

Flow velocity-based hydrokinetic resource assessment of Nigeria's major rivers for sustainable flywheel turbine deployment

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ABSTRACT: This study investigates the optimisation of river flow velocities for hydropower generation using a flywheel water turbine system, presenting a cost-effective and sustainable alternative to conventional dam-based energy infrastructure in Nigeria. The country suffers a persistent energy deficit aggravated by incomplete, silted and politicised dam projects, which have significantly impacted negatively on industrial productivity, compounded by high fuel and transportation costs. In response, this research explores a method of using hydrokinetic energy potential at three key locations: Lokoja (Upper Niger River), Makurdi (Lower Benue River), and Onitsha (Lower Niger River). The river velocities recorded from February to October 2023 ranged between 6.2–10.8 m/s, 5.6–10.4 m/s, and 5.3–9.6 m/s, respectively. Given these high flow velocities, the deployment of flywheel-based turbines emerges as a viable solution for decentralized hydropower generation. The system is designed using high-strength steel flywheels operating efficiently at 90%, and capable of functioning under hydraulic heads from of 4 meters. Utilizing a reaction-type (Kaplan) turbine with adjustable pitch blades whose configuration allows for adaptability to varying flow and head conditions. The turbine unit, mounted on a floating platform that maintains stability with water level fluctuations, includes a three-phase horizontal hydro generator. In some cases, partial submersion of the flywheel is employed to mitigate instability during high-flow events then positioned in deep gorges and connected to generator houses. These systems provide electricity ranging from 276 – 840 MW and support auxiliary functions like water supply and irrigation. When this work is carried out in some other rivers, it will offer a strategic resolution to Nigeria's persistent energy crisis.

Keywords: Energy, flywheel, river Niger, river Benue, velocity.

INTRODUCTION

In addressing Nigeria's persistent energy challenges, researchers continue to seek viable alternative renewable energy sources to replace expensive fossil fuels, reduce power outages, and mitigate environmental harm. According to reports from the Nigerian Electricity Regulatory Commission (NERC) between 2021 and 2023, the country's electricity generation capacity connected to the national grid stands at approximately 11,165.4 MW, which falls significantly short of the estimated 40,000 MW required to meet the basic needs of its growing population (Shao *et al.*, 2025). Nigeria is endowed with abundant water resources that remain largely untapped for power

generation. Although numerous dam projects Kainji, Jebba, Mambilla, Shiroro, among others, have been initiated to harness hydropower, many have proven costly, incomplete, or non-functional, often becoming under-utilised structures without fulfilling their intended roles in power generation, water storage, or multipurpose uses (Oladeji *et al.*, 2019).

Nigerian rivers and streams exhibit continuous flow with increased discharge and velocity during the rainy season, suggesting substantial potential for hydrokinetic power generation. Given the high costs and challenges associated with large dam projects, there is a growing

interest in developing more affordable and adaptable hydro-powered turbines that exploit river locations with optimal flow velocities for energy production (Ngancha *et al.*, 2024). The use of a flywheel water turbine requires lower cost, technology and low impact in the area where it is used. It only requires an adequate flow velocity and sufficient discharge, with its friendly impact on the ecosystem. The increasing demand for renewable energy, driven by population growth and the diminishing availability of fossil fuels, has led researchers to explore various alternative energy sources. Addressing socio-economic and environmental challenges, Ibrahim and Canan (2005) emphasised the effectiveness of solar photovoltaic technology as a cost-efficient and durable substitute for fossil fuels. Moreover, Kevin and Ahmed (2019) highlighted biomass conversion to bioenergy as a promising solution to energy shortages. Yildirim *et al.* (2021) investigated the use of cotton and sunflower straw as biomass feedstock for biofuel production, implementing pretreatment techniques to enhance sugar yield from the biomass. Additionally, Ozturk *et al.* (2017) discussed the prevalent use of biomass derived from agricultural and animal waste for heating and cooking in Turkey, which focuses on solar and biomass technology.

Schmitt *et al.* (2019) optimised a hydropower dam framework for the Mekong River Basin by balancing energy generation with sediment flow, concluding that a multi-scale approach can reduce ecological impacts on river systems. Eme *et al.* (2019) demonstrated that wind turbines offer both environmental and economic advantages as a viable alternative energy source by developing a 2 MW permanent magnet generating system with modified field and voltage orientation control schemes. Similarly, Chetan (2013) designed multiple renewable energy systems aimed at mitigating the global energy crisis. Eme and Tachere (2023) developed renewable energy solutions, including hydropower, wind turbines, biogas, and solar technologies, to improve energy reliability in four communities within Ogor Kingdom. Eme *et al.* (2019) further highlighted the advantages of harnessing streams and marine currents through hydrokinetic energy systems designed primarily for remote rivers in developing regions, such as the Benue and Lower Niger Rivers in Nigeria. Their hydrokinetic turbine design, where power output is directly proportional to flow velocity, was shown to reduce installation costs significantly from \$7,900 per kW to approximately \$2,500 per kW while offering environmental benefits including reduced noise pollution and zero greenhouse gas emissions. These prior studies focused on different sources of energy, including hydropower systems, but this study laid emphasis on non-dam kinetic solutions using flywheel turbine technology.

MATERIALS AND METHODS

The flow velocity of the rivers at the three study sites was

determined using the floating method, employing an object sufficiently heavy to remain partially submerged. The surface velocity at mid-stream was measured by timing (t) the duration it took for the floating object to travel a fixed distance (d) of 50 meters. The velocity (V) was then calculated using the formula: $V = d / t$, where V represents the surface velocity in meters per second (m/s), d is the distance in meters (m), and t is the time in seconds (s). Depth measurements were also taken at each location, and corresponding velocities were computed. Subsequently, the power output of flywheel turbines at each site was designed and evaluated, alongside other relevant parameters.

RESULTS AND DISCUSSION

The results of the three locations considered—Lokoja along Lower Niger (the confluence town where River Niger and River Benue meet), Onitsha in Anambra State along the Lower Niger, and Makurdi in Benue State along the River Benue—are presented in Table 1, as well as in Figures 1 to 3. Nigeria is characterized with two major rivers that is river Niger and river Benue. It is obvious from the velocities obtained as shown in Table 1, which ranges from 6.2 – 10.8 m/s at Lokoja, 5.6 – 10.4 m/s at Makurdi and 5.3 – 9.3 m/s at Onitsha, are above the average velocity of 2.5 m/s – 3.5 m/s, which can turn the turbine of the flywheel. The maximum velocity was recorded at Lokoja in the month of September, being 10.2 m/s, and the least in the month of February, being 6.2 m/s.

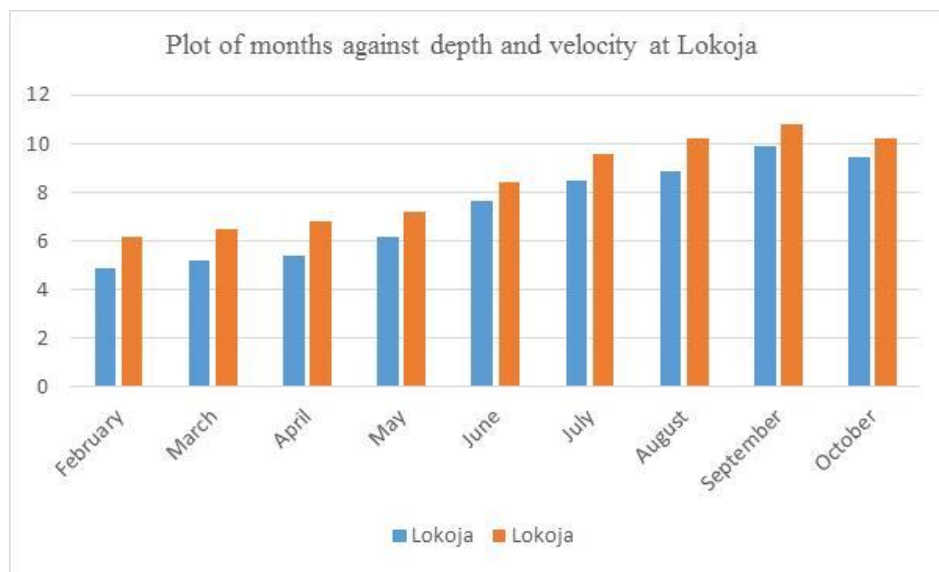
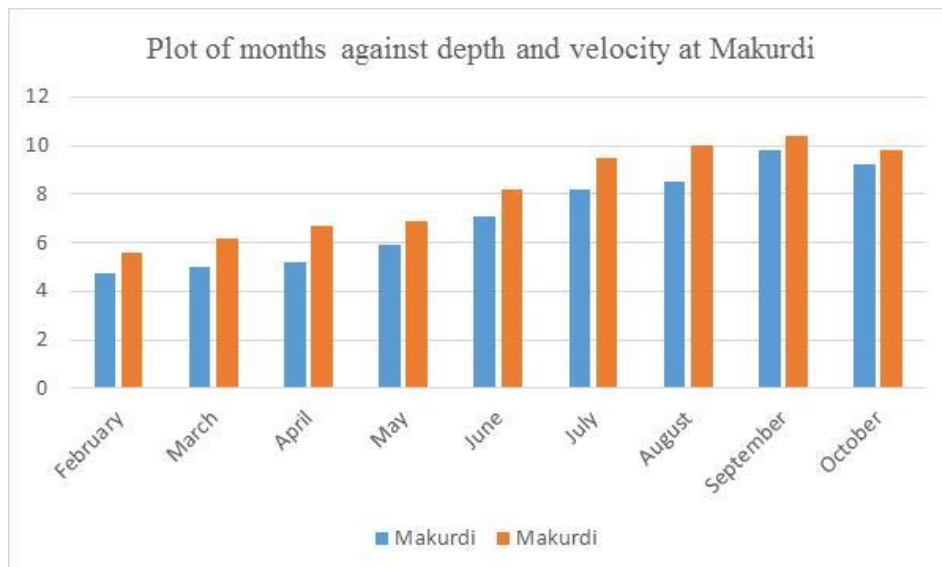
Figure 1 shows a model of the various months and the respective depths and velocities at the Lokoja River. It shows that velocity increases with the depth of the river at any location. The maximum velocity of 10.8m/s took place in the month of September during the peak of the rainy season. Similarly, Figure 2 shows a model of the various months and the respective depths/velocities at the Makurdi River. It shows that the velocity increases with the depth of the river at any location. The maximum velocity of 10.4m/s took place in the month of September during the peak of the rainy season. The chart in Figure 3 shows a model of the various months and the respective depths and velocities at the Onitsha River. It shows that the velocity increases with the depth of the river at any location. The maximum velocity of 9.92 m/s took place in the month of September during the peak of the rainy season. These findings are similar to those observations documented by Legleiter and Kinzel (2021), when river depths are significantly inferred with their flow velocities.

A comparative analysis of the data

This study presents a comparative analysis of the average river depth and velocity measurements at Lokoja, Makurdi, and Onitsha across the months of 2023.

Table 1. Average depth and velocity of the river at the three locations in 2023.

Months	Lokoja	Makurdi	Onitsha	Lokoja	Makurdi	Onitsha
	Average depth (m)			Velocity (m/s)		
February	4.90	4.72	4.6	6.2	5.6	5.3
March	5.18	5.03	4.8	6.5	6.2	5.7
April	5.4	5.2	4.9	6.8	6.7	6.5
May	6.2	5.9	5.64	7.2	6.9	6.74
June	7.68	7.1	6.9	8.4	8.2	8.05
July	8.5	8.2	7.8	9.6	9.5	8.74
August	8.9	8.5	8.1	10.2	10	9.2
September	9.92	9.81	8.84	10.8	10.4	9.6
October	9.43	9.2	8.62	10.2	9.8	9.3

**Figure 1.** Chart of monthly depth and velocity at Lokoja.**Figure 2.** Chart of monthly depth and velocity at Makurdi.

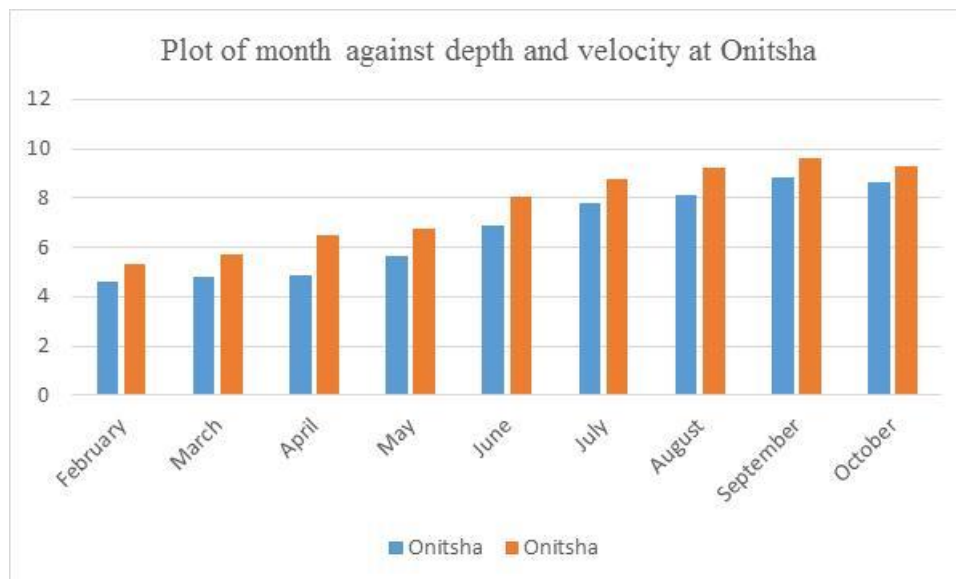


Figure 3. Chart of monthly depth and velocity at Onitsha.

Depth comparison

Lokoja exhibited the greatest water depths throughout the year, ranging from 4.90 m in February to a peak of 9.92 m in September. Positioned upstream, Lokoja benefits from concentrated river flows with minimal sediment accumulation, resulting in deeper channels. Makurdi, downstream of Lokoja, recorded slightly reduced depths varying from 4.72 to 9.81 m over the same period. Onitsha consistently registered the shallowest depths, ranging from 4.6 m in February to 8.84 m in September. This downstream decline in depth is attributed to the river's expansion across broader floodplains, which disperses flow and decreases channel depth.

Velocity comparison

Velocity patterns mirrored depth trends, with Lokoja showing the highest velocities, ranging between 6.2 m/s in February and 10.8 m/s in September. The elevated velocities at Lokoja reflect a steeper river gradient and narrower channel sections upstream. Makurdi exhibited intermediate velocity values from 5.6 m/s to 10.4 m/s, while Onitsha consistently showed the lowest velocities between 5.3 m/s and 9.6 m/s. The gradual reduction in velocity downstream corresponds with increased channel width and energy dissipation.

Seasonal variations

Dry season (February–May)

The lowest depths and velocities were recorded in February at all locations (Lokoja: 4.90 m and 6.2 m/s;

Makurdi: 4.72 m and 5.6 m/s; Onitsha: 4.6 m and 5.3 m/s). A steady increase in both parameters through May reflects the onset of seasonal rainfall.

Rainy season (June–September)

Depth and velocity peaked in September, with Lokoja reaching 9.92 m depth and 10.8 m/s velocity; Makurdi with 9.81 m depth and 10.4 m/s velocity; and Onitsha with 8.84 m depth and 9.6 m/s velocity. The rainy season thus drives significant hydrological fluctuations due to increased precipitation and surface runoff. By October, both parameters began to decline but remained elevated compared to dry season levels.

Design of power for the flywheel of each river

Seasonal variations in river depth influence system performance, with reduced flow rates and velocities during the dry season, and increased discharge, depth, and flow velocity during the rainy season (Istomi *et al.*, 2025). The flywheel operates on the principle of a reaction-type Kaplan turbine, specifically adapted for low-head conditions. It features adjustable pitch blades capable of functioning efficiently across a broad range of hydraulic heads, from as low as 2 meters to as high as 40 meters. Water flow is regulated using a large control valve. The system incorporates a hanging-type flywheel supported by bearings, a horizontal hydro-generator, and a three-phase power output configuration.

The power available to each river is given by the expression shown in Equation 1.

$$P = \eta \times \rho \times g \times Q \times H \quad 1$$

Where P = Power (Watts), η = turbine efficiency (90% = 0.9), ρ = density of water in kg/m³ (1000kg/m³), g = acceleration due to gravity (9.81m/s²), Q = flow rate in m³/s, and H = head in meter (m).

For Lokoja: Q = Average discharge is 7922m³/s, P = $\eta \times \rho \times g \times Q \times H$, P = 0.9 X 1000 X 9.81 X 7922 X 10, P = 839,320,056 Watt, and P = 839.32MW

For Onitsha: Q = Average Discharge is 6470.8m³/s, P = $\eta \times \rho \times g \times Q \times H$, P = 0.9 X 1000 X 9.81 X 6470.8 X 9, P = 514,176,238.8 Watt, P = 514.2MW

For Makurdi: Q = Average Discharge is 3477m³/s, P = $\eta \times \rho \times g \times Q \times H$, P = 0.9 X 1000 X 9.81 X 3477 X 9, P = 276,285,897 Watt, P = 276.3MW

It is evident that the flow rate is so high that such potential of the three rivers in Lokoja, Onitsha and Makurdi is sufficient to supply power to generate electricity to its users, since the rivers do not run dry throughout the seasons of the year. This aligned with the findings of Uzoukwu *et al.* (2025), during their streamflow modelling of River Niger.

Design of a flywheel energy storage system

The flywheel energy uses the kinetic energy principle (energy stored in moving bodies), based on the expressions shown in Equations 2 to 5.

$$E = \left(\frac{1}{2}\right) \times I \times \omega^2 \quad 2$$

Where E = Energy storage capacity of a flywheel (Joules), I = Moment of inertia, ω = angular velocity, M = mass of flywheel, R = radius of flywheel.

Mass of flywheel = 1200kg, Efficiency = 90%, Diameter of flywheel = 2.8m, R = radius = Diameter / 2 (D/2), RPM of flywheel = 3000rpm (low)

$$I = 0.5 M \times r^2 \quad 3$$

$I = \frac{1}{2} \times 1200 \times (1.4)^2 = 1176\text{kgm}^2$, $\omega = (2\pi \times \text{rpm}) / 60$ (conversion of rpm to rad/s), $\omega = (2\pi \times 3000) / 60 = 628.32$ rad/s, $E = \left(\frac{1}{2}\right) \times 1176\text{kgm}^2 \times (628.32 \text{ rad/s})^2$, E = 232,134,181.2 J

Time (t) required to discharge the energy stored in the flywheel.

$$t = E/P$$

$$t = 232,134,181.2 / 20,000,000 = 11.61 \text{ seconds.}$$

To discharge energy stored in the flywheel, 11.61 seconds will be spent if there is a sudden power surge.

$$T = I \times \alpha \quad 4$$

Where T = the torque output in the shaft (Nm), I = the moment of inertia, and α = the angular acceleration (assumption: flywheel reaches its maximum rpm in 8seconds).

$$\alpha = \frac{\omega}{t} \quad 5$$

Angular velocity (ω) = 628.32 rad/s / 8s = 78.54 rad/s²

Torque output in the shaft (T) = 1176 x 78.54

$$T = 92,363.04 \text{ Nm}$$

Pulley size

Let the pulley at the shaft be of a 20HP DC motor be 0.6 m in diameter (DM) that of the flywheel shaft 1.70 m in diameter be DF.

Speed ratio = DM/DF = 0.6m/1.7m = 0.429 speed at flywheel if the 20HP DC motor has a speed of 6000 RPM (High speed). Therefore, the speed of the shaft that carries the flywheel = 0.429 x 6000 rpm = 2574 rpm. Use 3000rpm. This system offers an effective approach to kinetic energy storage with high energy output potential.

Mounting of the flywheel

Submerged frame or platform

A submerged frame (like a cage) may be used to support the turbine while still allowing the river flow to move through it. For the flywheel, a floating platform or a cable-supported system should be used, keeping it at the optimal height above the riverbed or Platform for Flywheel: If the flywheel is heavy, it should be placed on a floating platform that can rise and fall with water levels but remains stable. The flywheel may also be partially submerged to prevent instability during high-water events. Strategically positioned in deep gorge locations, the flywheel system is connected to a generator housed nearby, supplying electricity for various applications, including domestic power, water supply, and agricultural irrigation. This approach offers a sustainable and scalable solution to addressing Nigeria's multifaceted energy challenges (Teodoro, 2024).

Power generation analysis

Lokoja: Discharge (Q) = 7922 m³/s; Head (H) = 10 m; Power (P) = 839.32 MW; Time constant (t) = 0.28 s

Onitsha: $Q = 6470.8 \text{ m}^3/\text{s}$; $H = 9 \text{ m}$; $P = 514.2 \text{ MW}$; $t = 0.45 \text{ s}$

Makurdi: $Q = 3477 \text{ m}^3/\text{s}$; $H = 9 \text{ m}$; $P = 276.3 \text{ MW}$; $t = 0.84 \text{ s}$

Lokoja's higher discharge and head yield the greatest power generation potential, followed by Onitsha and Makurdi. These results indicate significant capacity for large-scale electricity production through the proposed flywheel system (Xu *et al.*, 2023).

Solution to Nigeria's power shortage

As previously reported in NERC's quarterly publication, addressing Nigeria's persistent power deficit requires innovative solutions such as the deployment of flywheel water turbines (Ayamolowo *et al.*, 2019; NERC, 2023). To meet the national electricity demand target of 40,000 MW necessary to support the growing population, a strategic implementation plan involves the installation of 25 flywheel units at each of the selected locations at Lokoja, Onitsha, and Makurdi, situated along the Niger and Benue Rivers. The projected power outputs from these installations are as follows:

Lokoja: 25 units \times 839 MW = 20,975 MW

Onitsha: 25 units \times 514 MW = 12,850 MW

Makurdi: 25 units \times 276 MW = 6,900 MW

Total: 40,725 MW

This configuration slightly exceeds the targeted 40,000 MW, ensuring adequate capacity for generation, transmission, and distribution by Nigerian electricity distribution companies (DISCOs). Integrating flywheel technology at these key riverine locations, alongside existing hydropower infrastructure such as the Jebba, Kainji, and Shiroro dams, is expected to significantly bolster the country's power supply and energy reliability (Agwu *et al.*, 2023). Given the significant hydrokinetic potential of water resources in Lokoja, Onitsha, and Makurdi within the Nigerian catchment area, the integration of flywheel-based renewable energy systems presents a promising solution to the persistent power shortages in these regions. The proposed design utilises a low-type flywheel constructed from high-strength steel, operating with an efficiency exceeding 90% and rotational speeds ranging from 3,000 to 10,000 rpm. The system is optimised for a hydraulic head of approximately 9 meters.

Conclusion

This research was embarked upon to create a stable and reliable energy source for Nigeria's communities. A flywheel water turbine system was designed to operate in Nigeria's major rivers, and this will act as a sustainable

alternative to the conventional dam-based energy infrastructure in Nigeria. Basically, the system will incorporate a hanging-type flywheel supported by bearings, a horizontal hydro-generator, as well as a three-phase power output configuration, to achieve the goal of this study. The theoretical evaluation of the results revealed that the system can produce electrical power that ranged from 276 – 840 megawatts, and can also support public water supply and irrigation purposes. Remarkably, these research findings have illustrated that the application of indigenous technology and materials can be used to provide reliable electric power, which is a major challenge facing Nigeria's domestic and industrial sectors.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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