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Using SWAT To Simulate A Moroccan Watershed, Including An Assessment Of The Most Sensitive Modelling Parameters With SUFI2.

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---***ABSTRACT***---
Application of models to study of the hydrological function of watersheds has become a priority for countries wishing to conserve and protect their water resources. This need becomes essential for countries suffering from water stress such as Morocco where sustainable and predictable management is essential. It requires an in-depth knowledge of the variables influencing the functioning of the basins, particularly the land use and their basin characteristics for a correct implementation of the management model. In this study, the SWAT model is used to simulate the monthly inflow at the Kansera Dam for the period 2001-2010, including one year (2001) for the warm-up of the model. 2011-2014 constituted the validation period of the model.
Water balance indicates a dominance of evaporative water losses accounting for 41% of total rainfall including runoff from snowmelt. Runoff accounts for 13% of precipitation while lateral flow is 5%. The rest is divided between the deep aquifer recharge of 8% and percolation, in addition to the flow back to the river which represents about 32%.
The sensitivity analysis was performed for the calibration period using the SUFI-2 algorithm available from SWAT-CUP using 31 parameters hydrologic selected from the past available literature. Only 14 parameters that they represent the most sensitive parameters has been retained.
0.83, 0.77 and -3.9 are the respective values of R2, NSE, and PBIAS during the calibration period, which represents very good performance for simulations for Beht basin. These performances for the hydrologic model were reduced to good during the validation period following an increase in the value of PBIAS, which are 0.2% higher than the limit values.
Although the simulation estimates the water flows feeding the Kansera dam on a monthly time step, the results provide the means to develop a decision support system for this dam.

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I. INTRODUCTION

Moroccohas been committed for decades to a policy of mobilization of water resources through the construction of dams to ensure there is sufficient drinking water, including a sufficient supply to meet the industrial, energy and irrigation demands for this resource. The Sebou watershed encompassing 10 large dams and 44 small dams totaling the largest capacity of the Kingdom (5 800 Mm3) [1]. The catchment of Beht constitute the limit Eastern of the watershed of Sebou.

The development and management of water resources in the Beht catchment require the establishment of a sustainable model for the appropriate use of water resources including effective water supply management and an assessment of the impacts of land management, climate change and flooding, all of which must be integrated in an effective decision support system.

The rainfall-runoff models are tools commonly used for hydrological studies in engineering and research. They are used for various purposes, including the reconstitution of chronic flows from rainfall chronicles,[2][3] the management of water resources during periods of low water [4], the assessment of watershed response to climate variability [5][6] or variability of vegetation, [7][8] monitoring and management of water quality [9][10][11] and simulating the impact of anthropogenic practices on the hydrology of watersheds [12].

Since 1940, various algorithms have been developed, ranging from very simple empirical models to complex physically based spatial distributed models, with 10–15 parameters [13]. The most first models assume spatially uniform watershed characteristics, a larger computing time step, and a smaller number of conceptual elements to represent the water flow and storage through the basin [14]. The models complex require the spatial distribution of input variables. Several parameters are used to represent the water flow through the watershed [15].

The accuracy and skill of flow hydrological models can have a direct impact on decisions with regard to water resources management [16]. The choice of the appropriate hydrological model for carrying out simulated studies is still subject to financial constraints for third world countries. Studies conducted to compare the performance of copyright software and open source software for hydrological modeling, demonstrate the applicability of the SWAT tool for the estimation of downstream flow in watersheds [17], hence its choice for carrying out this study.

The Soil and Water Assessment Tool (SWAT), developed by the USDA Agricultural Research Service (USDA-ARS) [18], is a watershed scale model that simulates hydrology, water quality, and watershed management. It has been tested and evaluated under different contexts around the world, including Morocco by [19], [20], [21], [22], [23]. These studies have shown that SWAT has better performance when compared to existing hydrological models tested in the Moroccan context [24].

The main objective of this study was to: i) Assess the performance of the SWAT model to a catchment characterized by activities ranging from humid to semi-arid with snowfall upstream and variable use of soil resources, ii) Set up a hydrological model of the Beht catchment necessary for the subsequent establishment of an integrated plan to manage the water resources and soils of this catchment.

The contribution of this study is the application of SWAT and the Sequential Uncertainty Fitting algorithm SUFI-2 [25] for the first time in a Moroccan agri-sylvi-pastoral catchment characterized by a strong spatial irregularity of precipitation between its upstream called " water tower of Morocco " [26] located in the sub humid climatic zone with snowy precipitations and its downstream subjected to the effects of semi-arid climate. The previous use of pedagogical data taken from the SWAT soil database and the Harmonized World Soil Database [19], [20], [24], [27] due to the lack of general pedagogical coverage in Morocco at suitable scales (1/50 000) resulted in the neutralization and disabling of the soil impact of the soil factor across the basins studied in the development of SWAT final HRUs.

In this study, particular attention was given to the pedagogical factor by the use of 1/ 50 000 scale maps in the majority of the basin according to SWAT's standard procedure.

II. MATERIALS AND METHODS

2.1 Description of the study area

The Beht River is one of the main tributaries of the Sebou Basin (Figure.1), covering an area of 440,793 ha. The average volume of water inflow at the Kansera dam is estimated at 355 Mm3 / year.
The Beht river passes through the highlands of the Central Meseta and the Middle Atlas of Morocco, downstream it crosses the plateau of Meknes and the Rifaines wrinkles [28].

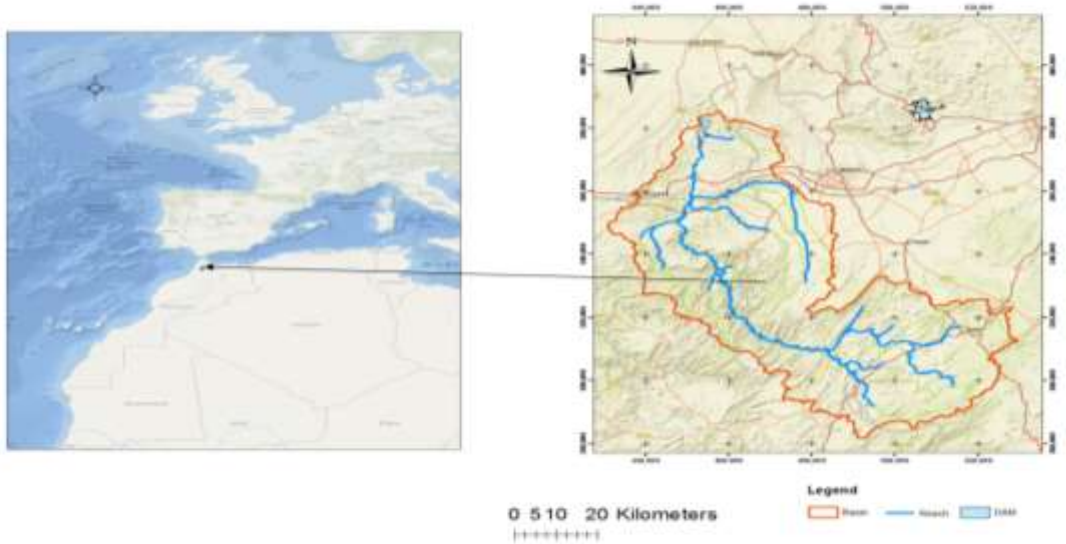

Figure 1. Geographical and hydrographic location of the study area

This basin straddles three major regions of Morocco: Rabat-Salé-Kenitra region, BéniMellal-Khénifra region and Fès-Meknes region. Its resulting area of the SWAT delimitation is 4,494 km2 subdivided into 31 sub-basins draining the whole Beht sub-basins (Figure.2). The morpho-structural ensembles identified in the study area are: Azrou plateau, Ben Smim depression, AïnLeuhcausse, Middle plateau Atlas, The causse of agourai, the causse of El Hajeb and The plateau of Saiss[29],[30], [31].

Geologically, the study area consists of Paleozoic soils composed mainly of shale, sandstone and quartzite outcrops in the Plateau to the Quaternary consisting of travertines and lacustrine limestones. The impacts of climate change and the strong anthropic pressures, to which the soil and water resources of the area have been subjected are clearly visible (spatio-temporal rainfall irregularities, droughts, floods). Therefore, sustainable and predictable long-term resource management is required. [32]

The Beht catchment is located in the Central High Plateau and the Middle Atlas. It is bounded to the North by the cities of SidiKacem and SidiSlimane, to the North East by the city of Meknes, to the East by the cities of El Hajeb and Ifrane and JbelHebri, to the South by the city of M'Rirt and to the west by the two urban centers of Oulmès and Khémisset. The pool is located between the rectangle designated by the following WGS 84 coordinates: (-6. 17; 34.06, -6. 17; 33.11, -4.99; 33.11, -4.99; 34.06) (Figure.1).

The Beht River is regulated by the Kansera dam in operation since 1934, and the new dam being built in the village of Ouljet Soltane [1]. This river is one of the tributaries of the watershed of Sebou considered one of the largest in Morocco.

Like the basins that come from the Moroccan atlas Beht watershed is humid climate upstream located at altitudes exceeding 2000 m with average annual rainfall of 900 mm. Downstream the dredging considerably up to the Kansera dam located at an altitude of 90 m, the average rainfall downstream of the basin is 440 mm/year.

The annual rainfall is also characterized by an uneven distribution over time, which gives rise to remarkable peaks of minimum and maximum flows.

The average runoff is 15% estimated by the research results described in [33][34]. The Beth is perennial although certain periods of low flow are severe less than 100 L/S. The maximal floods are important: 3 100 m3/s for the millennial rain, 1 800 m3/s for the centenary [35][34].

The climate varies from humid in the Southeast to semi-arid in the northern part of the basin.

The dominant land cover types are pasture and bare soil (52%), Evergreen Forest (22%). Spring Wheat occupies (19%) and lastly is the tree crops (1%) (Figure 3).

A land use map for the year 2006 generated by the Moroccan direction of water and Forests [36], converted to raster format, were applied in SWAT model. In the attribute data, the following SWAT codes were defined for current land use: Forest-Deciduous (FRSD), Forest-Evergreen (FRSE), Pasture (PAST), Winter Pasture (WPAS) Range Arid (SWRN), Spring Wheat (SWHT), Apple (APPL), Residential-Medium Density (URMD), Range-Brush (RNGB) and Water bodies (WATR).

The poorly developed soils dominate the soils of the Beht basin and occupy a third of the basin area. Calcimagnetic soils cover 20% and the remainder is distributed between the hydromorphic and browned soils, soils Crude minerals, soils Iron sesquioxides, Browned soils - Brunified forest, Fertialitic soils. isohumic and poorly evolved soils. Vertisol soils and complex soils are also present in the basin. [36]

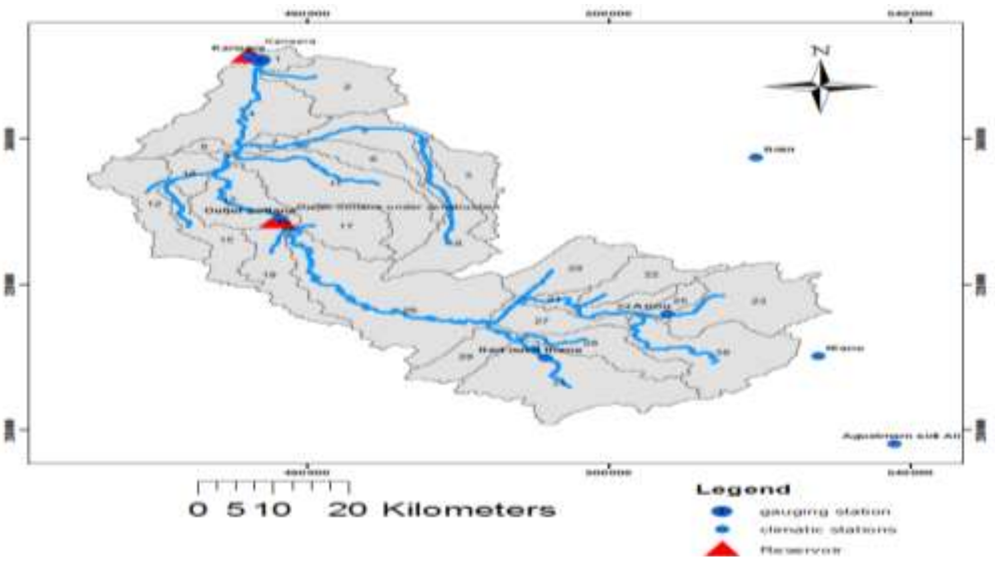

Figure 2. Delineation of sub-basins of the Beht watershed and position of rain fall stations and flow gauging

2.2 Description of SWAT

SWAT is a complete and semi-distributed hydrologic model that works on a daily basis, see schedule, evaluating the impact of management Soils and water on the hydrological functioning, water balances, chemical, agricultural watersheds [18]. SWAT is based on the use of several parameters of agricultural sciences and water

(rain, temperature, daily, soil characteristics, topography, use of water and soil resources, plant growth, nutrients, pesticides ... etc. ., which complicates the setting and calibration of the model. SWAT divides the studied basins into several sub-basins, which are further subdivided into hydrological response units (HRUs). HRUs are homogeneous combinations of soils, land use and topographic features in a sub-basin [36].
For more a detailed description of SWAT, see Soil and Water Assessment Tool input/output version 2009 [37] and the Theoretical Documentation, Version 2009 [38].

The water balance of each HRU is represented by four separate fractions: snow, water in the soil, shallow aquifer and deep aquifer. SWAT estimates the components of the water balance in a watershed as follows:
The hydrologic cycle as simulated by SWAT is based on the water balance equation (eq.1).

$SW_t = SW_0 + \Sigma(R_{day}-Q_{SUR}-E_a-W_{seep}-Q_{gw})$ (all parameters are in mm H2O) (1)

Where
- SW is the soil water content,
- t, time, Rday is the amount of precipitation on day i,
- Qsurf is the amount of surface runoff on day i,
- Ea is the amount of evapotranspiration on day i,
- Wseep is the amount of water entering the vadose zone from the soil profile on day i).

SWAT uses the simulation and calculation methods shown in Table 1, which constitute the methods adopted for this work.

Table 1. Method used to processing SWAT model

Parameter	Description of the method
Surface runoff	Two methods: the Green-Ampt infiltration method and the SCS curve number used in this study.
Lateral flow	Obtained after saturation of all soil horizons by the phenomenon of percolation.
Percolation to the shallow aquifer	Simulated by creating a shallow fictional aquifer storage.
Evapotranspiration	Three methods to estimate the potential Priestley & Taylor, Hargreaves &Samani and Penman-Monteith used in this work.
Routing of water towards river	Two methods: 1-routing method or routing method of the Muskingum River 2- variable storage used in this work.
Groundwater flow contribution to total streamflow	Simulated by routing a shallow aquifer storage component to the stream
Rainfall intensity during the watershed time of-concentration	Estimated for each storm as a function of total rainfall using a stochastic technique
Watershed time-of-concentration	Manning's Formula considering both overland and channel flow
Snow melted	On days when the maximum temperature exceeds 0°C. Melted snow is treated the same as rainfall for estimating runoff and percolation.

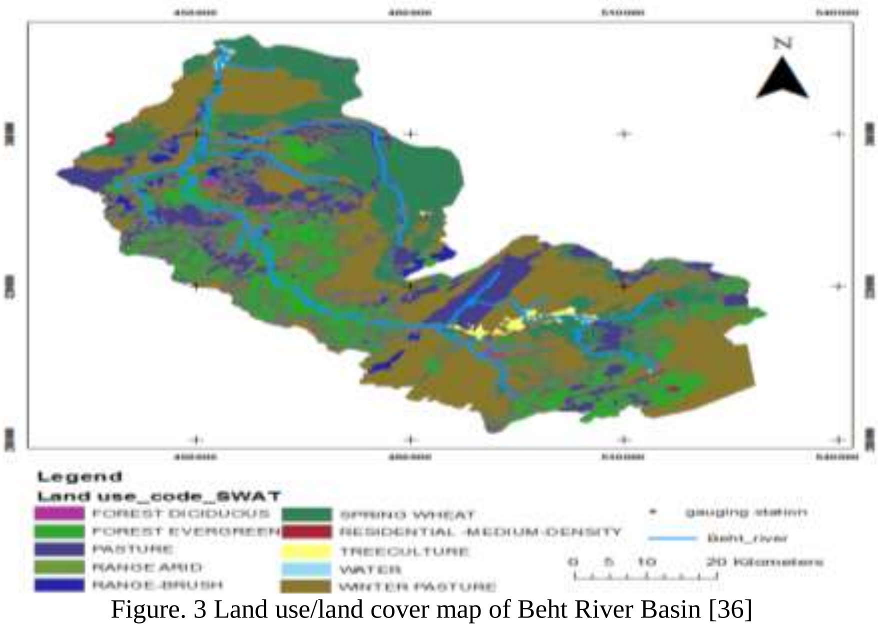

Figure. 3 Land use/land cover map of Beht River Basin [36]

2.3 Description of SUFI-2

To overcome the simulation errors from the model SWAT we are used the Sequential Uncertainty Fitting (SUFI-2) [9] algorithm accessible through the SWAT-CUP [39] application. It helps to calibrate the model and to validate the results generated during simulation. SWAT-CUP also provides the means to use other modeling error elimination procedures such as Glue [40], Parameter solutions (Parasol) [41] and Markov Chain Monte Carlo [42] (MCMC) . In this research, many SWAT parameters related to discharge were tested using the SUFI-2 algorithm in which the uncertainty is defined as the discrepancy between the measured and simulated variables.[43]

To eliminate modeling divergences, it is necessary to record observations identify and estimate the model uncertainty. SUFI-2 combines calibration and uncertainty analysis to find parameter uncertainties that result in prediction uncertainties bracketing most of the measured data, while producing the smallest possible prediction uncertainty band.

The estimated parameter uncertainties reflect all sources of uncertainties, i.e. conceptual model, forcing inputs and parameter [25], [39].

In SUFI-2 the performance and degree of model calibration are measured by an index referred to as the P-factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). The 95PPU is calculated at a rate of 2.5% and 97.5% levels of cumulative distribution of output variable obtained by Latin hypercube sampling [44].

In each iteration, previous parameter ranges are updated by calculating the sensitivity matrix, and the equivalent of a Hessian matrix followed by the calculation of a covariance matrix, 95% confidence intervals of the parameters, and a correlation matrix. Parameters are updated in such a way that the new ranges are always smaller than the previous ranges, and are centered on the best simulation.[39]

The R-factor index is also used to quantify the strength of a calibration. It is defined as the average thickness of the split 95PPU band divided by the standard deviation of measured data. SUFI-2, searches to bracket most of the measured data (P-factor approaching the maximum value of 100%) with the smallest possible uncertainty band (R-factor approaching the minimum value of zero) the uncertainty [9], [45].

For calibrating based on the discharge component, P-factor>70% and R-factor of around 1, have been recommended [44]. The combination of P-factor and R-factor together indicate the strength of the model calibration and uncertainty assessment, as these are intimately linked [46].

2.4 Data needs

In this study, the Beht watershed upstream Kansera dam was subdivided into 31sub-basins and 213 HRUs. The basic data sets required to building the model are topography, soil, land use and climatic data. The data used in modelling are as follows (Table 2)

2.5 Calibration/validation method/Sensitivity analysis

The calibration refers to a procedure where the difference between model simulation and observation are minimized. [25]. Two methods are used for model calibration, manual calibration and automated calibration [47]. In this work we used the manual method for recharging aquifers and the automatic method for the other parameters studied explicitly below. Calibration is inherently subjective and, therefore, intimately linked to model output uncertainty [25].

Validation is used to build confidence in the calibrated parameters. For this purpose, the calibrated parameter ranges are applied to an independently measured dataset, without further changes. The term validation has a broader meaning including any process that has the goal of verifying the ability of a procedure to accomplish a given scope [48].

Calibration/validation, uncertainty analysis, and sensitivity analysis were performed within the SWAT Calibration and Uncertainty Programs SWAT-CUP version 2012 using the SUFI-2 algorithm.

The calibration of the Beht hydrological model consists in adjusting the results obtained during the first simulations to reproduce as much as possible the values measured and observed at the measurement stations.

Two methods of sensitivity analysis are usually used. These are one-at-a-time (OAT) or local sensitivity analysis, and all-at-a-time (AAT) or global sensitivity analysis [46]. In OAT, all parameters are held constant while changing one to identify its effect on some model output or objective function [49].A t-stat and p-value is used to measure the sensitivity and relative significance of each parameter. [50]

The parameters, which have superior value of t-stat and smaller value of p-value, are most sensitive parameters[49]. Sensitivity analysis was performed with 1500 iteration and the results were examined. Parameter sensitivity analysis helps focus the calibration [46]. The initial input parameters used for the sensitivity analysis are listed in the Table 4. This operation can be done on SWAT or by adjusting the input values randomly or by carrying out a sensitivity analysis of the catchment parameters. In this work, the sensitivity analysis was carried out through SWAT-CUP.

Table 2. Data needs for project

Spatial data	Description	Source
Topography	The digital elevation model (DEM) 30 m×30 m was used to obtain the physical parameters of the basin including the slope, channel slope and reach length. SWAT was used to delineate and divide the watershed into several sub-basins related to their outlet's points, and to establish the flow direction, flow accumulation, and stream network generation (fig.2).	USGS Shuttle Radar Topography Mission (SRTM) [51].
Land use	The land use map used was obtained from the Beht watershed management project (Moroccan water and forest management).	Study of the watershed of the Beht river upstream of the El Kansera dam. [36]
Climatic data	Observed weather parameters from January 2001 to December 2014 including daily rainfall from 9 recording stations inside the watershed were imported to the SWAT model. The rain station locations used in this work is explained in tab.3.	ABHS records (Hydraulic Basin Agency of Sebou, Morocco). Directorate of National Meteorology in Morocco
	Wind, relative humidity, and solar were obtained from the global weather data.	The National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) [52]
Hydrological Gauge data	For calibration, hydrological datasets of Beht river observed flow are required. Observed flow data from January 2000 to December 2014 from 2 recording stations inside the watershed were used to calibrate and the validate SWAT model. (tab.3) The map (Figure 2) show the location of the gauging station of Kansera.	ABHS DRPE (The Directorate of Research and the Water Planning in Morocco), with a monthly time step from September 2000 to August 2015.
Soil types	Soil types: the parameters of soils requested to processed the SWAT model of beht were obtained from the soil survery reports and maps covering the study area at 1/50 000 scale for the regions of khemissat, meknes, Hajeb, Oulmes, and Khenifra. The 1/200000 scale map was used for the Tigrigra and AinAinLeuh sub-basins Located north of the watershed. The said reports included soil texture, soil hydrological group, number of soils layers, % of clay, sand, silt and the organic carbon in addition to pH and electrical conductivity. The functions of the pedo-transfers were used to calculate saturated hydraulic conductivity, soil erodibility factor, moist soil albedo, and moist bulk density necessary to process the model [53].	Ministry of Agriculture and Fisheries - Department of Agriculture

Table 3. Location of climatic and hydrometric stations

ID	Type	LAT	LONG	ELEVATION (m)
Aguelmamsidi Ali	Meteorology	33.08	-4.99	2078
Kansera	Meteorology	34.04	-5.91	90
Ouljet Soltane	Meteorology	33.63	-5.86	305
Azrou	Meteorology	33.41	-5.38	1075
Bittit	Meteorology	33.68	-5.37	800
Had ouedIfrane	Meteorology	33.29	-5.48	1075
Ifrane	Meteorology	33.30	-5.10	1600
Kansera	Gauging station	34.04	-5.91	90

Table. 4 Parameters considered for the sensitivity analysis.

Parameter_Name	Description	Min value	Max value
R__CN2.mgt	SCS runoff curve number*	-0.2	0.2
V__CH_K2.rte	Effective hydraulic conductivity of main channel	0	150
V__CH_N2.rte	Manning’s ‘‘n’’ for main channel	0.01	0.3
V__CANMX.hru	Maximum canopy storage	10	100
V__LAT_TTIME.hru	Lateral flow travel time	0	180
R__HRU_SLP.hru	Average Slope Steepness	-0.2	0.2
V__OV_N.hru	Manning’s ‘‘n” value for overland flow	0.01	30
R__SLSUBBSN.hru	Average slope length	-1	1
R__SOL_AWC(..).sol	Available water capacity of the soil layer	-0.2	0.2
R__SOL_BD(..).sol	Moistbulkdensity	-0.2	0.2
R__SOL_K(..).sol	Saturated hydraulic conductivity	-0.2	0.2
V__SNOEB(..).sub	Initial snow water content in elevation band	0	100
V__TLAPS.sub	Temperature lapse rate	-5	5
R__PLAPS.sub	Precipitation lapse rate	-100	500
V__SMFMX.bsn	Maximum melt rate for snow during year (summer solstice)	1.4	7.5
V__SMTMP.bsn	Snowmelt base temperature	-5	5
V__EPCO.bsn	Plant uptake compensation factor	0.01	1
V__ESCO.bsn	Soil evaporation compensation factor	0.01	1

Parameter_Name	Description	Min value	Max value
V__FFCB.bsn	Initial soil water storage expressed as a fraction of field capacity water content	0.01	1
V__SURLAG.bsn	Surface runoff lag time	0.001	10
V__SMFMN.bsn	Minimum melt rate for snow during year (winter solstice)	1.4	7.5
V__SFTMP.bsn	Snowfall temperature	-5	5
V__ALPHA_BF.gw	Base flow alpha factor (days)	0	1
V__GW_DELAY.gw	Groundwater delay	30	450
V__GW_REVAP.gw	Groundwater ‘‘revap” coefficient	0.02	0.2
V__REVAPMN.gw	Threshold in the shallow aquifer for ‘‘revap” to occur	0	500
V__GWHT.gw	Initial groundwater height	5	25
V__RCHRG_DP.gw	Deep aquifer percolation fraction	0.01	1
V__GWQMN.gw	Threshold in the shallow aquifer for return flow to occur	0	5000
V__DEEPST.gw	Initial depth of water in the deep aquifer	0	5000
V__SHALLST.gw	Initial depth of water in the shallow aquifer	0	5000

v__: means the default parameter is replaced by a given value, and r__ means the existing parameter value is multiplied by (1 + a given value), * Varies with land use and soil type from [51.17 to 95.62 the mean is 75]

2. 6 Performance Indice

To evaluate SWAT model performance, four model evaluation statistics were selected based on the recommendations suggested by [46] and [54] using NSE, PBIAS, RSR and R2 (Equations 2, 3, 4 and 5).

- The Nash-Sutcliffe efficiency coefficient (NSE) is a normalized dimensionless statistic that determines the relative magnitude of the residual variance compared to the measured data variance (Nash and Sutcliffe, 1970). NSE varies between negative infinity and 1. NSE is considered the best objective function for reflecting the overall fit of a hydrograph [55].

$$NSE=1-\left[\frac{\sum_{i=1}^{n}(Y_i^{obs}-Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs}-Y_i^{mean})^2}\right] \quad (2)$$

- Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts, the optimal value of PBIAS is 0. A positive PBIAS indicates that the simulated values are under-estimated with respect to the observations, while a negative PBIAS indicates that the simulated values are overestimated [56].

$$PBIAS=\left[\frac{\sum_{i=1}^{n}(Y_{i=1}^{obs}-Y_{i=1}^{sim})*100}{\sum_{i=1}^{n}(Y_i^{obs})}\right] \quad (3)$$

- RSR [54] is calculated as the ratio of the RMSE Root Mean Square Error is the standard deviation of the residuals. Residuals are a measure of how far from the regression line data points are; RMSE indicates how concentrated the data is around the line of the best fit. RSR and standard deviation of measured data, as shown in equation 4.

$$RSR=\frac{RMSE}{STDEV_{obs}}=\frac{\left[\sqrt{\left(\sum_{i=1}^{n}(Y_i^{obs}-Y_i^{sim})^2\right)}\right]}{\left[\sqrt{\left(\sum_{i=1}^{n}(Y_i^{obs}-Y_i^{mean})^2\right)}\right]} \quad (4)$$

- The coefficient of determination (R^2) describes the degree of collinearity between simulated and measured flow yield. R^2 varies between 0 and 1.

$$R^2=\frac{\sum_i\left[\left(Y^{obs}-Y_0^{mean}\right)\left(Y^{sim}-Y_s^{mean}\right)\right]^2}{\sum_i(Y^{obs}-Y_0^{mean})^2-\sum_i(Y^{sim}-Y_s^{mean})^2} \quad (5)$$

Arnold et al [46] reports that the above statistical indices only apply to the comparison of two signals and are not adequate when outputs are expressed as uncertainty bands. In this case, as the simulation results are expressed by the 95% prediction uncertainties (95PPU), they cannot be compared with the observation signals using the traditional R2 and NSE statistics. For these reasons we also used in this work the factors P and R suggested by [9], [44] detailed above.

III. RESULTS

3.1. Initial model run analysis

Preliminary results on topography retrieved from the model indicated elevation ranging from 122 to 2160 m with mean of 888.57 m and standard deviation of 449.32 m. The average curve number was computed to be 75.03 which meant the hydrological condition of the Beht River catchment ranged from high to medium potential for runoff [33],[35].The river Beht's direction in SWAT allowed the delimitation of the basin of the catchment of Beht. The delimitation obtained is the same as that obtained in other studies carried out by the DRWE [34]. The total area of SWAT basin is 4 494.25 km², which is less than the area announced by previous studies, which is of the order of 4 540 km², a difference of 1% [34].

The study of the directory of water and forests of Morocco [36] announce an area of 4 407 km² which seems slightly underestimated. The forms of the watershed and sub-basins are elongated and the concentration times in the majority of the sub-basins are low, which induces the appearance of inundations in the watershed.

3.2 Assessing water balance in Beht watershed

The water balance of the Beht catchment has been modeled by SWAT over the period of calibration. Initial simulation values based on the general land use, soil and slope, resulted in a significant over-estimation of low flows with regression slope of less than 0.5. This meant that the model was unable to drain the rainfall.
The results obtained show that the current land use contributes to a strong dominance of water losses by evapotranspiration; which is of the order of 224.2 mm; or more than 40% of the overall water balance.
The surface runoff calculated under SWAT is of the order of 73 mm / year for an average precipitation of 531 mm during the calibration period; or more than more than 13 % of the overall water balance.

The recharge of the existing aquifers in the Beht Basin has been estimated during the calibration period of SWAT model at 8%. The annual magnitude of rainfalls and flows used for the calibration is shown in Table 5. The highest flows are observed from December to March, low water flows are observed during the months of July and August.

Table 5. Simulated water balance components of Beht watershed during the period 2002 to 2010

MON	RAIN mm	SNOMELT mm	SURQ mm	LAT_Q mm	WYLD mm	ET mm
1	62.14	7.53	11.09	2.66	28.93	18.19
2	72.74	10.75	9.94	2.54	28.25	20.51
3	62.14	0.18	10.45	3.09	32.85	29.02
4	45.55	2.3	5.39	2.93	22.52	30.26
5	26.99	0	1.91	2.78	14.09	28.07
6	10.57	0	0.59	2.29	6.89	14.37
7	3.73	0	0.02	1.96	3.63	7.98
8	3.97	0	0	1.61	2.39	6.4
9	21.92	0	1.23	1.35	3.16	9.57
10	55.32	0	4.21	1.49	7.15	19.59
11	85	2.16	12.84	1.84	19.2	20.63
12	80.37	6.12	15.23	2.58	29.82	19.5
Total	530.44	29	72.9	27.1	198.9	224.1
Fraction out of rainfall and snow melt			13.03%	4.85%	35.55%	40.05%

- MON: Monthly time step
- PRECIP: Total amount of precipitation falling on the subbasin during time step (mm H2O).
- SNOMELT: Amount of snow or ice melting during time step (water-equivalent mm H2O).
- ET: Actual evapotranspiration from the subbasin during the time step (mm).
- SURQ: Surface runoff contribution to streamflow during time step (mm H2O).
- WYLD: Water yield (mm H2O). The net amount of water that leaves the subbasin and contributes to streamflow in the reach during the time step.
- (WYLD = SURQ + LATQ + GWQ – TLOSS – pond abstractions)
- LATQ: Lateral flow contribution to streamflow during timestep (mm H2O)

3.3Sensitivity analysis

The most sensitive parameter in this study area is CN2 followed by ALPHA_BF and the others parameters representing the functioning of the aquifers. The input parameters included fitted value of the most sensitive parameters; t-stat and p-values, rank of sensitivity are listed in the Table 6.

3.4Calibration and uncertainty analysis

The simulated and observed discharge was compared at Kansera gauging station during calibration period 2003–2010. The performance indices during the calibration period are listed in Table 7. In this study, the behavioral threshold was set at NSE>0.5. Using a threshold value of NSE>0.5, the SUFI-2 algorithm found 943 behavioral solutions in 1500 simulations. The r-factor is 0.85 while p-factor 0.72 was obtained during calibration.

The NSE and R² values were observed as 0.77 and 0.83, respectively. The PBIAS value is −3.9 while the RSR is 0.48 during model calibration which suggests very good model performance [57], [58]. Figure 4 described the observed and simulated pattern during calibration period. Sensitive SWAT parameters used in the calibration, t-Stat and p–value, max value, and min value.

Table.6 Sensitive SWAT parameters used in the calibration, t-Stat and p–value, max value, and min value.

Parameter Name	t-Stat	p-Value	Fitted_Value	Min_value	Max_value
R__CN2.mgt*	10.43	0	-0.03%	-20%	20%
V__ALPHA_BF.gw	5.62	0	0.92	0.01	1
V__ESCO.bsn	-2.04	0.04	0.91	0.3	1
V__LAT_TTIME.hru	-1.97	0.05	143.4	0	180
V__GW_REVAP.gw	-1.78	0.08	0.096	0.02	0.2
V__GWHT.gw	1.45	0.15	16.93	5	25
V__GWQMN.gw	-1.43	0.16	516.66	0	5000
V__CH_N2.rte	-1.1	0.28	0.067	0.01	0.3
V__GW_DELAY.gw	-1.06	0.29	48.2	30	450
V__EPCO.bsn	-0.92	0.36	0.68	0.3	1
V__SURLAG.bsn	0.83	0.41	1.63	0.001	10
V__SHALLST.gw	0.65	0.51	550	0	3000
V__CH_K2.rte	-0.21	0.83	69.5	0.01	150
V__REVAPMN.gw	0.11	0.91	238.33	0	500
V__DEEPST.gw	0.06	0.95	2030	0	3000

v__: means the default parameter is replaced by a given value, and r__ means the existing parameter value is multiplied by (1 + a given value), *Varies with land use and soil.

Table 7. Statistical index and results Uncertainty analysis for evaluation of monthly initial calibration, calibration (2002-2010) and validation (2011–2014)

Statistics	Pre-calibration	Calibration (2002-2010)		validation (2011-2014)	
NSE	-1.22	0.77	Very good	0.76	Very good
PBIAS	-172.2	-3.9	Very good	-10.1	Good
RSR	1.44	0.48	Very good	0.49	Very good
R^2	0.45	0.83	-	0.78	-
P- factor	-	0.77	Satisfactory	0.69	Not Satisfactory
R- factor	-	0.96	Satisfactory	1.53	Satisfactory

Figure 4 described the observed and simulated pattern during calibration period.

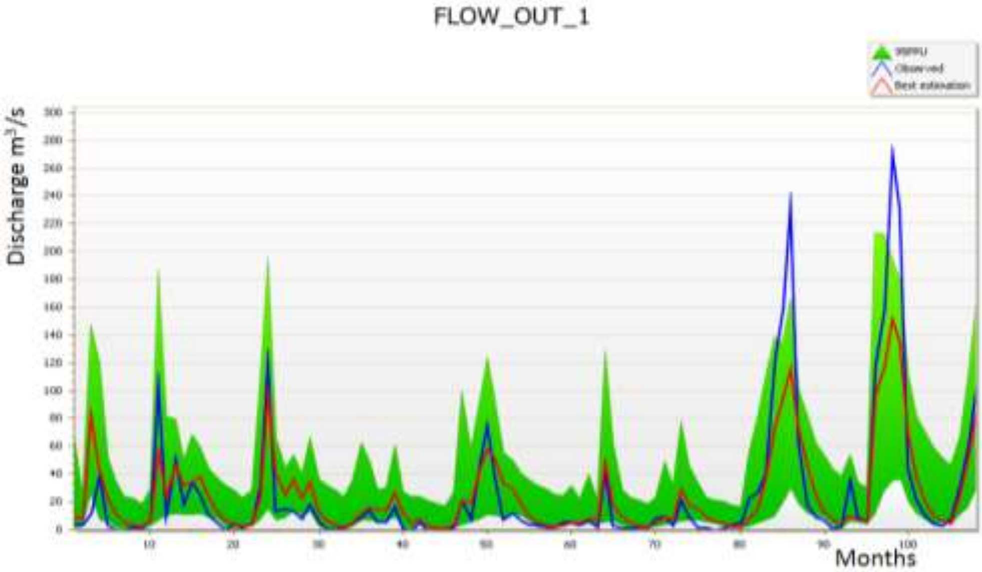

Figure 4.95% probability uncertainty plot and observed stream flow during a calibration (2002–2010)

The scatter plot (Fig. 5) shows relationship between observed and simulated variables with very good correlation (R2= 0.83).

The monthly discharge at the station gauging of Kansera was been significantly underestimated, and low flow was overestimated using the SUFFI-2 algorithm. The performance criteria obtained respected the recommendation given by Moriasi et al. [57].

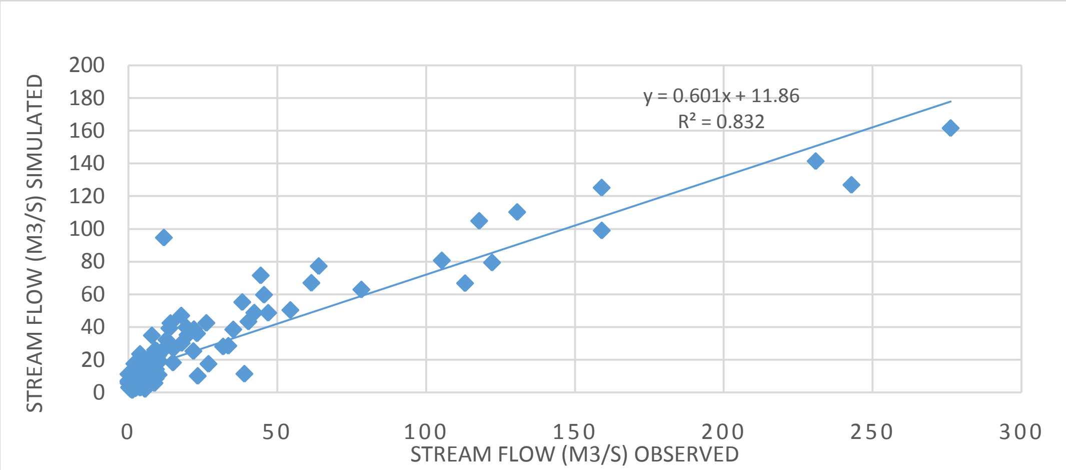

Figure. 5 Scatter plot of observed vs. simulated flow (calibration)

SUFI-2 uncertainty analysis results (P-factor and R-factor) during the calibration periods at the kansera gauging station are shown in table 7 and figure 4. In this figure, the green shaded region (95PPU) contains all uncertainties from the different sources except the peak flows observed during the calibration period.

The results indicated that the P-factor value is 0.77, and that the R-factor value is 0.96 during the calibration. In the station of Kansera, the model shows large uncertainties for extreme events during the calibration and validation periods.

3.5 Model validation

Validation of the Beht model is used to build confidence in the calibrated parameters. For this purpose, the calibrated parameter ranges are applied to an independent measured dataset, without further changes. [49][46]

Model validation of Beht was performed using same algorithm as in calibration with 1500 times run for the period 2011–2014. Graphically, the model reproduces well the monthly flows (Fig. 6).
The model performance for the validation period is presented in Table 7.

The NSE and R^2 values were observed as 0.76 and 0.78, respectively. The PBIAS value is −10.1 while the RSR is 0.49 during validation period of the model which indicate satisfactory model performance result [57], [58].

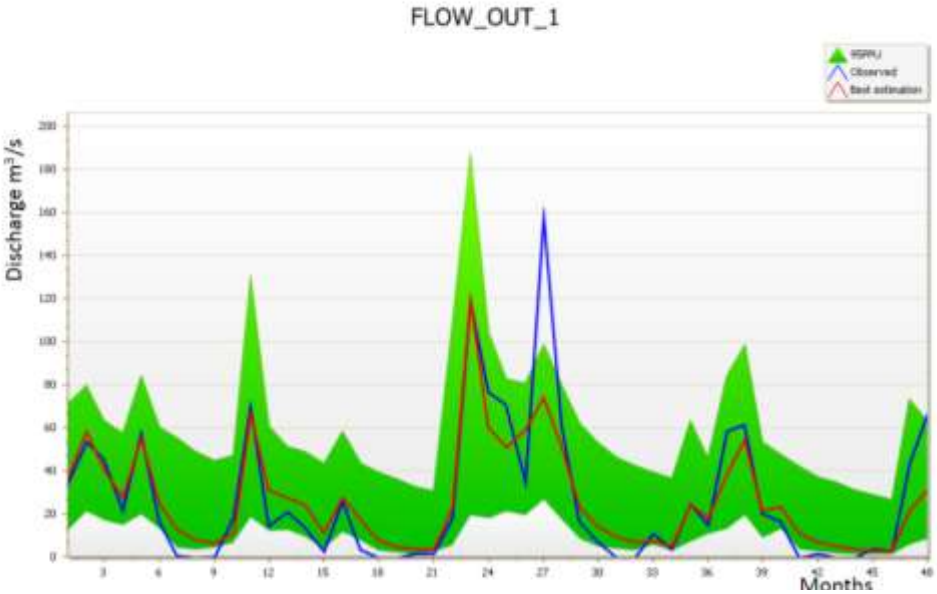

Figure 6.95% probability uncertainty plot and observed stream flow during a validation (2011–2014)

Uncertainty analysis results of SUFI-2 during the validation periods at the kansera gauging station is shown in table 8 and the figure 6. The shaded region (95PPU) in the figure 6 contains all uncertainties from the different sources except the peak flows recorded in 2013.

The results show that the p-factor value is 0.69, and that the r-factor value is 1.53 during the validation. As in the period of calibration, the model shows large uncertainties at extreme events during the validation periods.

IV. DISCUSSION

The main objective of the paper was to calibrate and validate the SWAT model in a typical Moroccan agri-sylvi-pastoral watershed characterized by a very limited of anthropogenic activity. This work will be a first step for the elaboration of an integrated water management plan.

Sensitivity analysis, model calibration and validation were used to evaluate the efficiency of the hydrological model of the Beht catchment.

Brouziyne et al 2017 [59] performed the Sensitivity analysis and found the CN2, SOL_AWC, ESCO and GQWN as most sensitive parameters in a semi-arid catchment.

Cao et al in Karst catchment characterized by the presence of important aquifer [60] indicated the CN2 is the most sensitive parameter in addition HRU_slp, Sol_K, RCHRG_DP, GW_Delay, OV_N, ALPHA_BF, GWQMN, followed by SOL_Z, REVAP_MN and ESCO.

In our study area among 15 sensitive parameters the sensitivity analysis shows that CN2, ALPHA_BF, ESCO, LAT_TIME, GW_REVAP, GWHT, GWQMN, CH_N2, GW_DELAY, EPCO, SURLAG, SHALLST, CH_K2, REVAPMN and DEEPST are the most sensitive parameters. They are listed in decreasing order of sensitivity.

A limitation with SWAT is that it cannot rigorously simulate groundwater flow [43](Guzman et al., 2015). In our study area, groundwater represent the very important origin of the final discharge of Beht River [31] and therefore the parameters wish represents the groundwater discharge are the most sensitive.

Many groundwater parameters were identified as the most sensitive parameters. Two of them GW_DELAY, and ALPHA_BF control the retention of the water in the soil via the groundwater to the river reach. ALPHA_BF has a value that set aquifers as a high velocity response to recharge [38].

Hence, both parameters are related to the timing of the process. The GW_DELAY measured in days regulates the time delay for recharging the shallow aquifer. An increase of this delay factor leads to a slower recharge process and vice versa. [61]

GW_DELAY was set to 48, as groundwater is not very deep in this region and thus has a short time lag. Note that the sub-bassins 23 and 30 (Figure 2) located in the upstream of the Beht catchment are characterized by the presence of karstic geological form that favor the infiltration of precipitation [31].

A similar study of a Spanish catchment[62] describes that the presence of ALPHA_BF, RCHRG_DP, GWQMN, and GW_REVAP) and lateral flow (LAT_TTIME), wish demonstrate that shallow aquifers have a relevant role and corroborates the results obtained in our case study.

The presence of GW_REVAP, EPCO and ESCO in the list of sensitive parameters identified can be explained by the important extraction of the evaporative demand from the lower soil layers.

The calibrated parameters were similar to previous references in areas with similar climate and vegetation cover characteristics.

For our study area, the SWAT model obtained did not correctly predict the peak values of discharging recorded respectively in the years 2009, 2010 for the calibration period and the year of 2013 for the validation period.

The underestimate of peak flow has been referred to several researchers working in hydrological modeling [63], [64], [65], [66, p. 1], which may constitute a limitation of the SWAT tool in the Moroccan context, particularly the Beht watershed characterized by flash-flood.

The results of the uncertainty analysis are generally satisfactory during the calibration period for the station of Kansera in terms of the percentage of data being bracketed (p-factor), but the uncertainties are larger as expressed by the r-factor in the same station.

The medium p-factor and r-factor in relation to the recommendations of Abbaspour[44] who proposes; p-factor>70% and r-factor of around 1; to have good results, indicate the uncertainty in simulation may be caused by error in the rainfall and temperature input [67], [68].

Calibration result can also be justified by seeing the trend of simulated and observed flow rates in 95ppu plot (Figure 4) which are following the same trend, with a significant underestimation of the simulated peaks flows values when compared to the observed data. The r-factor during calibration is relatively important but it is less than one means good result.

The use of the of the hydrological signature [2] tested in Italy in the two sub basins ungauged 23 and 31 which are at the origin of peak flows can be beneficial to overcome the simulation errors of exceptional events [69] weakly simulated with SWAT.

Note that, rainfall distribution in SWAT is undertaken by associating each sub-basin with the nearest rainfall gauging station closest to its centroid [70, p. 1], and because the catchment of Beht has only four rainfall gauging stations upstream from the control section located in the reservoir of Kansera. For this purpose, spatial distribution of rainfall in the Beht catchment may not have been representative.

The need to have representative and correct climate data, has also been confirmed by several researchers who have studied the impact of the quality of rainfall input data on the modeling results of catchments, particularly in mountainous terrain. [71], [72, p. 1] and [70, p. 1]

Hence, improved precipitation input of the upstream of Beht River is very important to obtain good results for this catchment subject to the influence of several climates from upstream to downstream.

During the period 2011-2014, the P-factor and R-factor obtained were 0.69 and 1.53 respectively.

The percentage of observed data grouped together by 95PPU during validation was 69%, which still fell short of the > 70 % suggested by [44] thus making the model performance unsatisfactory.

V. CONCLUSIONS

The SWAT model was applied to the Beht catchment to model its hydrological water balance. It was successfully calibrated and validated at the Kansera gauging station.

The hydrological water balance analysis showed that baseflow is an important component of the total discharge within the study area that contributes more than the surface runoff. More than 40% of losses in the Beht catchment are caused by evapotranspiration.

The calibrated model can be used for further analysis of the effect of climate and land use change, to establish an integrated management plan of water resources, as well as to investigate the effect of different management scenarios on streamflows and sediment yields. It can also be used in ungauged watersheds with similar natural features and comparable management practices to those used in the Beth catchment.

The model evaluation statistics for the Beht catchment gave very good results that were verified by NSE and R2 > 50 %. The use of SUFI-2 algorithm gave satisfactory results to minimize the differences between observed and simulated streamflows.

The uncertainty and its quantification overcome as a challenging task in the SWAT model predictions. The results shows that the SUFI-2 produces reasonable parameters for the calibration, uncertainty analysis, and validation of the SWAT model.

The p-factor and r-factor computed using SUFI-2 gave good results by bracketing more than 70% of the observed data during the calibration and around 70% for the validation period.

The monthly simulation for the Kansera station is very good during the calibration period while during validation the SWAT model exhibit small uncertainties and good validation result.

The weakness of the model to produce very good indices of uncertainty was due to the improper peak runoff simulation and the nature and accuracy of the measured flow and rainfall data.

In spite of the different source of uncertainties, the SWAT model produced very good simulation results for monthly time steps.

It is suggested in future studies, to use more uncertainty techniques in model calibration, sensitivity and uncertainty analysis, as well as the simulation of the catchment using a daily time steps.

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