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**TRANSFORMATION TOWARDS SUSTAINABLE
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Continuous safe water monitoring using 3G telemetry in IDP camp water supply systems: Iraq trial

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Water quality monitoring for disinfection using chlorine in humanitarian settings is predominantly measured through low-resolution manual sampling and analysis methods, that is subject to human error, as well as being highly dependent on accessibility of sites, capacity and availability of human resources. The Chloroclam, a small high-resolution chlorine analyser that transmits continuous real-time data through a 2G/3G mobile network, was trialled over a 7-month period in an IDP camp in Northern Iraq to determine its functionality and ease of use in a crisis context. The results validated the data produced by the Chloroclam, with datasets highlighting significant seasonal and diurnal variances in chlorine concentrations and noting that manual sampling was not representative of the functionality of the water supply system. The data was able to suggest adjustments to dosing regimes to ensure sufficient levels of chlorine is available throughout collection periods and across the year.

Monitoring water quality in water supply systems

To maintain effective disinfection throughout a Water Supply System (WSS) dosing should be done by continuous feed, which is subjected to control by feedback from continuously monitored points within the WSS. However, even in well-established WSS, whilst continuous feed and feedback controls are prevalent, the feedback is only generated close to the immediate dosing system outlet and not from points within the network. In humanitarian response settings where temporary or ad-hoc WSS are set up to provide essential safe water to disaster affected populations, field practitioners carry out water quality monitoring at point of collection, predominantly through the use of manual low-resolution methods, such as DPD (diethyl-p-phenylene diamine) testing using a pool tester and on a daily basis as best practice. This basic equipment can measure pH and Free Residual Chlorine (FRC) (i.e. the required active chlorine needed to ensure the water being supplied is protected from contamination when within the WSS, on collection and when stored by a household). However, this water quality monitoring method is greatly affected by human error, subjectivity of the reader, as well as the capacity, access and resources available to regularly carry out these manual tests in often volatile, disrupted environments.

The chlorine monitoring device

The novel device deployed for continuous monitoring within this trial is namely the Chloroclam (refer to Photos 1&2), which is a standalone, miniaturised Chlorine (Cl) analyser with built in 2G/3G telemetry, costing approx. £2000 each. The device takes a small sample of water from a distribution line where it is fitted, testing the water for its temperature and FRC level. The Chloroclam then stores the reading until the upload interval, transmitting the information to an online platform, via local mobile phone networks, where crucial water quality information can be analysed and reacted on by water supply service provider, to ensure drinking water is always protected from contamination whilst in the WSS and at point of collection. Currently, it is used by water service providers primarily in the UK and Australia. Their application in well-established WSS was driven by the ageing infrastructure, which for example makes discolouration and loss of disinfection residual more likely. The utility of long-term deployment of the turbidity sensing variant of the product – Hydraclam

– has been reported (UKWIR 2013) particularly the potential for mapping and thereby predicting compliance failures (Gaffney and Boulton 2012) and assessing discolouration risk (Starczewska et al. 2017). However, whilst the availability of this and similar instrumentation suitable for extensive monitoring of quality within WSS has been recognised (Mounce et al. 2015) they have only been used temporarily to solve acute issues. There is an opportunity to use this technology to offer a low-cost, simple solution to continuous monitoring of water quality in less established WSS or temporary WSS in emergency and development contexts. The Chloroclam device can attach to any water supply by a hose enabling the water to be sampled at a rate of 10ml/minute, sufficient to maintain the performance of the Cl electrode whilst minimising the loss of water from the WSS. The device has an IP-68 rating, demonstrating it can continue to work if left submerged in a chamber, however, data upload may be compromised under these conditions. The rate of data upload determines the operating life of the 2 lithium primary D-cells batteries that power the Chloroclam, a sampling rate of 4 times daily, will give you a battery life of 1 year. Other maintenance considerations include potential recalibration of Cl analyser and a new electrolyte and membrane cap every 6 months, dependent on the quality of the water.

This paper reports the first attempt to use continuous Cl monitoring within a temporary, small-scale WWS to improve efficiency and effectiveness of disinfection of water in a humanitarian context. Internally Displaced Peoples (IDP) camps in Northern Iraq managed by Save the Children International were selected as the trial site due to their *ad-hoc* WSS, which serves a vulnerable population in a volatile environment. A water supply that is manually dosed with Chlorine powder, with a pipe network near or at the surface making them vulnerable and responsive to ambient temperature, which varies widely seasonally and diurnally and whose water quality is also tested manually. Levels of FRC will vary temporally and spatially across a WSS. The vulnerability of the camp's *ad-hoc* network makes temporal variation likely to be higher than in a similar area of well-established WSS, and the consequences of disinfection failures are likely to be more serious, with large populations vulnerable to disease outbreaks, such as cholera, typhoid and acute watery diarrhoea. Having a representative measurement of FRC is therefore more difficult to obtain, however essential to protect vulnerable populations within the Camp.



Photograph 2. A Chloroclam device being installed in Laylan II by the WASH team in Iraq



Photograph 2. A Chloroclam device installed on a pipe close to the outlet of the water source in Laylan II

Methodology

The preliminary study aimed to demonstrate that continuous monitoring of disinfection within an *ad-hoc* WSS was practical and could be useful. To achieve the aim of the study 3 interrelated objectives were set:

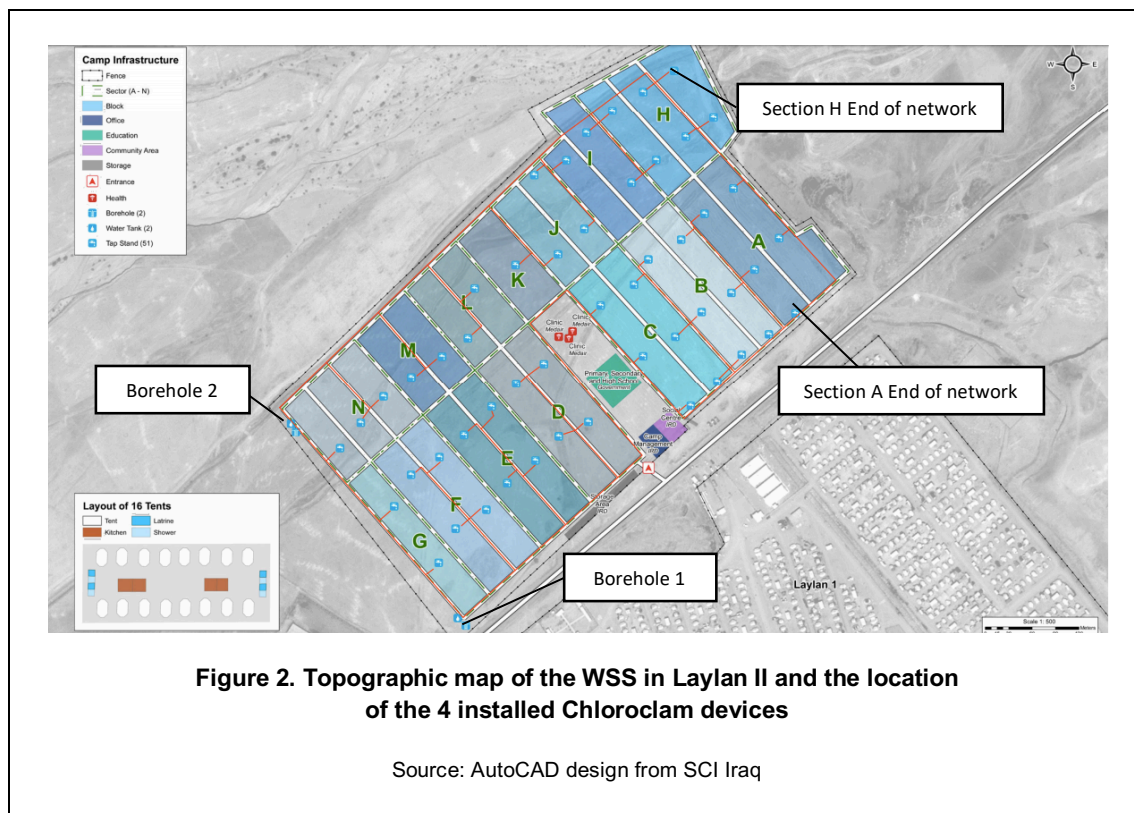
1. To determine whether the design and/ or mode of use of the Chloroclam device is viable in emergency contexts and whether there is need for any modification.
2. To validate the Chloroclam data by comparison to the standard method of analysis of DPD testing.
3. To determine ease of installation, data analysis system adjustment based on the data by water treatment and management entities.

The trial location

Laylan II IDP Camp is located in Kirkuk governorate in Northern Iraq, hosting a population of 4600 displaced people. The WSS was set up and is managed by Save the Children, supplying on average 500m³/ day in the summer and 155 m³/ day in the winter. The pipe network is constructed from 4" polyvinyl chloride (PCV) pipe and extends 3.1km across the IDP camp. The network is laid out as a grid topography (refer to Figure 2). Disinfection to make the water potable for the resident IDP population is conducted through the addition of a mixture of 450 gm of hypochlorite powder in 300 liters of water (reduced in the winter to 250 gm in 300 liters of water), which is then administered through chlorine inducers when water is supplied to fill up tanks along the network.

Deployment and installation of the chloroclams

Chloroclams were despatched from the UK pre-calibrated and energised, this was necessary in order to keep the electrode membrane polarised. A plastic bag containing a wet sponge was sealed around the membrane to keep it from drying during transit, the modem can be switched to airplane mode for safe transit. The Chloroclams were connected to the WSS by quick fit hoses at 4 points- 2 near the water sources and dosing points (Boreholes 1 and 2) and 2 at the ends of the network (Section A and H) (refer to Figure 2). Chloroclam set-up was done via the website, where the data is also uploaded. They were initially set to record temperature and FRC at 15 minute intervals and upload data hourly, this was later modified to record hourly and upload data every 6 hours to extend battery life. Chloroclam set up and data download could also be done by a wired connection and this was used to investigate problems if uploading to the website had failed.



The trial

Once the Chloroclams were installed in Laylan II continuous data was produced by the Chloroclams uploaded onto the online platform for analysis by the research partner, the University of Manchester, the manufacturer - Evoqua and the implementer Save the Children for analysis over a period of 7-months, from July 2017 – Jan 2018. Manual water quality monitoring was carried out by Save the Children to offer a comparison between a once daily, low-resolution manual method with a continuous high-resolution method that utilises 2G/3G telemetry. The ease of installation and operation was assessed through feedback from the implementation

team. The data produced was analysed to determine any adjustments or maintenance needed within the trial, and to determine any required modifications to the Chloroclams for further use.

Results of the Chloroclam trial

Seasonal and diurnal variations of FRC concentrations

The concentration of FRC is subject to wide temporal variability, both seasonally and diurnally. There is also a large decline in concentration between the source and the ends of the network, this decline is much greater under summer temperatures (30 -45⁰ C), than during winter temperatures (8-28⁰ C) (refer to Figures 3a – 3d). There is a clear diurnal variation in FRC, which shows a strong negative correlation with temperature. The clear capacity for the water to maintain high FRC levels - typically > 1mg/l between 10pm and 4am, demonstrates that the timing of disinfectant dosing could be optimised to counter the impact of high temperature. The latter was only apparent, as a result of the high-resolution monitoring, which has also similarly shown that once daily manual monitoring gives a wholly unrepresentative view of the functionality of Cl within the WSS (refer to Figure 4).

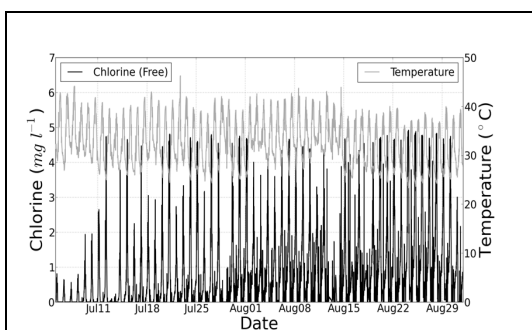


Figure 3a. Chloroclam data from Borehole 2 in the summer time, presenting temperature and FRC readings

Source: Direct data from Chloroclam

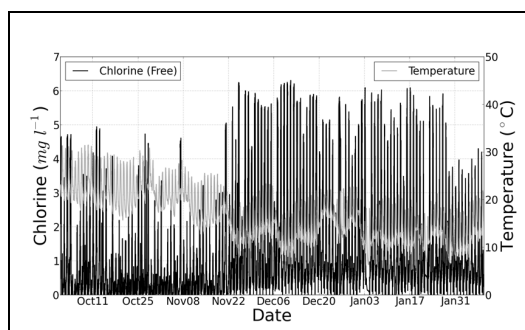


Figure 3b. Chloroclam data from Borehole 2 in the winter time, presenting temperature and FRC readings

Source: Direct data from Chloroclam

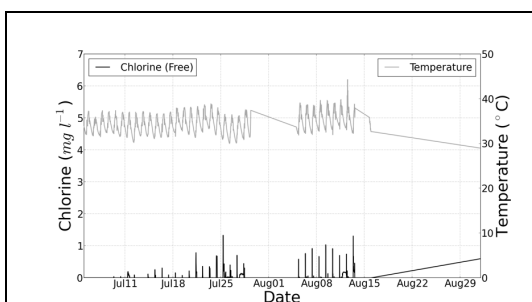


Figure 3c. Chloroclam data from Section A end of network in the summer time, presenting temperature and FRC readings

Source: Direct data from Chloroclam

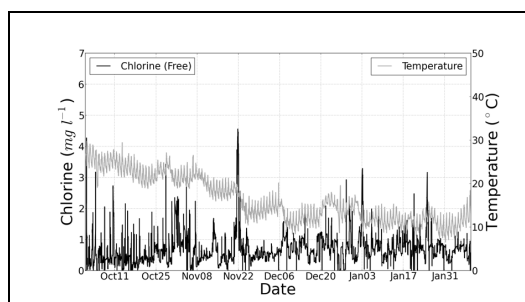


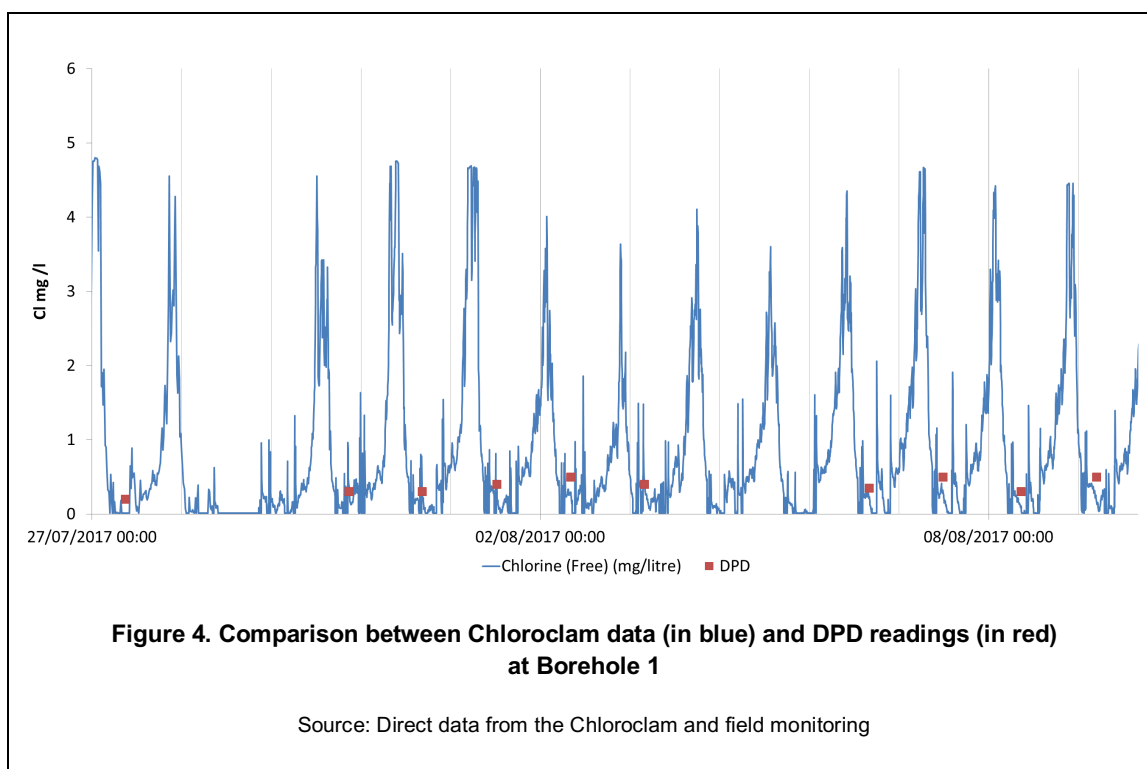
Figure 3d. Chloroclam data from Section A end of network in the winter time, presenting temperature and FRC readings

Source: Direct data from Chloroclam

Validation of Chloroclam data

It is clear that manual DPD testing did not coincide with the full range of FRC levels presented within the WSS on a daily basis, only reading FRC when at lower concentration, due to the time of day the reading was taken, which was a couple of hours after the water was pumped from the borehole to the distribution tanks and before required top ups of the tank later in the day. The spikes in FRC are a result of the freshly treated water being pumped through the network to top up storage tanks. The daily DPD tests correlated well with the Chloroclam FRC readings (refer to Figure 4). However, some disparities appear because whilst the error associated with ascribing a time to a Chloroclam reading is negligible, that associated with ascribing a time to a manual DPD test is relatively high – 2- 10 minutes. Discrepancies between Chloroclam and DPD can then arise because, as is apparent from the Chloroclam record, the FRC level changes very rapidly.

Occasionally DPD readings were very different to the extracted Chloroclam data, however, given that in most cases the readings were correlated it is most likely that the Chloroclam data is more reliable. The general correlation shows there are no gross errors in instrument performance and from then it can be regarded as less error prone than the complicated procedure of manual DPD testing, which may suffer from gross errors and often from inter-user differences. The quality of each Chloroclam data point can to a greater extent be internally validated by comparison to its immediate neighbours which can be recognised as similar or forming part of a trend. Having established the validity of the Chloroclam readings it was also apparent that the readings were at higher resolution, over a wider range, less liable to gross error and much easier to conduct, compared to manual DPD testing.



Modification to Chloroclam design and mode of use

Whilst attachment to the WSS was simple and effective the transit prior to this was problematic. The deployment was delayed by 6 weeks, which meant that although the electrodes did not dry out they had become so starved of Cl that they took several days of exposure to chlorinated water to recover. Replacement of electrode membrane caps and electrolyte would have been the optimum response to this treatment, however this was not possible at this time. Also, the units could not be air freighted without special permission and had to be carried as accompanied hand baggage due to containing lithium primary cells. The Chloroclam antenna is configured to operate with low signal strength, but whilst deployed there were periods when uploads failed; signal strength is recorded in the uploaded data and it was apparent that it occasionally varied. There should be no data losses resulting from this as the data is stored on the unit and eventually uploaded when signal is

sufficient, the data losses apparent in Figure 3c may have resulted from the units being accidentally turned off. If the alarm function were to be used – as is intended in later trials – it must be considered that signal strength failures could prevent real-time notification. Some data losses were from failures of the electrode, where temperature data was collected and uploaded, but the FRC has not. This deployment of Chloroclams in Laylan II has demonstrated to the manufacturer that the product should be supplied with a dry electrode and an activation/ maintenance kit so the user can be responsible for the electrode. This removes the limitations imposed by the shelf-life of a wet electrode and will allow predictable disconnection, such as during transit, and unpredictable to be better managed. Similarly, flexibility can be achieved by calibration against DPD testing in-situ, which will also be more effective as it is done in the water that is monitored rather than by Cl addition to deionised water in the UK calibration facility. Because there will be no need to ship the Chloroclam with an activated electrode it can be shipped without batteries and therefore these can be purchased at the point of use so overcoming problems with air freighting lithium primary cells. Further study, involving two other camps in Iraq is proceeding and the intention is to expand the datasets and use the data to better define optimum dosing patterns in the camp WSS. Ultimately, the ability of the devices to provide alarms – by SMS or by e-mail – will be tested should dangerously low FRC levels be detected.

Conclusion

The seven-month trial of 4 Chloroclams installed in an IDP camp in Northern Iraq has been able to demonstrate that the high-resolution Cl monitoring devices are able to provide near real time monitoring of FRC levels and temperature at any strategic point where connection to the portable water main is possible. The study was carried out in extreme weather conditions and showed that targeted monitoring is able to provide a comprehensive view of water quality throughout the entire network throughout the year. The trial, through the use of high-resolution data, was able to highlight significant seasonal and diurnal variations in FRC levels. It was noted there was a large decline in concentration between the source and the ends of the network, which was much greater under summer temperatures (30 -45⁰ C), than during winter temperatures (8-28⁰ C). There was also a clear diurnal variation in FRC levels, which showed a strong negative correlation with increased temperature. Demonstrating the importance of factoring in seasonality and temperature when managing Cl dosing in WSS. Using devices like Chloroclams will allow operators to manage Cl dosing confidently and effectively to ensure safe water is continuously provided. The trial was able to establish the validity of the Chloroclam readings, whilst demonstrating that they offer a monitoring method that is continuous, at higher resolution, over a wider range, that are less liable to gross error and much easier to conduct, compared to manual DPD testing that is predominantly being used throughout the humanitarian and development sector to monitor FRC levels. A couple of modifications and adjustments to installation and operation of the Chloroclams were recognised as a result of this trial, which will ensure ease of use by operators. Continuous chlorine monitoring through the Chloroclam provided an insight into chlorination of drinking water in extreme conditions (temperature effect) in a temporary WSS within a volatile humanitarian setting, identifying potential improvements to the current dosing practices, enabling data to be continuously collected from difficult to access sites.

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