MANAGEMENT OF WATER SCARCITY IN ARID AREAS.

Study case: Ziz watershed the way forward

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Key Points:

- Climate change, SDGs (6)
- Temporal downscaling
- Real-time dam management
- Hydropower
- Dam performance

Abstract

The 2030 Agenda for Sustainable Development aims to reach 17 Sustainable Development Goals (SDGs). The 6th goal (SDGs (6) deals with water security, which refers mainly to water use efficiency and water stress. Indeed, water security plays an important role in water-food-energy nexus. This work aims to enhance dam performance under climate change to overcome water scarcity. The study is conducted through the multiobjective Hassan Addakhil dam in Morocco. The novelty of this work is providing hourly precipitation and evaporation data through temporal downscaling and developing a real-time dam management tool. The real-time dam management algorithm is based on a water balance equation and rule curves. The model is coupled with the Hydrologic Modeling System (HEC-HMS). This tool provides information about (i) dam storage, (ii) dam release, (iii) dam evaporation, (iv) dam diversion, (v) spilled water volume, (vi) emergency spilled water volume, (vii) dam inflow, (viii) irrigation demand, (ix) irrigation shortage, (x) dam siltation, (xi) dam hydropower production, (xii) hydropower energy income. The result shows that real-time management can enhance dam management. In this sense, the dam reliability and resilience have increased respectively from 40% to 70% and from 16% to 66%. Besides, the vulnerability remained constant.

1 Introduction

According to the IPCC's Vth Report, 80% of the world's population faces a water security crisis (Jiménez Cisneros et al., 2015). Furthermore, renewable surface water and groundwater resources will significantly decrease in most dry subtropical regions (Kaito et al., 2000). The water security crisis will intensify water stress among agriculture and energy production. For the 2000-2080 fu-ture period, crop water demand will increase by 20%, under the A2 scenario (Fischer et al., 2007). Moreover, (Gain, 2016) shows that Africa will experience a very high water security crisis, which needs integrated strategies focusing on water management, enhancing water accessibility, water safety, and quality (Figure 1).

From 2000 to 2015, UN members have adopted the Millennium Development Goals (MDGs). This program concerns emerging countries. It aims eight goals: poverty, hunger, disease, unmet school-ing, gender inequality, and environmental degradation. Indeed, the (MDGs) concludes at the end of 2015, and global awareness about sustainable development brings a set of Sustainable Develop-ment Goals. In September 2015, the United Nations members adopted the 17 Sustainable Devel-opment Goals (SDGs), which concern all the word. The 6th goal deals with water security in a way to ensure availability and sustainable management of water and sanitation for all (Sachs, 2012).

Morocco is a Mediterranean country located in northwestern Africa, bathed in the North by the Mediterranean Sea and in the West by the Atlantic Ocean. The kingdom covers an area of 710850 km², with a population estimated to 35 M according to the 2014 census. Due to the topographic conditions, the influence of the Atlantic Ocean and the Mediterranean Sea, the climate in Morocco is variable (Figure 2). Based on Emberger's quotient (Condés & García-Robredo, 2012; Mokhtari et al., 2013), the climate in Morocco ranges from Humid bioclimatic stage to Saharan bioclimatic stage (Karmaoui et al., 2020) (Figure 2). Indeed, 80% of the country's area experiences precipitation less than 250 mm/year (Morocco, 2014). The availability of freshwater per capita in Morocco is below 1000 m3 per person per year, which makes it one of the African countries suffering from water scarcity, according to (Falkenmark et al., 1989), per capita availability of renewable fresh-water resources index.

Based on the future projections of regional climate model RACMO2/KNMI,(Philandras et al., 2011) shows that the mean annual precipitation within morocco will decrease between -40% to-50% dur-ing the period 2071–2100. In this context, Morocco is one of the countries highly treated by water security problems (Bank, 2017). To overcome this problem, Morocco has adopted a dam policy since 1960 (Karmaoui et al., 2020). This policy increased the number of large dams from 16 to 128 by 2009, mobilizing 11.7 billion m3. Furthermore, the kingdom is planning to build three new large dams to reach an additional 1700 million m3 per year by 2030 (Afilal, 2017). Moreover, Morocco has strengthened the legal water frame by adopting Law 10-95 in 1995 and Law 96-15 in 2016, aiming to ensure water security and strengthen decentralized water management. (Afilal, 2017; Avellà-Reus, 2019; Molle, 2017).

Moving to dam construction to guarantee water security begins in the 19th century (Shah & Kumar, 2008), which leads to the construction of 50.000 large dams in the 20th century (Sparrow et al., 2011). Dams are multiobjective in a way to guarantee agriculture demand, water supply (Zhao et al., 2012), Hydroelectric production, and flood control (Elhassnaoui et al., 2020). However, (Karami & Karami, 2019) and (Okkan & Kirdemir, 2018) show that, under RCP8.5 projections, reservoir inflow will decrease, in the Mediterranean in a way to alter the reservoir's sustainability. Therefore, sustainable management of existing dams become a real challenge for decision-makers (Karami & Karami, 2019). Then we need a better approach to enhance the performance of the ex-isting dams(Tiğrek et al., 2009).

In this sense, linear and dynamic algorithms are required for boosting dams operation to meet downstream demands (Hejazi & Cai, 2011). Many studies have developed models based on a water balance equation as an alternative to water resource management. (Tinoco et al., 2016) carried out a study over the Macul basin in Ecuador to maintain the sustainable balance between irrigation and river ecology. The results show that meeting irrigation demand supposes that the decision-makers should adopt for deficit irrigation and the modification of spillway dimension (Saha et al., 2017). A reservoir operation function under the HEC-5 model was proposed to analyze a system of reser-voirs at a daily time step using the water balance equation. (T. Silva & Hornberger, 2019) devel-oped a model that can better enhance dam performance by the optimization of irrigation satisfac-tion and hydropower demand. The model is based on the water balance equation at a monthly time step. The algorithm enhanced the multipurpose reservoir cascade system in Sri Lanka based on the reliability, resilience, and vulnerability indicators. (Jaiswal et al., 2020) propose a model based on a water balance equation coupled with the Soil and Water Assessment Tool (SWAT) model for efficient dam releases. The study was conducted over the Tandula dam in India at a daily time step. (Jingwen Wu et al., 2020) developed a reservoir operation function in the Soil and Water Assess-ment Tool (SWAT), based on a water balance equation at a daily time step. (Dong et al., 2020) de-veloped a model able to regulate dam storage best. The results show that the model can better relo-cate surplus stream flow in the wet season to the dry season and mitigate the extreme events. Fur-thermore, optimizing models were developed for overcoming extreme events impact and enhanc-ing the dam performance models. (Anand, Gosain and Khosa 2018; Appuhamige and Susila; Guariso, Haynes and Whittington 1981; Milano et al. 2013; Omar 2014; Wu and Chen 2013).

In this study, we propose a real-time dam management algorithm based on water balance and rule curves as a constraint condition to guarantee an optimal water policy. This model is coupled with the Hydrologic Modeling System (HEC-HMS), and a precipitation temporal downscaling model developed by HEC-HMS has been proposed for hydrological modeling to provide hourly inflows to the dam. The precipitation temporal downscaling model based on a combination of Intensity-duration-frequency curves (IDF) and designed hyetograph of Chicago, was used to provide hourly precipitation. Furthermore, to assess the water balance at an hourly time step, hourly evaporation was estimated by temporal downscaling of monthly evaporation, using polynomial regression. The real-time dam management tool was conducted through VB.net. This tool provides information about (i) dam storage, (ii) dam release, (iii) dam evaporation, (iv) dam diversion, (v) spilled water volume, (vi) emergency spilled water volume, (vii) dam inflow, (viii) irrigation demand, (ix) irri-gation shortage, (x) dam siltation, (xi) dam hydropower production, (xii) hydropower energy in-come.

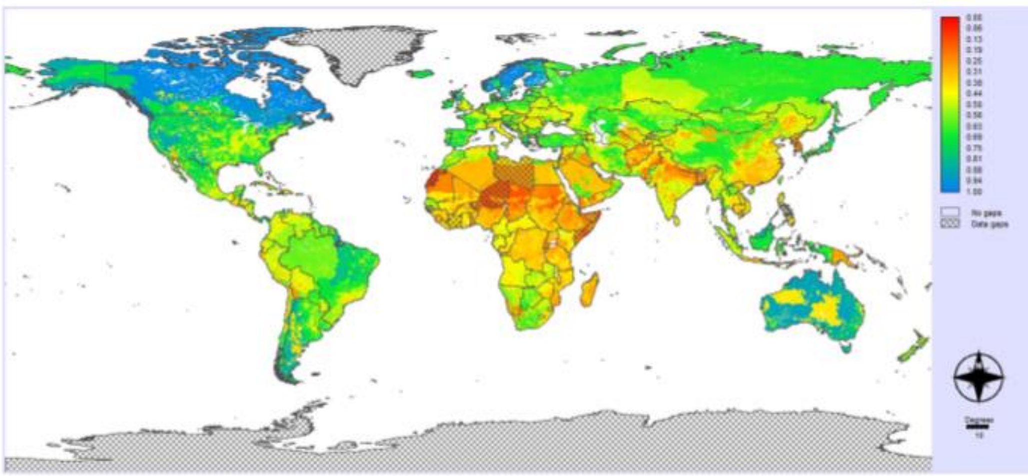


Figure 1: Global water security index(Gain, 2016)

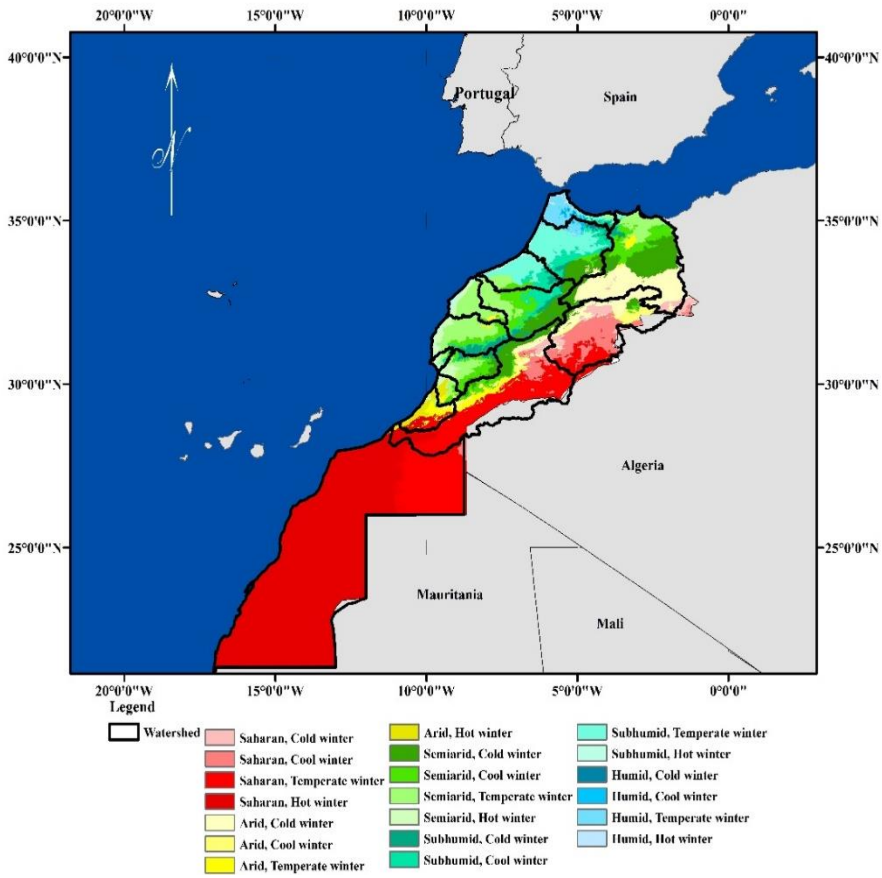


Figure 2: Bioclimatic stages of Morocco according to Emberger's quotient (source: authors)

2 Study Area

The study was carried out in Hassan Addakhil's Dam (Figure 3), which regularizes Ziz watershed out-flow. Indeed, across this watershed outlet, the Hassan Addakhil dam was built in 1971, with a ca-pacity of 347 million m3. Furthermore, this dam ensures irrigation supply and flood control essen-tially.

The extreme hazards in the Ziz basin caused longer and more intense periods of drought and ex-tremely wet years, as was the case in 2010, when the dam spilled for a few months. The climate change effect makes the management of the Hassan Addakhil dam a sensitive issue (Guir-Ziz-Rheriss, 2010). According to the Representative Concentration Pathway RCP 8.5, inflow to the Hassan Addakhil dam will decrease by -30% in 2050 (Ezzine, 2017).

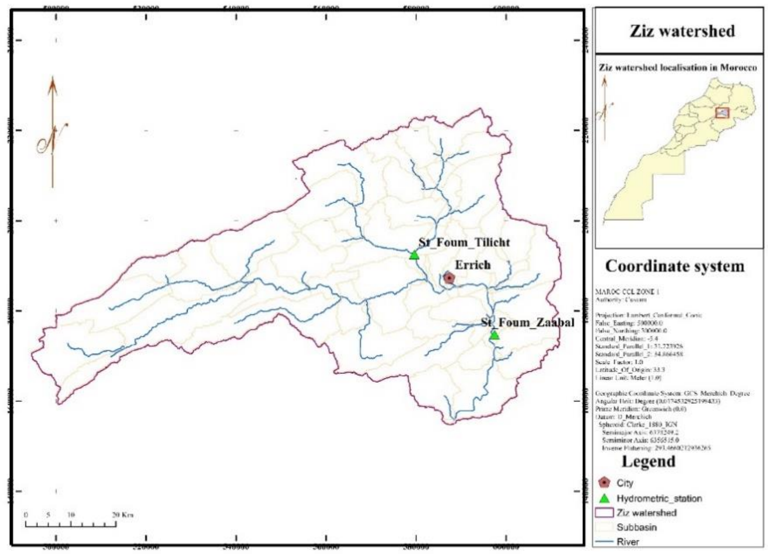


Figure 3: Upper ZIZ watershed (Elhassnaoui et al., 2020)

(Figure 4) shows that over the period (1939-2003), the regular dam inflow is very low; however, the reservoir is exposed to some extreme inflow, which may present a flood risk. Indeed, the rectangle of each box plot represents the interquartile range. Its length and position relative to the lower and upper bounds indicate the consistency and dispersion of the recorded values: the shorter the rec-tangle, the more homogeneous and less dispersed the values are. Therefore, for all months, the boxplot's rectangles are close to the minimum value. Besides, the boxplots have a length much less than the maximum of the boxplot. Hence most of the recorded values are relatively small and not widely dispersed. For example, for October, 75% of the dam inflow is less than 20.00 million m3, and 25% of the values are between 160.00 million m3 and 20.00 million m3.

Boosting the performance (Reliability, resilience, and vulnerability) indicators and flood control are the main goals for real-time dam management. (J. Wu et al., 2020) has developed a daily dam operation function under SWAT, but the novelty of this work is to develop hourly dam manage-ment, which can provide hourly information about the dam and simulate the forecasted reservoir inflow to assess future irrigation supply.

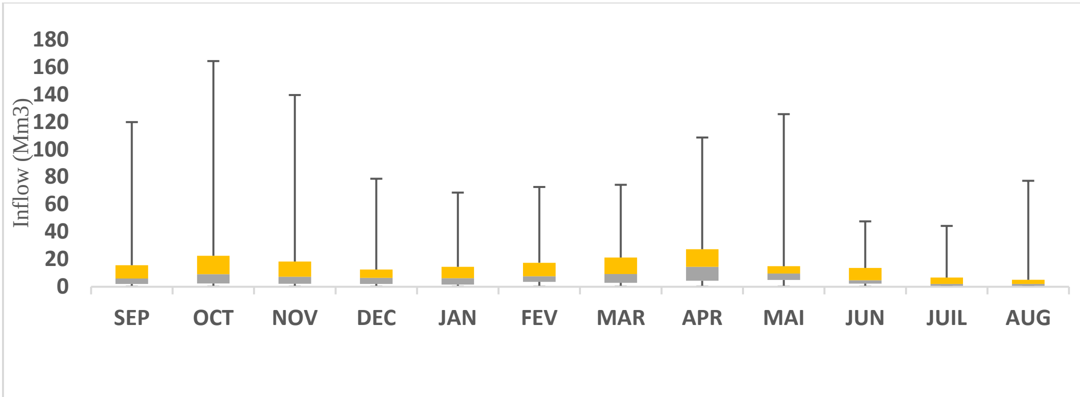


Figure 4: Hassan Addakhil monthly inflow (Mm³) over the period 1939-2003 (source: authors)

3 Materials and Methods

The operational management program aims to reduce the water release loss and highlight the opportunity to produce hydroelectric energy. Of course, this study aims to propose a model that can assess real-time water resource management as an alternative to enhance that dam performance. For HASSAN ADD-AKHIL Dam, the leading indicator that can measure the performance of the proposed model is the satisfaction of the irrigation demand with the minimum of water supply loss. The program was developed under visual basic and contains four modules, 1-loading input data module, 2-Height Area Volume curve interpolation module, 3-data analyzing and treatment module, 4-the data display module. The charts below demonstrate the algorithm's primary structure (Figure 5).

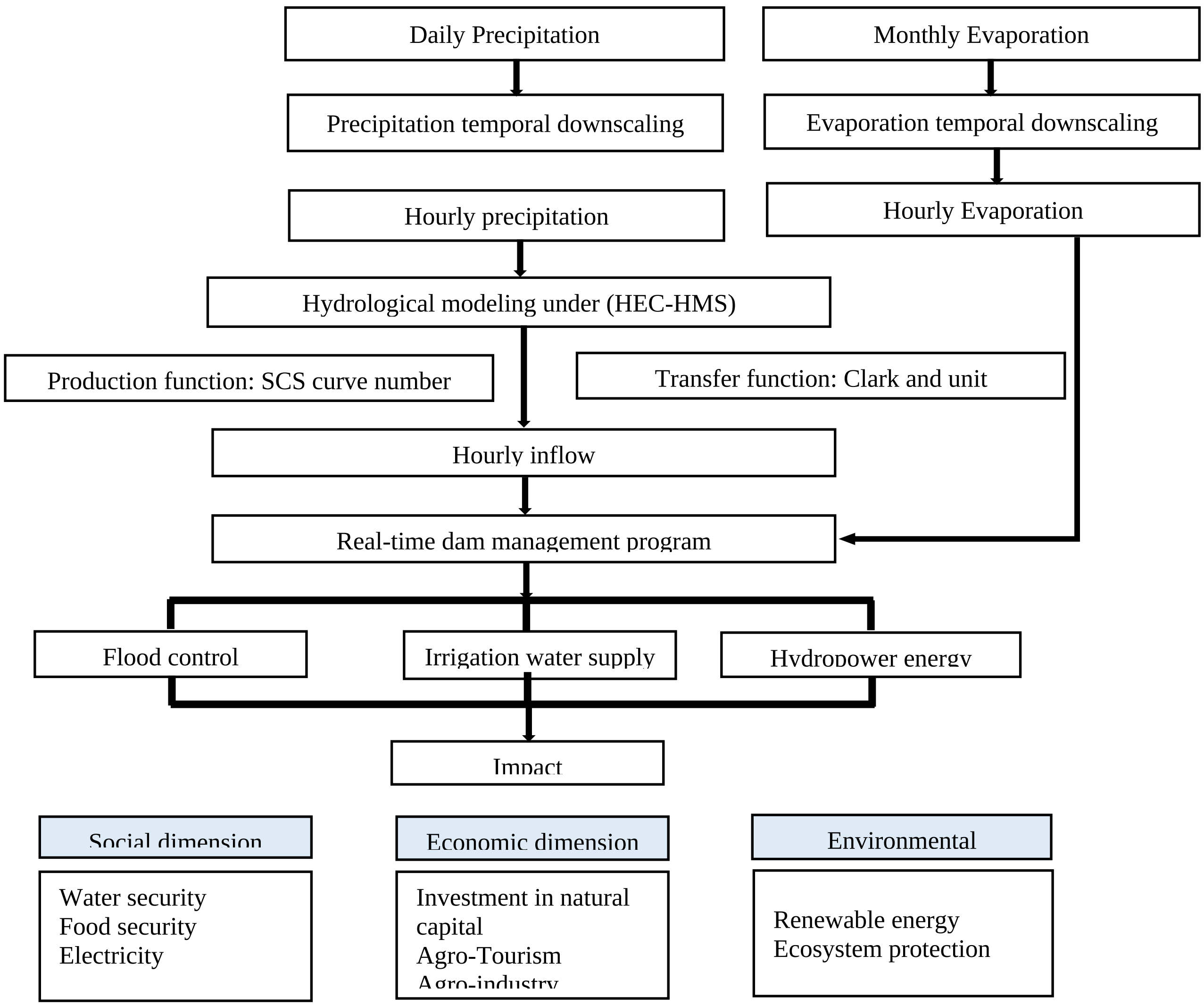


Figure 5: Schematic diagram of real-time dam management model processing (Source: authors)

2.1 Precipitation data and temporal downscaling

The daily maximum rainfall data were provided by the hydraulic basin agency of Guir-Ziz-Rheris over the period 1982-1993 (the most available data) of the rain stations of Zaabel and Foum Tillicht. The key input parameters of this study are the instantaneous precipitation. The precipitation temporal downscaling method used to downscale daily precipitation was conducted using a synthetic design storm hydrograph, developed by (Elhassnaoui et al., 2019). The approach consists of the mixture of the Intensity-duration-frequency curves (IDF) and the designed hyetograph of Chicago (Elhassnaoui et al., 2019).

2.2 Dam Data:

Dam release and storage data, Height-Area-Volume curves, and dam design characteristics were provided by the hydraulic basin agency of Guir-Ziz-Rheris over the period 1983-2002

2.3 Evaporation data and temporal downscaling

The monthly evaporation data were provided by the hydraulic basin agency of Guir-Ziz-Rheris over the period 1983-2002. In situ evaporation observations, data, and Height-Area-Volume curves for the Hassan Addakhil dam were conducted to assess the correlation between evaporation as an independent variable and water surface as a predictor variable. This correlation is assessed for every month over the period 1983-1993 using two-degree polynomial regression. After that, hourly evaporation data was provided using the two-degree polynomial function. The downscaling approach was validated using observed data over the period 1983-2002. Nash-Sutcliffe Efficiency (NSE) was used to assess the significance of the downscaling method.

2.4 The evaluation of hourly siltation:

According to the Agency of the hydraulic basin Ziz Ghir Rheriss and Draa, the annual rate of the dam siltation is 1.99 million m3 / year. Thus, we convert the rate of siltation per year to a rate per hour.

2.5 Hydrological modeling

In this study, we used the same hydrological model calibrated and validated by (Elhassnaoui et al., 2019) in the same watershed under HEC-HMS.

2.5.1 GIS data

The digital elevation model (DEM) has been derived from the following features: ASTER Global Digital Elevation Model (ASTER GDEM). The DEM is used to estimate the physical parameters that control water flow, such as slope, the longest flow path.

2.5.2 Land Use and soil data

The Land Use map was extracted from a Global cover map, a European Space Agency project (ESA) (Bicher et al., 2008). The soil map was obtained from the National Institute of Agronomic Research in Morocco (INRA)

2.5.3 Hydrological Model structure:

The SCS curve number method is used as a Production function, and the Clark and unit are used as a transfer function. The temporal downscaled precipitations are introduced to the model to estimate the discharge at the watershed outlet, in a way to assess the hourly dam inflow.

The goal of the current step is to estimate the hourly water supplies at HASSAN ADD-AKHIL’s dam, employing the rain-flow transfer model, in this case, HEC-HMS (W.Scharffenberg, 2016).

The methodology followed consists on conceptualizing the physical characteristics of the basin studied, using the HEC-GEOHMS extension to export them to the HEC-HMS hydrological modeling. In the presented case, Ziz Ghriss watershed has a semi-arid climate where the dry season lasts from 6 to 8 months (Maroc, 2018), then to estimate the water runoff the soil conservation curve number method (SCS-CN) (USDA, 1986) was chosen.

The SCS model described as:

Equation 1: SCS equation

$$R = \frac{P_e^2}{P_e + S}$$

In which:

$$P_e = P - I_a$$

$$I_a = \alpha S \quad (3)$$

$$S = \frac{2.540}{CN} - 25.4$$

Where:

R: cumulative runoff, P: cumulative rainfall; Pe: effective cumulative rainfall, S: potential maximum retention,

I_a : initial abstraction, α : initial abstraction coefficient, CN: curve number.

Once excess precipitation is known, it is transformed into the direct runoff. The HEC-HMS platform has several transfer functions: unit hydrographs of Clark, Snyder and SCS, user-defined hydrographs, Modclark transformation, and kinematic wave. Among these methods, the unitary hydrograph of Clark is frequently used for event modeling. This method is particularly useful for reproducing complex hydrographs, in basins with varied topography and land use (Sabol, 1988) (Chu et al., 2009)

Visual examination of the simulated hydrographs could give a previous idea about the quality of the simulation, but it is required to use the evaluating equation to assess the capacity of the rain-flow model to reproduce flood episodes. Those are described in detail in the paper of (Moriasi et al., 2007), the comment and the widely used coefficient is Nash (Nash & Sutcliffe, 1970), it is expressed as follows

Equation 2: The Nash-Sutcliffe Efficiency

$$EF = 1 - \frac{\sum_{i=1}^{n} (Q_{obs,i} - Q_{sim,i})^2}{\sum_{i=1}^{n} (Q_{obs,i} - \overline{Q_{obs}})^2}$$

Where,

$Q_{obs,i}$: Observed discharge, $Q_{sim,i}$: Simulated discharge, $\overline{Q_{obs}}$: Mean of the observed discharge, n : Number of the observed discharge.

2.5.4 Evaluation of the hydrological model performance:

The hourly dam inflows simulated using HEC-HMS was validated with the observed dam inflows over the period 1983-1993. The Nash-Suctclife Efficiency indicators were used to assess the accuracy of simulated hourly dam inflows.

2.5.5 Crop water demand

The irrigation demand in Ziz downstream is estimated by 100 million m3, according to Tafilalet ORMVA. Indeed, the crop water demand is generally 1000 m3 / ha (Hammani et al., 2012). The dam release program depends on the vegetation cycle of the cultivated species. Indeed, the dam release is following this schedule:

1st release: October – November
2nd release: January
3rd release: March – April
4th release: July – August

2.6 Hydropower production:

The Hassan Addakhil dam was designed primarily to ensure irrigation demand and flood control. However, this section aims to highlight the opportunity to produce hydroelectric energy over this dam, and how the hydropower income can cover the dam maintenance charges. We propose to integrate a hydropower plant to the Hassan Addakhil to enhance the sustainability mission of the dam. In this sense, we designed a hydropower plant.

The characteristics of the hydropower station are as follows:

Discharge of power plant: The maximum discharge.

Hydraulic charge: The difference between the water level and the hydropower plant level. The head power value is estimated by calculating the water head corresponding to the average useful dam reserve of 1988-2009 years.

Efficiency: Efficiency of the turbine-generator set which varies between 0.6 and 0.9

Installed Capacity: The installed capacity is the sum of the rated capacities of all of the units in the power plant. The rated capacity of a unit is the capacity it is designed to deliver at a given head, discharge, and efficiency.

The hydropower production function is as follow:

$$P = \rho . g . \eta . Q . H$$

Where:

P : Hydropower production (kW), ρ : Density of water (kg.m^3), g : Acceleration gravity (m.s^{-2}), Q : Discharge of the power plant (m^3.s^{-1}), H : Effective head (m), η : The hydropower plant efficiency

2.7 Flood control:

The real-time information about the dam inflow can be simulated to provide information about the reservoir outflow. Real-time dam management can assess the outflow discharges and estimating the water volume lost. Hourly dam diversion information can help the decision-maker to avoid flood risk.

2.8 Real-time water management tool:

The real-time water management program was conducted using VB.net. Figure 6 shows the program interface. Indeed, the interface is composed of four sections: 1) the dam parameter section, 2) the hydropower plant section 3) the data loading section, and finally 4) the dam management processing.

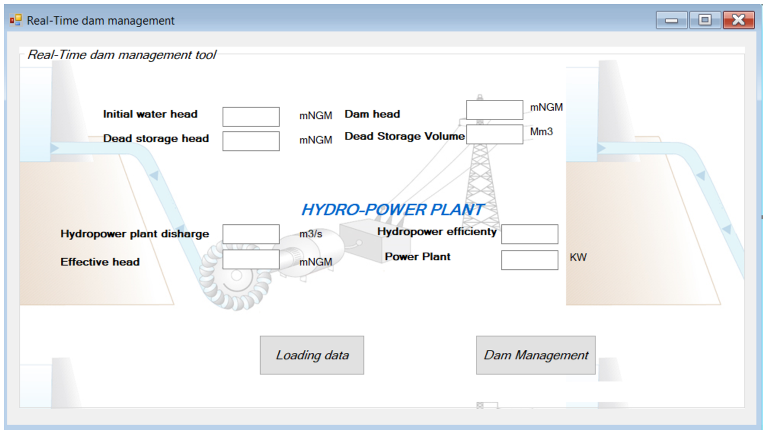


Figure 6: Program interface of Real-time dam management tool (Source: authors)

2.8.1 Water balance equation:

The real-time dam management program is based on the water mass balance equation (Equation 3). The water balance equation aims to update dam storage at an hourly time step, including dam inflow, dam outflow, evaporation volume, irrigation release, water volume spilled, and water volume evacuated. Figure 7 shows the real-time dam management algorithm operation.

Equation 3: the water mass balance equation

$$S_{i+1} = S_i + \left(Q_{if(i+1)} + Q_{if(i)}\right) \times \frac{\Delta T}{2} - \left(Q_{of(i+1)} + Q_{of(i)}\right) \times \frac{\Delta T}{2} - V_{evp} - V_{spill} - V_{evac} - F_{Irr}$$

Where S_{i+1}: Reservoir storage at $i+1$ time, S_i: Reservoir storage at i time, $Q_{if\,(i+1)}$: dam inflows at $i+1$ time, $Q_{if\,(i)}$: dam inflows at i time, ΔT : Hourly step, $Q_{of(i+1)}$: Dam outflow at $i+1$ time, $Q_{of(i)}$: Dam outflow at $i+1$ time, V_{evp} : Evaporated volume, V_{spill}: Spilled volume, V_{evac} : Emergency Evacuated volume, F_{Irr} : Irrigation Supply.

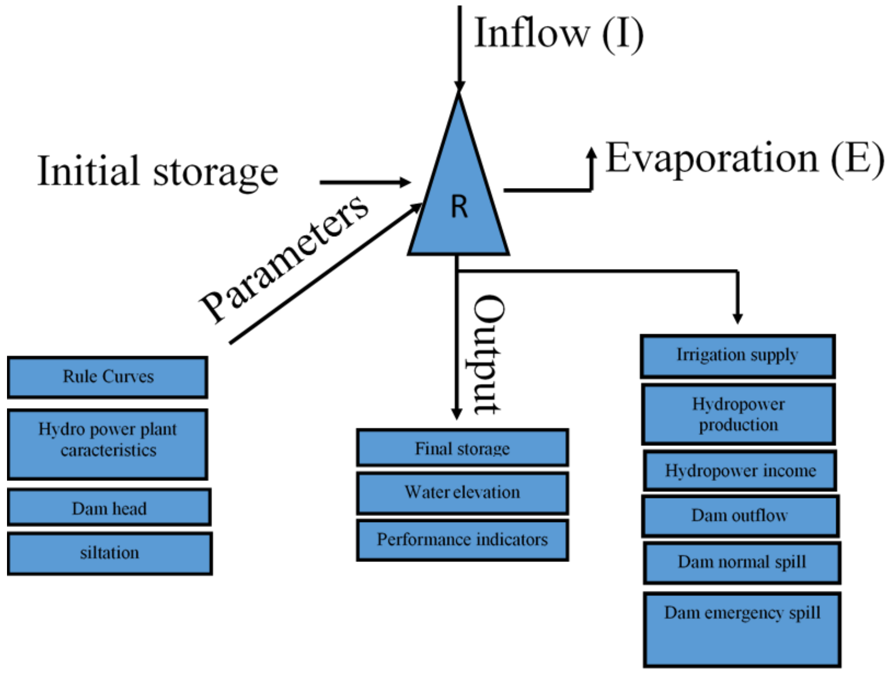


Figure 7: Real-time dam management algorithm operation (Source: authors)

2.8.2 Rule curves:

The dam rule curves are used to guarantee the reservoir safety as well as water security. Many studies have developed rule curves for flood control (Chaleeraktrakoon & Chinsomboon, 2015) and dam operating (Thongwan et al., 2019). Furthermore, using these curves is a way to guarantee an optimal water policy (De Silva M. & Hornberger, 2019). (Figure 8) shows that the real-time dam management program will release 100% of irrigation demand when the dam capacity is above the storage segmentation 1 (SG1). Else if the dam capacity is between the storage segmentation 1 (SG1) and the storage segmentation 2 (SG2), 70% of the irrigation demand will be released. Else if the dam capacity is between the storage segmentation 2 (SG2) and the dead storage, 50% of irrigation demand will be released.

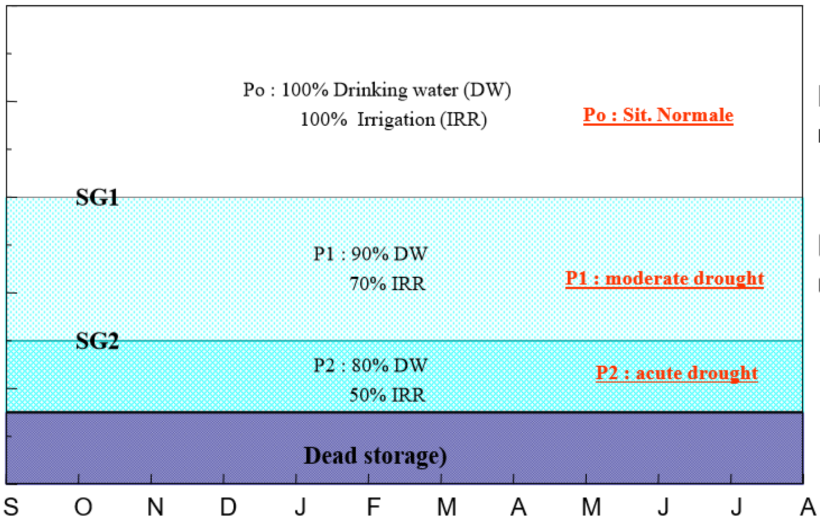


Figure 8: Rule curve schema based on Moroccan hydrological season (Source: Ministry of Equipment, Transport, Logistic and Water)

2.8.3 Real-time dam management model validation:

The real-time dam management model is validated over 1983-1993 to confirm its ability to reproduce the dam storage. The Nash-Suctclife Efficiency indicators were used to assess the accuracy of simulated dam storage compared with observed storage data over this period.

2.8.4 Reservoir Performance Indicator

The dam performance is assessed by three indicators Reliability, resilience, and vulnerability. Indeed, reliability is the success of providing demands. Resilience describes how the dam recover from a failure and vulnerability describes the intensity of failure (Ajami et al., 2008; De Silva M. & Hornberger, 2019; Hashimoto et al., 1982).

The volume reliability is the number of successful hydrological year $X(t)$ that the dam meets the downstream demand over a period T

Equation 4: Reliability

$$Reliability = \frac{\sum_{i=1}^{T} X(t)}{T}$$

The resilience is the dam's potential to recover $Y(t)$ from a failure $T - \sum_{t=1}^{T} X(t)$ to meet downstream requirement over a period T

Equation 5: Resilience

$$Resilience = \frac{\sum_{t=1}^{T} Y(t)}{T - \sum_{t=1}^{T} X(t)}$$

The vulnerability describes the maximum number of successive failures, which highlight the severity of dam failure.

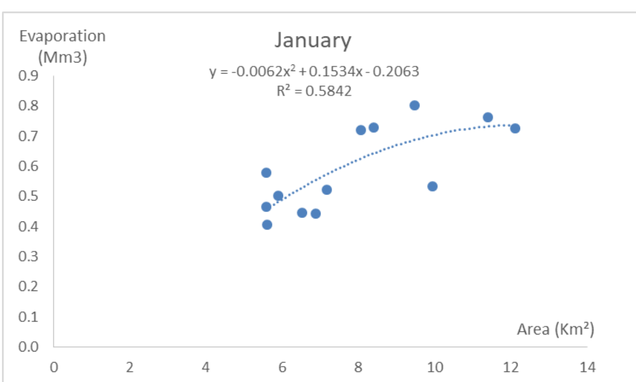
Equation 6*: vulnerability*

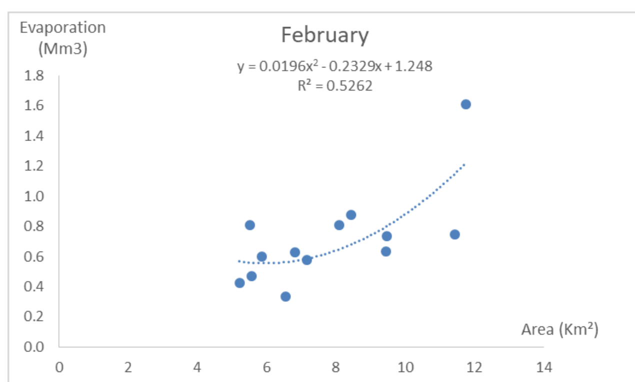
$$Vulnerability = \max(V(t))$$

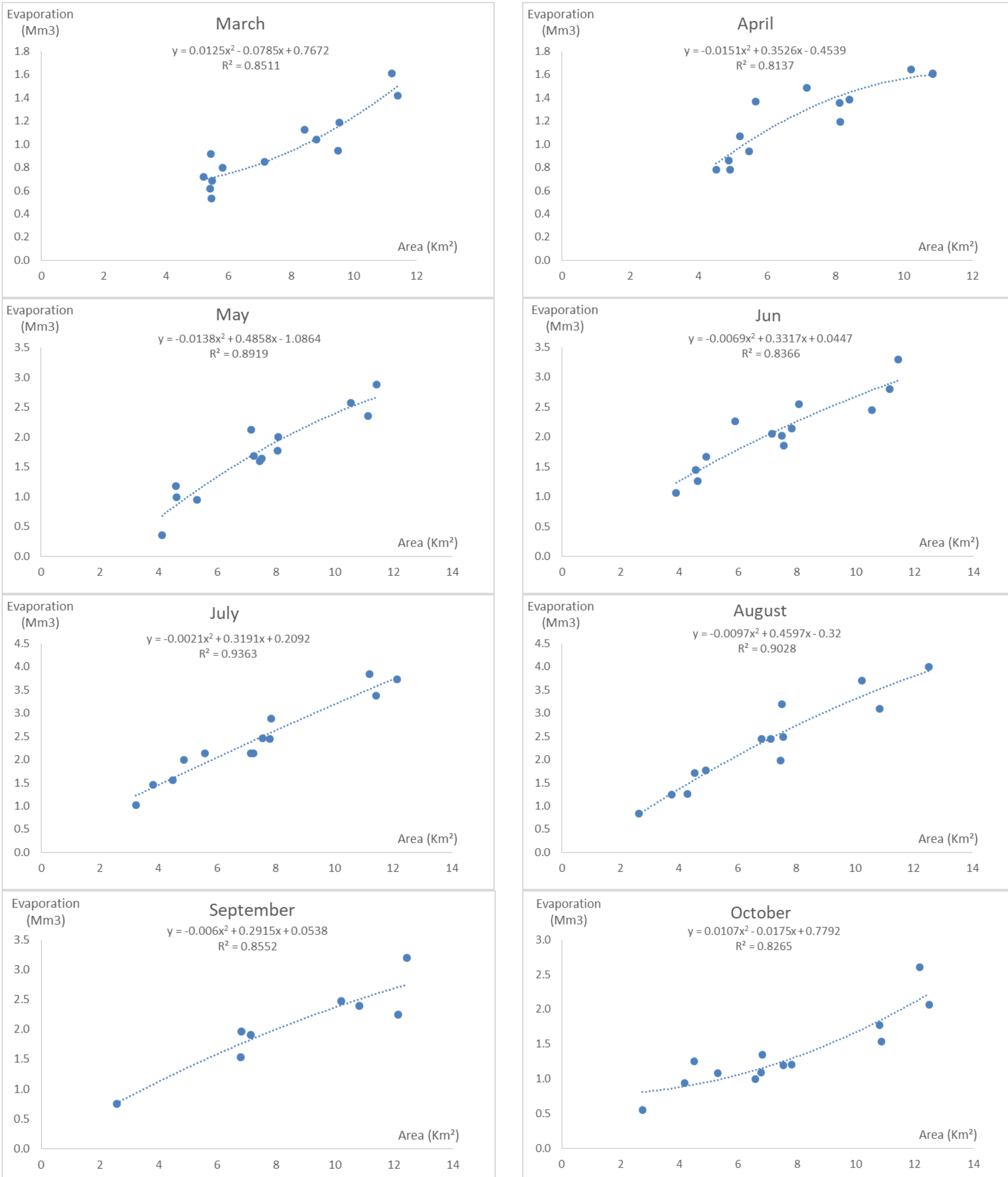
3 Results

3.1 Temporal Evaporation downscaling:

Many studies have performed multiple regression methods and method of fragment for temporal downscaling of hydro climatic data. (Sachindra & Perera, 2018) performs the desegregating of annual evaporation to monthly evaporation using method of fragment. Monthly disaggregation consist on estimation of the ration of the evaporation value in a given month to the total evaporation value over the year. Other authors' performs the same approach in desegregating corpse temporal hydro climatic data (Rebora et al., 2016; A. T. Silva & Portela, 2012). Furthermore many authors shows that multiple regression lead to a good accuracy in temporal downscaling of hydro climatic data (Contreras et al., 2018; Herath et al., 2016; Hofer et al., 2015; Sharifi et al., 2019). In this study, the temporal downscaling method was processed by evaluation of the accuracy of the dam area with degree two polynomial regressions to predict evaporation from monthly to hourly scale. Figure 9 shows that the R square R2 ranges from 0.42 to 0.93, with an average of 0.73. The R square metric for all months is significant and proves that the dam area can best fit evaporation in polynomial regression.






March
Evaporation (Mm3)
y = 0.0125x² - 0.0785x + 0.7672
R² = 0.8511
Area (Km²)
April
Evaporation (Mm3)
y = -0.0151x² + 0.3526x - 0.4539
R² = 0.8137
Area (Km²)
May
Evaporation (Mm3)
y = -0.0138x² + 0.4858x - 1.0864
R² = 0.8919
Area (Km²)
Jun
Evaporation (Mm3)
y = -0.0069x² + 0.3317x + 0.0447
R² = 0.8366
Area (Km²)
July
Evaporation (Mm3)
y = -0.0021x² + 0.3191x + 0.2092
R² = 0.9363
Area (Km²)
August
Evaporation (Mm3)
y = -0.0097x² + 0.4597x - 0.32
R² = 0.9028
Area (Km²)
September
Evaporation (Mm3)
y = -0.006x² + 0.2915x + 0.0538
R² = 0.8552
Area (Km²)
October
Evaporation (Mm3)
y = 0.0107x² - 0.0175x + 0.7792
R² = 0.8265
Area (Km²)

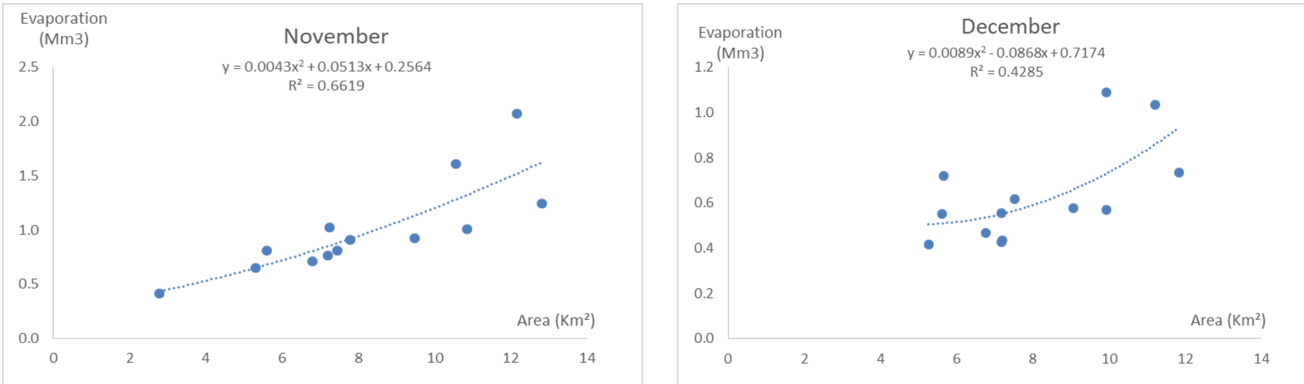


Figure 9: The trend curve for the reservoir evaporation or month by month over the period 1983 and 2002

3.2 Validation of temporal evaporation downscaling:

The observed evaporation in the Hassan Addakhil dam, over the period 1982-1993, was considered for the validation of downscaled evaporation using a polynomial trend equation. The Nash-Sutcliffe Efficiency (NSE) for the result of simulated and observed evaporation data is 0.84, which is very significant in terms of the evaporation downscaling model accuracy (Figure 10 and Table 1).

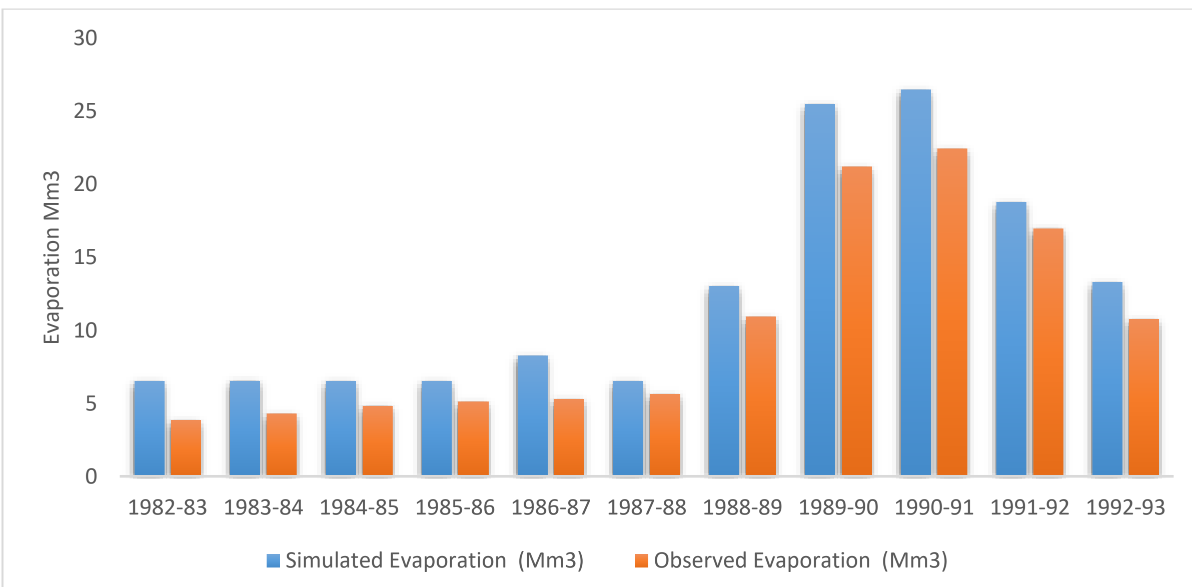


Figure 10: Comparison between downscaled and observed evaporation

Table 1: Modeling Efficiency for evaporation downscaling over the period (1982-1993)

Period	Watershed	Evaporation	NSE
1982-1993	Upper Ziz	Hourly Evaporation validation	0.84

3.3 Evaluation of the hydrological model performance:

The hourly water supplies at HASSAN ADD-AKHIL's dam was conducted through HEC-HMS software, using SCS-CN method. Many studies have been widely used the SCS-CN method for application in continuous rainfall modeling, in arid, subtropical and tropical regions (Geetha et al., 2008; Gumindoga et al., 2017; Halwatura & Najim, 2013; Hrissanthou & Kaffas, 2014).

The SCS loss model is adapted to account for the initial humidity conditions of watersheds in the event modeling scale. The parameter CN can indeed be linked to different soil moisture indicators, measured in the field (Huang et al., 2007; Brocca et al., 2009; Tramblay et al., 2010), derived from models (Merchandise and Viel, 2009) or satellite data (Brocca et al., 2010). Based on the simulated water supply to the dam, the real-time dam management tool was validated in terms of dam inflow (Figure 11). The Nash-Sutcliffe Efficiency (NSE) for the result of temporal inflow provided by the HEC-HMS model and the observed data over the period 1982-1993 is 0.79 (table2). The NSE is significant. The same method was carried out by (Jaiswal et al., 2020)

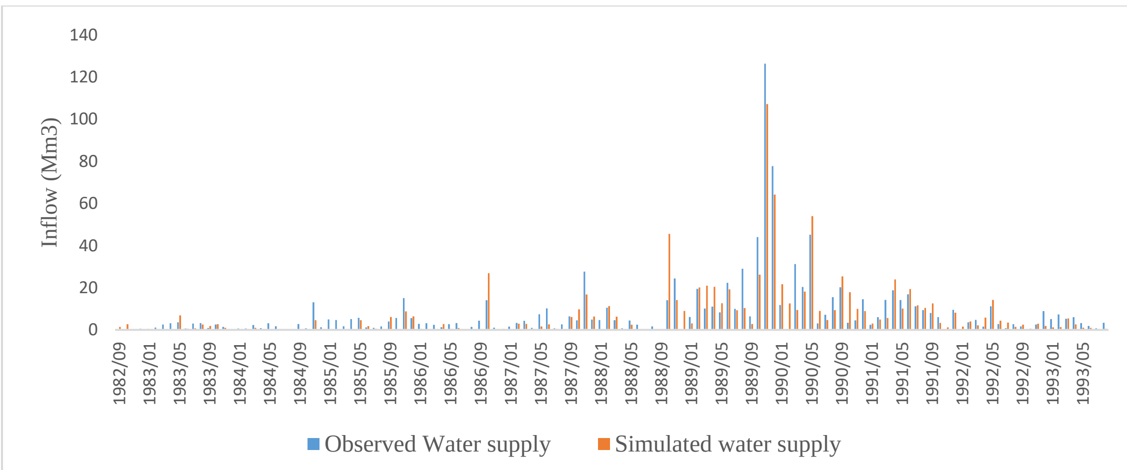


Figure 11: Comparison between Simulated and observed water supply for HASSAN ADD-AKHIL dam

Table 2: Modeling Efficiency (EF) of dam inflow over the period (1982-1993)

Period	Watershed	Outlet	NSE
1982-1993	Upper Ziz	Hassan Addakhil dam	0.79

3.4 Real-time dam management model validation:

The comparison between observed and the simulated dam's storage over the period 1982-1993, shows that the real-time dam management algorithm can accurate the dam storage (Figure 12). Indeed, the Nash-Sutcliffe Efficiency (NSE) for the observed and the simulated dam storage over the period 1982-1993 data is 0.96, which is very significant (Table 3). The validation of the dam management model was carried out as well using the Nash-Sutcliffe Efficiency indicator by (Jaiswal et al., 2020; T. Silva & Hornberger, 2019).

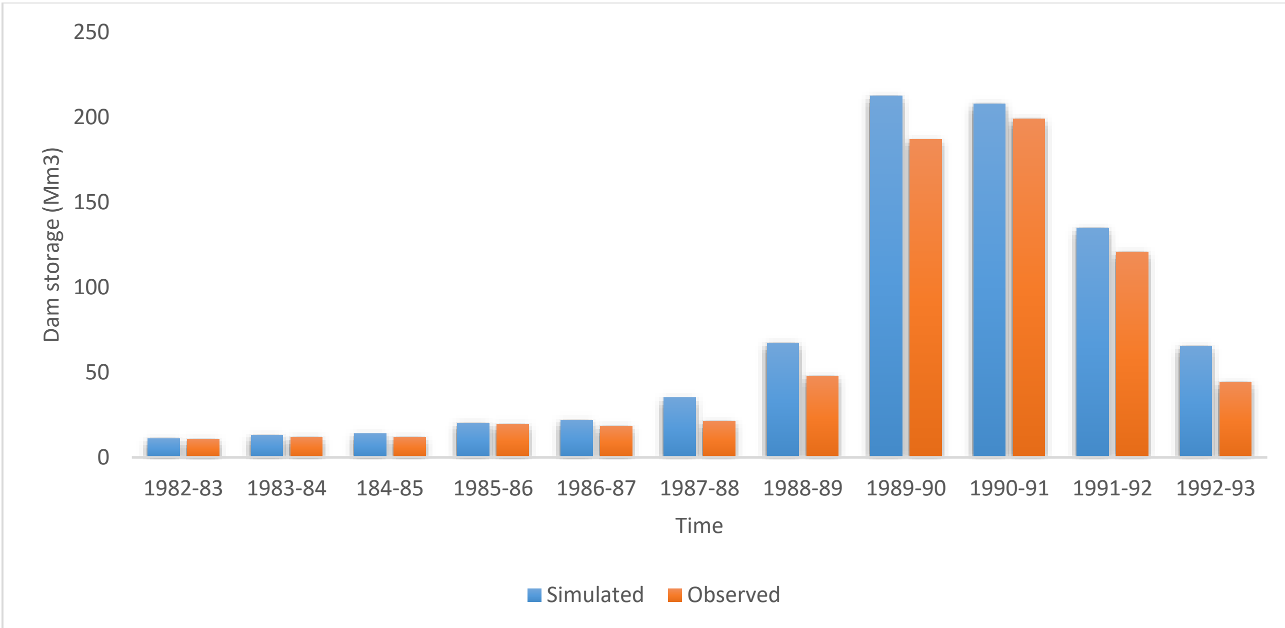


Figure 12: Comparison between simulated and observed dam storage between the period (1982-1993)

Table 3: Modeling Efficiency (EF) of dam storage over the period (1982-1993*)*

Period	Watershed	Dam storage	NSE
1982-1993	Upper Ziz	Hassan Addakhil dam storage simulation	0.96

3.5 Real-time dam management performance:

The real-time dam management tool enhanced dam performance. Comparison based on agricultural demand satisfaction over the drought period ranged from 1983 to 1992 (Figure 13) shows that real-time dam management tool has enhanced the dam release by an average of 18.33 million m3, which represents 20% of the agricultural demand in Ziz downstream over a hydrological season. Indeed, over the same period, the lower dam release volume increased from 4.9 million m3 to 13.1 million m3, and the high dam release volume increased from 54.8 million m3 to 89.64 million m3.

On the other hand, it can remedy to water release losses. Over the period 1987-1991, the model provides the agricultural requirement without water release losses, however, over the same has released an average surplus of 32 million m3, which represents 32 % of agricultural demand over a hydrological season. Moreover, in 1992 the model algorithm has succeeded in meeting the agricultural demand. However, classical dam management has failed to satisfy the agricultural requirement for the same year.

Based on the rule curves and the water balance equation performance at an hourly time step, table 4 shows that the dam reliability and resilience have increased respectively, over the period 1982-1992, from 40% to 70% and from 16% to 66%. Besides, vulnerability remained constant during the same period. The same indicators was performed by (Saha et al., 2017; T. Silva & Hornberger, 2019) to assess the dam performance.

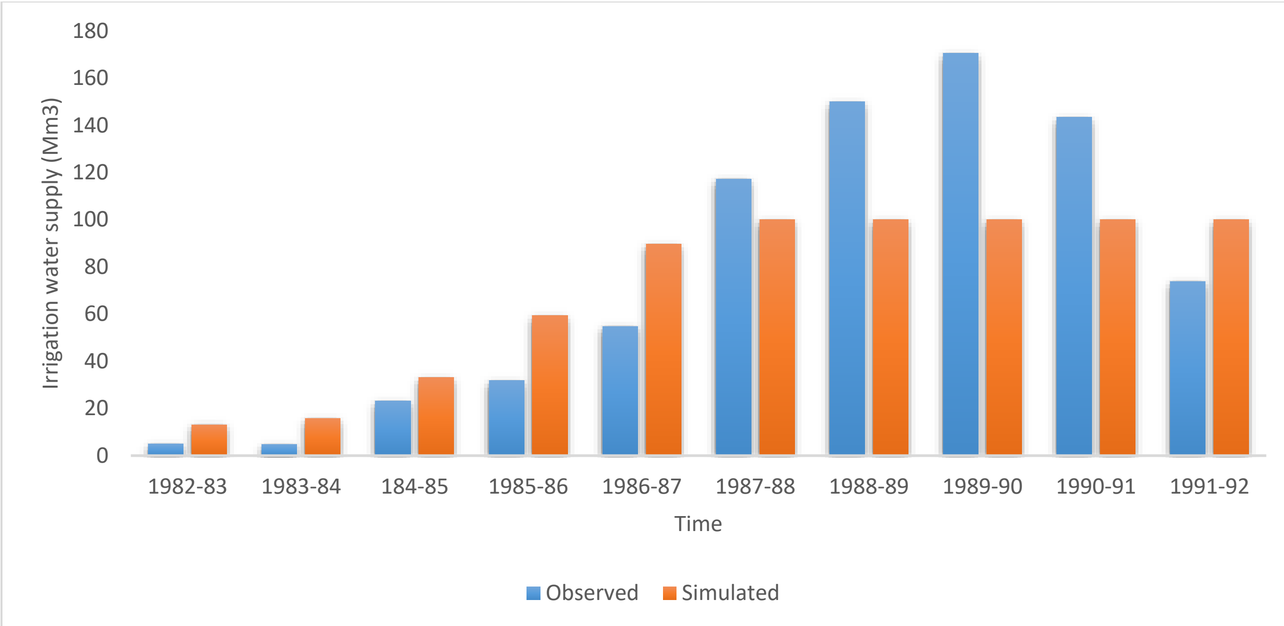


Figure 13: Comparison between observed and simulated irrigation water supply

Table 4: Dam performance indicators

	Reliability	Resilience	Vulnerability
Classical dam management	40%	16%	5
Real time-dam management	70%	66%	5

3.6 Hydropower production

The annual electricity consumption is 0.5 TEO / inhabitant (Taoumi, 2008). Besides, the average annual simulated hydropower production over this period is 57.64 GWH, which is equal to the annual consumption of 9912 inhabitants. In the case of a moderately rainy year, the hydropower production will be 89.4 GWH, which is equal to the annual consumption of 14857 inhabitants (Figure 14).

The average annual income from hydropower supply between 1982 and 1992 is equal to 57.6 Million Dirham. The decision-maker must take into account this vital budget to cover all expenses, including dam maintenance (Figure 15).

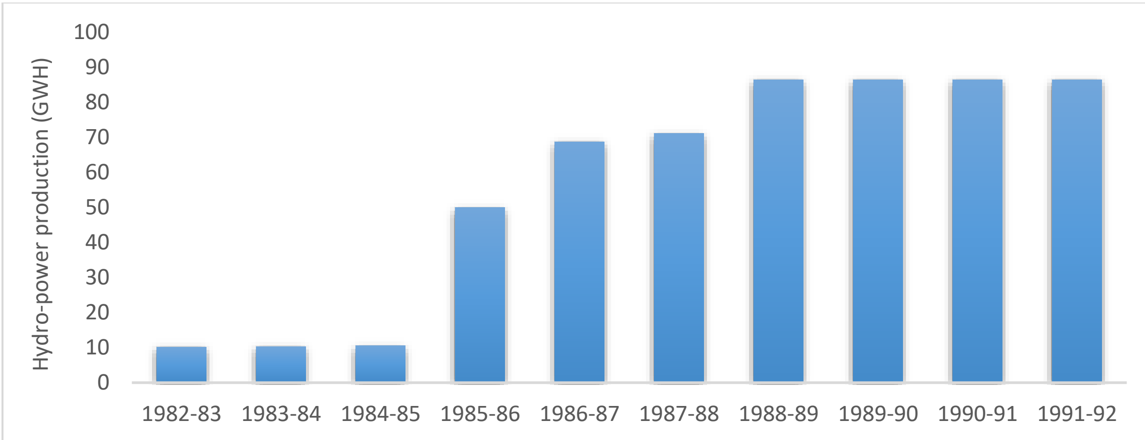


Figure 14: Hydropower production (GWh) over the period (1982-1992)

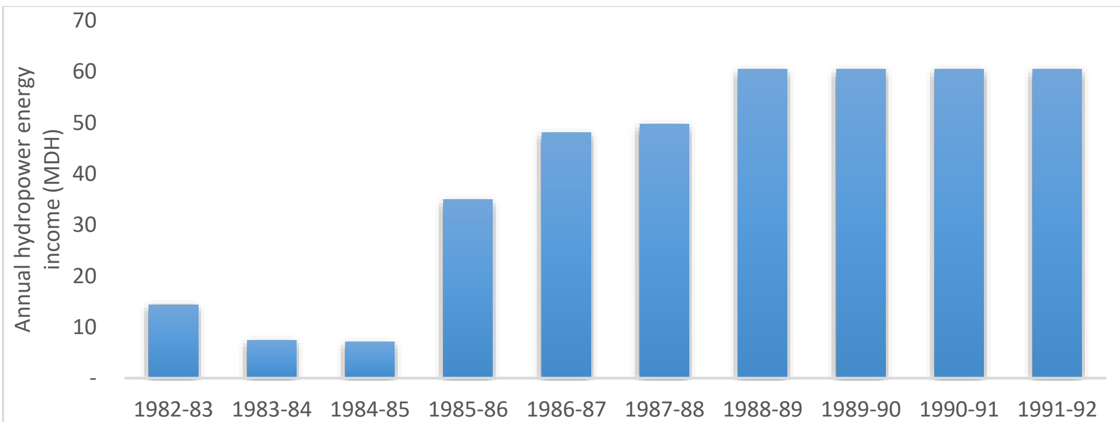


Figure 15: Annual hydropower energy income (MDH) over the period (1982-1992)

5 Conclusions

The operational management program aims to improve the HASSAN ADD-AKHIL dam efficiency by proposing a new adaptive approach for management by valorizing the water cubic meter and by demonstrating that the installation of a hydropower plant is an opportunity to produce clean electric energy. These results can urge the decision-maker to think about improving dam management strategy, especially in an arid and semi-arid watershed.

The program provides a real-time regulation of the dam, which can help make an optimal schedule and project strategies related to droughts, impact mitigation, water security, energy conservation, and agriculture development, in case the input data projections are provided.

The results obtained during this reflection may be subject to specific errors inherent mainly in the nature and precision of data used and/or the lack of specific data. Indeed, the meteorological and hydrological time series used have several discontinuities and gaps. On the other hand, the number of rainfall and hydrometric stations used is insufficient for a precise assessment of the hydrological behavior at the catchment scale. Therefore, it is essential to optimize the network of measurements and ensure the quality of the instantaneous and daily data records. In this sense, it should be noted that the suggestions and recommendations given above must be considered when interpreting the results obtained by this study.

The adopted approach goes hand in hand with sustainable development goals. A sustainable environment can be attained by preserving, improving, and valuing the environment and natural resources in the long term, maintaining the principal ecological balances, on the risks, and the environmental impacts. A sustainable society can be maintained if it satisfies human needs and meets a social goal by encouraging the participation of all social groups in health, housing, consumption, education, employment, culture. Finally, a sustainable economy aims to develop growth and economic efficiency through sustainable production and consumption patterns (UN 1987), in other term switching from the linear to the circular economy.

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