# Automatic water level and water quality monitoring

**A Gujral** *Encardio-rite Electronics Pvt. Ltd., India*

**A Bhalla** *Encardio-rite Electronics Pvt. Ltd., India*

**DK Biswas** *Encardio-rite Electronics Pvt. Ltd., India*

## Abstract

*For any programme of efficient water management to be successful, continuous monitoring of water level and quality in the ground, rivers, lakes and reservoirs etc. is necessary. It is essential to map, measure and monitor extent and quality of both subsoil aquifers and surface fresh water resources. In case of water level, reliable and accurate data is required, well in time, to assess groundwater conditions such that adverse situations like drought and loss of pumpage in agriculture and domestic water supply can be efficiently handled. However, the monitoring task becomes gigantic and expensive when the number of sites and parameters to be monitored increases requiring not only suitable sensors but also automated monitoring from a central location.*

*This paper discusses economical automatic water monitoring systems that provide a variety of solutions ranging from unattended monitoring of a single borehole for use by industry to monitoring of hundreds of boreholes spread over a wide geographical area from a central location. The paper discusses critical parameters monitored, a comprehensive range of water level and quality sensors that are available and can be monitored online, sophisticated dataloggers, typical installation schemes, few typical data monitored and the useful conclusions drawn from it.*

*The paper also discusses telemetry and Web-based monitoring solutions that allow water level/quality at remote locations to be monitored continuously, in near real time, from a central location that also sends alerts through Short Message Service (SMS) and e-mail. The solutions enable groundwater researchers and decision-makers to have quick access to the groundwater/surface water data at less effort and cost.*

## 1 Introduction

Around 3% of water on Earth is fresh water. About 69% of this is locked up in glaciers and ice caps; 30% is found as groundwater and 1% is accounted for in lakes, rivers, reservoirs and the atmosphere. We are presently faced with the grim reality of ever depleting fresh water resources due to a variety of reasons such as overexploitation for human use, high degree of pollution, drying up or depletion of sources of recharge such as glaciers and run off of rainwater. Depletion of fresh water reserves is going to make life extremely difficult for future generations.

For devising, implementing, monitoring and reviewing the effectiveness of plans for reduction in water consumption, conservation, preservation and improvement of water quality and regeneration of fresh water reserves, it is essential to comprehensively map, measure and monitor the extent and quality of both subsoil aquifers and surface fresh water reservoirs and streams, as well as sources of recharge like rainfall.

An effective and extensive fresh water extent and quality monitoring plan spread over the length and breadth of a country is both an expensive proposition and a logistic nightmare due to the sheer number of sampling sites that will include many remote locations and the large trained manpower required to collect and send the data to designated central locations. It is also essential that the huge amount of collected data is meaningfully analysed and promptly presented to all stakeholders who may be located at dispersed locations.

A properly designed and executed instrumentation plan can go a long way in reducing total monitoring costs, increase the quality and reliability of collected data, reduce manpower requirement, automatically analysing the collected data and presenting it in relevant tabular or graphical forms and making it available to authorised users, located anywhere in the world, simultaneously over the Internet with least possible time delay consistent with user requirement.

Automated monitoring from a central location provides an advantage to monitoring and regulatory bodies and authorities. The data from remote locations can not only be monitored in near real time, but it also eliminates any chance of human error in recording data, and the actual data cannot be intentionally or unintentionally modified by any person.

The discussion in this paper is limited to the economical instrumentation and telemetry solutions available that can cater to the need of users interested in state or country wide monitoring from a central location. The large number of locations from which data has to be collected requires the installed systems to be very reliable and almost maintenance free. This paper discusses such an online Web-based monitoring system requiring minimal maintenance being installed in India.

## 2 Methodology

For planning of depleting water resources, monitoring of water level is of great significance. Automatic water level recording systems are extensively used for monitoring levels in rivers, lakes or boreholes. A variety of solutions are available ranging from unattended maintenance free monitoring of a single borehole for use by industry to country-wide monitoring of hundreds of boreholes from a central location.

Automatic water level monitoring systems can be programmed to make measurements in observation wells at a specified frequency over long periods of time. Continuous monitoring provides the highest level of resolution of water level fluctuations. Hydrographs constructed from frequent water level measurements collected with a continuous monitoring system can be used to accurately identify the effects of various stresses on the aquifer system and surface water and to provide the most accurate estimates of maximum and minimum water level fluctuations.

An automatic water level monitoring system basically consists of a fluid pressure sensor connected through a cable to an automatic datalogger with provision of data retrieval/transmission and online Web data monitoring.

### 2.1 Sensors

A method for automatically monitoring water tablein a borehole or level in a river, reservoir or lake is to use a high accuracy fluid pressure sensor installed at a depth below the minimum expected water level. It measures the water level using the relationship that pressure is equivalent to 10 kPa for every 1 m of water column for pure water of specific gravity 1.00. For water with dissolved solids, the specific gravity of water at that location has to be separately determined and a correction factor applied to the measured value. Brackish water in coastal areas often has a specific gravity as high as 1.1 and, therefore, requires a specific gravity correction in the measured value.

The full scale measurement range of the pressure sensor is chosen to be just larger than the maximum expected variation of water level/table at that location. This allows the water level/table to be monitored with highest possible resolution and accuracy.

The most frequently specified parameter for water level/table measurement is depth of water from the surface at any location. This is inadequate if data from neighbouring locations need to be correlated. It is advisable to determine the water table/level in terms of elevation from Mean Sea Level (MSL) as topographic variations at different locations will introduce errors if the water level/table is reported in terms of depth from ground surface.

The output of the water pressure sensors are also affected to some degree by the change in the temperature of the water surrounding the pressure sensor. This behaviour is called temperature drift. The effect is more pronounced in lower cost sensors than premium grade sensors which are quite expensive. However, for groundwater monitoring applications the temperature drift is not too relevant as for groundwater at a depth of more than 10 m the change in temperature is typically found to be less than 1°C over a whole year. Versions of pressure sensors are also available with temperature sensors built in so that the same sensor can measure both pressure and temperature. These are very useful in monitoring surface water in lakes, rivers and reservoirs.

The measuring range, accuracy class and temperature drift figures of the pressure sensor should be carefully specified as over specifying increases the total cost of the instrumentation many folds. Considering that more than a few hundred to a thousand boreholes or gauge wells may need to be monitored in each state/country, the cost escalation is very significant if the sensor performance is over specified. For groundwater monitoring where in all but a few locations the water temperature remains between 0 to 50°C, specifying pressure sensors with much extended operating temperature range only increases the cost of instrumentation without any corresponding increase in the quality or usability of logged data.

A variation of pressure sensor used for monitoring of water quality is available with an integral conductivity sensor. These types of sensors are known as conductivity, temperature, and depth (CTD) sensors. The conductivity measurement gives a measure of salinity of the water from which the density of the water can be calculated. The calculated value of density can then be used to correct the pressure sensor reading to give the actual height of the water head over the pressure sensor. This kind of sensor is useful in areas where the salinity of the groundwater varies with time, as the varying salinity would introduce error in water level (or depth) measurement due to the changing specific gravity of the water.

Compared to water level and conductivity measurement, water quality measurement sensors for unattended automatic measurement of parameters like Total Suspended Solids (TSS), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Organic Carbon (DOC), Disssolved Oxygen (DO), Nitrite, Nitrate, pH, turbidity, oil in water, arsenic and chromium etc. are expensive. They are available for online monitoring of surface water in rivers, lakes, reservoirs and effluent discharge from industry and sewer treatment plants. However, the pollution level of groundwater changes relatively very slowly, so a manual sampling and lab test method conducted once every few weeks may be sufficient to effectively monitor the water quality at a particular location. Online instrumentation for groundwater quality may be expensive without much attendant benefit if the parameter being monitored takes months to show significant change.

Another important parameter for water resources management is rainwater as it is the most common source of recharge for subsoil aquifers. Tipping bucket rain gauges provide an accurate measurement of the amount of rainfall at a particular location. Tipping bucket rain gauges can be integrated with dataloggers for automation. In practice, the datalogger detects the cumulative value of rainfall over each hour and also calculates the total rainfall over 24 hours. The daily rainfall reading is reset to zero at 2400 h each night. Other types of rain gauges are also available.

Rain gauges are installed in the open and subject to direct sunlight and weather. Rain gauges with plastic, resin or aluminium construction tend to crack or corrode within a few years, especially in hot, humid weather and strong sunlight conditions as in tropical countries like India. For remote locations, where frequent maintenance or replacement is expensive, heavy duty rain gauges with stainless steel housing should be specified as they can work for decades without degradation and turn out to be more economical in the long run.

Correlation of rainfall data with change in groundwater table gives a valuable qualitative insight about the magnitude of percolation of rainwater in the aquifer being monitored and any change in rate of percolation taking place over time. Correlation of rainfall data with upstream river water levels is regularly used for flood forecasting.

### *2.1.1 Limitations of existing water level monitoring systems*

In commercially available existing systems for online Web-based automatic monitoring of water resources, the output of the pressure sensor is proportional to the head of water above the pressure sensor. The output is also affected by any variation in atmospheric (also known as barometric) pressure. The daily variation in atmospheric pressure can typically be up to 40 mm water column (mm WC) and over a period of time can typically be around 150 mm WC. To get the correct water level/table, it is therefore necessary to nullify the effect of atmospheric pressure variation on the output of the pressure sensor.

The easiest way to do so is to use a gauge pressure sensor which has one side of its pressure measurement diaphragm open to atmosphere to differentially compensate for the change in atmospheric pressure. The pressure sensor is suspended from the datalogger using a special cable that has a built-in vent tube with internal diameter of around 2-3 mm. It allows the interior of the pressure sensor to be connected to the atmosphere at ground level thus eliminating any effect of atmospheric pressure variation on the water table reading. Most manufacturers the world over, use this approach.

In order to prevent the vent tube from getting clogged with condensing moisture, a desiccant chamber with desiccant is provided at the end open to the atmosphere. The desiccant changes colour when it gets saturated with moisture thus warning that it needs to be replaced. In areas with heavy rainfall, the desiccant needs to be changed regularly, sometimes even 2-4 times a year. Checking the colour of the desiccant regularly and changing it if required is a lot of effort specially in Countries where thousands of systems are installed.

A large number of installed systems fail because of delay in changing the desiccant in time. This results in clogging of the vent tube giving rise to error in the reading and sometimes in permanent damage to the pressure sensor. As a solution, a double vent tube is provided inside the cable by some manufacturers which in case of clogging could be flushed clean with dry air or nitrogen. This helps to detect and correct any blocking in the vent tube that gives rise to incorrect water level readings.

The problem of frequently changing desiccant cartridges, however, still remains.

### *2.1.2 Option of using individual barometric pressure sensor with each system*

The problem is overcome by using an absolute pressure sensor (refer to Figure 1) for monitoring the water level and a barometric pressure sensor to compensate for atmospheric pressure variations. The use of barometric pressure sensor eliminates the apparent variation in water level due to variation in atmospheric pressure.

Such a system therefore gives simultaneous measurement of water level, temperature and barometric pressure to the user. In case monitoring of rainfall is also added to the system, it adds to the usefulness of monitored data.

The use of an individual barometric pressure sensor eliminates the necessity of using a vent tube in the sensor cable for atmospheric pressure correction. The output is free from any error that may be generated due to clogging of the vent tube.

This automatic water level monitoring system is almost maintenance free as no desiccant is used which requires periodic replacement to avoid moisture ingress in the vent tube and consequent blockage of the vent tube.

**Figure 1 Absolute pressure sensor**

Use of a of stainless steel construction sealed electron beam welded pressure sensor with a vacuum of around 1/1,000 Torr inside it, instead of a gauge pressure sensor, increases the system reliability. The sensor body of stainless steel construction provides resistance against rusting or corrosion against several kinds of dissolved impurities found in water under field conditions. For saline water application, a sensor with additional protection is recommended.

## 2.2 Automatic datalogging system

For automatic logging of height of water column above the pressure sensor some kind of datalogger is required. In most cases, the datalogger sits at the top and the pressure sensor is suspended down inside the water through a non-stretch cable that carries both power for the sensor from the datalogger and signal from the sensor below to the datalogger above.

Figure 2 shows a typical datalogger suitable for use with borehole water level sensors. The narrow cylindrical housing allows the datalogger to be installed at ground level inside a borehole for protection from vandalism. The pressure sensor is connected to the datalogger with the help of a non-stretch cable. Often a telemetry module is also installed inside the datalogger cap.

**Figure 2 Datalogger with sensor**

The dataloggers used for monitoring water level/table are generally low power equipment that can either be operated from replaceable standard torch sized cells or from a battery backed power supply connected to a small solar panel. Some of the current products available in the market allow the datalogger to function unattended for up to ten years from a set of lithium primary cell battery making them suitable for deployment at remote sites where frequent battery replacement could be a logistic problem.

For monitoring at very remote or difficult to approach sites where users can afford to collect data at intervals of many months, the large internal memory of the dataloggers allows years of data to be stored inside the datalogger until it is collected.

For accessing the data stored in the dataloggers, users will have to go to each datalogger periodically and download the data from the dataloggers to a laptop computer or a smart mobile phone running an Android operating system.

If the laptop computer has an internet dongle, or in the case of mobile phone if a GSM/GPRS cellular network is available, the downloaded data can be sent to a central PC over the cellular phone network without having the user to physically visit the central office to submit the data.

Two options of automatic datalogger containing the barometric pressure sensor, batteries and GSM/GPRS modem for telemetry are illustrated in Figure 3:

- Cylindrical version — housing is mounted at the ground level inside a borehole casing.

- Box version — suitable for installation above ground level near the borehole or in a close-by room with provision of also connecting a tipping bucket rain gauge to it.

The datalogger can be programmed to take a measurement from every 5 secs to every 168 hrs in linear or event sampling mode. However, number of measurements taken per day should be kept to a minimum as higher frequency of measurement drains the power supply battery at a faster rate. In event-based recording, frequency of recording data can be increased in case set threshold value is exceeded.

Water level/table reading from a pressure sensor is dependent on specific gravity of water at that location. For example, if specific gravity is 1.08, the pressure sensor will give an 8 % higher output as compared to normal water which has a specific gravity 1.0. In coastal areas or in water with high dissolved solid content, the specific gravity of water will have a value higher than 1.0. The measured value of specific gravity must be entered in the datalogger so that it can provide the corrected value of water level/table.

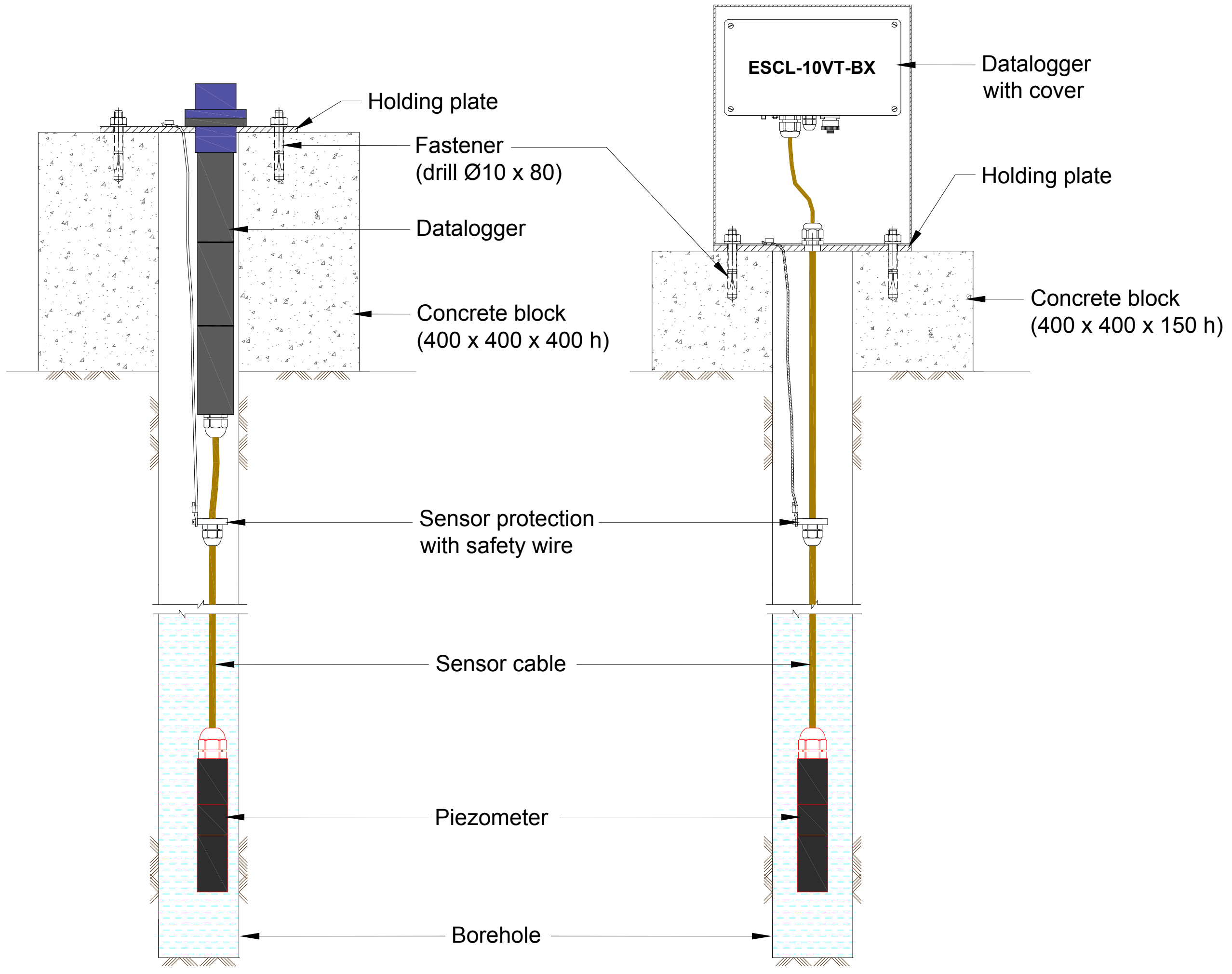


**Figure 3 Typical installation schematic for borehole type and box type dataloggers installation**

The datalogger measures the output from the absolute and barometric pressure sensors, as well as temperature in units of degrees Celsius and calculates the pressure in terms of water column after correcting for the measured barometric pressure and water density.

The data is stored, together with the current date, time and battery voltage, as a data record in internal non-volatile memory of the datalogger.

The datalogger in boxed version (refer to Figure 4) contains all the above features. Besides this, it also has a number of power supply options. It has provision to attach a rain gauge for simultaneous monitoring of rainfall. This helps in analysing the variation in water level with respect to the rainfall.

**Figure 4 Box type datalogger for automatic water level monitoring with provision to connect rain gage**

## 2.3 Automatic water quality monitoring system

Water is not only essential for all forms of life on our planet, but is also a vital resource for agriculture, manufacturing and many other activities. Despite its importance, water is the one of the most poorly managed resources in the world. Contamination of ground and surface water happens from several sources. In agricultural areas, fertilisers are the major source of contamination. In urban areas, the careless disposal of industrial effluents and other wastes leads to poor quality of water. Effluents affect our environment and health and demand constant monitoring and control. Thus, government bodies today are enforcing guidelines wherein polluting industries have to deploy Effluent Treatment Plants (ETP) to properly treat their effluents before they are discharged into rivers. Municipal bodies of the cities have to install Sewage Treatment Plants (STP) before discharging them in any water body.

Water quality monitoring is also an integral part of most water conservation program to monitor pollution due to human activities or overexploitation. Online monitoring of water quality allows the pollution level of water at remote locations to be monitored continuously in near real time from a central location and requires very little skilled or unskilled manpower.

Pollutants can be of many types, including heavy metals; pesticides; oils and greases; other inorganic or organic chemicals; biological agents; and thermal, such as discharge of hot water from power generating stations.

Many of the polluting agents of interest can now be measured with the help of low maintenance small size electronic sensors. Most of the currently available sensors are able to monitor only a few types of pollutants. A cluster of sensors that can measure a range of pollutants with a datalogger can be set up at each remote monitoring site and the data collected through a low power datalogger. The sensors and the datalogger can be powered from small solar panel-based battery backed power supply.

Blindly monitoring for all possible types of pollutants is not economically or technically feasible. A careful study of the present level of pollutants in the water at that site should be carried out first. An assessment of potential activity around that site should also be carried out to identify any potential pollutant that can rise to alarming level in future. Once the parameters are identified, a set of sensors suitable for measurement of the identified parameters can be installed together with a suitable datalogger and power supply at that site.

Many of the water quality parameters of interest can be measured using different techniques. However, the different methods often give from slightly different to significantly different results for the same sample. Also the sensor for a particular parameter may give an inaccurate value in the presence of some other particular parameter. The data from the installed sensors should be periodically correlated with measurement done on water samples, from the same site, in a lab.

Selection of water quality parameter sensors is a more involved exercise. Sometimes different types of sensors using different principles may be available for measuring the same parameter. The various trade offs and advantages/disadvantages of competing sensor types should be carefully evaluated before making a selection. The type of service is also important as there may be different sensor models for use in still and flowing water. Similarly, sensor model for drinking water would be different from sensor used for industrial effluent for the same parameter type. Finally, the sensor measurement range and operating temperature range should be chosen with care. Electronic sensors for online systems often have some means for cleaning the sensor inlet periodically.

Electronic water quality parameter measurement sensors require a datalogger for recording the sensor readings. The sensor output should be compatible with the input of the datalogger chosen for the whole sensor cluster.

Online monitoring increases the efficiency of the treatment process. A monitoring plan can reduce total monitoring costs, increase the quality and reliability of the collected data, reduce manpower requirement, automatically analyse the collected data and present it in a relevant tabular and graphical form and make it available to authorized agencies located anywhere in the world, at fixed intervals, 24 x 7. Simultaneously, the data is available over the internet with least possible time delay consistent with user requirement. The system can also alert authorised personnel through email, if the water quality readings exceed regulation. The real-time monitoring system keeps watch over the effluent

## 2.4 Telemetry through GSM/GPRS modem

The sheer number of locations that need to be monitored to effectively map and monitor water resources makes the job of reliably collecting the data from these locations and sending them to a central location a gigantic task in itself.

The ubiquitous cellular phone network can be leveraged to collect data in real time from dataloggers that are used to collect data from the water quantity/quality monitoring sensors and rain gauges.

Some dataloggers have an inbuilt GSM/GPRS cellular phone modem that allows the datalogger to send data over the cellular phone network to a remote PC at a central office located anywhere in the world. The dataloggers are programmed to wake up every day at a set time and send the data collected over the past one day to the remote PC. Though the dataloggers can be programmed to send data more frequently if required, the power consumption goes up and the batteries get exhausted much faster.

The user will need to get a data SIM card for each GSM/GPRS modem under a suitable data plan from the local mobile phone service provider depending on the volume of data transfer expected.

The system is supplied with Windows-based datalogger application software that allows the user to set the sensor calibration coefficients, recording intervals, datalogger or location code (identification tag numbers), sensor serial number, real-time clock time etc. of the datalogger.

The user can monitor readings and GPRS signal strength for diagnostic purpose, start or stop scan or manage data files, download data from the datalogger, perform data correction and save and export the data files. A screen shot is reproduced in Figure 5.

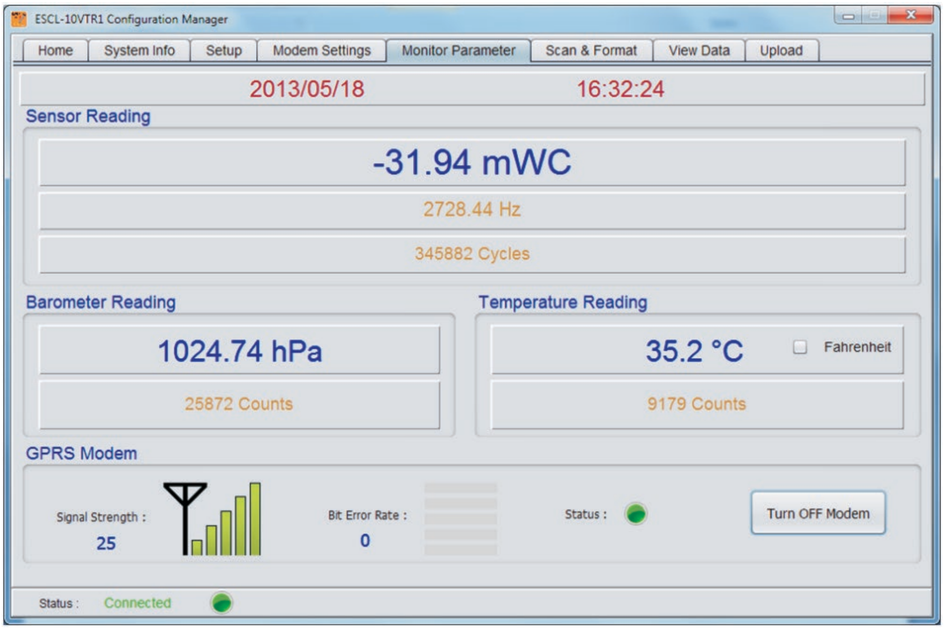


**Figure 5 Application display showing the sensor reading, temperature reading, barometric pressure and the network signal strength together**

## 3 Results from real-time online data monitoring

Figure 6 is a typical web map of India showing location of states where real-time monitoring of water level, temperature, barometric pressure and rainfall etc. is being done.


**Figure 6 Automatic water level monitoring systems in different states of India**

Using a suitable and commercially available software, the data collected by the remote PC can be automatically formatted as different types of graphs and tables and published over the internet. Any authorised user can log onto the web server remotely over the Internet to see the graphs and reports in real time.

The system presents the user with a log on screen where the user enters his login credentials like user name and password. Once the system verifies the user credentials, it allows the user to access data for which the user has permission.

After successful logon, a user is presented with a map or diagram of the area of their interest with locations marked as squares. The states on the map of India where monitoring is being done are also marked with squares. Clicking on any square opens up a view of the state with the location of instrumentation installed.

Figure 7 is a typical web map of the State of Punjab with locations of boreholes being monitored marked as small purple square dots. If the user hovers the pointer over these dots, a table pops up showing the value of the measured parameter and the last update time. Any alert condition is signalled with a change in colour of the square. If the user clicks the table a new view opens showing the change in parameter value with time in graphical form.

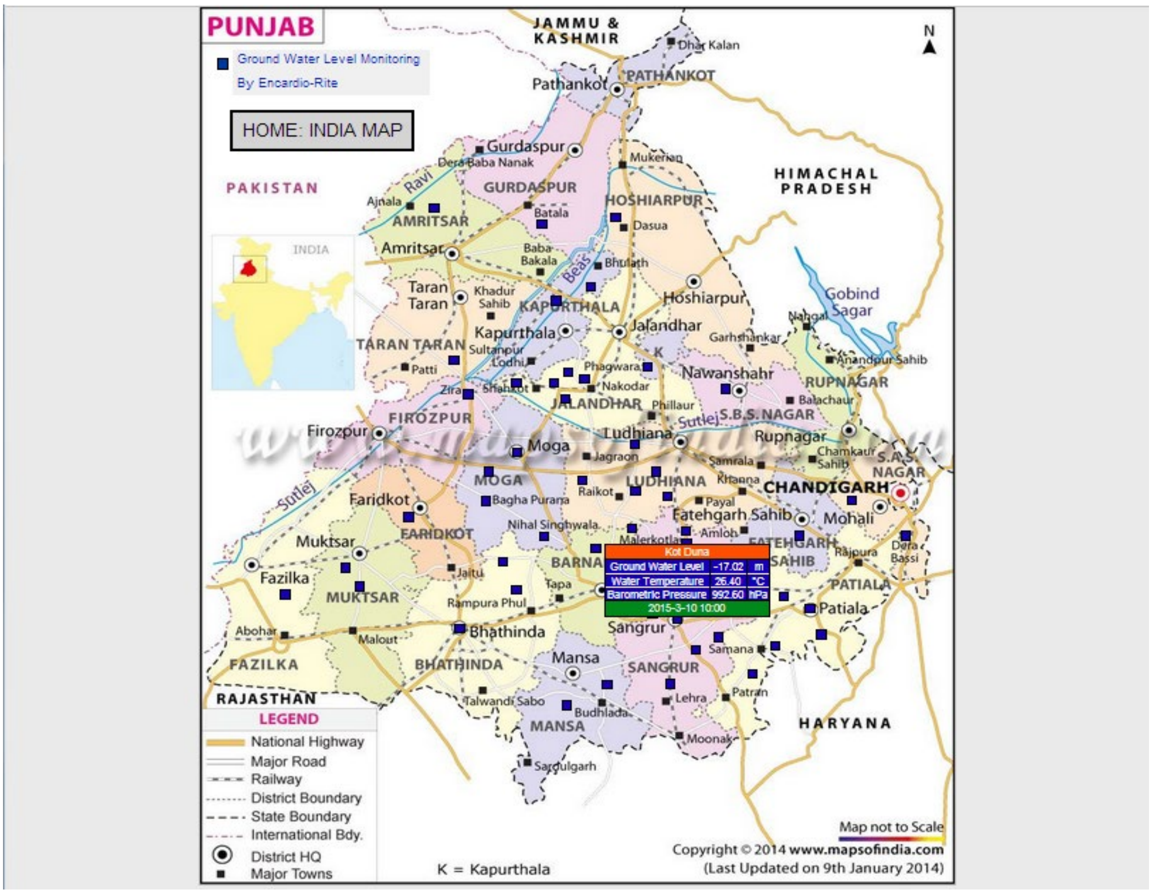


**Figure 7 Locations of automatic water level monitoring systems in Punjab**

The user has the choice to view the data in the form of graph or table. In graph view the user can select the time period for which the data is to be plotted and can scroll the time axis in any time increment, starting from one day to many months both in the forward and backward direction as long as data is available. The pages are preformatted and the graphs are generally composite graphs that show the relevant parameters together on a single graph. For example, a graph may show water level, temperature and conductivity on the same graph. If a rain gauge is also installed at that location it can also show the daily and cumulative rainfall recorded by the rain gage. Figure 8 is a graphical record of water level, temperature and barometric pressure. Graph is showing data for six days but the time axis can be any value from two days to one year.

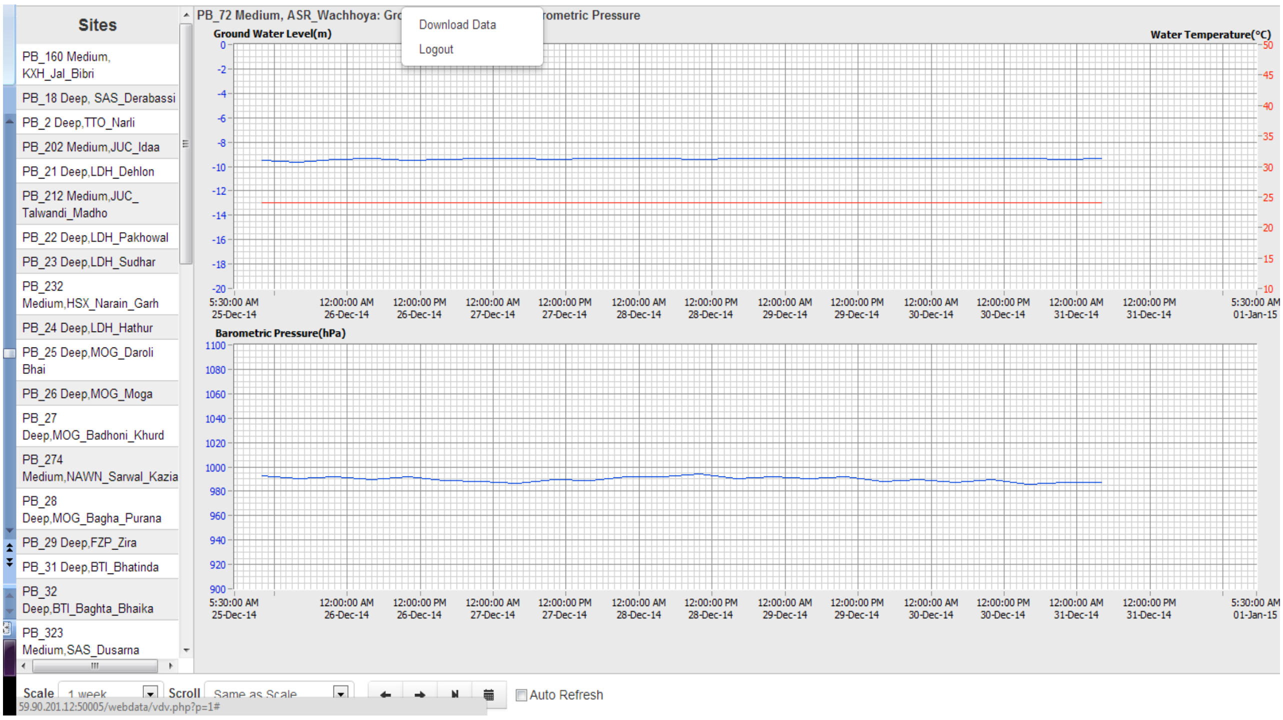

**Figure 8 Graphical presentation of data for water level, temperature and barometric pressure of systems installed at a location**

A typical screenshot correlating depth of water table with rain fall during a period of one year is reproduced in Figure 9. Please notice that the water level is constantly going down even during the rainy season. The depth of water table at this location is around 36 m.

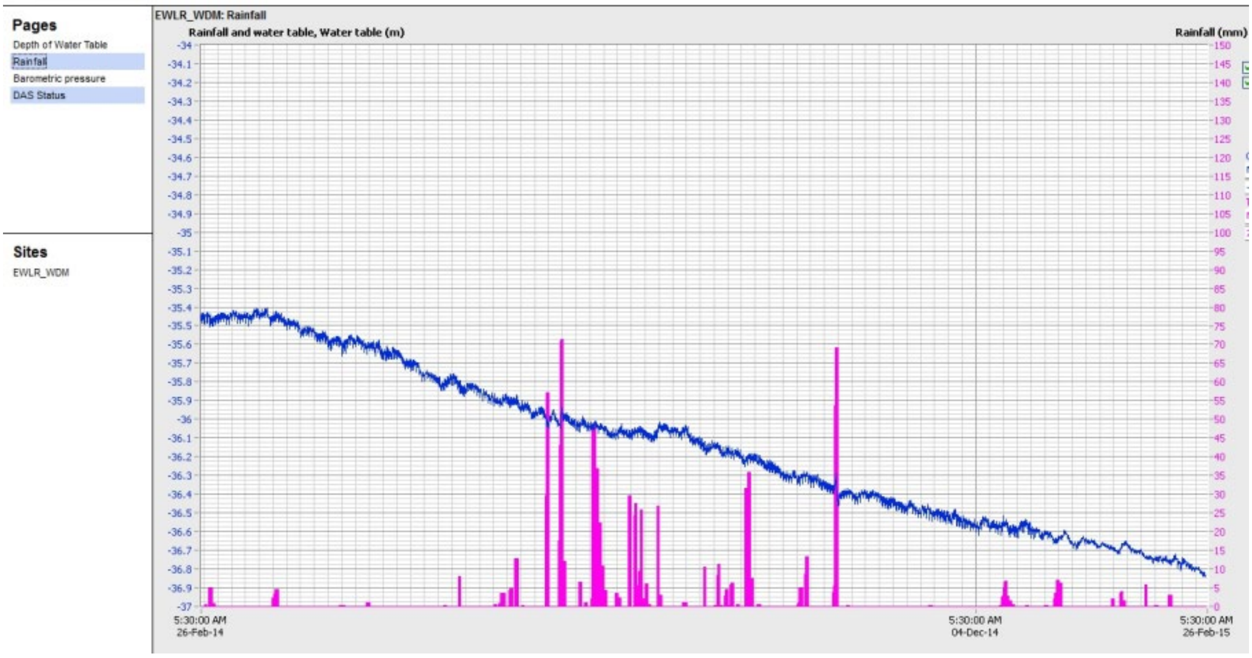

**Figure 9 Typical graphical presentation of data for water level with rainfall**

The time axis on the graph can be changed for any value from one day to one year.

The system also allows alarm limits to be set so that if any monitored parameter crosses the preset alarm limits an alarm is automatically triggered and SMS or email alerts are sent to preset mobile phone numbers or email ids.

Figures 10 is a typical plot of barometric pressure variation and water table on a screen during a period of one year.

Figure 11 is a screen shot of various water quality monitoring parameters.

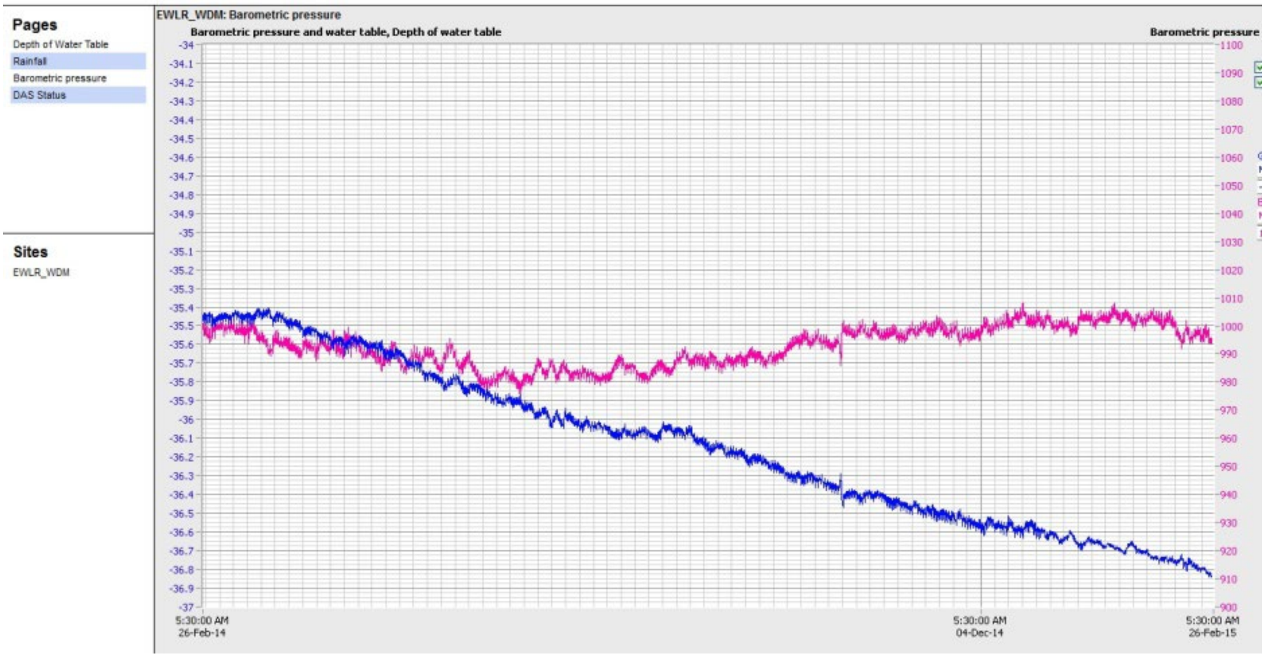


**Figure 10 Typical graphical presentation of data for water level with barometric pressure**

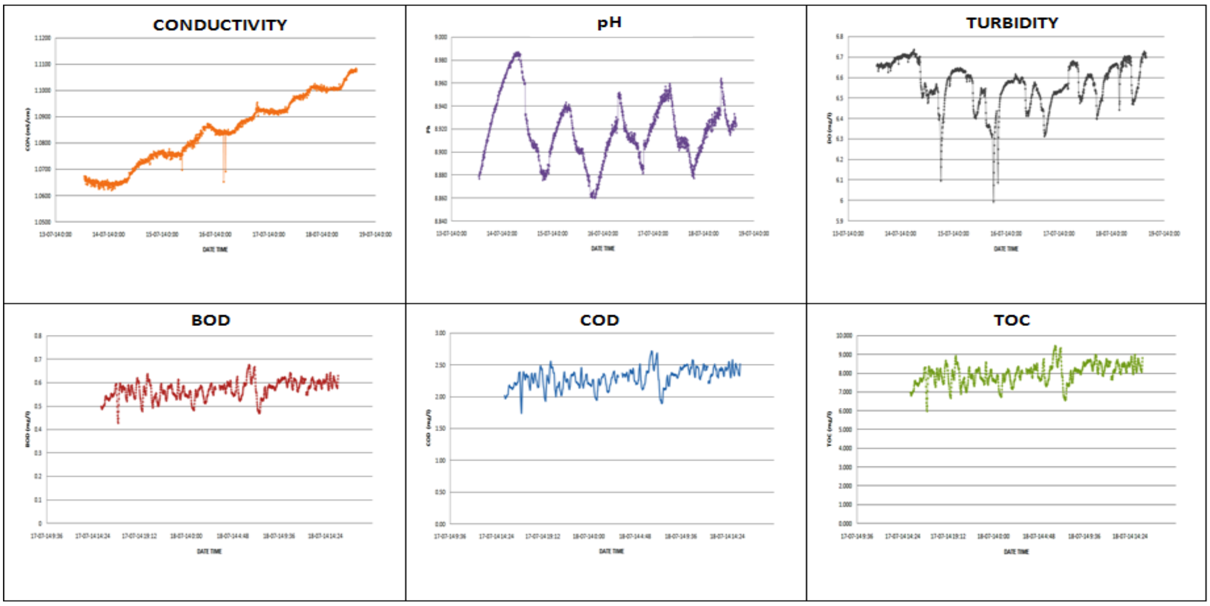


**Figure 11 Typical graphical presentation of data for various water quality monitoring parameters**

The user organisation has to maintain a server at the central monitoring office with a sufficiently broad band internet connection with static IP address. This server hosts the different software modules that are used to collect data from the field sensors at scheduled intervals, add them to the database on the server, prepare the graphs and tables in suitable pre designed formats and then publish them over the Web for access by authorised users. The software suite also checks the integrity of the collected data and manages the security of the data in the database to prevent unauthorised access or modification.

The real-time data is fed to the server at one location. If any organisation does not have the necessary IT manpower and/or resources for maintaining a data centre, they can avail the services of specialised service providers who maintain suitable high reliability data centres and application specific back end processing software. The server has all the software needed for its processing with modems and for sending SMS alarms if the parameter value exceeds a pre-set level. The data can be viewed by any number of authorised users over the internet using any standard browser without requiring any special software to be installed at each user's computer or mobile device. These servers are not ordinary computers but are sophisticated systems consisting of rugged servers, redundant power supplies, data backup and archival devices, security appliances and reliable broadband internet connection. Maintenance of these servers require a 24 hours stable uninterrupted power supply, air-conditioning, reliable internet connections and availability of maintenance personnel round the clock.

# 4 Conclusion

For online Web-based automatic monitoring of groundwater level using a pressure transducer, the output of the sensor is affected by variations in atmospheric pressure. To compensate for the change in atmospheric pressure, a gauge pressure sensor is generally used which has one side of its pressure measurement diaphragm open to the atmosphere through a vented tube cable. To prevent moisture for entering the vent tube and clogging it, a desiccant chamber is provided. This requires regular time consuming manual maintenance. System described in this paper uses an absolute pressure sensor with an individual barometric pressure with each installation to eliminate the apparent variation in water level due to variation in atmospheric pressure. For covering thousands of installation distributed over large areas in Countries, this solution has real advantages in maintenance of the systems.

The type, range, resolution, accuracy and operating temperature range specification of all sensors in a particular instrumentation project should be consistent with actual requirement.

For water quality monitoring, the parameters to be monitored online should be selected carefully. Monitoring insignificant parameters will only increase the cost of instrumentation.

The choice of sensors, dataloggers, power supplies, telemetry systems, back end servers (central computers), database servers, custom application software etc. requires a lot of knowledge and field experience.