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Seasonal Measurement of Kainji Dam Water Level Using Ultrasound Wireless Sensor and Microcontroller Based Monitoring System

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Abstract

Kainji dam is a dam across the Niger River in Niger state of northern Nigeria. It was one of the longest dams in the world. Kainji dam water storage, which depends on water level, is an easily available source of water for many sectors of economy such as agriculture, domestic and hydropower. Poor electricity generation in Nigeria is a very serious problem. Accurate monitoring of water levels in dams is very important in power planning. Effective power planning helps in ensuring steady supply of electric power to consumers' water levels determine the power outputs in dams. The variations in water level lead to variations in water flow across the water turbines which generate electricity and consequent variation in electric power outputs from the generators. Hence, frequent monitoring of water levels in dams is very important in generation planning. This paper presents the development process of Wireless sensor system for water level monitoring. It consists of HC-RO4 ultrasonic sensor, a data display device, AT89C52 microcontroller and GSM module for data transmission to the remote monitoring center to be access in any place of the country. The highest water level was recorded in wet season with the range of 120.40 to 133.50m compared with 71.20 to 69.20m recorded in dry seasons.

Keywords*; Microcontroller, water level, ultrasonic sensor, wireless sensor monitoring, dam*

INTRODUCTION

Annually sediments are being carried into the river, accumulation of these sediments causes reduction in carrying capacity of the river's channels. Accumulations of sediments in rivers always cause water to overflow their boundary which is called flooding. Due to the high rainfall, flood often occurs in some regions, especially in the area adjacent to the river banks that led to the idea to make the river water level detection system. Nigeria is a country that has a fairly high rainfall which potentially causes flooding. The flood hazard is still common in some areas, particularly areas in adjacent to the river banks. Floods cause a lot of harms, not only material damages but also facilities. The impact of flooding can be minimized if the society has adequate preparation

against the coming flood. One way is to deliver flooding information as soon as possible to the community as an early warning system. Flood continues to gain enormous research attention over the years, most especially in developing nations which Nigeria is not excluded. The essence of its attention in research is never unconnected to its causes, resultant effects of painful loss of properties and irreparable loss of lives, and its control measures. Flood is one of the major factors that prevent Africa's population from escaping poverty level (Action Aid, 2006); and the most hit by flood are usually urban poor (Adetunji and Oyeleye, 2013). A flood result when a stream runs out of its confines and submerges surrounding areas (Stephen, 2011). Similarly, (Adetunji and Oyeleye (2018) defines flood as an overflow of an expanse of water that submerges land. (European Union 2007) sees flood as a temporal covering of land by water, not covered by water before incidence. (Nelson 2001) defines flood as a natural consequences of stream flow in a continually changing environment. Water level monitoring is commonly used in some of the applications like flood monitoring, river level monitoring, wetland studies, tidal studies, ground water monitoring, surface water monitoring. The flood resulted in the destruction of crops and livestock affecting main sources of livelihood, contaminated water sources and damaged houses in vast geographical areas .As of 26 September 2023, the Nigerian Red cross(NRCS) has been supporting an initial 7.549 vulnerable people in the worst affected states focusing on providing community-based health; water, hygiene sanitation ; and basic food and non-food items through a DREF operation founded by the international federation of Red Cross Crescent (IFRC). Unprecedented rainfall continued into September, resulting in Nigerian's two major rivers -Niger Rivers and Benue River overflowing into surrounding communities. On 17th September 2018 the government declared a state of emergency in the four states: Kogi, Niger, Anambra and Delta. According to the National emergency Management Agency (NEMA) issued on October 10, the floods have affected an estimated number 1,921,026 people, displacing 210,206 people and injuring at least 1,036 people. On 11 October, a state of emergency was declared in 5 more states (Adamawa, Bayelsa, Kebbi, Rivers, Taraba) by NEMA. Additional assessments are planned for those states by IFRC and NRCS. To prevent loss of lives and properties to flooding, adequate and efficient monitoring of water level in rivers and dams in order to get information about the deepness or shallowness of the river or dam, then follow by dredging. A dam is an artificial barrier usually constructed across a stream or river channel to capture waters. Dams must have spillway system to convey normal streams and flood flow over, around, or through the dam. Spillway is commonly constructed of non-erosive materials such as Concrete. Dams should also have a drain or other water withdrawal facility for controlling the water level and to lower or drain the lake for normal maintenance and emergency purposes. Dams are constructed especially for water supply, flood control, irrigation, energy production, recreation and fishing

The multi-purpose nature of the Kainji Dam, with its projected benefits of hydro-power, flood control, regulated water for navigation and the growth of the fisheries industries, as made the program the most wide-ranging waters resources scheme to-date in Nigeria. Poor electric power generation and supply as remained a very serious problem in Nigeria ever since the 80s. The problem has hampered power generation in Nigeria has been a top priority of successive Nigerian government since 1999. Apart from insufficient number of power generation plants, existing ones

are facing declining output (Nwobi-okoye and Igboanugo, 2013). Water levels lead to variations in water flow across the water turbines which generate electricity and consequent variations in electric power outputs from the generators (Nwobi-okoye and Igboanugo, 2013). Hence, accurate monitoring of water levels in Dams is very important in electricity generation planning. Proper and effective power planning helps in ensuring steady supply of electrical power to consumers. Improved electric power supply to consumers will lead to increase in gross domestic product of the country and better standard of living for the populace. Water level variations are a time series. National Institute of Standard and technology (NIST 2010) defined time series as an ordered sequence of values of a variable at equally spaced time intervals. To monitor the level of water is often a key requisite in dam , river , coastal , fisheries , irrigations and canal control , oceanography and so on (Nwobi-okoye and Igboanugo ,2013). Moreover, to detect the water level of water reservoir through wire communication is not a flexible and tedious ways. For this purpose a robust, real time, portable and easy to operating system is needed for monitoring the level of water. There are much of the technologies used today to execute the basic tasks as water level measurement, water quality characterization and so on. For monitoring the level of water, the system is a kind of structure which measures water deepness through ultrasonic sensor technology. Modern microcontroller and wireless sensor can provide a range of solutions for the automated monitoring of water levels in many applications. In most of the cases, costly radio moderns are employed for fastest access for remote data, because it provides a long distance and reliable link between the sensors networks (Khaled Reza et al., 2010). Simultaneously the processed digitized data is transmitted via a wireless network (while using a wireless system) to a remote location or device. In another sense, the transmission step is made over a wireless network control channel using GSM, CDMA, 3G, WIFI, RF OR Zigbee digital technology. Also, a Wireless Data Acquisitiom System (WiDAS) which is a romote sensing device designed to obtain multi-angle infrared remote sensing data in remote distance. Till now several attempts have been made to provide an effective monitoring system to observe the level of water. A number of papers reported with different technologies to develop this kind of monitoring system.

WATER LEVEL

Depth or water level of various dams has been determined by several worker sand they varied from one reservoir to another. The depth of the water body determines whether the dam is shallow or deep and can be measured in meters (m) or centimeters (cm). The mean depth obtained from various dams are sometimes used in determining the morpho-edaphic index of the dam which is a biological index used in determining the productivity of the dams. Ibrahim et al., (2009) working on physic-chemical parameters of Kontangora reservoir reported that the reservoir has the depth of 7.74m in rainy season and mean depth of 6.94m in dry season. Mustapha (2009) reported a mean depth of 2.6m for Oyun reservoir while Edward (2012) reported a mean depth of 5.23m Egbe dam.

WATER LEVEL SENSOR

Level sensors are used to detect the level of substances that can flow. Such substances include liquids, slurries, granular material and powders. Level measurements experiments can be done inside containers or it can be the level of a river or lake. Such measurements can be used to determine the amount of materials within a closed container of the flow of water in open channels. HC-SR04 is most commonly used sensor for determining distance of an object. Transmitter, receiver and control circuit are three parts of HC-SR04. It has four pins vcc, ground, trigger and echo which connect it to arduino. Holding this sensor high above the water container will give us the depth of the water from surface. Maximum threshold distance in the code for this project is 200m. Figure 1 shows HC-SR04 sensor.

Figure 1: Ultrasonic sensor (courtesy of flipkart.com).

It can be easily interface with arduino board or other microcontroller. It used Io trigger for at least 10 us high level signal. This module automatically sends high frequency (840 kHz) sound waves and detect whether there is a pulse signal back. If the signal back, through high level, time of high output IO duration is the time from sending ultrasonic to returning. Water depth sensor (Ultrasonic sensor) detects the level or depth of the water. This sensor emits high frequency acoustic waves which will reflect back and receive back by the emitting sensor as shown in figure 2.

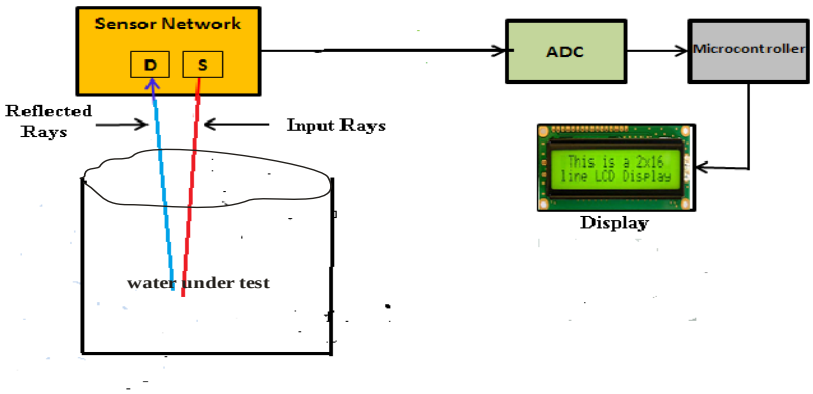


Figure 2: Operation of water depth sensor

Distance = velocity of sound (340m/s) x high level time × / 2.

$$d = \frac{vt}{2}$$

SYSTEM DESIGN AND DEVELOPMENT

Figure 3 shows the general block diagram of water level monitoring system. The developed water level monitoring system consisted of five units: data monitoring nodes, data base station, remote monitoring center, power supply unit and display unit. The power supply unit consist the solar cell and lithium cell. The ultrasonic sensor was used to measure and monitor the water level. The sensor generates high frequency sound waves and evaluates the echoes from the water level of the dam.

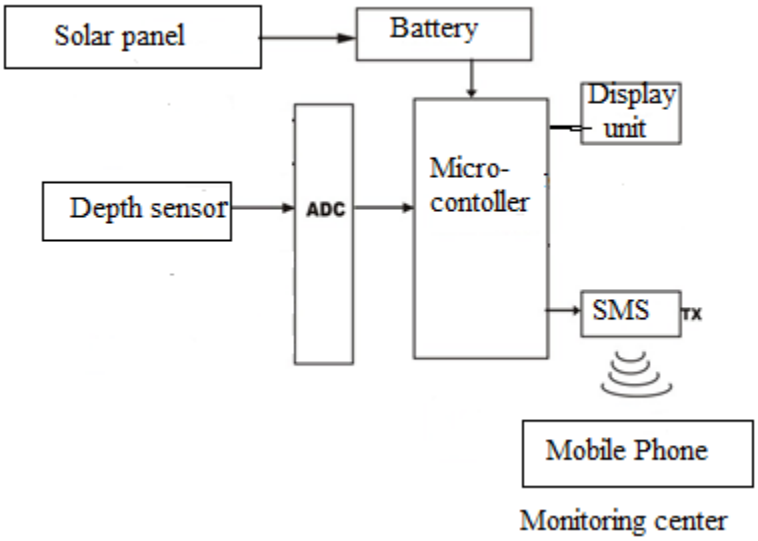


Figure 3: Block diagram of the system

A microcontroller chip was used for processing the data collected, SMS module were also used for data transmission to the remote monitoring center; the data can also displayed on the liquid crystal display (LCD) unit. The water level of the dam was successfully measured and sent through GSM module for auto-monitoring.

STUDY AREA

River Niger is a principal river in Western Africa with the length of 2,600 miles (4,200 km), it is the third longest river in Africa, after the Nile and the Congo.

The River rises from Guinea (9°05′ N, 10°47′ W) on the eastern side of the Fouta Djallon highlands, 150 miles (240 km) inland from the Atlantic Ocean. It flows due north over the first 100 miles (160 km). It then follows a northeastern direction, during the course of which it

receives its upper tributaries and enters Mali. From Mali, the river takes a more east-northeastern direction, and its bed becomes fairly free from impediments for about 1,000 miles (1,600 km) and flows about 1,100 miles (1,770 km) in all to enter Niger. From Niger it flows flowing east-southeast and enter Nigeria through Kebbi state. In Nigeria, the river was blocked in New Bussa which results into kainji dam. Kainji Dam is a dam across the Niger River in Niger State of Northern Nigeria. It was one of the longest dams in the world. The dam was 136 km (84 mi) long, about 30 km (19 mi) wide; it was the first dam to be built in Nigeria.

Construction of the dam was carried out by Impregilo (a consortium of Italian Civil Engineering Contractors) to designs by Joint Consultants, Balfour Beatty and Nedeco. The construction began in 1964 and completed in 1968. The total cost was estimated at US$209 million (equivalent to about US$1.3 billion dollars in 2018), one-quarter of this amount used to resettle people displaced by the construction of the dam and its reservoir (Oluborode et al., 2023). Figure 4 bellow shows the diagram of kainji lake.

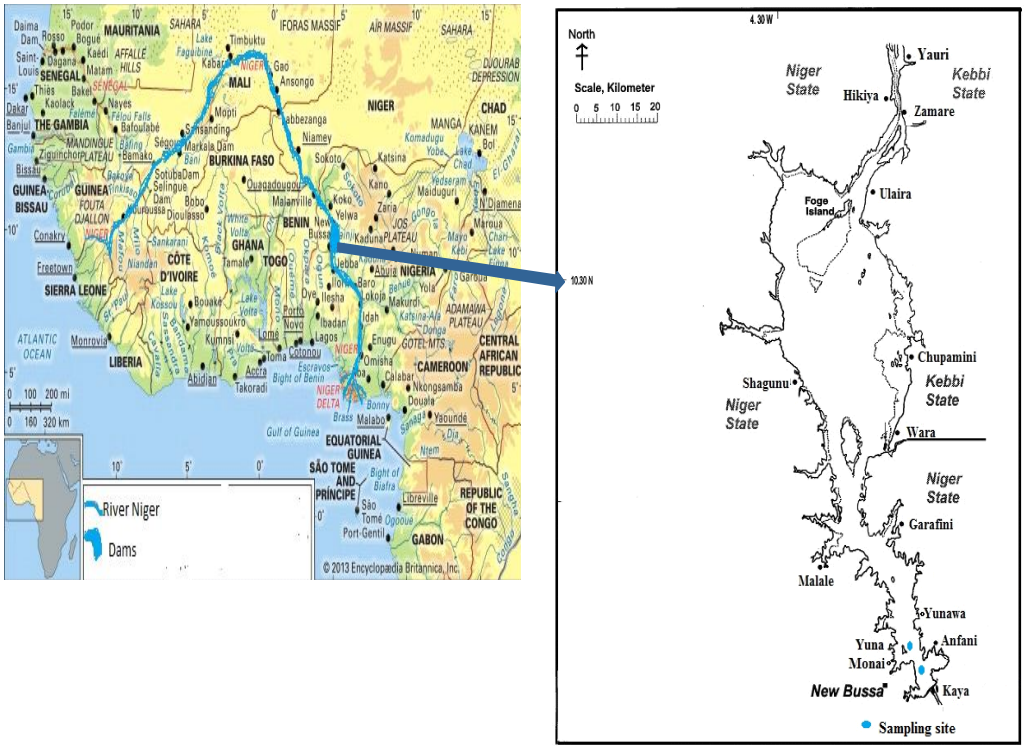


Figure 4: The study area

In compliance with the international law on dams across International River, Kainji dam has two navigational locks (upper and lower locks). These locks are opened for the passage of barges or boats from upstream and downstream of the dam (Nwobi-okoye and Igboanugo, 2013). The dam constructions cause the formation of the lake known as Kainji Lake. The lake acts as a reservoir for the dam (Nwobi-okoye and Igboanugo, 2013). The lake has two flooding season namely the white and the black flood. The white flood is the inflow of flood into the dam, from rain within

the catchment areas of the river within Nigeria (Nwobi-okoye and Igboanugo, 2013). On the other hand, the black flood is the inflow flood into the reservoir from rains in the catchment areas of the river outside Nigeria eg Guinea, Mali, Niger etc. the white flood arrives the lake around the month of July since its journey is not far. The black flood arrives in December as it has to travel long distance from those country mentions above.

FIELD TRIALS

Field trials were conducted in April 2023 on kainji dam in Niger State. Some of these trials were conducted between 11:00 am and 11:40 am. First of all, the system was switched on before deployed it into the water. During the period of each experiment, water level data were collected with a constant time interval.

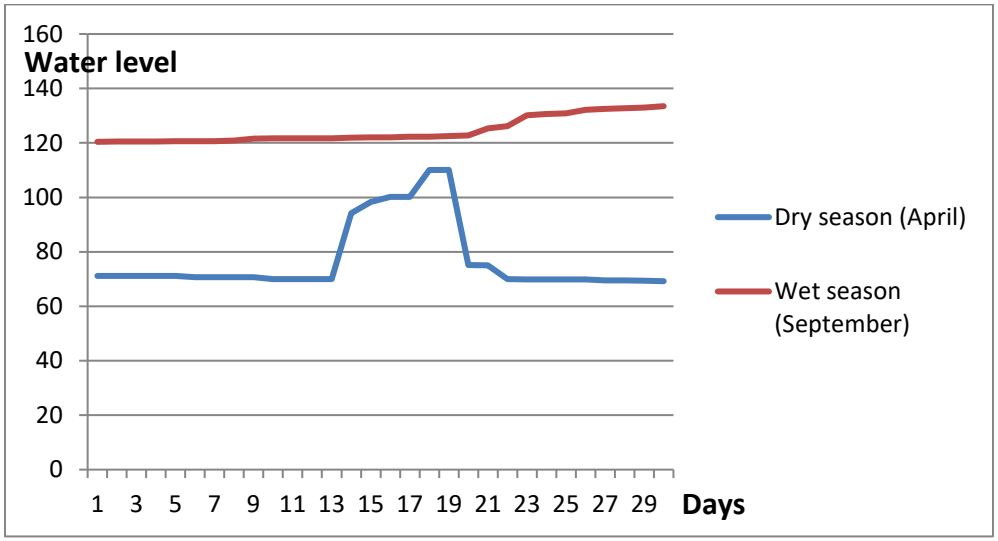
Figures 5 show the photos of the field trials at Kainji Dam. A long-hour field experiment was also conducted from 11 am to 5 pm from 1st April to 30th April 2023 in order to investigate and monitoring the diurnal changes of the water level. The experiment was repeated from 1st of September to 30th September, 2023 during the raining season.

EXPERIMENTAL RESULTS

The seasonal variations in water level of study area (Kainji dam) were presented in Table 1 and corresponding plots have been demonstrated in figure 6. There was gradual decrease in water level values from1st April (Day 1) to 30th April (Day 30) during the dry season while there was an increase from 1st September (Day 1) to 30th September (Day 30) during the wet season. The sharp increase of water level values from April 14th (Day 14) to April 19th (Day 19) during the dry season may be as a result of the closure of spillway to allow more water to flow across the turbine for effective electricity generations.

Table 1: Table of daily water level of Kainji dam during the dry and the wet season in 2023

Days	Water Level (m)	
	Dry season (April)	Wet season (September)
1	71.20	120.40
2	71.20	120.50
3	71.20	120.55
4	71.20	120.55
5	71.20	120.58
6	70.70	120.61
7	70.70	120.63
8	70.70	120.90
9	70.70	121.60
10	70.00	121.69
11	70.00	121.70
12	70.00	121.70
13	70.00	121.70
14	94.20	121.90
15	98.30	122.01
16	100.20	122.10
17	100.20	122.30
18	110.00	122.32
19	110.10	122.50
20	75.10	122.70
21	75.00	125.30
22	70.00	126.20
23	69.80	130.20
24	69.80	130.60
25	69.80	130.90
26	69.80	132.20
27	69.50	132.50
28	69.50	132.80
29	69.40	133.00
30	69.20	133.50



The highest water level was recorded in wet season with the range of 120. 40 to 133.50m compared with 71.20 to 69.20m recorded in dry season.

CONCLUSION

In this study, the development and demonstration of a low cost, continuous water level monitoring equipment prototype were developed. The equipment used low cost sensor and hardware aiming at providing continuous water level measurements at substantially reduced cost. The equipment was used to monitor seasonal variability of kainji dam water level. The equipment can measure water level up to 150m or more. Study carried out on water level of kaiji dam shows that the values obtained during the wet season were higher but lower during the dry season. The highest water level was recorded in wet season with the range of 120. 40 to 133.50m compared with 71.20 to 69.20m recorded in dry season. The developed system has been practically verified as a strong and reliable instrument for monitoring water level in a wide range of applications.

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