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Hydrological Study, Site Selection and Potential Evaluation of Small Hydropower in Kedougou Basin using Soil Water Assessment Tool

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Abstract

The objective of this study is to evaluate the hydropower potential of Kedougou stream gage on Gambia River using Soil and Water Assessment Tool (SWAT) for a small hydropower plant with at least a head of 20 m. The daily average flows and the daily observed precipitations on the period from 1999 to 2003 are used as inputs for calibration, and the period from 2004 to 2006 are used for validation. The two criteria of goodness of fit used for calibration and validation steps are respectively: coefficient of determination R^2 and Nash-Sutcliffe Efficiency coefficient (NSE). The first have been found to be equal to 0.76, and the second to 0.75. Fifty-one sites have been found on the 13 streams flows of the watershed. Since these sites are all ungagged, daily flow have been generated on each of them using SWAT hydrological model. Then Flow Duration Curves have been plotted for each of these sites using Weibull plotting position. Discharges met or exceeded 40, 50 and 60% of time are evaluated and the corresponding hydraulic potential estimated. A total of 118701 KW, 42771 KW, and 5689 KW can be estimated with 40, 50 and 60% dependability respectively, in the 51 sites. These results will help policy makers, public authorities, and investors in the energy sector to select suitable sites for implement small hydropower plants and to optimize the available renewable resources. They will by this way meet the energy needs of rural areas for productive uses.

Keywords: Small hydropower, SWAT, hydrological, hydropower Potential, site selection

INTRODUCTION

At the current rate of energy consumption, we are faced with two major problems: the increasing scarcity of fossil fuels (oil, natural gas, etc.), which account for 81% of the world's energy production, and the climate warming threat associate with. This energy is dwindling and is trending towards total disappearance within a few years. The depletion of fossil fuels leads to an increase in the level of Carbon Dioxide (CO_2) in the atmosphere,

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accentuating the greenhouse effect (Ferreres and Font, 2010). Most of the people living in rural areas in the world don't have access to electricity. The better way for rural electrification is to utilize renewable energy resources (Kong *et al*., 2015). Both the developed and developing countries are embarking on the diversification of energy and more particularly in renewable energy like wind, bioenergy, solar thermal or photovoltaic, hydroelectric. Among these energies, hydropower is flow energy that uses almost exclusively part of the water cycle, that part concerns the flow of water between the arrival of precipitation on land and the return of the water to the sea. Hydroelectricity is the first primary electricity production on a global scale, offers many advantages against the negative environmental effect, should contribute significantly to sustainable development. Hydropower represents the greatest source of renewable energy, contributing 19% of the total global energy consumption (Butera and Balestra, 2015). Small hydropower systems need a matured technology and efficient coast construction. So, in many countries, small and medium-sized rivers are exploited for the development of small hydropower systems. They do not require large storage reservoirs, then need a run of the water systems. Only one portion of the river's water is diverted to a waterwheel or turbine through a channel, pipeline, or penstock, making the wheel, turbine, and shaft rotate. The moving of the shaft creates mechanical energy, coupled with an alternator or generator to generate electricity (Butera and Balestra, 2015). The first step of the process is to ensure that a sufficient quantity of flowing water is available: hilly or mountainous sites are the best. The second step is to evaluate the head. Further, estimate the timely amount of power corresponding to the flowing water at each site. The power depends on the product of the net head and flow rate. The head is the vertical distance between the water surface level at the intake and the tailrace for the turbine. The basic hydrologic data required for the estimation of the energy potential in a small hydropower plant is the mean daily flow series at the scheme's water intake in a period that has to be long enough to represent on average the natural flow regime. Many researchers have worked on small hydropower assessments. Manzano-Agugliano *et al*. (2017) summarized in a paper a general view of small hydropower in Europe and how the small-scale schemes, is one of the most cost-effective energy technologies to be considered for rural electrification in developing countries. Adhikary *et al*. (2015) evaluated the applicability of multi-criteria optimization to decision-makers during the small hydropower site selection for novel approaches. Rahman *et al*. (2013) makes research to understand the hydrological regime of the Rhone River watershed located in Switzerland, simulated streamflow, and assessed sensitivity due to changes in land use. Gergeľová *et al*. (2013) used a GIS-based assessment of hydropower potential in the Hornad basin and said that for the needs of administrators of watercourses and operators of water systems, a GIS model can be an important tool for decision-making about its implementation activities.

The small hydropower schemes are frequently located in the upper zones of the streams where recorded streamflow series are not available. Among these, hydrological models are often used to estimate head and streamflow where flow data are not directly available (Zaidi and Khan, 2018). A hydrological model is a mathematical representation of the water cycle used to perform rainfall-runoff transformations in a given river basin or sub-basin. In some conceptual models, storage systems include the whole catchment processes without considering the specific detailed information on the catchment (Loliyana and Patel, 2015). The model divides the basin into smaller subareas considering the spatial variability of the data and the model's parameters (Onate-Valdivieso *et al*., 2016). Distributed models are generally used when accurate data are available, while conceptual models are better suited to poorly gauged sites, where data acquisition is difficult (Leauthaud *et al*., 2013). The distributed hydrological models are preferred over other conceptual models in the prediction of runoff provided extensive database related to topography, land use - land cover, soil types, and hydrological data available at finer scales in the catchment. In the model, the watershed is divided into small catchments with uniform as possible characteristics. These models combine the advantages of both lumped and distributed models (Ntoandis and Mimikou, 2013). Distributed models are very popular in the community of hydrologists. Among them, SWAT is a semi-distributed hydrological model in basin-scale, physically-based, continuous-time. It has been developed by the United States Department of Agriculture and allows to simulate runoff response and nutrient transport.

We make this study using GIS and hydrological model (SWAT) to determine the flow rates of a watershed then assessed the potential hydropower to selecting sites for a small hydropower project.

LITERATURE REVIEW

For the assessment of hydropower potential and the hydrological study GIS and SWAT have been used by many researchers. Kusre *et al*. (2010) used GIS and the Soil and Water Assessment Tool (SWAT) to assess the hydropower potential in the Kopili River basin in Assam India. Pandey *et al*. (2015) assessed the hydropower potential of Mat River, Southern Mizoran India by using spatial technology and SWAT modeling. Mathi and Desmukh (2016) presented a study to identify suitable sites for ROR hydropower plants in the Basin of Krishna River using Arc-GIS and SWAT. Christian (2015) evaluated the theoretical Run of River (ROR) hydropower potential of Nepal using a GIS-based spatial tool and SWAT hydrological model. Kayastha *et al.* (2018) proposed to assess primary potential hydropower sites and explicitly identify possible hydropower locations spatially, over a large area in a short time. Soulis *et al.* (2016) presented a paper with a geo-information system for the evaluation of each hydro site, which estimates streamflow values at every point of the drainage network. Tarife *et al.* (2017) focused on the application of GIS tools to identify and classify the theoretical hydropower potential sites in Misamis Occidental, Northern Mindanao in the Philippines. Mosier *et al.* (2016) presented a novel modeling package, referred to as the hydropower potential assessment tool, to estimate and projected future small-scale ROR hydropower resource potential at a single location or distributed over a study region. Larentis *et al.* (2010) used GIS-based procedures for hydropower potential spotting by presented a methodology for a large-scale survey of hydropower potential sites to be applied in the inception phase of hydroelectric development planning.

MATERIALS AND METHODS

To build a small hydropower plant, the first step is to have a suitable site: along with a river network of hundreds of kilometers long, there may be only a few places where a successful power plant can be built. The type of hydropower plant will depend on the topography of the site. The amount of energy that can be taken from any river will depend on two factors, the volume of water flowing along with it and the drop in riverbed level, known as the head of water (Breezy, 2018a, 2018b, 2018c). The methodology used to determine the potential site and his estimation of the Kedougou watershed are presented below.

Study area: The Gambia River originates in the Fouta Djallon Mountains in North Guinea. The total catchment of this river lies between latitudes 11°22 North (in the Fouta-Djallon) and 14 ° 40 North (in the South-East Ferlo) and between the longitudes 11 ° 13 West (Fouta-Djallon) and 16 ° 42 West (Banjul, mouth) (Bader *et al.*, 2003). The climate is Guinean at the southern end and Sudanian at the northern part. The rainfall regime is unimodal, with a dry season growing from 3-4 months in the southern part (Fouta Djallon) to 7-8 months in the Ferlo part.

In this present study, the Gambia River sub-catchment upstream of Kedougou city has been considered and presented in Fig. 1. The total area of this watershed is 9050 km². The length of the river from the source to the confluence is 516 km. The maximum altitude is 1535 m and the minimum altitude is 102 m, i.e., a vertical drop of 1033 m and an average slope of 0.42%. The relief is accentuated. The watershed is covered with dense forest.

The rainfall regime combines two seasons: one rainy, from May to October, and the other dry, the rest of the year. The average monthly temperature at the Kolda synoptic station is maximum in May (42°C) and minimum in December (26°C). The average annual precipitation decreases regularly from south (1500 mm) to north (1900 mm).

Morphometric study: The DEM presented in Fig. 1 on the location map allows to delimit the watershed delineation and to compute morphometric parameters characterizing its relief. The hypsometric curve represents the distribution of the surface of the watershed according to its altitude. This curve provides a synthetic view of the slope of a given basin and describes the dynamic equilibrium state of a basin. The hypsometric curve of Gambia River Basin upstream Kedougou stream gauge (Fig. 2) is typical of a sedimentary basin with great erosive potential.

Flow duration curve: The FDC of a series of daily flows is the complement of the cumulative distribution function of the daily stream flows based on the complete record of flows. It relates flow values to the percent of the time those values are met or exceeded. Constructing non-parametric metric FDC can be made in different ways. One is as follow:

- Rank the observed stream flows in ascending order
- Plot each ordered observation versus its corresponding duration D_i

The duration D_i is often expressed as a percentage of time a flow is met or exceeded. It coincides with the exceedance probability ε_i of the ith observation in the ordered sample. If ε_i is estimated using a Weibull plotting position, the duration D_i is as follow:

$$D_i = 100\varepsilon_i = 100(1 - \frac{i}{n+1}) \quad (1)$$

For $i = 1\ to\ n$, n is the length of the sample (Castellarin *et al.*, 2007).

In an FDC, low flows are exceeded a majority of the time, floods are exceeded infrequently. The x-axis

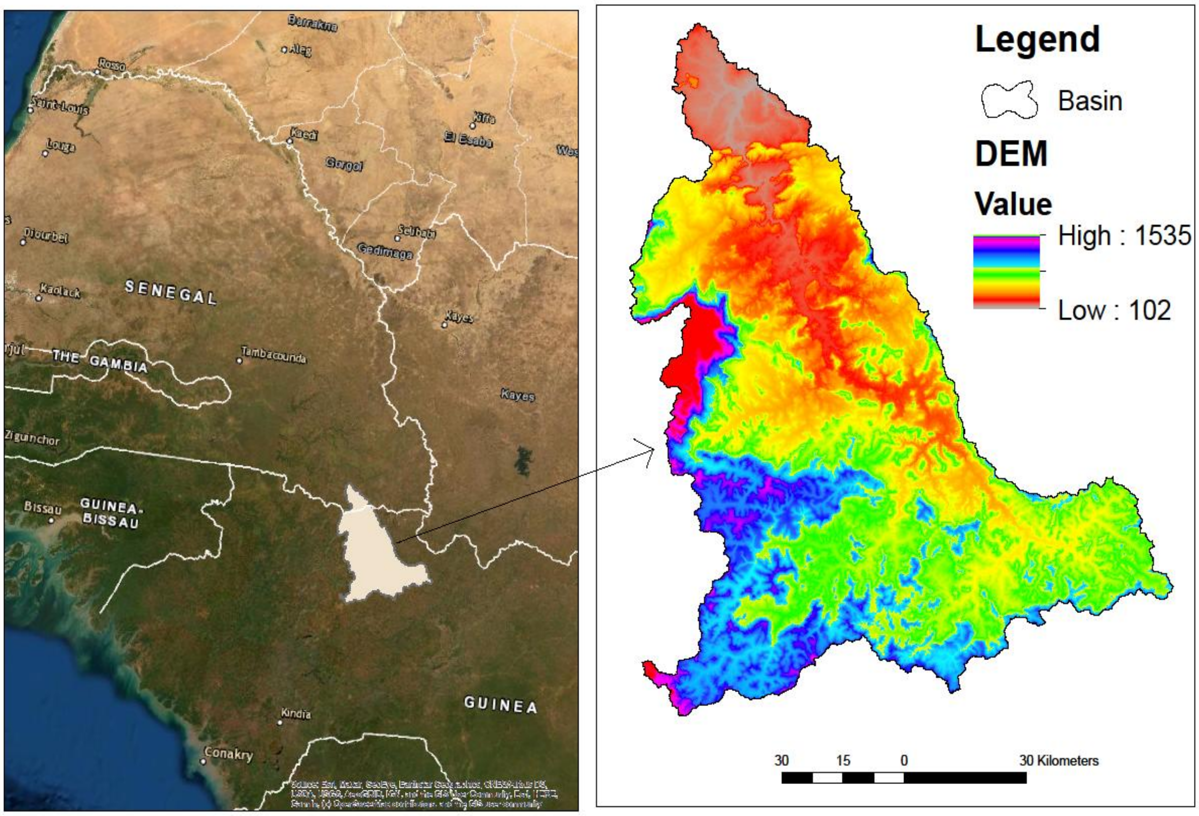


Fig. 1: Location map of Kedougou watershed

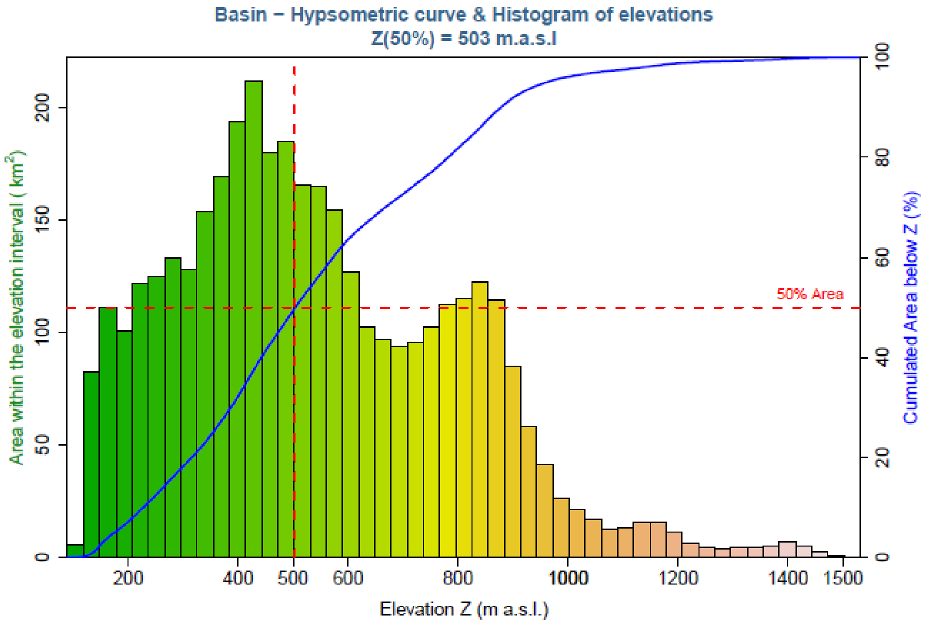


Fig. 2: Hypsometric curve of Kedougou watershed

represents the duration amount D_i while the y-axis represents the flow values associated with the duration D_i. There are two ways of flow duration curve assessment:

- Daily stream flows observed on the whole period
- Annual flow duration curve

Criteria for identification sites:

Availability of flow: One should ensure the availability of flow. Streams are linked by assigning a unique number to each link (or segment) in the stream raster. Then creating the stream order for the stream network from flow direction and converting stream raster to a polyline feature. Kusre *et al*. (2010) used the only fifth and higher-order streams are considered for the selection of sites to ensure a sufficient amount of water flow. Pandey *et al*. (2015) considered streams in third-order or more. Mathi and Desmukh (2016) have been considered Fourth and higher-order streams having sufficient flow of water for selection of sites, as for lower-order streams the flow is too less for generation of power. To have sufficient runoff of a powerhouse we decided in this study to take stream with third-order or more (Fig. 3 and 4).

Site spacing: Since there are no space requirements for water storage in a small project, a minimum of 500 m horizontal distance between an intake point and its turbine point is usually considered sufficient. Mathi and Desmukh (2016) used 1000 m as the Minimum distance between two successive sites, to have a sufficient gap between the tailrace of one site and the diversion arrangement of the next site. The spacing between the two plants was also assumed to be from 500 to 3000 m. A series of plants can be proposed along the river in such a way one after another.

Head availability: Head is a vertical distance between two points (intake and turbine). It can also be defined as the pressure created by the elevation difference between intake and turbine (Tarife *et al*., 2017). The Hydropower potential assessment requires the elevation along the river as presented in Fig. 5. There are different methods of estimating the head drop along the river course. One of the simple methods is to overlay the DEM of the basin, sub-basin, and river network shapefile and obtain the raster value of the upstream and downstream endpoint of each sub-basin river. The difference in raster value between the upstream and downstream endpoints of the river in a given sub-basin is the potential head drop of the river. At least 20 m of the head is necessary for a hydropower project.

Assessment of flow rates: SWAT hydrological model:

SWAT model description: SWAT is used for the

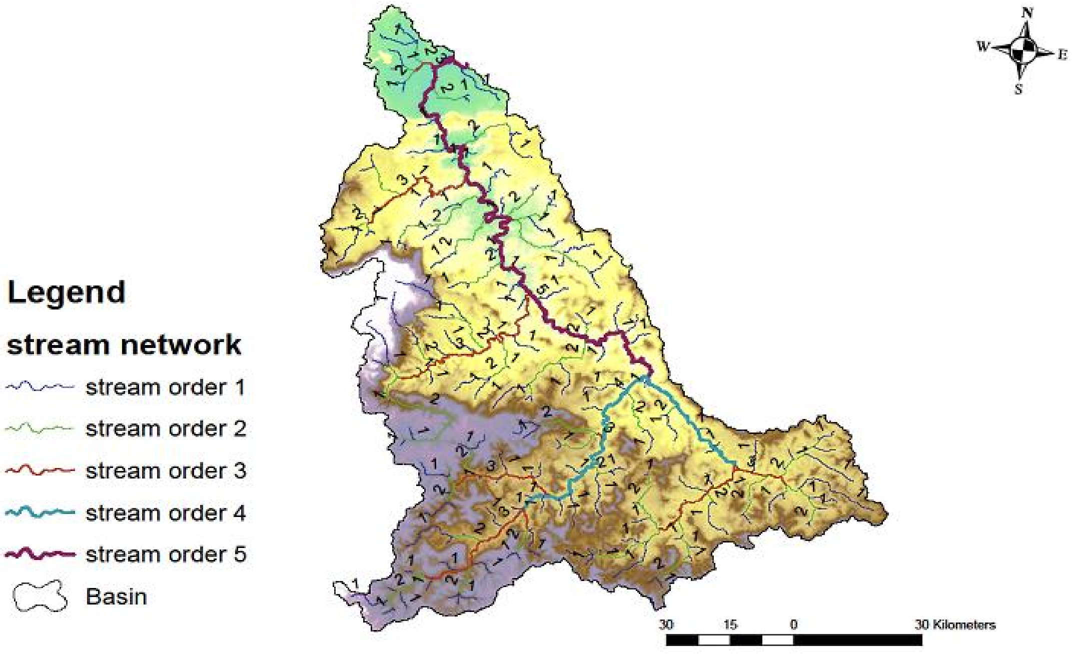


Fig. 3: All stream order of the watershed

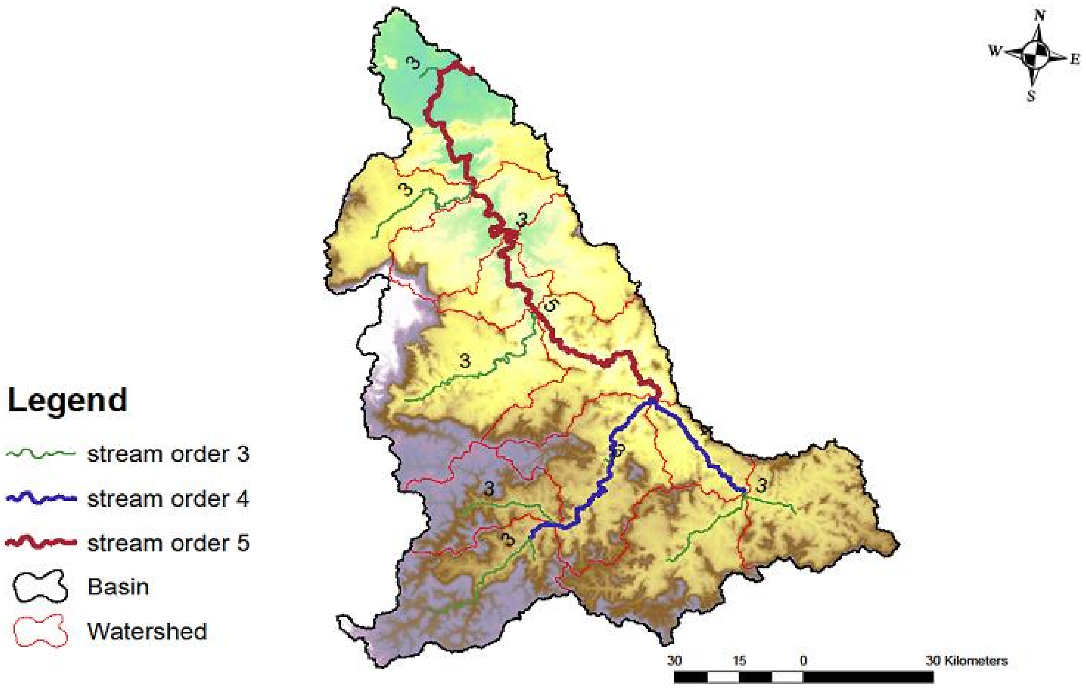
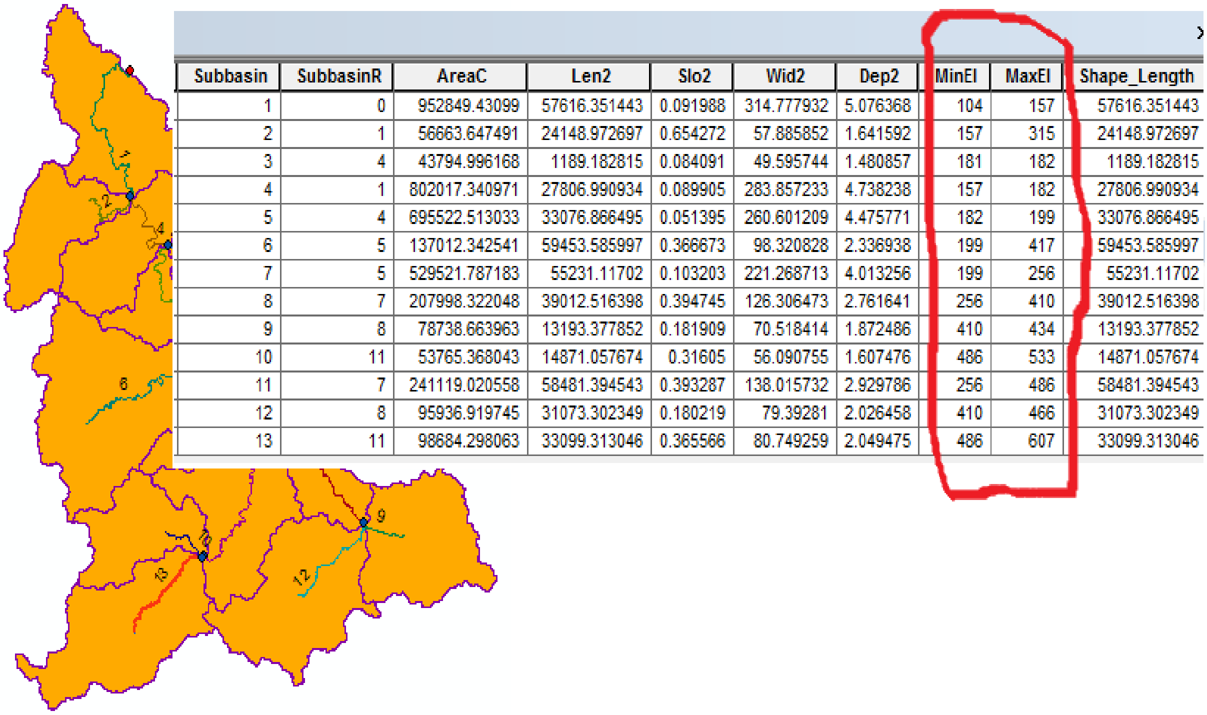


Fig. 4: Stream in third order and more



Subbasin	SubbasinR	AreaC	Len2	Slo2	Wid2	Dep2	MinEl	MaxEl	Shape_Length
1	0	952849.43099	57616.351443	0.091988	314.777932	5.076368	104	157	57616.351443
2	1	56663.647491	24148.972697	0.654272	57.885852	1.641592	157	315	24148.972697
3	4	43794.996168	1189.182815	0.084091	49.595744	1.480857	181	182	1189.182815
4	1	802017.340971	27806.990934	0.089905	283.857233	4.738238	157	182	27806.990934
5	4	695522.513033	33076.866495	0.051395	260.601209	4.475771	182	199	33076.866495
6	5	137012.342541	59453.585997	0.366673	98.320828	2.336938	199	417	59453.585997
7	5	529521.787183	55231.11702	0.103203	221.268713	4.013256	199	256	55231.11702
8	7	207998.322048	39012.516398	0.394745	126.306473	2.761641	256	410	39012.516398
9	8	78738.663963	13193.377852	0.181909	70.518414	1.872486	410	434	13193.377852
10	11	53765.368043	14871.057674	0.31605	56.090755	1.607476	486	533	14871.057674
11	7	241119.020558	58481.394543	0.393287	138.015732	2.929786	256	486	58481.394543
12	8	95936.919745	31073.302349	0.180219	79.39281	2.026458	410	466	31073.302349
13	11	98684.298063	33099.313046	0.365566	80.749259	2.049475	486	607	33099.313046

Fig. 5: Elevation drop information of each stream of the watershed

assessment of flow rates. It is a physically-based, continuous-time, semi-distributed, computationally efficient hydrological model developed by the United States Department of Agriculture (USDA) for application to large and complex watersheds over long periods (Gassman *et al*., 2007). It is freely available at the website http://www.brc.tamus.edu/swat/. SWAT system is integrated into a Geographic Information

System (ArcGIS interface), in which different spatial environmental data, including climate, soil, land cover and, topographic characteristics. The model allows the division of the watershed into smaller sub-basins connected by a stream network. These sub-basins are further subdivided into a unique combination of land use, land cover, soil characteristics, and slope named Hydrological Research Unit (HRU). HRUs have no spatial connection. SWAT then simulates the various hydrological processes of a watershed in two steps: the land phase and the routing phase. The land phase estimates in each sub-basin the amount of water that contributes to the main channel flow by computing the hydrological processes for each HRU of this sub-basin separately and they predict hydrologic components that include surface runoff, evapotranspiration, groundwater, lateral runoff, and return flow (Jha, 2009). The routing phase simulates the streamflow at the outlet of the whole basin based on a routing method such as the Muskingum method or the variable storage coefficient method (Mehan *et al*., 2016). The land phase of the hydrological cycle of the SWAT model is based on the water balance Eq. (2):

$$SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \quad (2)$$

where,

SW_t : Final water content at time t
SW_0 : Initial water content at time 0
R_{day} : Amount of precipitation at time t
Q_{surf} : Amount of surface runoff at time t
E_a : Evapotranspiration at time t
W_{seep} : Water entering in the vadose from the soil profile at time t
Q_{gw} : Amount of return flow at time t

Data input: The spatially distributed data (GIS input) required for the ArcSWAT interface include the meteorological data, the Digital Elevation Model (DEM), soil data, land use, and stream network layers. Topographic data of the Gambia basin upstream Kedougou stream gauge have been clipped out from the Shuttle Radar Topography Mission (SRTM) 30*30 m Digital Elevation Model available on web site https://vertex.daac.asf.alaska.edu/?#. Climate data such as Rainfall, Max and Min Temperature, Solar radiation, Relative Humidity, and wind speed were obtained on the SWAT website https://globalweather.tamu.edu/. The land use/land cover map used in this study has been downloaded from the FAO website (http://faostat.fao.org) with a 1km x 1km resolution for Africa data sets. The average daily flows are issued part from the Water Resources Management and Planning Office database (DGPRE Dakar, Senegal) and the IRD (Institution for Research Development). Daily observed precipitation comes from the Organization for the Development of the Senegal River Basin Database (OMVS) and the IRD (Institution for Research Development). The period of study is respectively 1999-2006 for discharge data.

Land use and soil type activity are intimately related, and their combined actions have a singular influence on surface flow.

Soil type: A soil map is a geographical presentation showing the spatial distribution of various soil types and their properties in the catchment (Mathi and Desmukh, 2016). The soil types intervene in the speed of rising of the floods and on their volume. Indeed, the rate of infiltration, the capacity of retention, the initial losses, and the coefficient of run-off (Cr) are functions of the type of Soil and its thickness. The soil map is illustrated in Fig. 6. Leptosols predominates in the Kedougou basin (94.60%), followed by Regosols (4.95%) and Greysols (0.45%).

Land use: Land use and soil type activity are intimately related, and their combined actions have a singular influence on surface flow. Land use is one of the most important factors that affect infiltration, evapotranspiration, and hence in turn the runoff from a watershed. The land use map of the Kedougou watershed is presented in Fig. 7. The land use map of the Kedougou watershed is presented in Fig. 7. It is at most covered by Forest-Deciduous (FRSDO) 54.69%, range brush (RNGB) 44.51%, at the remaining part of the land, it is occupied by Western Wheatgrass (WWGR) 0.48% and Crested Wheatgrass (CWGR) 0.31%.

Sensitivity analysis: Sensitivity analysis helps us reducing the number of parameters to test for effective use of the model. A careful study of input parameters and their sensitivity is required before calibration to identify which input parameters affect the output of the model most. They allow determining the cause-and-effect relation between model parameters and modeling results (Thavhana *et al*., 2018). A sensitivity coefficient is the change of a response variable caused by a unit change of an explicit variable while holding the rest of the parameters constant (Jha, 2009). For a given hydrological model, if $f(P_i)$ is a response variable depending of P_i , $i = 1\ to\ N$ independent parameters, and ΔP_i is a change in the parameter P_i, the sensitivity coefficient of the parameter P_i is given by the following equation:

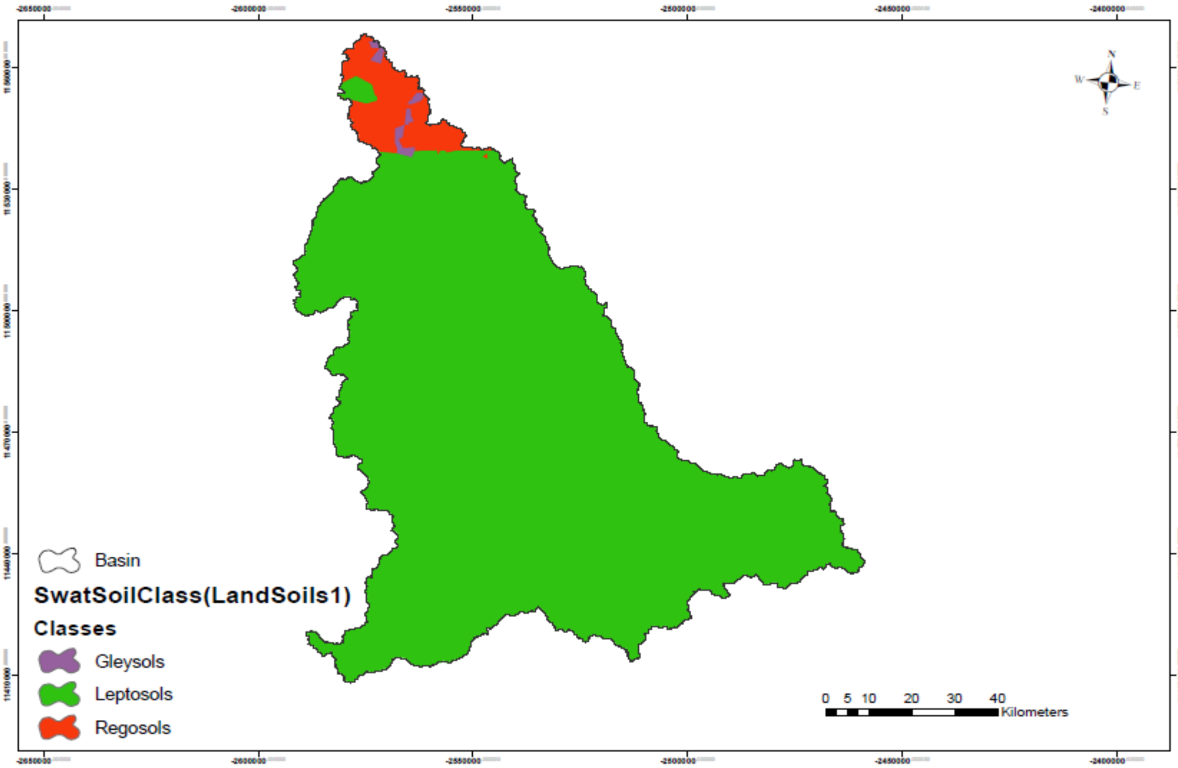


Fig. 6: Soil map of Kedougou watershed

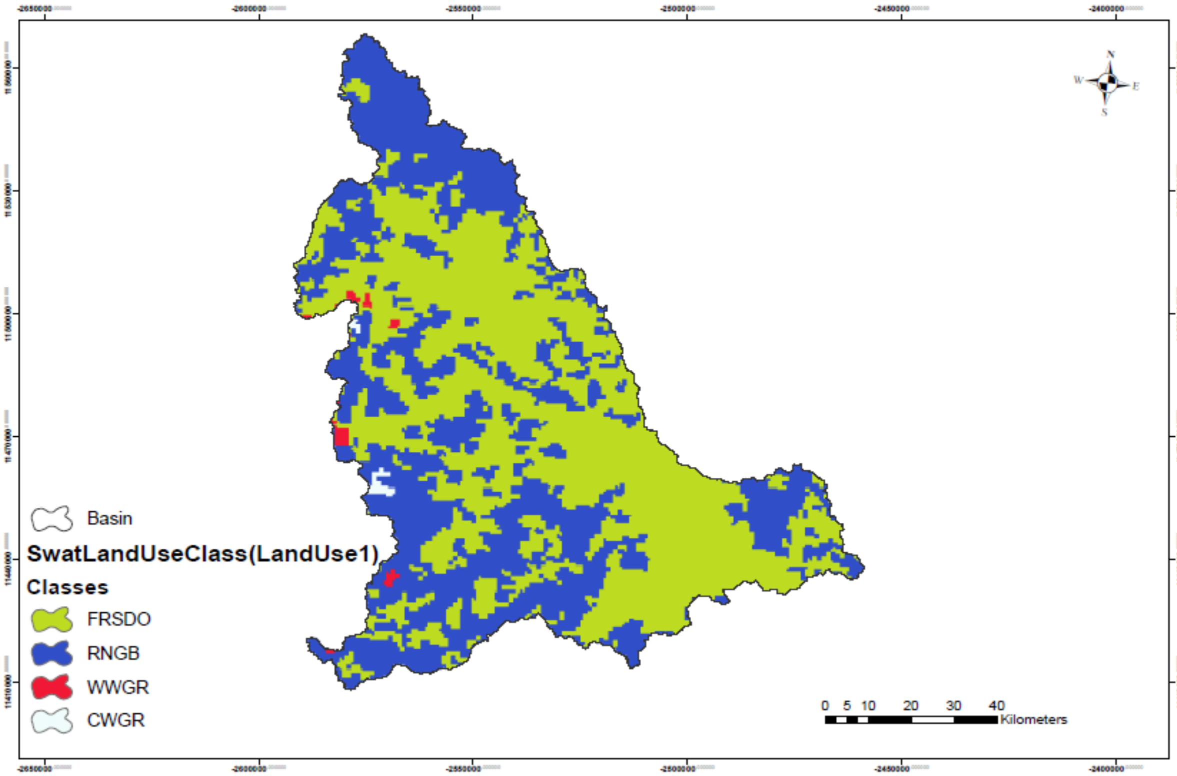


Fig. 7: Land use map of Kedougou watersh

$$\frac{\Delta f}{\Delta P} = \frac{f(P_1,P_2,\ldots,P_i+\Delta P_i,\ldots,P_N)-f(P_1,P_2,\ldots,P_i\ldots,P_N)}{\Delta P_i} \tag{3}$$

The parameters used for the flow were selected based on the literature and the SWAT documentation. The initial simulation to determine the sensitivity of the model to different parameters was performed using default parameter values (Da Silva *et al*., 2015).

A sensitivity index allows comparing meaningfully different sensitivities. This sensitivity index s_i is computed from the sensitivity coefficient as below:

$$s_i = \frac{P_m}{f_m}\frac{\Delta f}{\Delta P} \tag{4}$$

P_m and f_m are respectively the mean of the highest and lowest values of the explanatory parameter and the selected response variable.

Calibration and validation: Calibration and validation of the SWAT model have been processed after determining the sensitive parameters. Model calibration is the adjustment of model parameters within a recommended range so that the model output matches the observed data as closely as possible, therefore better representing the simulated process (Pandey *et al*., 2015). A wide range of statistics has been used to evaluate SWAT hydrologic predictions. By far the most widely used statistics reported for hydrologic calibration and validation are the regression correlation coefficient (R^2) and the Nash-Sutcliffe model Efficiency (NSE) coefficient (Abbas *et al*., 2016; Arnold *et al*., 1998). The R^2 value measures how well the simulated versus observed regression line approaches an ideal match and ranges from 0 to 1 and the NSE ranges from -∞ to 1 and measures how well the simulated versus observed data match the 1:1 line (Gassman *et al*., 2007; Arnold *et al*., 2005). The R^2 is calculated by Eq. (5) and the NSE by Eq. (6). According to these criteria, a model is considered satisfactory and can be used for further application if NSE >0.5 and R^2 >0.6. It is adequate if NSE is between 0.5 and 0.75 and very good if NSE and R^2 >0.75 (Christian, 2015). Validation is the way of determining the degree to which a model or simulation is a correct representation of the observed behavior from the perspective of the intended uses (Pandey *et al*., 2015). Several simulation runs were done until satisfactory goodness of fit between the observed and simulated streamflow was obtained:

$$R^2 = \left(\frac{\sum_{i=1}^{n}(Q_i^{obs}-Q_{mean}^{obs})(Q_i^{sim}-Q_{mean}^{sim})}{\sqrt{\sum_{i=1}^{n}\left(Q_i^{obs}-Q_{mean}^{obs}\right)^2}\sqrt{\sum_{i=1}^{n}\left(Q_i^{sim}-Q_{mean}^{sim}\right)^2}}\right)^2 \tag{5}$$

where,

Q_i^{obs} : The ith observed streamflow

Q_i^{sim} : The ith simulated streamflow

Q_{mean}^{obs} : The mean of observed streamflow

Q_{mean}^{sim} : The mean of simulated streamflow:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_i^{obs}-Q_i^{sim})^2}{\sum_{i=1}^{n}(Q_i^{obs}-Q_{mean}^{obs})^2} \tag{6}$$

Hydropower potential calculation: The theoretical hydropower potential in this study is estimated by Eq. (7). The hydropower potential is a function of two parameters such as the head drop and the discharge at a certain flow:

$$P = \rho\, g\, Q\, H \tag{7}$$

where,

P : Power generate (W)

ρ : Density of water (1000 Kg/m^3)

g : Acceleration due to gravity (9.81 m/sec^2)

Q : Discharge (m^3/sec)

H : Head (m)

RESULTS AND DISCUSSION

Morphometric parameters: The details of the morphometric parameters and the drainage basin characteristics are presented in Table 1. According to this table, the geometric parameters (area, perimeter, basin length) and topographic parameters (height difference, overall slope index, and specific height difference) are stable values.

Sensitivity analysis: Sensitivity analysis has been carried out for 23 parameters related to streamflow by changing each of the independent parameters, one at a time (Abbas *et al*., 2016). The most sensitive parameters have been considered to run SWAT. During the sensitivity analysis, only 16 parameters are significant among the 23. The selected parameters for sensitivity analysis for the Kedougou watershed and their value are presented in Table 2. According to this table, the most sensitive parameters are the saturated hydraulic conductivity coefficient of the first soil layer (SOL_K) and, depth to the bottom of the first soil layer (SOL_Z). The less sensitive parameter is manning's "n" value for overland flow (OV_N).

Calibration and validation: The SWAT model has been calibrated during the period 1999-2003 and validated during the period 2004-2006. Criteria of goodness of fit are respectively R^2 = 0.76 and NSE = 0.75

Table 1: Characteristics morphometric of Kedougou watershed

Morphometric parameters and units	Formula	Kedougou
Area(A) in km^2	ArcGis	9020
Perimeter (P) in km	ArcGis	999
Compactness coefficient (C_c)	$C_c = 0.28\, P.A^{-1/2}$ (8)	2.95
Basin Length (L) in km	$L = A^{1/2} \frac{C_c}{1.12}\left[1 + \sqrt{1 - \left(\frac{1.12}{C_c}\right)^2}\right]$ (9)	516.95
Minimum altitude (H_{min}) in m	ArcGis	102
Maximum altitude (H_{max}) in m	ArcGis	1535
Average altitude (H_{moy}) in m	$H_{moy} = \sum \frac{A_i h_i}{A}$ (10)	405
Median altitude(H_{med}) in m	Hypsometric curve	503
Height difference (D)	$D = H_{5\%} - H_{95\%}$ (11)	650
Overall slope index (I_g)	$I_g = \frac{D}{L}$ (12)	1.71
Specificheight difference (D_s)	$D_s = I_g.\sqrt{S}$ (13)	162.41
Drainage density (D_d) in km/km²	$D_d = \frac{\sum l_i}{A}$ (14)	0.50

Table 2: Parameters after calibration

Parameter	Value before calibration	Value after calibration
SOL_K	8.410	50
SOL_Z	300	375
WQMIN.GW	1000	1500
CN2.MGT	74	35
REVAPMIN.GW	750	100
DELAY.GW	31	100
CH-N2	0.014	0.30
CH-K2	0	-0.01
SOL_AWC	0.062	0.02
SOL_BD	1.300	1.70
CH-N1	0.014	5
ESCO	0.950	0.05
SOL_CBN	1.600	3
CH-K1	0	0.10
LAT_TTIME	0	0
OV_N	0.150	0.01

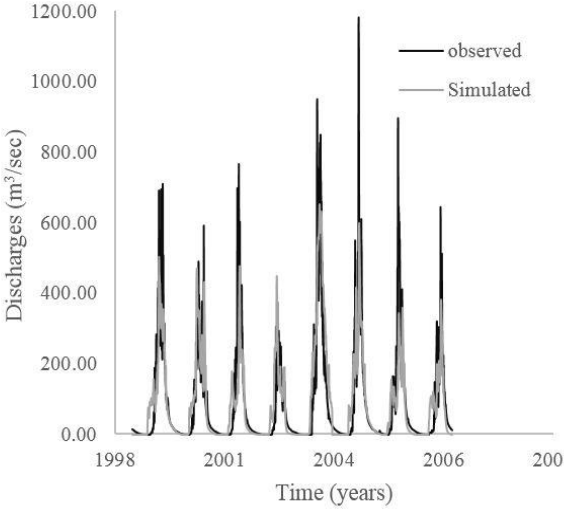


Fig. 8: Observed and simulated discharges or calibration and validation of SWAT model

for the calibration period and $R^2 = 0.67$ and NSE = 0.65 for the validation period. The values of R^2 and ENS for the calibration and validation show a good agreement between the simulated and observed daily flow. The calibrated parameters after sensitivity analysis and their numerical values are presented in Table 2. We plot in Fig. 8 the observed and calculated discharges for the calibration and validation of the SWAT model. According to this figure, the rising part and the recession of the simulated hydrograph are well restituted.

Identification and location of potential sites: The methodology used in the identification of potential sites depends on two major criteria: a head of 20 m or more is available; a distance between two sites varying from 500 m at least to 3000 m maximum is measured. As well as hydrological, many other criteria have also to be met to finalize the site of hydropower projects (Pandey *et al.*, 2015). To identify and locate the potential sites on river streamflow, we follow the different steps:

For a given stream:
Locate site 0 at the outlet
Measure along the river a distance L0 corresponding to a 20 m vertical drop from the outlet site 0 using DEM and ArcGIS.
If L0 lays between 500 and 3000 m, locate the position of next potential site 1 at distance L0, and take a drop as H = 20 m.
If L is less than 500 m, locate the next site 1 at L = 500 m. Note that the new vertical drop H that will be greater than 20 m.
If this distance is greater than 3000 m, place the site k+1 at a distance L = 3000 m from the previous site and note that the new vertical drop will be less than 20 m. Do the same to locate all other sites on this stream.
Do the same for all other streams of the river network.

Table 3: Characteristics of each stream

N° stream	Stream order (strahler)	Stream length (Km)	Max. elevation (m)	Min. elevation (m)	Elevation difference (m)	Number of sites	Slope	Avg. between sites (Km)
1	5	57.61	157	104	53	2	0.09	28.80
2	3	24.14	315	157	158	7	0.65	3.44
3	3	1.18	182	181	1	0	0.08	0
4	5	27.80	182	157	25	1	0.09	13.90
5	5	33.07	199	182	17	0	0.05	0
6	3	59.45	417	199	218	10	0.36	5.94
7	5	55.23	256	199	57	2	0.10	27.61
8	4	39.01	410	256	154	7	0.39	5.57
9	3	13.19	434	410	24	1	0.18	6.60
10	3	14.87	533	486	47	2	0.31	7.43
11	4	58.48	486	256	230	11	0.39	5.31
12	3	31.07	466	410	56	2	0.18	15.53
13	3	33.09	607	486	121	6	0.36	5.51

Min.: Minimum; Max.: Maximum; Avg.: Average

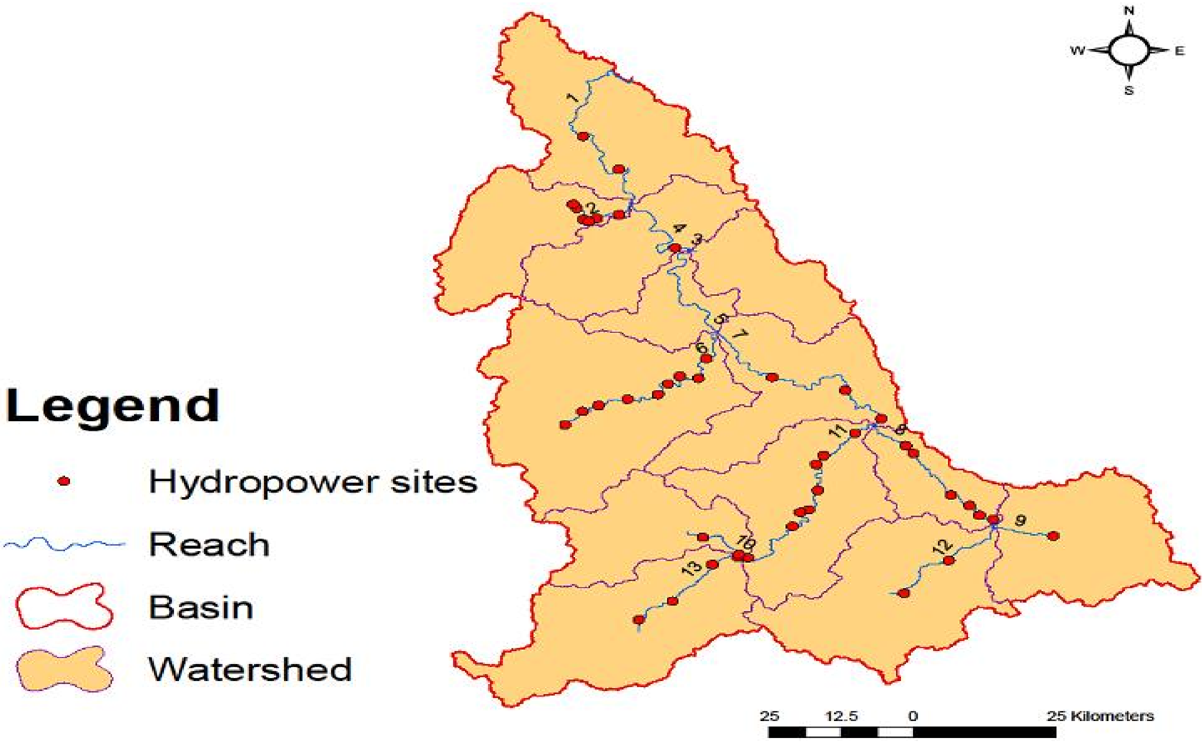


Fig. 9: Hydropower sites selected with at least 20 m head in Kedougou watershed

Using this method, 13 streams having been found to have stream order equal to three or more in the basin of the Gambia River upstream Kedougou. 51 potential sites and their location have been identified on these streams. In Table 3 we present all these streams with their length, the stream order, the elevation, the number of sites, the bed slope, and the average spacing between two potential sites. We present in Fig. 9 the locations of all the sites in the river basin of study. As we can see, it's not the longest stream (59.45 Km) who have more potential sites (10) with 218 m of elevation difference and the shortest (1.18 Km) have just (0) sites due to his elevation difference value (1 m).

Flow duration curve: SWAT model has been used to generate the daily flow at each site from 1999 to 2006. The flow duration curves for all of these sites have been represented using the Weibull plotting position method (Fig. 10 to 14). In each figure, we plotted the curve of the sites with the same flow interval. Sites in Fig. 10 and

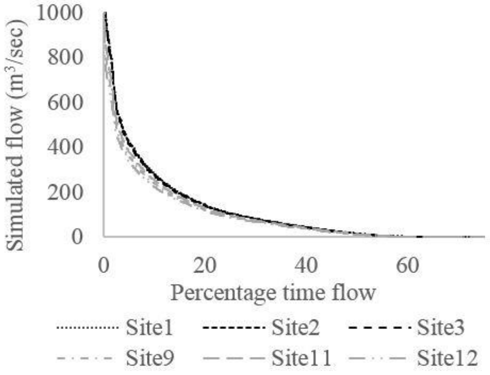


Fig. 10: Flow duration curves for the potential sites (1, 2, 3, 9, 11 and 12)

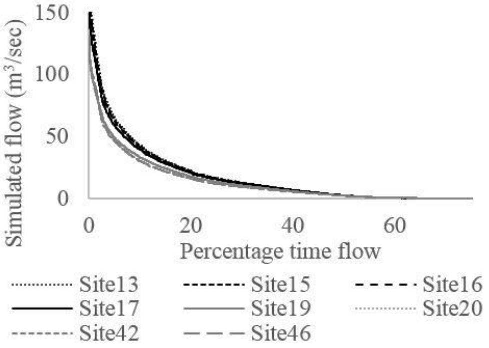


Fig. 11: Flow duration curves for potential sites (13, 15, 16, 17, 19, 20, 42 and 46)

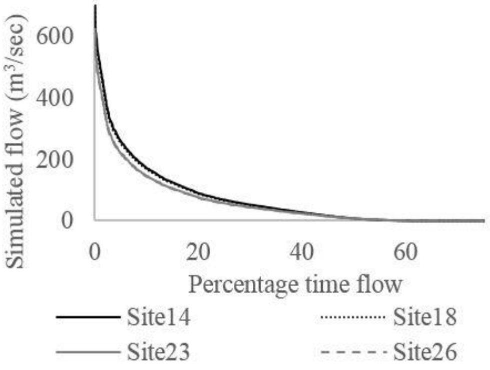


Fig. 12: Flow duration curves for the potential sites (14, 18, 23 and 26)

12 have a higher flow than we have sites in Fig. 11, 13 and 14 with low flow. We note that the flow decrease completely after 60% of the time reason why we choose the discharges at 40, 50, and 60%, respectively to estimate the potential. The save curve patterns have been observed in Mathi and Desmukh (2016) study.

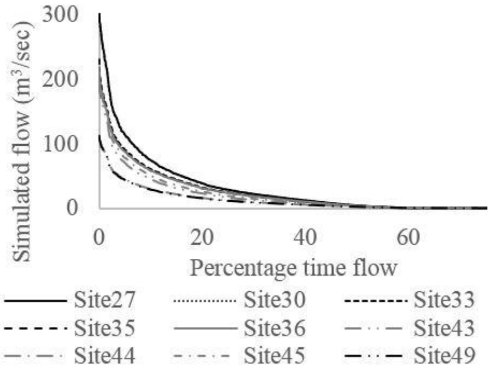


Fig. 13: Flow duration curves for the potential sites (27, 30, 33, 35, 36, 43, 44, 45 and 49)

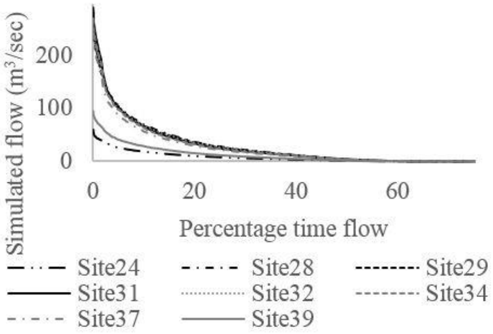


Fig. 14: Flow duration curves for the potential sites (24, 28, 29, 31, 32, 34, 37 and 39)

The estimated power potential of all the sites: The methodology used here is a simple way to choose potential sites from a hydrological angle but other criteria have to be taken to finalize the hydropower plant. The total length of the Kedougou watershed is about 517 Km with different elevation rivers that vary from 104 to 607 m. All sites are estimated by Eq. (7) when a head of 20 m is available and a distance of 500 at least between two sites. The discharges at each identified site met or exceeded 40, 50, and 60% of the time are simulated by the model (Q40, Q50, and Q60), respectively. Then, the corresponding hydropower potential of each site is calculated (P40, P50, P60). All the results are represented in Table 4. In this table we have sites located in fourth and fifth-order streams, that’s why the flow in these sites are more important and the sites in third streams order are less power. The total power potential of the watershed at 40% of the time is 118701 KW, at 50% we have 42771 and 5689 KW at 60%. This means the more the percentage of time flow increase, the more the power decrease. We found the same kind of results in Pandey *et al*. (2015) and Kusre *et al*. (2010)

Table 4: Estimated power potential for Kedougou watershed

	Discharge Q (m^3/sec)			Power (KW)		
Located sites	Q40	Q50	Q60	P40	P50	P60
1	46	17	4	9025	3335	784
2	45	16	1	8829	3139	196
3	44	16	1	8632	3139	196
4	2	1	0	392	196	0
5	2	1	0	392	196	0
6	2	1	0	392	196	0
7	2	1	0	392	196	0
8	2	1	0	392	196	0
9	39	13	1	7651	2550	196
10	2	1	1	392	196	196
11	41	15	1	8044	2943	19
12	37	12	1	7259	2354	19
13	7	3	0	1373	588	0
14	29	9	1	5689	1765	196
15	7	3	0	1373	588	0
16	7	3	0	1373	588	0
17	7	3	0	1373	588	0
18	28	9	1	5493	1765	196
19	6	2	0	1177	392	0
20	6	2	0	1177	392	0
21	5	1	0	981	196	0
22	4	1	0	784	196	0
23	25	8	1	4905	1569	196
24	3	1	0	588	196	0
25	3	1	0	588	196	0
26	24	8	1	4708	1569	196
27	12	4	1	2354	784	196
28	12	4	0	2354	784	0
29	12	4	0	2354	784	0
30	12	4	1	2354	784	196
31	11	4	1	2158	784	196
32	12	4	1	2354	784	196
33	11	4	1	2158	784	196
34	10	4	1	1962	784	196
35	11	4	1	2158	784	196
36	10	4	1	1962	784	196
37	4	4	1	784	784	196
38	5	1	0	981	196	0
39	2	1	0	392	196	0
40	2	1	0	392	196	0
41	5	1	0	981	196	0
42	8	2	0	1569	392	0
43	6	3	1	1177	588	196
44	9	2	1	1765	392	196
45	5	4	1	981	784	196
46	5	2	1	981	392	196
47	3	2	0	588	392	0
48	5	1	0	981	196	0
49	4	2	1	784	392	196
50	2	2	1	392	392	196
51	2	1	0	392	196	0
Total power	118701	42771	5689			

CONCLUSION

The present work is aimed at estimating the hydroelectric potential of the Kedougou watershed. A GIS-based approach is used to identify the suitable sites for hydropower plants and to estimate the hydropower potential of all these sites by simulating discharges from the SWAT model. Firstly, a sensitivity analysis was done to find the best parameters, with the influence coefficient method who is one of the most common methods for computing sensitivity coefficient in surface and groundwater problems. Then, we calibrated and validated for a period from 1999 to 2006, the SWAT model with a Nash of 0.76 and 0.65, and an R2 of 0.75

and 0.64 respectively for calibration and validation. Then we used the simulated flows at the level of each site to estimate their hydroelectric potential from Eq. (1). The location of the sites is based on two major criteria: a head of 20 m, a spacing between 2 sites between a minimum of 500 m, and a maximum of 3000 m. And finally, we plotted the flow duration curve for each site and then determined the potential P40, P50, and P60 respectively equal to 118701 KW, 42771 KW, and 5689 KW.

Hydropower is one of the best ways to fight against climate change. It is essential to preserve and develop it. A necessary compromise between the various uses of water is necessary to enable future generations to benefit from a real choice of renewable energy sources. In this respect, development prospects must be strongly encouraged by the public authorities and accompanied by the creation of a stable environment from both a regulatory and a financial point of view. In Africa, the development of hydropower has not changed at all yet. There is no shortage of resources and accessible technology, except for the determination and lack of awareness on the part of the majority of African authorities. From this angle, this work shows that renewable energies offer great prospects that are not yet fully exploited.

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