Real Time Monitoring of Ganges River Basin during Kumbh Mela ceremony

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Introduction

The Ganges is a trans-boundary river which flows through India and Bangladesh. The 2,525 km river rises in the western Himalayas in the Indian state of Uttarakhand, and flows South and East through the Gangetic Plain of North India into Bangladesh, where it empties into the Bay of Bengal. By discharge, it is the third largest river of the world after Amazon and Congo River.

An Action Plan was initiated by the Indian Government in 1984 with the financial support of the World Bank and the Government of Netherlands, aiming at the control of the rising levels of pollution. Plan was to identify and mitigate major sources of wastewater and other point-source discharges into the River through the construction of interceptor sewers, sewage diversion mechanisms and sewage treatment plants. Despite substantial investments done, since then no agreement on the effect of the Ganges Action Plan could be found between the stakeholders. One major problem was the lack of data as a basis to evaluate and optimize the effect of the investments.

More recently, the Kumbh Mela ceremony, in which more than 100 million Hindu pilgrims bath in Ganges River to wash their sins away, moved into the focus of interest. To monitor and control pollution during this event, a pilot project was initiated. The installation of a smart water quality monitoring network was part of the “Clean Ganges” initiative. Supported by the World Bank, the Central Pollution Control Board (CPCB) assigned s::can Messtechnik GmbH and their local partners with the design and implementation of a 10-station pilot network. Main targets of the pilot were:

- To monitor diurnal variation of different physic-chemical parameters, as well as to detect events from episodic discharges of pollution sources (industrial as well as municipal) along the Ganges River, as a basis to undertake corrective measures before and during the event.
- To assess reliability and sustainability of smart modern real-time monitoring sensors and technology as a basis for the monitoring and control of pollution along the river basin, in contrast to old-fashioned, reagent based on-line analyzers. This network should provide the basis to steer future investments into water infrastructure along least-cost/best-effect tracks, and enable to evaluate and optimize the effect and sustainability of such investments.

Description of installed base

Monitoring stations were installed by s::can together with local alliances such as companies Aaxis Nano, Tritec, and Techspan, at ten different locations along the Ganges River (see figure 1.1, 1.2 and 1.3), to monitor ten parameters each: Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Electrical Conductivity (EC), pH, Temperature, Ammonium (NH4-N), Nitrates (NO3-N), Dissolved Oxygen (DO), and Chloride.

Interest is focused on organic pollution (expressed by COD and BOD), and to nitrogen nutrients (NH4, NO3). Especially for those normally expensive and difficult to measure parameters, a so far unknown level of reliability and stability has been reached. All parameters are measured by innovative sensors, preferred optical, that are reagent-free and can operate almost without maintenance. There are no moving parts both for the measuring as well as the cleaning process. The monitoring stations consist of:

- 4 sensors each to measure 10 parameters (more possible)

- Station terminal with postgress data base, interfaces for - almost any number of - digital and analogue sensors, SDI-12, Modbus, USB, TCP/IP-Ethernet, 4-20 mA, and other interfaces, integrated GSM/GPRS/3G modem, advanced graphical touch screen interface
- moni::tool station and data management, data validation and event detection software
- Battery charging system (battery, solar panel)
- Compressor for automatic air cleaning
- Cameras and alarm sirens, security cages and other protection against vandalism

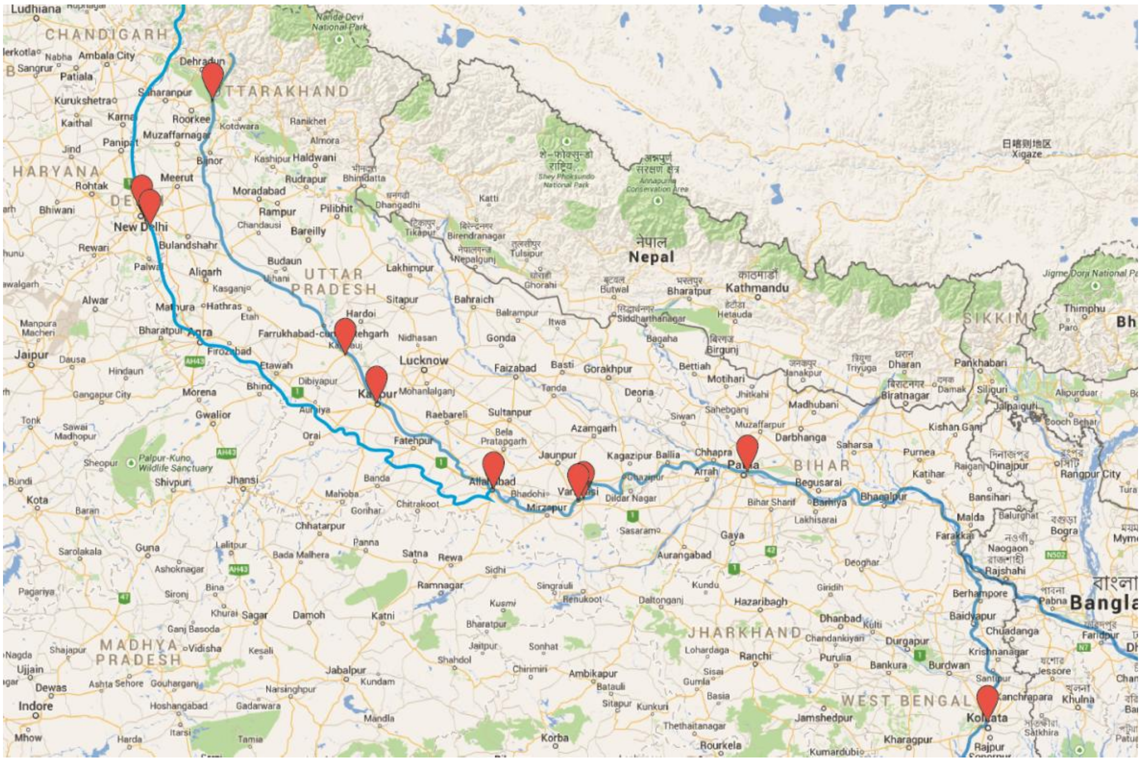

Figure 1. 1. Overview of monitoring station locations

Figure 1.2. Floating monitoring station

Figure 1.3. River side monitoring station

s::can's smart monitoring concept and software consists of several modules according to figure 2.

The stations had to be tolerant to extreme environmental conditions (high and low temperatures, and high humidity). Although stations are secured against vandalism, local people take care of the stations because they are in favor of such project to protect their holy Ganges River against pollution.

All real-time data are automatically transferred via a GPRS network to a centrally receiving FTP server located at CPCB central office in New Delhi. The central system has capability to receive, analyze, display and store the data received from the ten remote monitoring stations, and links the information to a GIS-system for geographical display and analysis. All the monitoring stations are operational in a real-time mode, and each station can be accessed from the central server.

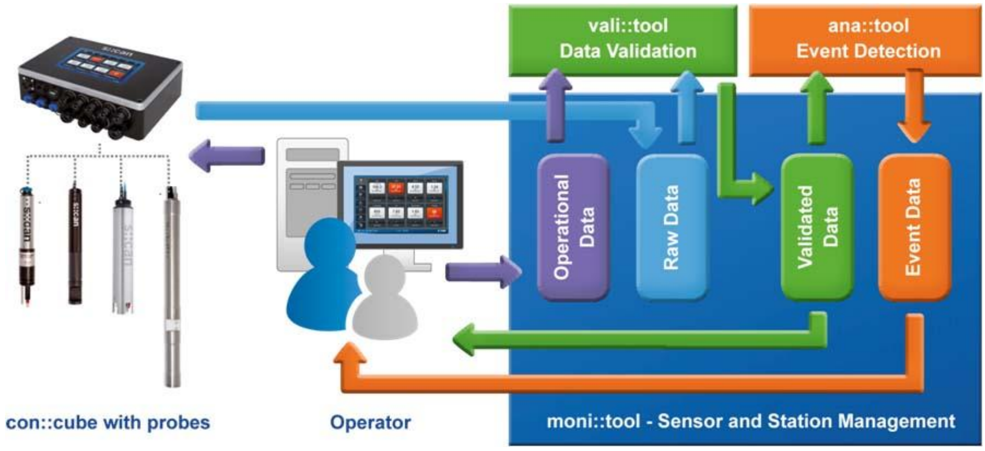

Figure 2. Scheme of the station, sensor, and data management solution provided by moni::tool software

Smart Software Spotlights

The purpose of real-time data validation is to detect problems in the measurement data quality. Real-time data correction cleans up undesired data quality problems; however, primary goal of the data validation step is to provide feedback to the operator that allows to detect installation and sensor issues, and to take measures to improve.

The purpose of the event detection step is to detect alarming changes in the water quality and composition. The event detection system self-learns the typical relation of water quality parameters under normal conditions within typical fluctuation, and compares this baseline to current measurements, to detect any deviations.

In order to verify the behavior of real-time data validation, and to determine the source of effects detected by real-time data validation, the collected data additionally went through a manual offline data analysis validation process.

Three examples of the value of smart data management and real-time analysis are presented here:

1) *Real-time data validation by vali::tool*

vali::tool analyzes the data to detect inconsistent noise levels, outliers, data gaps, drops to zero and other features in the data. Figure 3.1 and 3.2 show examples of raw data time series together with validation results.

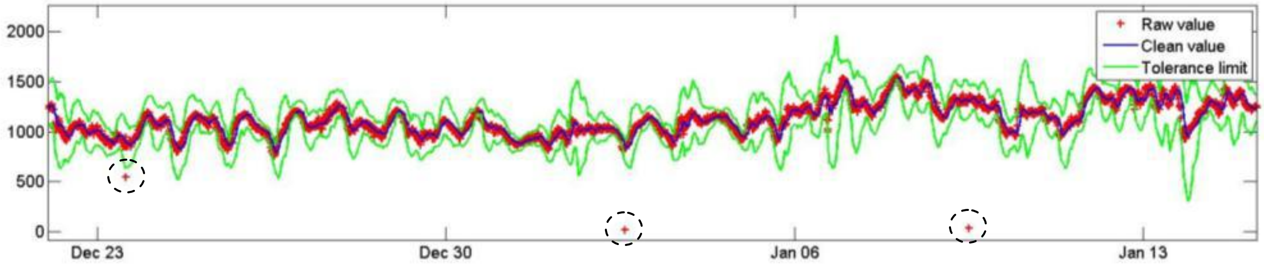

Figure 3.1 The outlier detection algorithm calculates an upper and a lower tolerance limit around a prediction for the next parameter value. Values outside the tolerance are outliers (marked with dashed circles around). The tolerance limits are automatically adapted to the typical prediction errors: $T_k \pm = s_k \pm \max\left(\sum_{i=1, where\ no\ outlier}^{N} \left(f\frac{|p_i - s_i|}{N}\right), \mathrm{minTol}\right)$, where p_i are the actual measurements, s_i are predicted measurement values and minTol a minimum tolerance

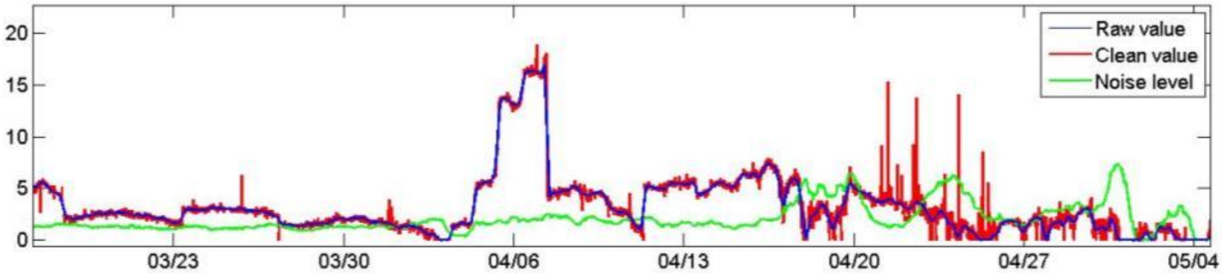

Figure 3.2 The noise detection algorithm measures uses typical deviations of the parameter values from a smoothed time series to estimate the noise level. Deviations from typical noise levels are often an indicator of installation problems such as in this figure, where the elevated noise level after 04/18 was the result of the monitoring station partly falling dry.

2) Event detection software

The event detection software uses water quality parameters such as TSS, COD, BOD, etc. and their relations, as well as the UV-Vis absorption spectra and ratio of all 250 single wavelengths, to detect deviations in water quality. The software automatically collects data during times of normal water quality, and uses these data as a reference in a (self)-training process. Several learning modes are available, depending on the characteristics of the water. The software learns the normal ranges of the parameters, and the relation between each parameter and the others. The learning is done by a nearest-neighbor type of algorithm in the case of event detection based on single water quality parameters. The deviation from the normal values and relations is expressed by an alarm value and is given by $\mathrm{A} = \min\left(\sum_{i}^{N}\left(\frac{(r_{ji} - p_i)^2}{N}\right)\right)$, where r_{ji} is the parameter I of reference sample j and p_i is the parameter I of the current measurement. The alarm value is determined by the reference sample that minimizes the sum in the expression.

This value is low / close to zero / for normal water quality conditions; a stable, close to zero baseline indicates a well-trained event detection software. The higher and the more distinct the alarm value, the more abnormal the event. An alarm is set off whenever the alarm value exceeds a pre-defined threshold. The value of the threshold is a configuration parameter that determines the sensitivity of the event detection system.

3) *Offline data analysis and evaluation*

Several stations delivered data with gaps in regular intervals as seen in Figure 4. Typically these gaps followed a daily pattern, with interruption at a certain point in time during the night hours, and auto-restarts in the morning hours.

An analysis of the available data showed that the interruptions occurred whenever the battery voltage dropped below a critical level during the night hours. After sunrise, the solar panel started to collect energy again and at some point in the morning hours, the voltage level reached a sufficient level to restart the monitoring station. Figure 4 shows the daily pattern of the voltage level. The stations show robust behavior and auto-restart every day without any problems. Although the cleaning system is not active during the station shut down, the parameter results follow a consistent line and show no drift over the observed period.

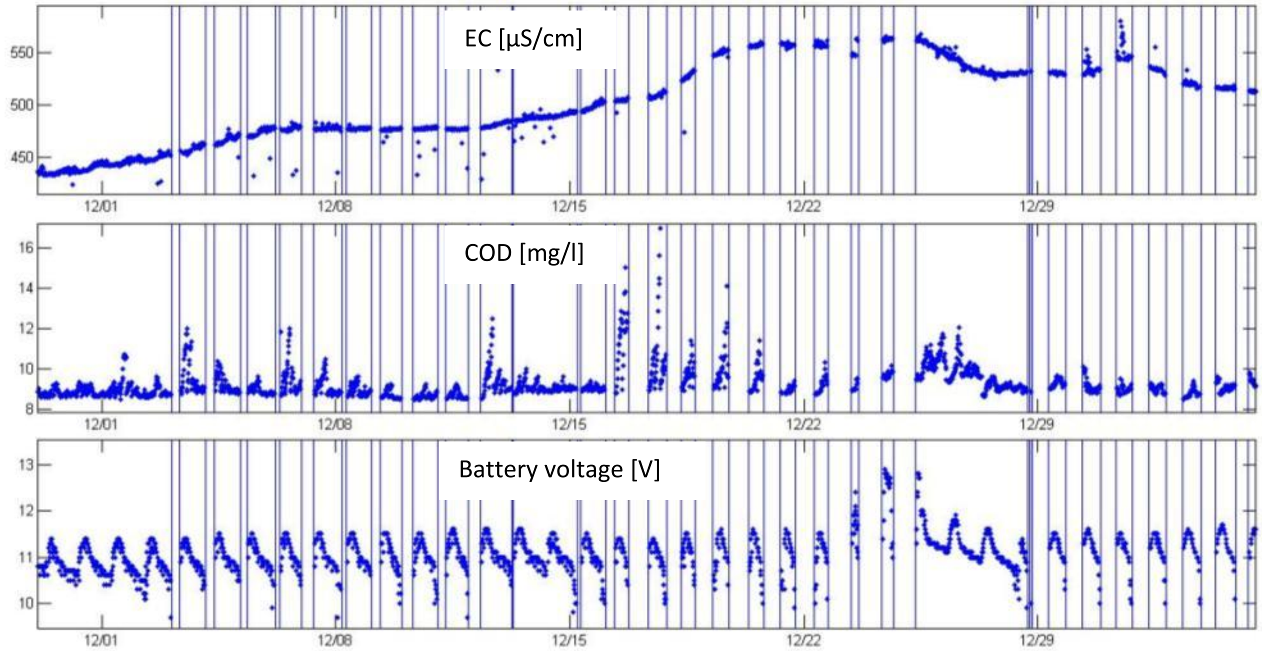

Figure 4. Results from Varanasi2 station showing battery voltage and the interrupted time series of conductivity and CODeq.

Lessons learned

Long-term and stable on-line water quality monitoring was achieved on a unprecedented level by using smart on-line monitoring hardware and software.

The identified bottlenecks were:

- Power supply: For some stations, power consumption had to be optimized to fit to the given size of solar panels and batteries.
- Hydraulic stability / good installation: Some stations had to be removed because water was flooding the cabinets during hard rain events. Waterproof cabinets are considered. During dry season, some stations fell dry and had to be moved to other locations.
- Preventive maintenance concept: Although the equipment requires relatively low maintenance, a well-planned preventive maintenance scheme should replace the applied maintenance-on-demand procedures.
- Self-diagnosis feedback: Feed the real-time self-diagnosis information about sensor and station health given by moni::tool software back to the maintenance team in order to trigger reactive maintenance, but also to introduce into regular maintenance schedules, and with this, minimize station down time.

Results of the pilot project prove that smart on-line monitoring technologies, our “eyes into water”, are extremely useful to gather an information base which is crucial before deciding about financial investments into expensive infrastructure. Using such dynamic information, the origin, nature and peaks of pollution can be detected and documented. It is possible to assess where to invest next at least cost and best effect, and to optimally select, design and build infrastructure. And finally, control the proper and sustainable operation of the constructed infrastructure, and also to monitor, evaluate and compare the effect of the investments.