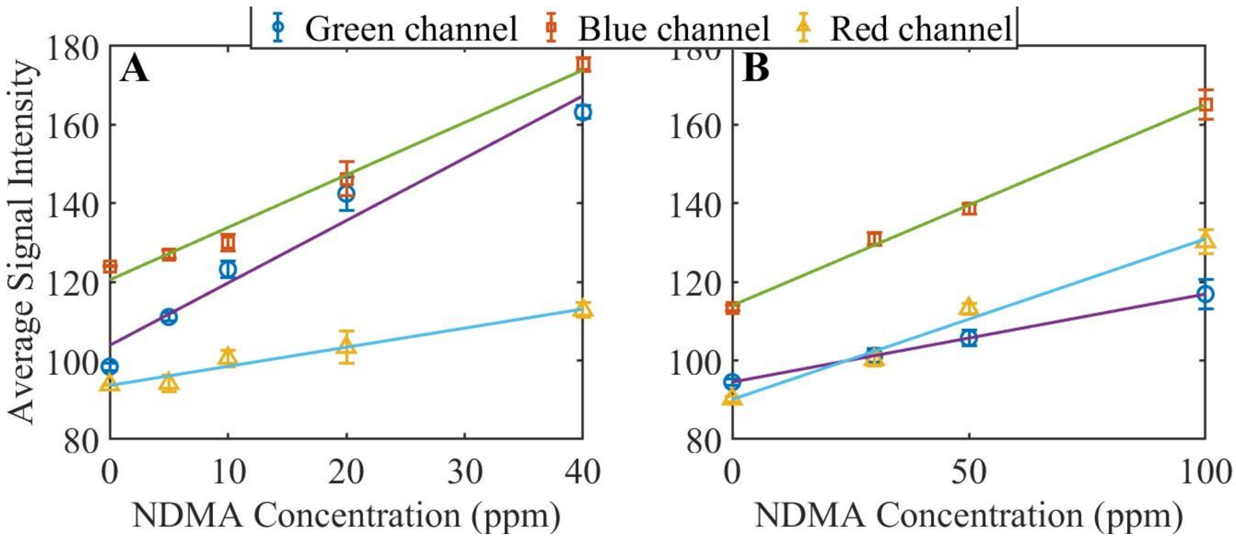

Figure S1. Image analysis color-channel selection for NDMA detection. Images were analyzed using ImageJ and separated into red, green, and blue (RGB) color channels. For NDMA–Co assays (A), the green channel was selected, while for NDMA–Fe assays (B), the blue channel was used, as these channels exhibited the highest sensitivity for their respective reactions.

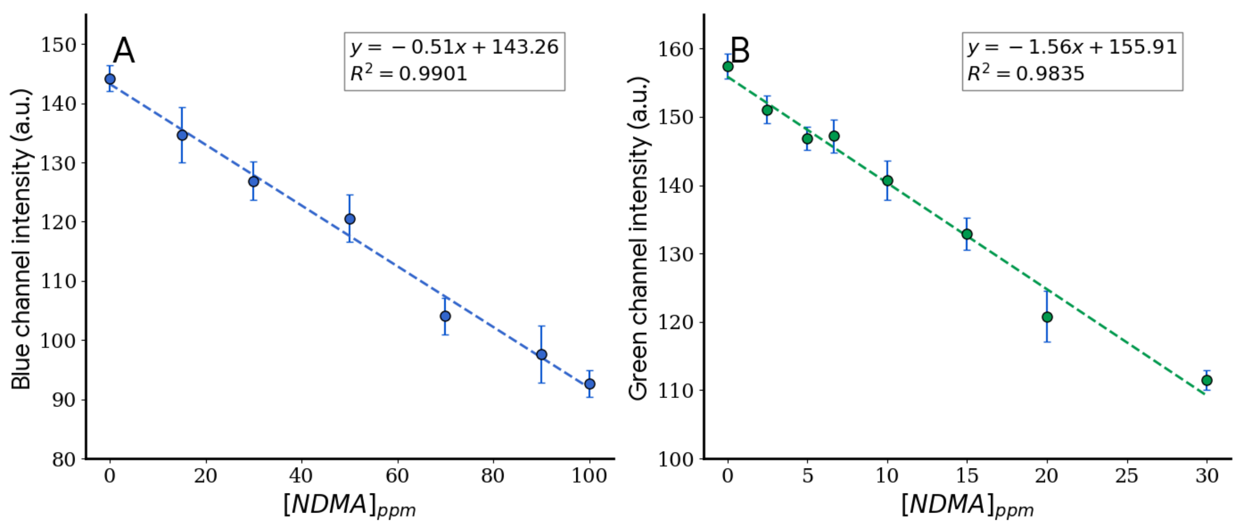

Figure S2. Sensor's compatibility with smartphone-based system (RGB color detector smartphone app). A = Fe^{2+} based system, B = Co^{2+} based system.

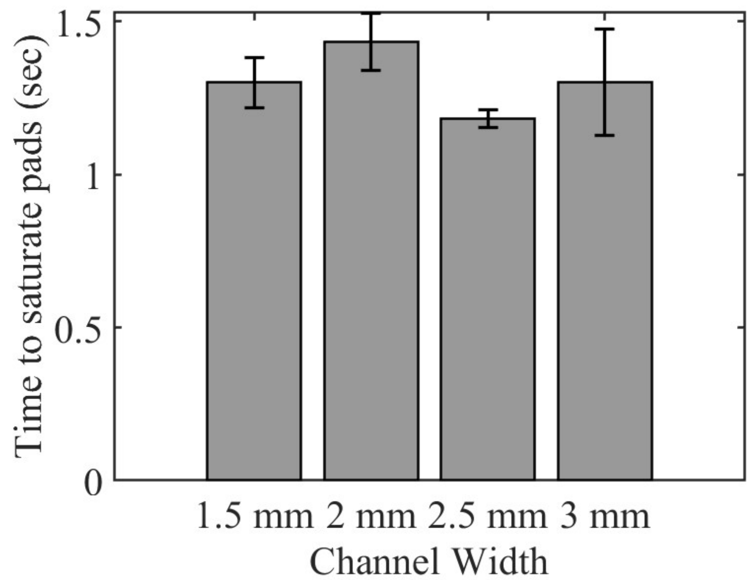

Figure S3. Channel width optimization for the capillary flow–driven microfluidic device. Average flow performance metrics (mean ± SD) are shown for channel widths of 1.5, 2.0, 2.5, and 3.0 mm, demonstrating that a channel width of 2.5 mm provides the most consistent and reliable flow behavior and was therefore selected for subsequent device fabrication and testing. The replicate measurement seconds were rounded to the nearest 0.5.

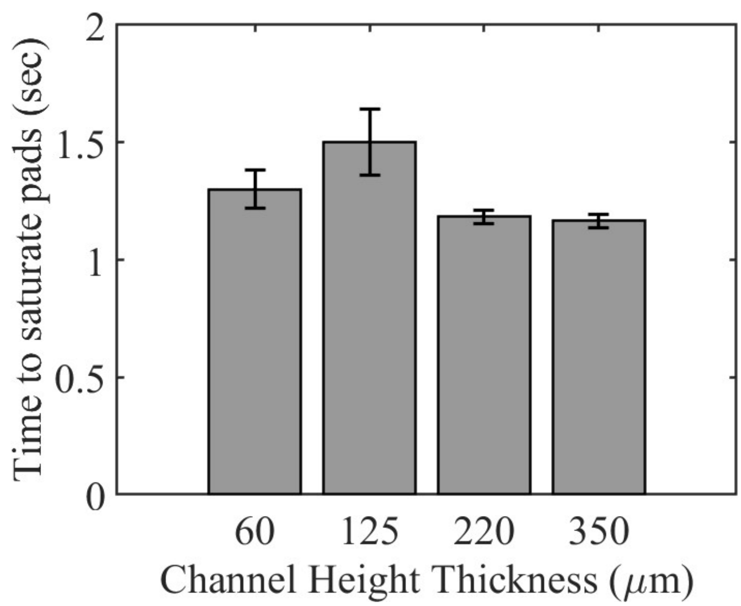

Figure S4. Channel height optimization for the developed sensor. The replicate measurement seconds were rounded to the nearest 0.5.

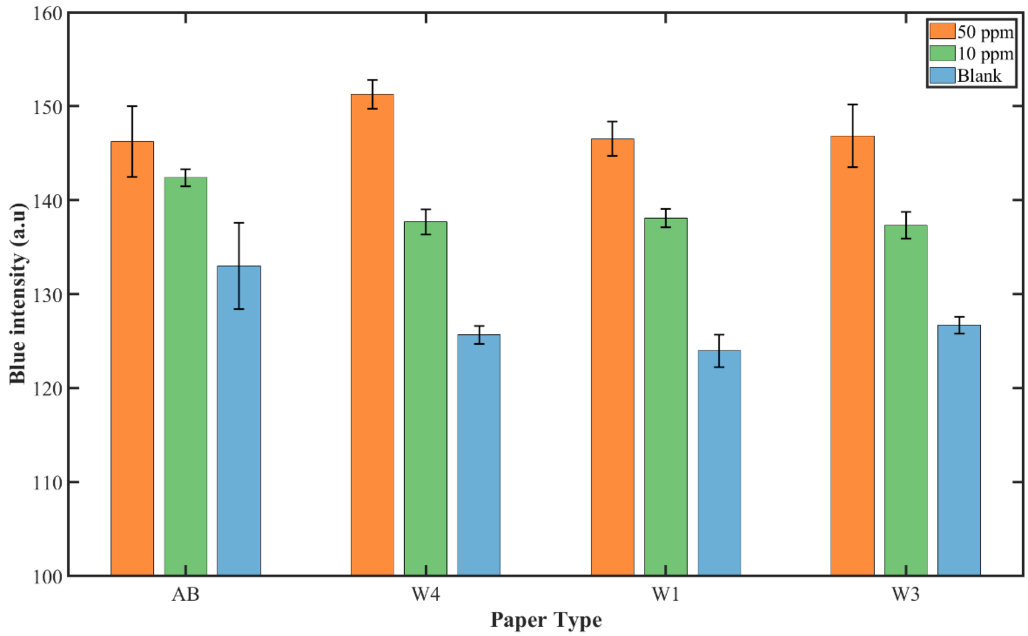

Figure S5. Substrate optimization on the developed sensor. W4 was chosen for its best differentiation of signal with lower SD.

Figure S6. AGREE Greenness score of the developed sensor

Table S1. Criteria and justification for the AGREE Greenness Score of the sensor

Criterion	Selection/Input	Justification
Direct analytical technique	In-field sampling and direct analysis	Dip-and-read workflow with no external sample handling
Sample size	0. 10 mL	The capillary channel defines a low sample volume (~100 µL)
Device positioning	At-line	Measurement performed at sampling site, not continuous
Sample preparation steps	3 or fewer	Integrated workflow (dip, fold, irradiate) with no external preparation
Degree of automation	Semi-automatic	Minimal user input; flow and reactions proceed autonomously
Derivatization	No	Photochemical nitrosation and colorimetric reaction, but it's automated and not off-chip
Analytical waste	~0.010 mL	Waste is limited to a small sample and reagent volume within the device
Number of analytes	1	Single analyte (NDMA) detection
Sample throughput	~3 samples/hour	Limited by ~20 min UV irradiation time
Energy consumption	~0.004 kWh	Low-power UV LED source and minimal smartphone use
Renewable reagents	No bio-based but very low volume	The volume used is very small that is insignificant
Toxicity/safety	The volume used is very low	Metal salts and acidic reagents are present in insignificant amounts

Table S2. Physical and fluidic characteristics of paper substrates evaluated for capillary flow-driven microfluidic device detection zones. nd – no data

Material	Thickness [mm]	Porosity [µm]	Flow rate	Grammage [g m^{-2}]
Glass fiber	0.3	nd	nd	~60
Whatman Grade 1 Chromatography Paper	0.180	nd	57 mL/min	87
Whatman Grade 4 Qualitative Filter Paper	0.205	20–25	247 mL/min	96
Whatman Grade 3 Qualitative Filter Paper	0.390	6	28 mL/min	187
Ahlstrom Blotting Paper Grade	0.5	19	360 mL/min	179

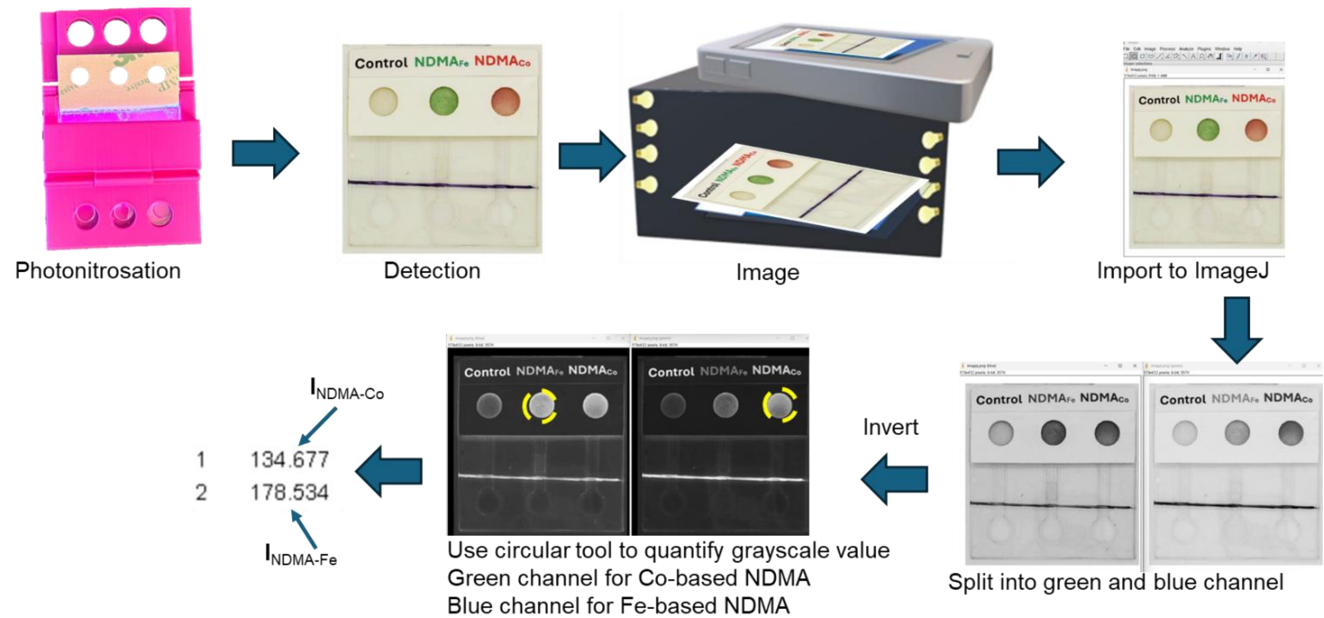

Figure S7. Image quantification workflow for the NDMA sensor

Table S3. Intra and inter-device variability in the developed system.

System	Intra-device (n=3)		Inter-device (n=3)	
	NDMA (ppm)	RSD (%)	NDMA (ppm)	%RSD Range
Co^{2+}	5	0.94	5	6.1–8.0
Co^{2+}	15	2.19	15	5.9–7.5
Co^{2+}	30	2.88	25	6.9–9.4
Fe^{2+}	15	2.49	25	9.0–9.9
Fe^{2+}	50	0.91	50	5.7–8.8
Fe^{2+}	70	3.36	75	6.6–9.2