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Simple-to-use paper microfluidic devices for monitoring contaminants in fresh water

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Monitoring water quality traditionally involves experts collecting samples for laboratory-based analysis; a time consuming, costly process.¹ It has been recognised that frequent measurements are needed to understand patterns and pressures of changing contaminant concentrations.² One approach empowers citizens with simple tools, enabling them to monitor water quality regularly.³ Generally, citizen-led sampling has involved volunteers collecting samples for later analysis by experts. We describe an approach comprising of a series of paper-based sensors, that when coupled with a smartphone, enable citizens to participate in simultaneous collection of samples and generation of onsite measurements.

We developed paper microfluidic analytical devices (PADs) for the detection of contaminants (nutrients, metals, organics). All devices were designed to be simple to use with rapid colour readout achieved with minimal user input. Filter paper was patterned with hydrophobic wax barriers to create reaction zones. Within these zones, chemical reagents were stored, that would, upon sample addition, change colour proportionally to the analyte concentration. After addition and drying of reagents, devices were sealed by lamination with a hole cut to allow for sample entry. For water analysis, the devices were placed directly onto the water sample and incubated for a short time (< 10 min). The coloured reaction products were visible to the naked eye; more precise quantification was achieved by capturing a digital image followed by colour intensity analysis.

We adapted spectroscopic determination chemistry, so that it was suitable for use on a portable paper platform; successfully developing separate devices for phosphate (LOD 3 mg L⁻¹), copper (LOD 2 mg L⁻¹), chromium (LOD 0.5 mg L⁻¹), nickel (LOD 3 mg L⁻¹), and triclosan (LOD 3 mg L⁻¹). To detect very low concentrations (>µg L⁻¹) of contaminants (metals, organics) usually found in the environment, we aim to combine the simple paper-based readout with an in-field pre-concentration step. By incorporating an electrospun membrane with a simple filtration system, adsorption of copper ions on the membrane surface was demonstrated. Coupling such a pre-concentration method with colour-generating paper readout devices, would potentially provide a simple means for on-site monitoring at environmentally relevant levels.

Citizen-led sampling was undertaken to monitor phosphates in freshwater across the Humber region (UK), Belgium, Germany and the Netherlands. Devices featured six reaction zones, two control zones and internal calibration (coloured squares). Results were captured using a custom-developed app, RiverDIP (Natural Appitude) that also recorded location, turbidity (photos), GPS, date, time and waterbody. Submitted data were analysed, and subsequently plotted on an online map, allowing volunteers to see all sampling efforts with > 300 results returned so far. Engagement with volunteers was investigated to empower people by informing them of sources of domestic pollution.

In summary, we have developed a series of simple-to-use paper-based devices to detect water contaminants and demonstrated the feasibility of citizen-led sampling to monitor water quality. Future work will involve further development towards a system for simple onsite pre-concentration and monitoring of heavy metals involving volunteers in the sampling process.

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- 2.Sens., 5, **2005**, 4-37.
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