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Research Paper

Determining The Hydro-Power Potential of the Surface Drainage System in Federal Polytechnic, Bauchi, Nigeria: Towards Improving Sustainable Energy Supply

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ABSTRACT: *Energy poverty is a major cause of failure and inefficiency in many businesses and households in Nigeria. This cause high rate of unemployment and underdevelopment accompanied by diseases due to pollutants resulting from unsustainable energy systems. This problem has lingered for too long in spite of the abundant energy resources available for power generation. This article presents the result of a study conducted to determine the hydro-power potential of the surface drainage system of the federal polytechnic, Bauchi. The aim is to show that the energy in the flowing water in those drainages can be harnessed to produce energy for the system to reduce the impact of high energy cost and use of fossil fuels. Plausible sites were identified by visual inspection, then a full topographic survey was conducted to determine the actual location of the identified sites and head of water obtainable. Flow and geometric characteristics of the drainages were determined such as flow speed, discharge, geometric radii. The power generation potential was afterwards determined using appropriate relations. The results showed that site C had the highest head of 8 m with an average power generation potential of 19.67 kW; Site B had the least average power generation potential of 6.33 kW. Cascading the three sites to work simultaneously will result in an average annual power output of* $21,852.96\,kWh$ *resulting in a financial savings of*₦841,994.55*, from just 5 daily hours and 106 days of operation per annum. It is recommended that the energy in the surface drainages be harnessed to reap the potential to complement other sources and increase sustainable operation of the institution.*

Key words: *hydro-power, Sustainability, Energy, Surface drainage.*

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I. INTRODUCTION

One of the major causes of underdevelopment and high rate of unemployment in Nigeria is acute energy poverty [1; 2], resulting from poor access to efficient/sustainable energy systems manifesting as poor performance of the electricity grid system, underutilization of the abundant renewable energy resources, high cost, and poor billing systems [3; 4; 5]. This situation cause many businesses and households to depend on fossil fuels and other inefficient systems in total neglect of the environmental and public health consequences, resulting in low quality and expensive products [6; 7].

The United Nations has set goals 7 (Affordable and clean energy) and 13 (Climate action) to encourage sustainable energy supply and consumption. Consequently, Nigeria has developed its Sustainable Energy for All Action Agenda (SE4All-AA) and reviewed its national energy policy and national energy master plan with the aim of increasing sustainable energy supply and consumption through increased renewable energy deployment, increased adoption of sustainable energy practices in industry, development and implementation of energy sustainability codes and standards and many more [8; 9; 10].These goals can be achieved through the utilization of resources available in Nigeria, especially the unconventional ones.

The Federal Polytechnic, Bauchi is locateat Gwallameji village (10.257°N 9.768°E), along Dass road, Bauchi, Nigeria. It occupies a total area of 750 hectares [11]. It hastwo sources of Power: the national grid and a Stand-by,Mikano diesel generator. The deteriorated grid system hardly supplies the institution up to 10 hours of electricity per day. The generator is therefore necessary to keep the institution functional. However, high fuel cost sometimes hamper the operation of the generator. Individual departments and units have therefore resorted to the use of small gasoline generators or installation of small capacity solar power systems, toalleviate the sufferings. While the solar systems however mostly cover only administrative buildings, the generators, in addition to the low coverage, increase the carbon footprint of the polytechnic. The financial burden of maintenance also makes these systems difficult to run. Students therefore find it difficult to conduct practical sessions and study in the night on campus during an outage, thereby negating the primary purpose of the institution.

The polytechnic has a network of surface drainages whose main purpose is to discharge the run-off water away from the institution during the rains with no further economic gains.Some of the drainages flow throughout the rainy season, while others flow for three to six hours during the rains, depending on the intensity and duration of the rain. In spite of the intermittent nature and seasonality of the water supply, these drainages can be harnessed to provide power through the use of micro and Pico hydro power systems, to alleviate the energy poverty in the system. Such systems can also be made to complement the photovoltaic systems in the departments or a central system in the institution. Research towards identifyingand establishing the power potential of plausible sites is therefore necessary. This study therefore seeks to determine the hydropower potential of the drainage system of the Federal polytechnic, Bauchi, with the aim of providing a basis to propose the development of a sustainable power system for the institution. Specific objectives of the study include:

a. To identify plausible sites for hydro-power generation;
b. To characterize the identified sites;
c. To determine the hydro-power potential of each of the sites.

Over the years, hydroelectric power plants have been reputed as being robust and very durable. It is a sustainable energy source, causing little environmental pollution compared to other conventional sources. The emissions intensity of any energy source is the amount of GHG emitted per unit of energy produced (mostly expressed in gCO_2-eq/kWh). A study covering 480 global hydropower reservoirs presented the median value of lifecycle greenhouse gas emission for hydropower as 23 gCO_2-eq/kWh, aligning with the Intergovernmental Panel on Climate Change (IPCC) estimate of 24 gCO_2-eq/kWh. This value compares favorably with other energy sources, with only nuclear and wind power having a lower average lifecycle GHG emission intensities, both about 12 gCO_2-eq/kWh. Solar energy has 48 gCO_2-eq/kWh, while gas and coal have 490 and 820 gCO_2-eq/kWh respectively[12].In 2017, the adoption of hydroelectric power over coal led to significant environmental benefits worldwide, where about 4 billion tons of greenhouse gases and other harmful pollutants were avoided; apart from 148 million tons of dangerous particulate matter, 62 million tons ofsulfur dioxide and 8 million tons of nitrogen oxide [13; 14].

Large hydropower plants had hitherto been used to generate power in many countries of the world, including the US, China, Canada, Brazil, and Nigeria [15]. The trend is however changing recently with preference shifting to small and micro hydropower plants, owing to sustainabilityissuessuch as flooding, displacement of large populations, and disruption of eco-systems associated with large dams[16].Furthermore, small-scale hydropower plants are most suitable for addressing energy crisis in developing nations due to ease of construction, reliability, low cost, etc[17].

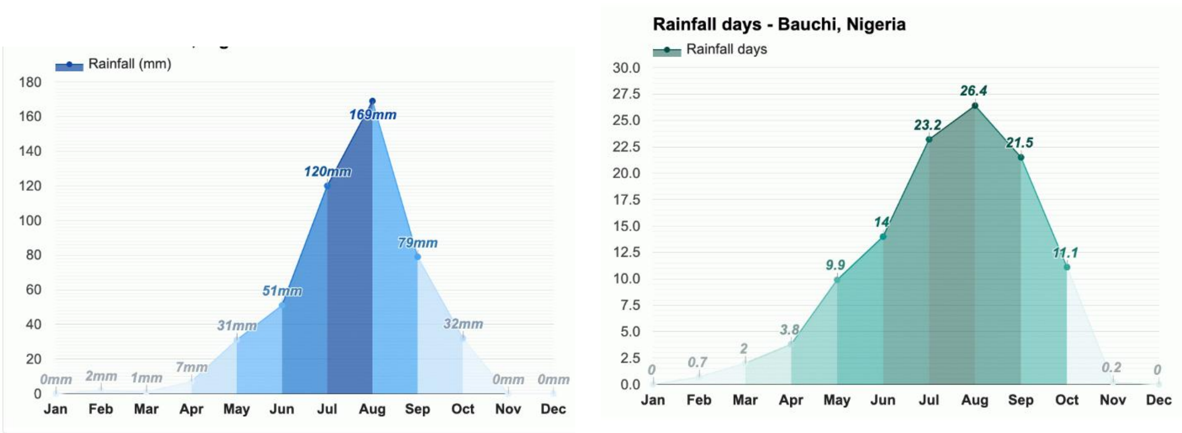
Many countries have therefore embraced the small, micro and Pico hydropower plant options. China has a total generation of 19000 MW of electricity from 43000 small hydropower plants [16]. In Switzerland, nineteen economically viable sites have been identified to produce 9.3 GWh/year of cumulative hydro-electric power in waste water treatment plants to ‘cope with electricity expenditures in waste water systems’. Spain also has an established 16778 waste water systems with over 80 % of them having an average hydropower potential of 15 kW, resulting in about 11000 tons of CO_2 emissions saving potential. A pico-hydropower plant of 3 kW capacity have been constructed using a concrete culvert and a wooden dam and weir to power Ebuaro II village, Ovia North-east LGA, Edo state, Nigeria[18]. Some other existing small-Scale hydropower plants in Nigeria are presented in table 1.

The average rainfall intensity and rainfall days for the years 2022 – 2024 are presented in figure 1 (a) and (b). It shows a total rainfall intensity of 482 mm, in a total of 106 rainfall days between May and October which is the rainfall period of the state. This shows that a hydro-power plant dependent on surface drainage systems without a reservoir can operate for about a 106 days in a year. This is almost one-third of the year, substantially reasonable for economic gains from a low-cost, environmentally sustainable power system.

TABLE 1: Existing Small-scale Hydro Schemes in Nigeria

SN	River/Dam	State	Installed Capacity	SN	River/Dam	State	Installed Capacity
1	Bagel I	Plateau	1.0 MW	1	Tiga	Kano	6.0 MW
2	Bagel II	Plateau	2.0 MW	2	Oyam	Ogun	9.0 MW
3	Kura	Plateau	8.0 MW	3	Waya	Bauchi	150.0 kW
4	Lere I	Plateau	4.0 MW	4	Ezeoha-Mboro	Enugu	30.0 kW
5	Lere II	Plateau	4.0 MW				
6	Bakalori	Sokoto	3.0 MW	5	Tunga	Taraba	400.0 kW

Sources: [19; 20]



(a) Rainfall intensity/month – Bauchi (b) Average number of rainfall days/month

Figure 1: Average Rainfall Pattern of Bauchi, Nigeria

Source: [21]

II. MATERIALS AND METHODS

2.1 Site Identification and Characterization

The entire surface drainage systems of the polytechnic were visually inspected and plausible locations for hydro-power plantwere identified by mere observations. A topographic survey was conducted using Differential GPS to identify the specific locations of the sites and determine their slope. Further observations and appropriate measurements were made through the rainy season to determine the drainage characteristics and obtain flow parameters, and to determine the extent to which the site characteristics meet the hydropower site selection criteria outlined by [22; 23], which include access to water, height of drop/head, catchment, proximity to low voltage utility lines, ecological impact and property status.

2.2 Flow Characteristics

The flow characteristics for each of the proposed power plant locations and drainage channels connected to it were studied throughout the rainy season (May – October) of 2023 as recommended by [16]. The depth, width, average flow speed, discharge and hours of flow of the drainage channels at each location were determined for each rainy day. Depth and width of the channels were determined using measuring tape. The depth of the water in the drainage was measured severally during peak and least flow using steel rule and the average taken.Float method was used to measure the speed of flow; A plastic coke bottle with some stones in it was allowed to flow with the water in the drainage over a distance of 10 m, and the time taken to cover the distance was taken with a stop watch. The water slope was determined by using leveling rods.The flow rate (discharge) of the stream was determined using manning’s formula:

$Q = VA$ (m^3/s)(1)

Where: A = Cross sectional area of the wetted drainage channel, m^2; V= Flow speed, m/s.

The useable discharge (Q_u) was taken to be 50 % of Q to allow for flow imperfections [24]. Therefore, equation 2 was used.

$$Qu = 0.5Q \quad (2)$$

2.3 Power Generation Potential

The power available in the flowing water was determined using the relation

$P = \frac{\rho g Q H \eta}{1000}$ (kW) (3)

Where: ρ = Density of water, kg/m^3; Q = Flow rate or discharge, m^3/s; H = available head, m;
η = Overall efficiency of the proposed power plant, assumed to be 80 % for small run-off schemes [25].
The total energy to be produced in a year was determined using the relation

$P_t = P \times N \times h$ (kW) (4)

Where: P_t = Total power generated; h = hours of flow; N = number of rain days.

III. RESULTS AND DISCUSSION

3.1Site Identification and Characterization

3.1.1 Site location

All the drainage channels considered are located in the federal polytechnic, Bauchi. The specific points considered (Plausible sites) for hydro-power generation are indicated on the composite map (Figure 2a) as 'proposed hydro-power station A' (Near Entrepreneurship development center), 'proposed hydro-power station B' (Near ML Audu Auditorium) and 'proposed hydro-power station C' (Off Polytechnic Consultancy Services Limited, towards the Polytechnic main gate, by the right). The coordinates for each of the sites are shown in Figure 2 (b). Figure 3(a) and (b) show the contour and 3D analysis respectively. The purpose of the 3D analysis is to visualize the slope. The Figure shows that the highest point (the first intake of the channels) is at 662 m, while the lowest point (proposed site 3) is at 654 m above sea level. This slope is expectedly good enough to allow free flow of water.

The following observations were also made regarding the hydro-power site location criteria as outlined by [22]:

✓**Access to *water***. The drainages have access to water via the landscaped/green land spaces between buildings and roof run-offs through minor drainages around buildings.

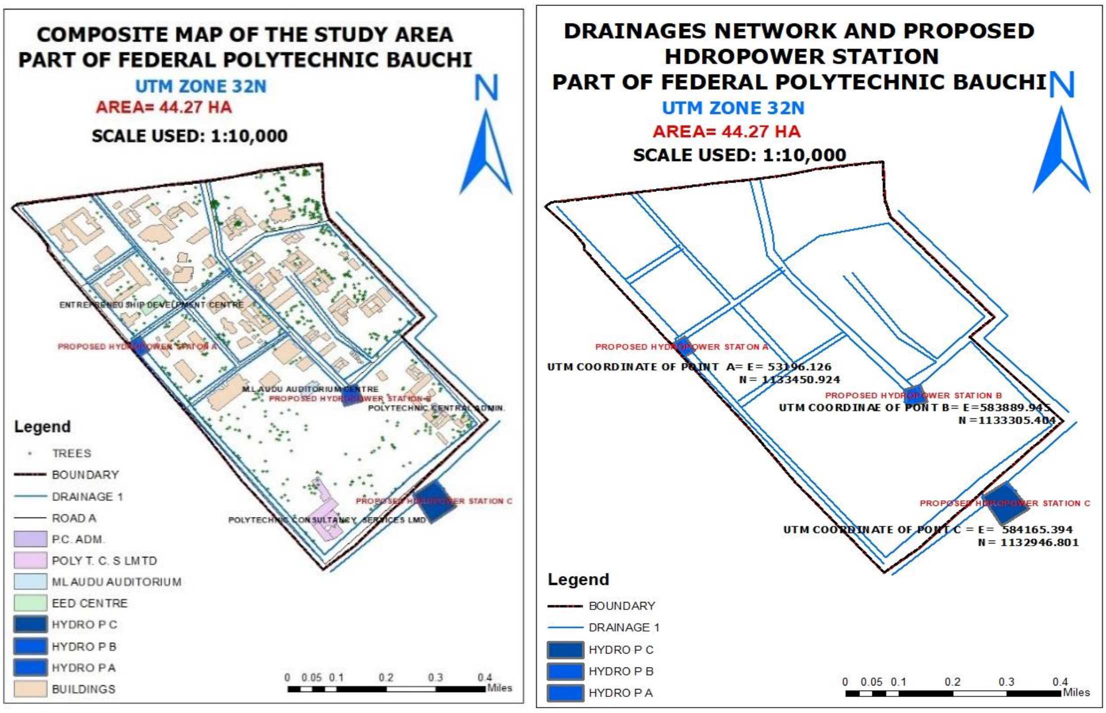
✓***Height of drop***. The drainages A, B and C have a head of 3 m, 4 m, and 8 m respectively based on survey result as presented in figure 3.

✓***Catchment area***. The catchment area of the proposed project is 44.27 hectares of land, mostly developed with several buildings for institution's activities. All run – off water from the buildings flow to the drainages to be discharged from the area.

✓***Proximity to low voltage utility lines***. The area is already electrified, so low voltage utility lines are available to connect to.

✓***Ecological impact***. Drainages are already in existence at the site, and only minor construction may be required to accommodate the hydropower equipment. No negative ecological impact is envisaged.

✓***Property status***. The land already belongs to the polytechnic, who is the potential beneficiary of the power plant that may result.

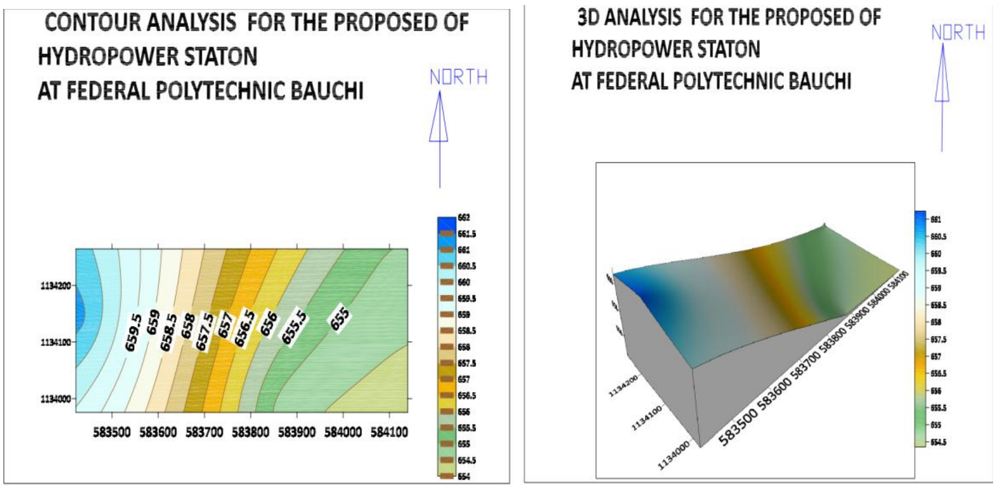


(a) Composite map (b) Drainage network

Figure 2: Composite map and drainage network of study area

3.1.2 Flow Characteristics

The results of the survey shows that the flow through the catchment area is mostly towards the south-east direction (Figure 4). This is important in providing a guide for any construction work towards the execution of the proposed power plants to avoid wrongful diversions that may result in flooding and other related problems.



(a) Contour analysis (b) 3D analysis

Figure 3: Contour and 3D analysis of study area

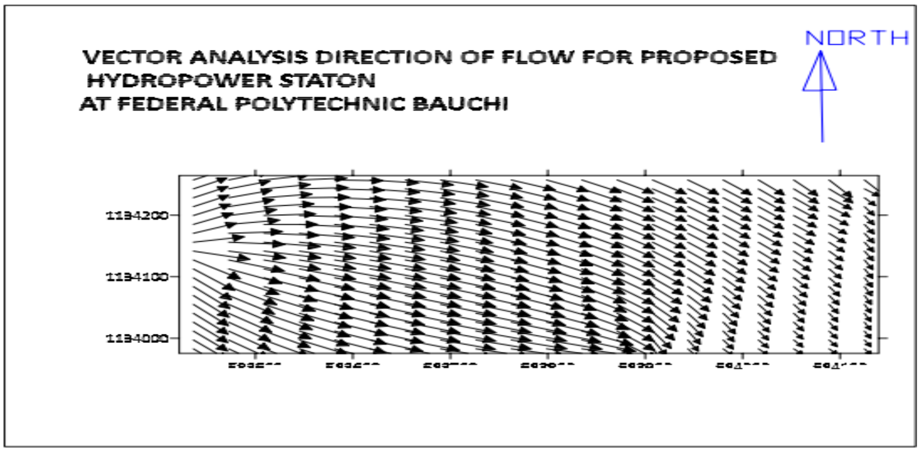


Figure 4: Vector analysis/direction of flow for study area

The flow characteristics of the drainage channels associated with each of the proposed hydro-power sites are presented in table 2. The data represents mean values of replicated observations.It shows that all proposed sites have their highest flow speeds, water depths and discharge in August, which has the highest rain intensity and rainfall days. The values increased from June through July and peak in August, and thendropped gradually through September to its least in October, when the rainsstopped. Site B has the least drainage width of 0.8 m compared to A (1.2 m) and B (1.0 m). Site C however has more discharge due to its relatively deeper drainage and being at the bottom of the slope. The head at C is 8 m as shown in Figure 3. Sites B and A have heads of 4 m and 3 m respectively. All these influenced the power generation capacity as shown in table 3.

Table 2: Flow characteristics of Proposed Hydro-power Sites

Month	Site A						Site B						Site C					
	V (m/s)	**Depth** (m)	**Width** (m)	**CSA** (m^2)	**Q** (m^3/s)	**H** (m)	**V** (m/s)	**Depth** (m)	**Width** (m)	**CSA** (m^2)	**Q** (m^3/s)	**H** (m)	**V** (m/s)	**Depth** (m)	**Width** (m)	**CSA** (m^2)	**Q** (m^3/s)	**H** (m)
June	0.87	0.4	1.2	0.48	0.42	3	0.85	0.2	0.8	0.16	0.14	4	0.89	0.4	1.0	0.4	0.36	8
July	0.98	0.6	1.2	0.72	0.71	3	1.23	0.3	0.8	0.24	0.30	4	1.34	0.6	1.0	0.6	0.8	8
Aug.	1.78	0.8	1.2	0.96	1.71	3	2.13	0.6	0.8	0.48	1.02	4	1.66	0.7	1.0	0.7	1.16	8
Sept.	0.75	0.5	1.2	0.60	0.45	3	1.34	0.4	0.8	0.32	0.43	4	1.12	0.5	1.0	0.5	0.56	8
Oct.	0.67	0.3	1.2	0.36	0.24	3	0.76	0.2	0.8	0.16	0.12	4	0.83	0.3	1.0	0.3	0.25	8

3.2 Power Generation Potential of Proposed Hydro-Power Sites

The power generation potential of each of the proposed sites is shown in table 3. The table shows that site A has the highest potential of 20.21 kW in august and least potential of 2.81 kW in October. However, its average power generation potential is 8.33 kW. Site B has its highest and least potentials of 15.98 kW in august and 1.88 kW in October respectively.Its average generation potential is 6.33 kW. Similarly, site B has its least potential (8.15) in October and highest (36.34) in August with an average of 19.67 kW. If the three sites are cascaded, they are potentially going to generate an average of 34.36 kW. This result is similar to what obtains in many other hydro-power sites and is promising, considering the current price of energy in Nigeria.

Table3: Power Generation Potential of Proposed Hydro-power Sites

Proposed Site of Power Plant	**Month of Observation**	**Parameters** η	ρ	**g**	**H**	**Q**	Q_u	**Power P (kW)**
	June	0.8	998	9.81	3	0.42	0.21	4.93
	July	0.8	998	9.81	3	0.71	0.36	8.46
A	August	0.8	998	9.81	3	1.71	0.86	20.21
	September	0.8	998	9.81	3	0.45	0.23	5.40
	October	0.8	998	9.81	3	0.24	0.12	2.81

		Average						**8.36**
	June	0.8	998	9.81	4	0.14	0.07	2.19
	July	0.8	998	9.81	4	0.30	0.15	4.70
B	August	0.8	998	9.81	4	1.02	0.51	15.98
	September	0.8	998	9.81	4	0.43	0.22	6.89
	October	0.8	998	9.81	4	0.12	0.06	1.88
		Average						**6.33**
	June	0.8	998	9.81	8	0.36	0.18	11.28
	July	0.8	998	9.81	8	0.8	0.40	25.06
C	August	0.8	998	9.81	8	1.16	0.58	36.34
	September	0.8	998	9.81	8	0.56	0.28	17.54
	October	0.8	998	9.81	8	0.25	0.13	8.15
		Average						**19.67**
		Total (Average)						**34.36**

If the three sites were developed and cascaded to run for an average of 6 hours per day for 106 rainfall days, then the power generated would be:

$$P_t = 34.36\, kW \times 106\, Days \times 6\, Hours = 21{,}852.96\, kWh$$

With the current price of ₦38.53/kWh, the annual power generation would be worth

$$21{,}852.96\, kWh \times ₦38.53 = ₦841{,}994.55.$$

This figure is quite substantial and represents some good saving, though it's just an average value and can be exceeded in real live operations. Also recall that the useful discharge Q_u (equation 2) was assumed to be half of the actual discharge, which can be higher in real operations.

IV. CONCLUSION AND RECOMMENDATION

The goal of this study has been achieved. Three sites have been identified with promising hydro-power generation potentials. This has the potential to create a saving of about a million naira annually in electrical energy, reduce the carbon footprint of the polytechnic, hence making its operations more sustainable. The discovered potential can also be harnessed to form part of a hybrid power system with solar and other sources to serve a complementary role.

It is recommended that the polytechnic should take advantage of this hydro-power potential to increase its energy supply and ease its operation. It should also explore other plausible sources in nearby water bodies and other renewable sources.

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