




Systematic Synthesis of Knowledge Relating to the Hydrological Functioning of Inland Valleys in Sub-Saharan Africa

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Abstract: The potential of inland valleys to enhance food security and improve agricultural resilience to climate change in Africa is constrained by a limited understanding of their hydrological functioning and inadequate water management. In order to synthesize knowledge on hydrological responses in inland valley areas, this work reviewed 275 studies from tropical Sub-Saharan Africa (SSA). Data from the literature search were collected from ScopusTM, ScienceDirectTM, Web of ScienceTM, Google ScholarTM, and doctoral theses repositories such as ZEF, HAL, and Theses.fr, covering studies published from the inception of these databases through 31 May 2023. Our approach involved, firstly, a bibliometric analysis of all papers to gain insights into research trends and interests. Secondly, we performed a quantitative synthesis of results from 66 studies examining stream flows in a set of 79 inland valleys to better understand factors that govern runoff dynamics in these environments. Correlative analyses and clustering methods were applied to identify potential links between runoff and watershed physical parameters. The findings highlight the varied responses of inland valleys over both time and space, influenced by a combination of catchment drivers. The correlation matrices between hydrological indices and physical parameters indicate a strong relationship among runoff and a range of parameters, of which the most significant are rainfall ($R^2 = 0.77$) and soil silt content ($R^2 = 0.68$). Challenges in accurately spatializing information related to potential determining components of the water cycle, such as groundwater dynamics and soil moisture, seem to have limited the exploration of interactions between river flow, soil moisture, and groundwater. Future works should prioritize the development of accurate and user-friendly hydrological models that balance complexity and data availability to enhance the understanding of inland valley behavior at fine scales and consolidate food security in Africa.

Keywords: inland valleys; genesis and dynamics of runoff; hydrological modeling; Sub-Saharan Africa



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1. Introduction

In Sub-Saharan Africa, the agricultural development of wetlands in general and inland valleys in particular has experienced rapid growth in recent years [1,2]. Inland valleys become an important agricultural asset for achieving food security and poverty reduction in this part of the world [3]. The interest to develop these small wetlands is driven by various factors, including the need to adapt production strategies in response

to increasingly unpredictable climatic conditions and the declining fertility of plateau lands [4,5]. Inland valleys are also suited for high-value crop production, agriculture intensification, and diversification [3]. They are now rightfully considered as the “pantry of the future” in tropical Africa, and their good management is decisive for achieving food sovereignty objectives [6]. Across Sub-Saharan Africa, inland valleys cover an estimated area of approximately 190 million hectares, accounting for approximately 10% of cultivable land [7].

Despite their immense potential, the productive capacity of inland valleys in tropical Africa remains largely underexploited [3,8,9]. Inland valleys are often neglected for agricultural development due to constraints linked to their exploitation such as difficult tillage, water control issues, and waterborne diseases. In particular, the complexity of the hydrological regime [10] is problematic for designing appropriate hydro-agricultural management infrastructure [7]. Due to their upstream position in the hydrographic network and their spatial distribution, inland valleys seem to exhibit “hydrological specificities”. Enhancing water resource management of inland valleys, therefore, needs a better understanding of their hydrological functioning.

Accordingly, numerous studies have explored various aspects of the hydrological functioning of these unique wetlands over the past half-century. However, from the synthesis of knowledge obtained from these research works, little consensus has been reached regarding the processes governing water dynamics in these environments [11–17]. Ref. [17] explains this situation by a lack of comparable precise data between the inland valleys studied. Other sources underscore the difficulty of capturing fundamental hydrological processes to be generalized on the different sites [10]. Uncertainties persist regarding the mechanisms driving the spatio-temporal dynamics of water in these catchments. The ability to forecast hydrological characteristics, especially runoff, in ungauged inland valleys has gained even greater significance in the face of climate change impacts on tropical regions. In light of these observations, two fundamental questions emerge: (1) What are the key results of hydrological studies of inland valleys; and (2) What are the most promising lines of research not yet explored on the subject? Addressing these questions necessitates a comprehensive review of works related to water dynamics in inland valleys, including the areas of study, research themes, applied methodologies, and data/results obtained. This review can help to consolidate existing knowledge and identify the most promising directions for future research in the field. In addition, the current advances in earth observation and availability of high-resolution spatio-temporal data [18] offer unprecedented opportunities to augment knowledge from reported field studies and reduce the uncertainty in the characterization of these hydrological systems.

In this study, we used a mixed approach combining bibliometric analysis—examining publication trends over time, geographic focus, and research themes—and statistical synthesis of previous studies to better understand the mechanisms governing key aspects of water dynamics, such as runoff, infiltration, soil moisture, and groundwater flow in inland valleys. These methodologies enable knowledge accumulation through a stronger focus on data extraction from available peer-reviewed articles and allow previous studies to be analyzed in a hydrologically meaningful way [19]. In the same spirit, ref. [20] argue that meta-analysis can be a powerful complement to field studies in hydrology by facilitating the retrospective synthesis of published research in which divergent results on the same research question seem to be apparent. Preceding the quantitative synthesis in this study, bibliometric analysis offers an opportunity to quantify the written information and generate a support for an objective understanding of the authors’ points of view. Coupled with the analysis of textual content, bibliometrics make it possible to better identify the structuring of the research that was conducted and helps to study the frontiers of research

in a particular field [21]. This approach has been used in several research fields, including hydrology, to assess, understand, and predict areas of interest, as well as to identify knowledge gaps on a specific topic [22–25]. By drawing on existing references in the field of inland valley hydrology, we aim to evaluate the evolving knowledge of hydrological responses in these areas.

2. Methodology

2.1. Definition of “Inland Valleys”

In Sub-Saharan Africa (SSA), wetlands include: (1) coastal plains—comprising deltas, estuaries, and tidal flats; (2) inland basins, which consist of extensive drainage depressions; (3) river floodplains characterized by recent alluvial deposits bordering rivers; and (4) inland valleys [6,26].

Depending on the authors and the regions of the study, inland valleys have been the subject of a multitude of definitions in the literature [27]. They are also called “dambos” and “vleis” in Southern Africa; “inland swamps”, “lowland valleys”, and “mbugas” in East Africa; and “fadama”, “bas-fonds”, “valley bottom”, and “bolis” in West Africa. According to [28], inland valleys are periodically flooded grass-covered depressions at the head of a drainage system in a region of dry forest or bush vegetation. Ref. [29] defines them as the flat or concave bottoms of the valleys, small valleys, and gutters of floodable flows, which constitute the elementary drainage axes nested in the thick alterations of the peneplanized crystalline bases. Their soils are waterlogged or submerged for a, more or less, long period of the year. Ref. [30] considers them as the upper parts of watercourses in which alluvial sedimentation processes are absent or of minor importance. More recently, Ref. [3] defines inland valleys as seasonally flooded wetlands, including both valley bottoms and hydromorphic fringes, but excluding floodplains.

The lack of a consistent and fixed definition of inland valleys has been a significant constraint in comparing or synthesizing different studies on the hydrology of these environments [27,31]. The multitude of definitions in the literature, combined with linguistic divergences, has prompted the proposal of a standardized definition within the framework of this study. Therefore, inland valleys are referred to as sub-catchments: (1) located upstream of the hydrographic network; (2) with an area less than or equal to 200 km²; (3) with a main stream with a gentle longitudinal slope (<5%); and (4) soils with low permeability, presenting an aptitude for waterlogging or submersion for a, more or less, long period of the year. The choice of 200 km² as the upper limit for the area aligns with previous works [13,32]. The slope threshold is also in accordance with previous studies and criteria considered in decision support tools for inland valley management [33].

In practice, inland valleys are fundamentally differentiated from floodplains by their catchment area size (over 200 km²). Typically, inland valleys are found at the level of 1st-to-4th-order streams. Beyond this, lowlands are considered as floodplains [34]. Inland valleys also differ from ponds/marshes in the strict sense, as the latter lack an outlet and are perceived as hydrological and biological systems without their own dynamics [35]. However, in certain regions, particularly in the semi-arid areas, inland valleys may contain hydrological units similar to ponds or dams within their catchment or outlet zones [35]. Finally, the inland valleys differ from the permanently waterlogged mangroves, which generally exhibit, apart from the waterlogging observed in the marshes, a high-water salinity.

2.2. Research Database

Data from the literature search were collected from ScopusTM, Science DirectTM, and Web of ScienceTM databases. The choice of its bases is justified by the reliability of the peer-reviewed scientific publications provided therein [36]. Additionally, relevant documents

from the Google Scholar™ database and the thesis dissertation (from ZEF, HAL, and Theses.fr doctoral theses) were also considered. We applied “keyword search”, which offers the advantage of covering a wide range of articles compared to searching by title alone. The selected keywords focused on the hydrological functioning of inland valleys in Africa. The research equations incorporated three factors: (1°) the known names of the inland valley ecosystems, (2°) the research object (hydrological functioning and water flow dynamics), and (3°) the geographical zoning (Africa, south of the Sahara). The types of documents considered are articles, book chapters, conference presentations, and doctoral thesis reports. To include all the documents produced on the subject, the terms presented in Table 1 were used in the field (title, abstract, and keywords). Additionally, a “citation hunting” strategy was employed by reviewing and selecting relevant references cited in the initially selected documents. A summary of the keyword combinations used to capture inland valley hydrology literature is provided in Table 1.

Table 1. Criteria used to identify documentation on inland valley hydrological functioning in tropical Africa in web databases.

Search Engine	Search Equations
Scopus™, Science direct™, Google scholar™	(inland valley) OR (inland swamps) OR (lowland valley) OR (valley bottom) OR (bottomland) OR (fadama) OR (dambo) OR (bas-fond) OR (vlei) OR (small wetland) OR (headwater wetland) OR (headwater swamp) OR (headwater-catchment) OR (small catchment) OR (small watershed) AND (hydrology) OR (hydrological functioning) OR (modeling) OR (modeling) OR (water resource management) OR (water balance) OR (water budget) OR (runoff dynamic) OR (soil moisture dynamic) OR (groundwater dynamic) OR stream flow AND (Africa) OR (Africa tropical climate) OR (African country name)

To ensure the relevance of the search results, a screening process was conducted to exclude duplicate documents. The remaining documents were then verified based on their titles and abstracts, with those deemed outside the scope of the study being excluded. Only documents written in French and English were considered for this study. In addition to scientific documentation, grey literature sources were explored, including project reports and existing documentation from various non-governmental organizations (NGOs) involved in inland valley management. This grey literature served as a valuable resource and supported the analysis and discussion in this study.

2.3. Data Collection, Processing, and Analysis

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [37], as illustrated by the flow diagram (Figure 1) and the checklist included in Appendix A (Table A1). Figure 1 summarizes the documentation identification and validation procedure as part of the study. Within this study, we initially assessed all the documents having dealt with an aspect of the hydrological functioning of inland valleys. These documents were then divided into two main classes, namely the “primary documents”, which deal with the analysis of raw hydrological data, and the “secondary documents”, which represent the literature review documents. Both the primary and secondary documents were used for the narrative analysis of the hydrological functioning.

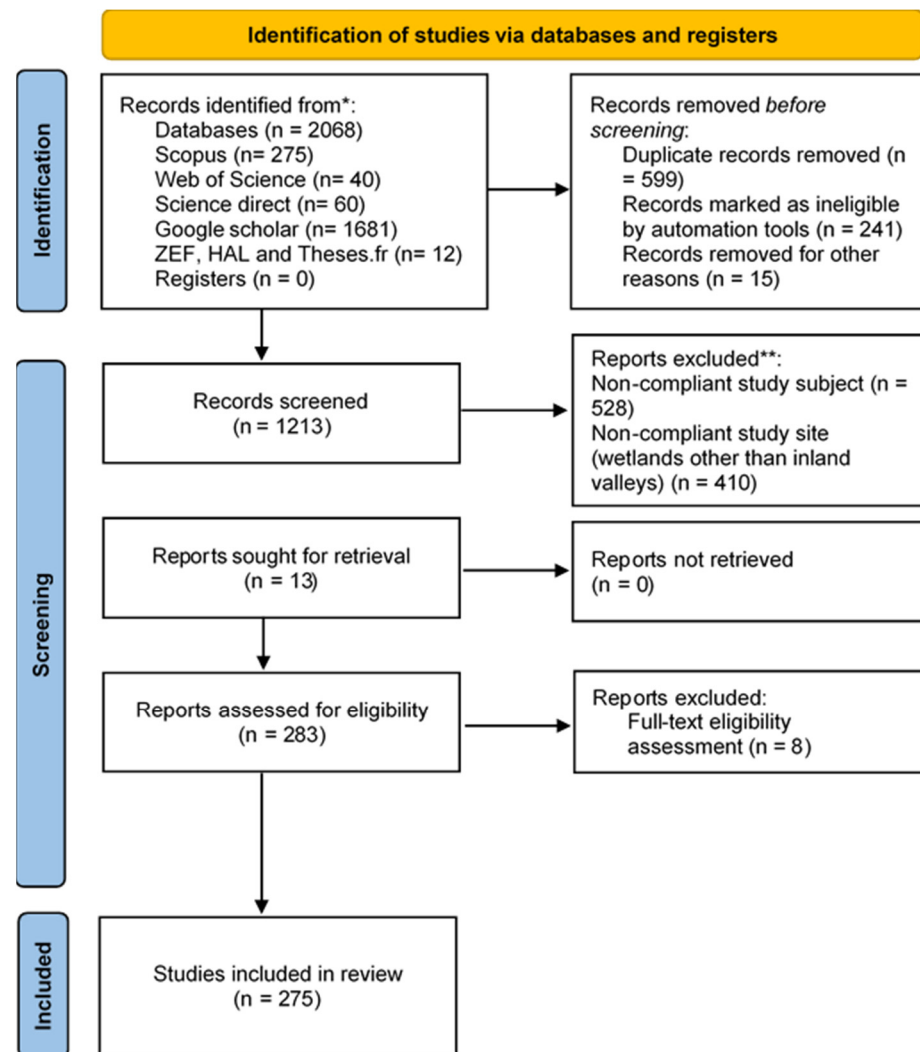


Figure 1. Screening sheet of the document classification and selection procedure (according to PRISMA 2020 flow diagram for new systematic reviews, which included searches of databases and registers only). * Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/register). ** If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

The full bibliometric data of the primary documents were collected and analyzed for a better understanding and the mapping of studies on the dynamics of water in inland valleys (Table 2). The use of descriptive statistics and pivot tables allowed us to highlight the spatio-temporal dynamics of the studies. Collaboration networks between the 100 most productive authors (in terms of participation in a research paper) in the field of inland valley hydrology were obtained on the Cortext Manager platform based on the Louvain cluster detection algorithm [38]. The analysis of the textual content conducted on the key words of the various documents allowed the extraction of the terms with the highest frequency of use. For a better reading of the themes of interest addressed in the field, terms associated with the names of the inland valleys and the geographical zoning were disregarded for this analysis. To analyze the priority study topics covered in the literature, the primary studies were categorized based on the main aspects of the water cycle they address: surface water dynamics, soil water dynamics, and/or groundwater dynamics.

Table 2. Summary of data collected and processing methods used for the analysis of bibliometrics and methods for studying the hydrological functioning of inland valleys.

No.	Rubric	Data Collected by Study/Variables	Analysis Methods
1	Bibliometrics	Title of document, year of publication, type of documents, language of publication, name of authors, author keywords, abstracts, name of the journal of publication, countries studied	Descriptive statistics Text and network analysis
2	Applied study methodologies	Climatic zone, name and number of watersheds studied, surface area of the inland valleys studied (km ²), duration of the experimental study (months), main hydrological aspects addressed	Descriptive statistics Literary critical analysis

Following the bibliometric analysis, which mapped the landscape of research on water dynamics in inland valleys, the focus shifts to a more targeted quantitative synthesis of experimental studies. By considering runoff as the reflection of the aggregate hydrological behavior of the system, we focused on the studies addressing the question of surface runoff at the outlet of inland valleys. Only experimental studies were considered in this section. The following documents were, therefore, excluded from this section: review of inland valley hydrology, study of certain aspects of hydrological functioning (soil moisture and aquifer dynamics) without addressing the question of surface runoff, and study of runoff based on generic data estimations or experimental data conducted on a plot scale.

We conducted a quantitative summary of the results obtained from these studies of surface runoff in inland valleys outlet by structuring data collections around two questions:

- (1) What are the physical parameters that govern the genesis and dynamics of runoff in inland valleys?
- (2) What specific challenges does hydrological modeling currently face in the inland valley systems?

Table 3 presents the breakdown of the variables and indicators collected in the different studies according to these questions.

The first question was examined from three different temporal perspectives. First, at the “event” scale, to gain a deeper understanding of hydrological responses to individual rainfall events. Second, at the “hydrological year” scale, to analyze annual or seasonal water balance components. Lastly, at a multi-year scale (averaging data over a minimum of 3 years), where the hydrological characteristics could provide a more representative depiction of the underlying dynamics of the ecosystems under investigation.

Table 3. Summary of data sources and analysis methods performed for quantitative synthesis of the main drivers of hydrological flows in inland valleys.

No	Questions	Components	Variables	Source	Analysis Methods	
1	What are the physical parameters that govern the genesis and dynamics of surface flows in inland valleys areas?	Morphology	Area (<i>A</i>), Maximum Elevation (<i>E_{max}</i>), Minimum Elevation (<i>E_{min}</i>), Total Relief (<i>TR</i>), Mean slope (<i>S</i>), Slope of flow axis (<i>S_r</i>), Topographic Wetness Index (<i>TWI</i>), Percentage of Upstream Drainage Area (<i>U_d</i>)	SRTM 30 m [39]	Descriptive statistics Correlation analysis and regression tests between physical parameters and hydrological responses	
		Soil properties	Main Soil texture, % of Sandy-Loam (<i>SaLo</i>), % of Clay-Loam (<i>ClLo</i>), % of Sandy-Clay-Loam (<i>SaClLo</i>), Mean Clay Content in Catchment Surface (<i>Cl-C_{sf}</i>), Mean Sand Content in Catchment Surface (<i>Sa-C_{sf}</i>), Mean Silt Content in Catchment Surface (<i>Si-C_{sf}</i>), Mean Clay Content in Bottom Valley Surface (<i>Cl-B_vsf</i>), Mean Clay Content in Catchment at a depth of 2 m (<i>Cl-C_{2m}</i>), Mean Clay Content in Bottom Valley at a depth of 2 m (<i>Cl-B_v2m</i>), Average of Absolute Depth of Bedrock in Catchment (<i>D_{bed}</i>)	iSDAsoil [40], Soil Grid [41]		
		Basin geology	Aquifer Type and Productivity, Main geological layer	Africa Groundwater Atlas [42]		
		Land cover	Main Land Cover, Annual Normalized Difference Vegetation Index (<i>NDVI</i>), Annual Amplitude of NDVI (<i>NDVI-Am</i>), Tree Cover (<i>TC</i>), Non Tree Vegetation Area (<i>NTVeg</i>), Non Vegetated Area (<i>NVA</i>), Tree Canopy Cover of Catchment (<i>TCC-C</i>), Tree Canopy Cover of Bottom Valley (<i>TCC-B_v</i>)	MODIS Land Cover Type Yearly, Terra Vegetation Continuous Fields Yearly Global, Global Forest Cover Change [43]		
		Climatic data	Multi years	Climate Class/Group, Mean Annual Rainfall (<i>P_{mean}</i>), Mean Annual Actual Evapotranspiration (<i>AET_{mean}</i>), Mean Annual Potential Evapotranspiration (<i>ETP_{mean}</i>), Aridity Index Mean (<i>AI_{mean}</i>)		Papers, MODIS Global Terrestrial Evapotranspiration, TerraClimate [44]
			Annual	Climate Class/Group, Annual Rainfall (<i>P_a</i>), Annual Actual Evapotranspiration (<i>AET_a</i>), Annual Potential Evapotranspiration (<i>ETP_a</i>), Aridity Index (<i>AI</i>)		
			Event	Climate Class/Group, Event Rainfall (<i>P_e</i>), Event Intensity (<i>I_e</i>)		
		Runoff data	Multi years	Mean Total Runoff (<i>Q_{mean}</i>), Mean Runoff Coefficient (<i>Cr_{mean}</i>)		Papers
			Annual	Annual Total Runoff (<i>Q_a</i>), Annual Total Runoff Coefficient (<i>Cr_a</i>), Annual Quick flow (<i>Q_{qa}</i>), Annual Baseflow (<i>Q_{ba}</i>), Annual Baseflow Index (<i>BFI_a</i>)		
			Event	Event Runoff depth (<i>Q_e</i>), Event Runoff Coefficient (<i>Cr_e</i>)		
2	What specific challenges does hydrological modeling currently face in inland valleys system?	Runoff (simulated—observed)	Models Used, Temporal and Spatial Resolution of Use of the Model, Statistical Performance of Simulations (NSE, R ²), Residual in % of Observed Values	Papers	Descriptive statistics, Critical analysis	

The variables to be explained are the terms of the hydrological response for different time extension scales (event, annual mean, and multi-year data). The documents used here are those providing at least information regarding the “stimulus” (rainfall in our case) and the “response” (runoff height and/or coefficient, as well as total flow) for at least one time extension scale. The climatic and hydrological information collected (Table 3) is extracted directly when reading the document or by using the WebPlotDigitizer version 4.6 software [45] to read the graphs and figures. Out of 163 documents focusing on surface flows, 55 provided annual quantitative data, and 11 presented event-scale data that were specifically utilized in the context of this study. Tables A2–A4 in Appendix A present the documents used for detailed analysis of runoff in the inland valleys.

To understand the influence of environmental components on runoff, the choice of physical parameters or explanatory variables used (Table 3) is inspired by relevant hypotheses formulated in previous syntheses, most of which remain to be verified or confirmed [17,46,47]. As these parameters are frequently lacking in the documents we used, and for the purpose of standardizing our data sources, we utilized a combination of validated generic datasets to describe site properties (Table 3). We used Shuttle Radar Topography Mission (SRTM 30 m) to obtain the catchment shapefile and determine inland valley characteristics. This process includes georeferencing of site, outlet coordinate extractions, catchment delineation, and analysis using geographic information systems like QGIS in this review. Differences can occur in catchment delineation operation due to variations in digital elevation model (DEM) data and the precision of outlet coordinates. To ensure the accuracy of the obtained shapefile with studied catchments, we analyzed catchment shape and area. Following the approach used by [48], we have considered, for analysis, inland valleys for which the delineated area deviates by less than 20% from the area originally reported by the authors. The validated catchment shapefile has been subsequently integrated as an asset into the Google Earth Engine (GEE) platform to acquire supplementary site-specific data. Since the majority of studies/experiments were conducted during the period from 2000–2020, we have shown a particular interest in databases covering this temporal range. Additional evapotranspiration data are estimated with the TerraClimate and Moderate Resolution Imaging Spectroradiometer database (MODIS Global Terrestrial Evapotranspiration 8-Day Global 1 km). MODIS Terra Vegetation Continuous Fields Yearly and Global Forest Cover Change have been used as alternative information sources for land cover estimations. Soil data were obtained from World Soil Information (SoilGrids) and Innovative Solutions for Decision Agriculture (iSDAsoil), which provide generic soil data for Africa. Geological information was extracted from the Africa Groundwater Atlas Country Hydrogeology Maps. In addition to the parameters obtained at the watershed scale, we further estimated soil and vegetation parameters within a buffer zone extending 50 m from the main flow axis. The accuracy and quality of the extracted data were assessed through expert validation, including comparisons with established benchmarks and, when possible, with data provided by the authors.

The analysis performed on the obtained database initially involved exploring the rainfall–runoff relationship at various scales. We applied the clustering K-means method to identify similar classes in the hydrological response in studied inland valleys. Then, we performed correlative analyses between mean annual runoff and inland valley physical parameters. According to observed correlations, we tested regression approaches to determine a predictive equation of annual runoff based on the most reliable physical parameters. We employed a random allocation pattern with 80% of the data designated for calibration and 20% for validation.

To address the second question concerning the specific challenges of hydrological modeling in inland valley systems, we have conducted a critical analysis of studies that

have explored this issue. In this exercise, the objective functions considered for the analysis of the modeling results include the NSE and R^2 , since these are the usual functions used in the majority of studies. When the data provided by the authors allowed, we also assessed the residual between observed and simulated annual runoff. The modeling results obtained by the authors were objectified according to the classification of [49] for river flows at the catchment scale. A critical analysis is conducted on the impacts of climate change and land use on inland valley hydrology and on the capacity of the usual models to reproduce the main processes governing the dynamics of water in the areas.

3. Results

3.1. Global Evolution of Research on the Hydrological Functioning of Inland Valleys in Tropical Africa

This study incorporates findings from 275 publications that present results on the dynamics of water in inland valley areas in tropical Africa. The earliest paper dates back to 1973, but the bulk of the literature—77%—was published in the last 23 years (2000–2022). The analysis of the statistics in relation to the documentation used for narrative purposes in this study (188 documents) reveals a difference in the format of the rendering of the documents pre- and post-2000. Documents from the first period, presented mainly in the form of reports, did not allow the exploitation of experimental data as desired here. For the post-2000 period, the average of eight publications per year highlights the substantial increase in scientific production (Figure 2). The scope of research has broadened, moving beyond the rain–runoff relationship to encompass other aspects of the hydrological cycle in inland valley areas, such as soil moisture and groundwater dynamics. The field is still growing, but most studies are mainly project-dependent, and this reality impacts publication trends. For example, there was a noticeable surge in publications in 2009 when a significant set of scientific advancements from the AMMA-CATCH observatory were presented in a special issue of the *Journal of Hydrology* [50]. Eighty nine percent of the documentation used is in the form of a scientific article, with 96% of the documents written in English, reflecting the predominant mode of scientific communication on the subject.

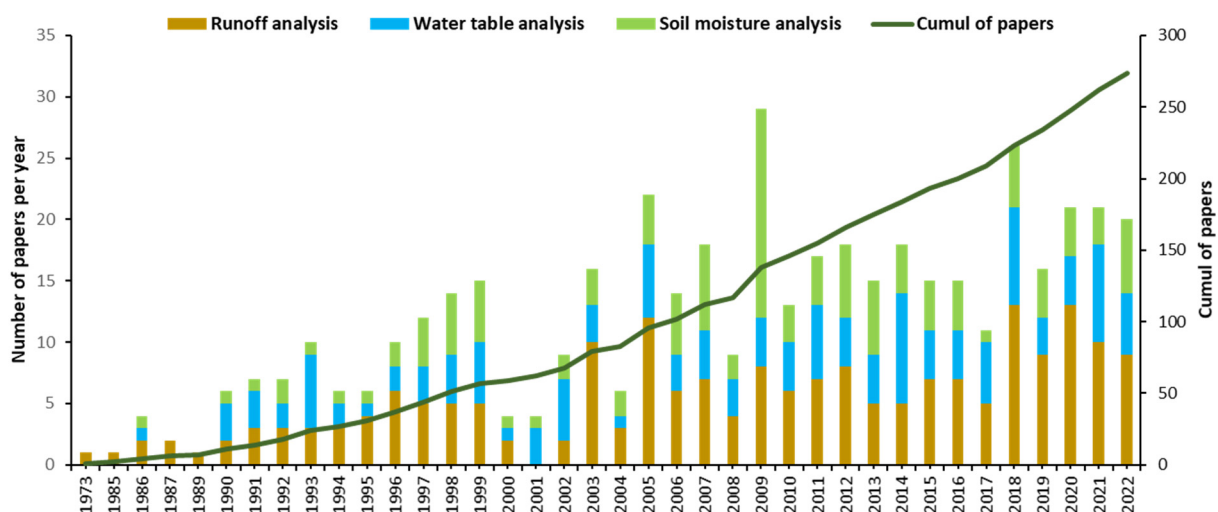


Figure 2. Temporal dynamics of inland valley hydrology research in Africa.

In terms of geographical zoning, the studies focus on West, East, and Southern Africa and extend from the semi-arid to rainforest zones (Figure 3). According to the Köppen classification [51], three climatic sets are particularly represented in runoff studies, namely the tropical savannah climate with dry winter (Aw), the semi-arid tropical climate (BSh), and the warm temperate climate with dry winter (Cwb). This geographic focus could be

reflective of the distinctive hydrological challenges these regions face due to their unique climatic conditions.

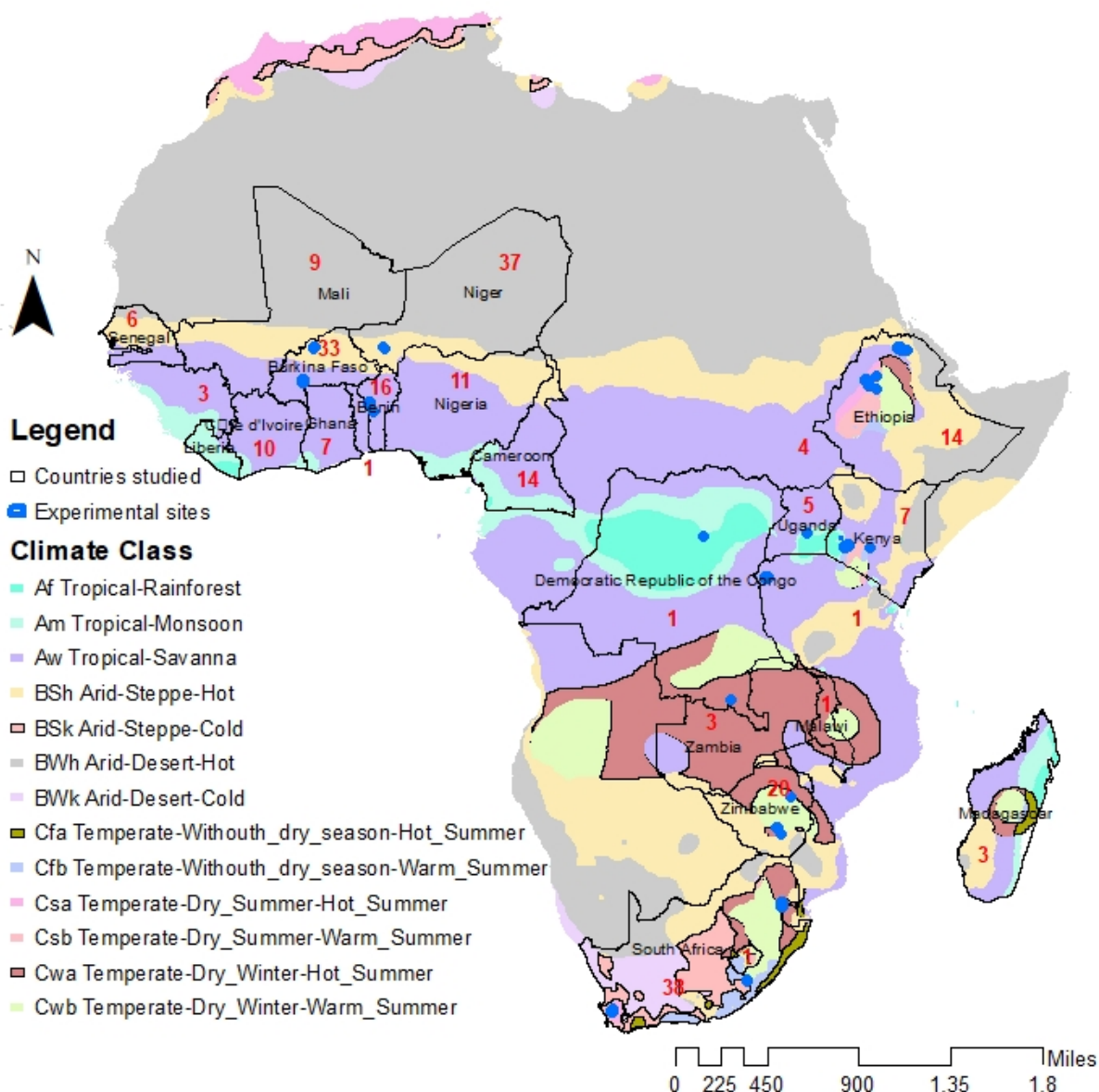


Figure 3. Distribution of studies on hydrological issues in inland valleys areas in Africa. Red numbers are the number of studies per country and blue dots represent experimental sites used for quantitative synthesis. In background, the climate map according to the Köppen classification.

It is crucial to note that some watersheds, similar to inland valleys in some points but fundamentally different regarding the longitudinal slopes of the mainstream, have been observed in the Eastern and Southern zone of the continent and have not been considered in this study. Examples of these basins include Debre Mawi, Ene Chilala, Zenako-Argaka, Andit Tid, Maybar, Bekafa, Enkulal sub-catchments, Gomit in Ethiopia, Kwalei in Tanzania, Cathedral Peak Forestry Research Station, Two-stream research catchment, and Bosboukloof-Langrivier in South Africa. Certain catchments were excluded due to lack of the necessary elements to assess their nature, particularly regarding discriminatory physical criteria such as surface area, longitudinal slope of the flow axis, or soil type. These include the basins of Kromme (K90A and K90B), national gauging stations code A2H039, A2H038 in South Africa, and Mpamadzi and Mpira river catchment in Malawi. Most of

these wetlands are located in the steep slope regions of the eastern and southern parts of the continent.

In terms of collaboration, we note the existence of four (04) research clusters with no apparent connection seen from the angle of co-working (Figure 4). This reality is nuanced by a weak but existing relationship for collaboration between authors in terms of citations. Collaborative efforts can still be improved between institutions. The main cluster is made up of the research network of the Institut de Recherche pour le Développement (IRD) and research teams from the University of Bonn, which operate in West, Central, and East Africa. The sites of interest of the other clusters cover the eastern part and the southern region of Africa. The size of the dots in Figure 4 reflects the level of productivity of different authors in terms of the number of articles published. On the institutional level, the Research Institute for Development (France) and the University of Bonn (Germany) are the most productive structures from the point of view of the publication. Their research teams also have the highest ratios of documents cited. With their proposal to classify inland valleys soils according to runoff abilities, ref. [52] represents the most cited document (256 citations as of 31 May 2023).

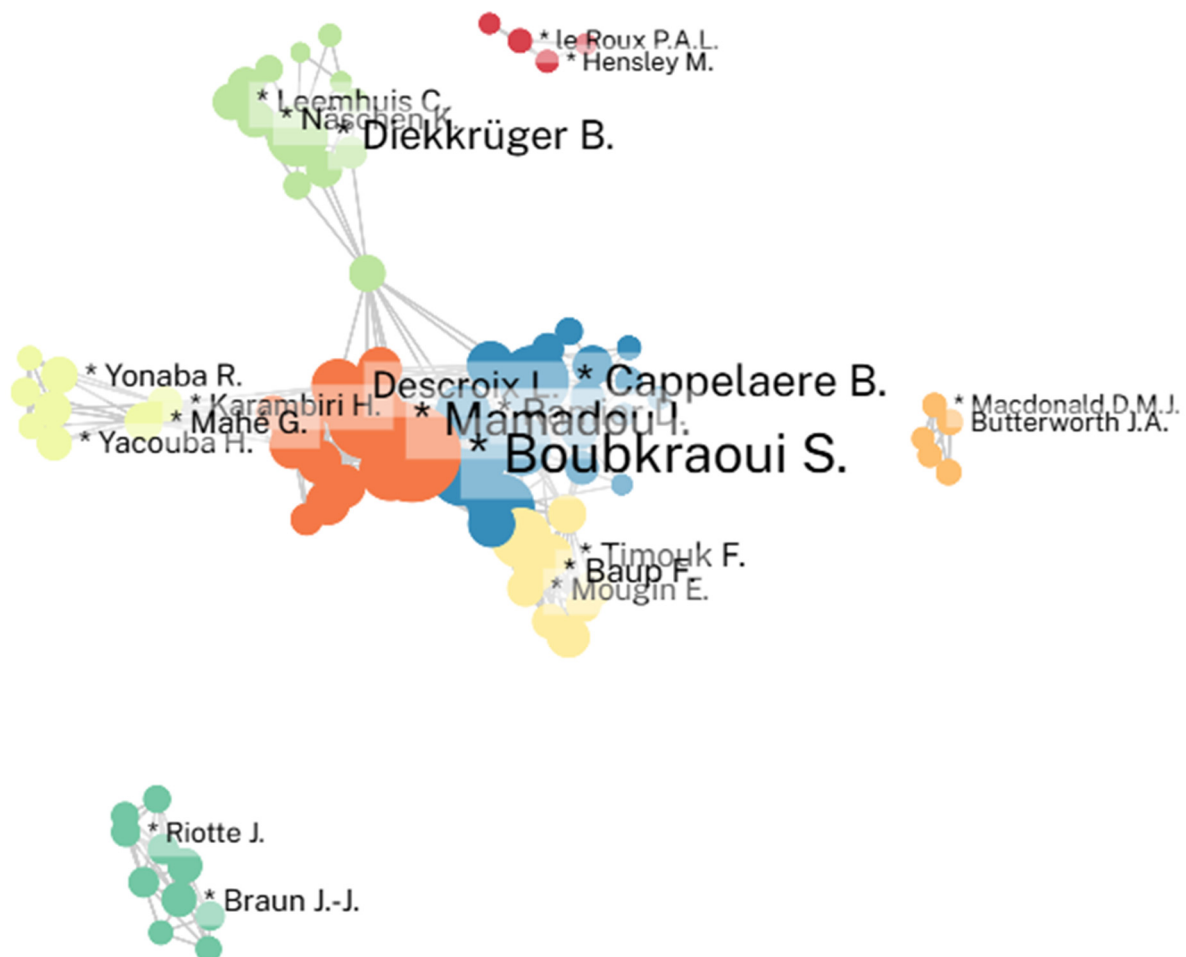


Figure 4. Network of collaborations between researchers working on the hydrological functioning of inland valleys; '*' refers to the name of the most important collaborator of the cluster.

One hundred eighty-three documents provide information related to the key words of the completed research. Their titles and keywords were analyzed according to the occurrence of the main terms used. The 15 main terms used by authors (Table 4) indicate that the primary focus relates to the process of runoff genesis and land use, likely as an explanatory factor. Regarding hydrological processes, soil moisture and groundwater

dynamics are also analyzed in relation to factors such as soil properties or the physical characteristics of the study sites. Specific emphasis seems to be placed on the valley bottom as a distinct study portion within the hydrological unit that constitutes the inland valleys. Seasons, which dictate the hydrological regime, are analyzed in correlation with water and soil management practices due to the potential impacts of global changes on hydrological regimes. Trends in terms of themes of interest center on understanding the physical determinants of surface runoff, the variability of inland valley soil moisture, or groundwater recharge mechanisms. These trends are corroborated by the work of [53,54].

Table 4. Summary of the 15 terms most used as keywords by authors.

Shapes	Frequency	Distinct Number of Documents
Surface runoff and runoff generation	37	28
Land use and land use change	34	25
Soil moisture and soil water	34	28
Groundwater levels and groundwater recharge & water table	32	18
Water resources and water resource management	30	19
Hydrological processes and hydrologic process	21	21
Water balance and water budget	19	17
Season and dry or wet	17	11
Soil data and soil surface	15	9
Climate change	11	10
Valley bottom	8	7
Water erosion	6	6
Physical properties	5	4
Scale effects	5	3
Hydrological regimes	5	2

Regarding publication channels, it should be noted that the top 10 journals account for 50% of all scientific communication on the subject of the hydrological functioning of inland valleys. In order of publication count, these are the Journal of Hydrology (28 papers), Hydrology and Earth System Sciences (23), Hydrologic Processes (17), IAHS-AISH Publication (16), Physics and Chemistry of the Earth (11), South African Journal of Plant and Soil (10), Hydrological Sciences Journal (09), Agricultural Water Management (07), and Catena (06).

3.2. Methodologies Used in Literature to Study the Hydrological Functioning of Inland Valleys

A holistic approach that goes beyond considering only water dynamics in the bottom valley area and that considers the broader hydrological processes occurring throughout the entire watershed is generally adopted to study the hydrological functioning of inland valleys. This integrated perspective provides a more accurate understanding of the complex interactions and interconnectedness of water resources in this environment. The main approach is based on the so-called representative basins method [13]. This method is summarized in four steps:

- Choose inland valley catchments (between 1 and 200 km²) that are representative of the environment (relief, vegetation, soils);
- Observe all elements of the hydrological cycle intensively for 2–5 years to deduce reliable rainfall–flow relationships;
- Extrapolate the rainfall–runoff relationships over time on the representative basin and perform statistical analysis on them;

- Regionalize results to extrapolate hydrological data to ungauged basins.

Studies adhered to this schema, with a significant evolution in terms of the temporal scale of data collection, which has seen improvements with technological advancements (e.g., automatic recordings at fine time steps and improved precision). Considering the extreme rapidity of runoff responses in inland valley areas [55,56], the use of automatic flow monitoring devices enables better tracking of hydrological responses. Based on information collected for this review, the experimental studies on the observation of surface flows in the inland valleys cover an average period of 5.5 years. Seventy one percent of the studied basins have areas of less than 10 km². An analysis of the parameters explored in the studies of inland valley hydrology indicates the need to enhance their physical characterization, particularly in the areas of morphology, soils properties, land cover, and geology (Table A6). While remote sensing data provides valuable information at the watershed scale, there remains a desire for more precise data to enhance our understanding of processes at finer spatial scales in these smalls' ecosystems. For example, on this question, recent studies have shown that digital elevation models (DEMs) derived from satellite data (such as SRTM and ASTER) lack the precision required for investigating micro-processes in small catchments, such as inland valleys [7,57]. Studies also highlight that there are few systems for continuous hydrological monitoring of inland valleys, mainly in West and Central Africa. Ref. [58] addressed this issue by pointing out that, despite the growing socio-economic issues related to the control of hydrological risks, few permanent facilities for hydrometeorological monitoring and environmental observatories have been identified in tropical environments. A critical analysis of the installations conducted reveals that efforts should be made in terms of densification of instrumentation networks, particularly in the less studied climatic zones. Long-term experimental sites will need to be established to allow for an analysis of possible alterations in these environments. Table A5 in Appendix A presents a summary of the hydrological datasets available in the literature for inland valleys studied in tropical Africa.

Many physical parameters, which seem to interact with the dynamics of water in inland valley areas, such as the depth of the impermeable layer and the surface area of the valley bottom, are infrequently studied or specified in the various studies. Aquifers are poorly investigated, partly due to a paucity of existing hydrogeological information in many regions of Sub-Saharan Africa [59]. Studies rarely explore deep aquifers. The piezometric study depths remain generally in the range of 1 to 10 m and, therefore, relate mainly to the shallow aquifer. The literature also highlights the scarcity of high-resolution and good-quality time-series data on hydrological parameters like soil moisture with frequent gaps in the available datasets due to measurement constraints and malfunctioning of commonly used devices [60]. A major constraint related to devices for in situ measurement of hydrological parameters such as soil moisture is that they provide point measurements and do not consider the spatial variability of the parameters studied [61]. These difficulties circumvented by large hydrological systems by the contribution of remote sensing data remains a real challenge for the study of inland valleys, mainly because of the small areas studied. Recent advances in terms of spatial data analysis tools offer however unique opportunities to improve the monitoring of semi-arid wetlands of varying sizes, which was not previously possible, using traditional remote sensing techniques [62]. Low-cost proxy detection methods and data from citizen science [63] could address a part of the need for monitoring of physical and hydrological parameters in the inland valleys. Alongside field investigations and generic data, modeling studies should be conducted simultaneously to test hypotheses on the behavior of the process at the catchment scale [64].

3.3. Hydrological Functioning of Inland Valleys

Analyses performed on hydrological functioning of inland valleys are based on 66 studies in a set of 79 inland valleys. The major agro-ecological units studied cover tropical (A), dry (B), and temperate (C) climatic group according to the Köppen classification [51]. Among the inland valleys studied, 16 deal with runoff at the event scale and 72 at the annual scale (Tables A2–A4). Thirty-three of the inland valleys studied at the annual scale were monitored for at least 3 years (Table A4).

3.3.1. Mains Flows at Inland Valleys Catchment Scale

The literature agrees in recognizing that inland valleys are mainly supplied by four water sources: direct precipitation, subsurface throughflow from the interfluves, overland flow from the interfluves, and overbank contributions from river channels [14]. The respective shares of this different sources during and at the end of the rainy season vary greatly from one inland valley to another or from one place to another in the same inland valley [29]. Two theories are put forward as to the main source of water supply for the inland valleys. One argues that direct precipitation is the main water source of this ecosystem [28,65], while the other considers that it is rather subsurface and groundwater flow [66]. Water brought to the soil of an inland valley, either by precipitation or by irrigation, has three possible fates: infiltration, immediate runoff, or evaporation [13]. Table 5 presents a synthesis of the main components of water balance at the annual scale in inland valleys according to climatic zones.

Table 5. Water balance at annual scale in inland valleys areas according to studies reviewed.

		Total Rainfall (mm)	Total Runoff (mm)	Actual Evapotranspiration (mm) *
Dry Climate N = 93	Min–Max	150–1430	10–520	323–804 ⁽⁸⁰⁾
	Mean	531	149	517
	Standard Deviation	166	96	10
Tropical Climate N = 53	Min–Max	787–2031	50–665	772–1184 ⁽³⁷⁾
	Mean	1260	247	940
	Standard Deviation	285	163	99
Temperate Climate N = 122	Min–Max	658–2599	27.34–1348	506–1319 ⁽⁶⁶⁾
	Mean	1565	504	861
	Standard Deviation	521	320	195

Note: * Number of Estimation Years Used.

Evapotranspiration is the main component of water loss in inland valley areas: between 60 and 86% of the water supply is lost there [67–72]. In terms of the evapotranspiration balance, Ref. [72] showed that evaporation is greater than transpiration. Inter-annual variability of evapotranspiration is low compared with that of rainfall [70]. At certain study sites, notably high coefficients of variation in annual rainfall (approximately 42%) have been observed and documented [73]. Infiltration, which is the least-reported component of the water balance at catchment scale, mainly depends on the surface features; that is to say, the vegetation and the surface organization of the soil. The surface features also determine the processes of runoff genesis [52,74]. Annual runoff greatly varies among zones and represents between 5% and 60% of annual rainfall.

During the hydrological year, response in inland valleys can be broken down into four (04) phases, namely soil saturation, groundwater recharge, surface runoff initiation, and finally drainage. These different phases are closely linked to the hydrogeological

model of the inland valleys, which is presented as consisting of two or three underground reservoirs [64]. Independently of the number of layers constituting the aquifer, inland valleys are very often characterized by a rapid decrease in permeability with depth due to the accumulation of clays, constituting an impermeable layer and allowing for the formation of perched water tables in the bottom valley [55,67]. This impermeable layer plays an important role in the hydrogeology of the inland valleys by preventing or limiting communication between the surface hydrological system and the deep water table [17]. There is no established consensus on the hydrogeological model of inland valleys and the subject of connectivity between deep groundwater and shallow aquifer. While some sources argue that the two aquifers are hydraulically connected [75–77], others claim there is no or a poor connection in the system [59].

At the start of the rainy season, soil saturation and groundwater recharge are very sensitive to rainfall, increasing after each rainfall event and decreasing rapidly during dry periods [78]. At the temporal scale, precipitation strongly controls the variability of inland valley soil moisture. At the spatial scale, soil properties, topography, distance from the flow axis, and land use seem to be the factors controlling its dynamics [5,79,80]. Significant relationships have been observed between the soil moisture profile and groundwater level [73]. The groundwater recharge process is dominated by direct infiltration through the unsaturated zone in general [71,81] and temporary drainage networks in certain cases [82]. The response of the system depends, to a large extent, on the distance from the nearest infiltration area, the hydraulic characteristics of the aquifer [82], and the soils [83]. In the Sahelian zone, the works of [82,84,85] have updated the specificities of the groundwater recharge process and the determining role that endorheic pools play in it. Recharge rates vary between 5 and 24% of the annual rainfall [70,86].

Although the mechanisms of the genesis of surface flows in inland valleys areas are not fully established, it is recognized that runoff is generated by rainfall following its heights and intensities. The process is reported to also be controlled by the state of the soil [87] and the hydrogeological structure of aquifer [77]. The presence of two main types of surface flow, hortonian and excess saturation flow, has been documented. At the beginning of the rainy season runoffs, mainly the hortonian flow is observed on the areas of steep slopes. This flow develops simultaneously with the infiltration processes to saturate the soils of the valley bottom as the rainy season evolves. Ref. [88] has shown that, depending on the characteristics of rainfall events, the vertical variability of the saturated hydraulic conductivity (K_{sat}) of slope soils controls at what lateral depth runoff is induced. Ref. [89] also highlights the role of the soil as an indicator of hillslope hydrological behavior and how the saturated conditions in bottom valleys drives overland flow due to impairing infiltration. The runoff initiation process follows different periodicities by climatic zone, with cumulative rainfall before observation of the streamflow period varying considerably from 1 year and one site to another. Refs. [55] and [90], respectively, report 203 mm and 664 mm for inland valleys located at tropical savanna climatic zone, respectively, of Ivory Coast and Benin. On one distinct inland valley, the variable values of cumulated rainfall depth before the beginning of the permanent flow show that the onset of the streamflow does not depend on a constant basin storage capacity [70].

Depending on the rainfall gradient and hydrogeological system, the runoff can take an intermittent or seasonal form. While the runoff on inland valley rivers in semi-arid zones seems mainly made up of surface flow, due to the sparsely covered soils and encrusted surfaces [16] and relatively deep aquifers [91], flows in humid zones are characterized by the coexistence of the surface, subsurface, and base flow [92]. The three flows occur during the rainy season, but only baseflow ensures the runoff in the absence of precipitation [70]. Under initial soil saturation conditions, double-peak hydrographs are reported in some

inland valleys, with the first peak mainly consisting of surface runoff, and the second was essentially induced by subsurface flow [55,72]. Mixed trends are reported on the subject of the runoff component. Some authors suggest that baseflow is the major contributor to the streamflow [70,90,93]. Inversely, refs. [4,72] observed some case where direct runoff, composed of subsurface and overland flow, is the main component of flow. At the end of the rainy season, and particularly in the inland valleys with a fairly thin and shallow impermeable layer, the flows generally continue for a few days and cease when the piezometric level in the valley bottom, near the flow axis, is below the impermeable clay layer [65]. Drainage processes usually start a few days after the rain stops. At the peak of the dry season, two hypotheses can explain the origin of the drawdown of the water tables in the inland valleys: either a resumption of evapotranspiration, or deep circulation and large-scale drainage. Local evapotranspiration measurements tend to validate the first hypothesis. Evapotranspiration would, therefore, be responsible for the drop in underground water stocks during the dry period [70,90].

3.3.2. Driving Factors of Hydrological Response in Inland Valleys

To determine driving factors of hydrological responses in inland valleys, we firstly analyze rainfall–runoff relations by applying the clustering Kmeans method to datasets of different scales. We relied on the silhouette coefficient to identify the optimal number of clusters for each dataset. This exploratory analysis revealed a good correlation between rainfall and runoff at all scales: $R^2 = 0.50, 0.80,$ and $0.76,$ respectively, for event, annual, and multi-year scales. Classes of similarities emerge along the rainfall gradient (Figure 5). The observed classes can be synthesized into three main categories: low, intermediate, and high rainfall. The limited dataset at the event scale does not allow for differentiation of hydrological response between low and intermediate events but remains consistent with the rainfall gradient. By incorporating information about the climatic zone into the obtained clusters, we note a prevalence in high rainfall events (>80 mm) in dry climatic zones. At the annual and multi-year scales, the observed clusters align nearly with the climatic groups (dry, tropical, and temperate). Low annual rainfall is observed in dry regions, while intermediate and high annual rainfall are aligned with tropical and temperate zones.

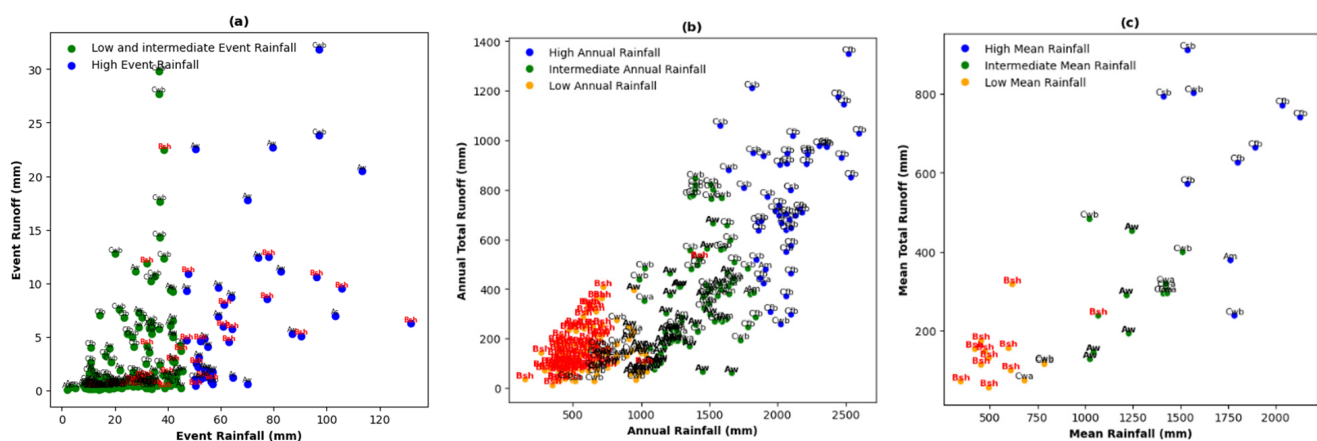


Figure 5. Rainfall–runoff relations according to time scale in inland valleys: (a) at event scale, (b) at annual scale, and (c) at multi-year scale. Bsh, Aw, and Cwb, respectively, refer to dry, tropical, and temperate climatic groups according to the Köppen classification.

Runoff coefficient trends per cluster/climate groups show a regional pattern in the hydrological response (Figure 6). On annual and multi-annual scales, in particular, inland valleys in dry and temperate areas exhibit higher runoff coefficient. At the event scale, runoff magnitude is also especially important in these regions. These observations are in

adequation with the literature, which highlight the intense nature of runoff in semi-arid zones due to soil crusting in the temperate regions of Africa.

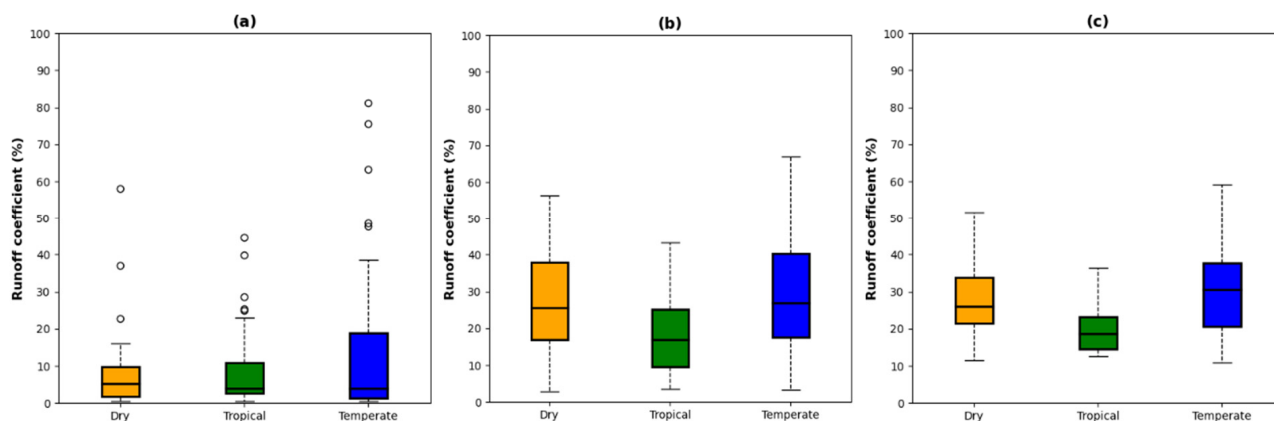


Figure 6. Runoff coefficients according to time and climate scales in inland valleys: (a) at event scale, (b) at annual scale, and (c) at multi-year scale. Circles refer to individual observations.

Analysis performed on runoff relations with other covariables was conducted at annual (Figure 7) and multi-year scales (Figure 8). Due to the limited availability of data at the event scale in studies, it has not been possible to explore the influence of other parameters (rainfall intensity, antecedent precipitation, and catchment physical characteristics) on the runoff. However, event duration mentioned by some authors indicates a rapid response time [94] and confirms the usefulness of fine time scale monitoring.

The correlation matrices between hydrological indices at multiyear scale and physical parameters confirm the strong relationship between runoff and a panel of parameters (Figure 8). In disregarding parameters assessing potentially the same characteristics, the parameters exhibiting the highest correlations with runoff are the rainfall ($R^2 = 0.77$) and soil texture ($R^2 = 0.68$ with silt content). Clay content (at a depth of 2 m and at catchment surface) emerges as crucial discriminant factors, with clayey soils tending to exhibit higher runoff coefficients and a high baseflow index (BFI). Topographic parameters like the upstream drainage area and elevation factors present high correlations with the mean runoff coefficient. Tree cover, globally, presents a threshold effect on runoff and has a negative correlation with quick flows ($R^2 = -0.53$).

Relations between runoff coefficient and land cover factors at annual scale provide a good illustration of impact of tree cover on runoff in studied sites (Figure 9). Land use appears to have a differentiated impact on runoff according to climatic zoning, particularly in relation to the non-tree vegetation area. In areas with high rainfall, there is like a threshold at which the effect of rain on runoff becomes negligible at annual scale. Due to this observation, we hypothesize that land cover in general, and tree canopy in particular, through interception plays a crucial role in this threshold effect by reducing the portion of rainfall that contributes to runoff. Annual tree cover (TC) relations with runoff coefficient tend to confirm this hypothesis.

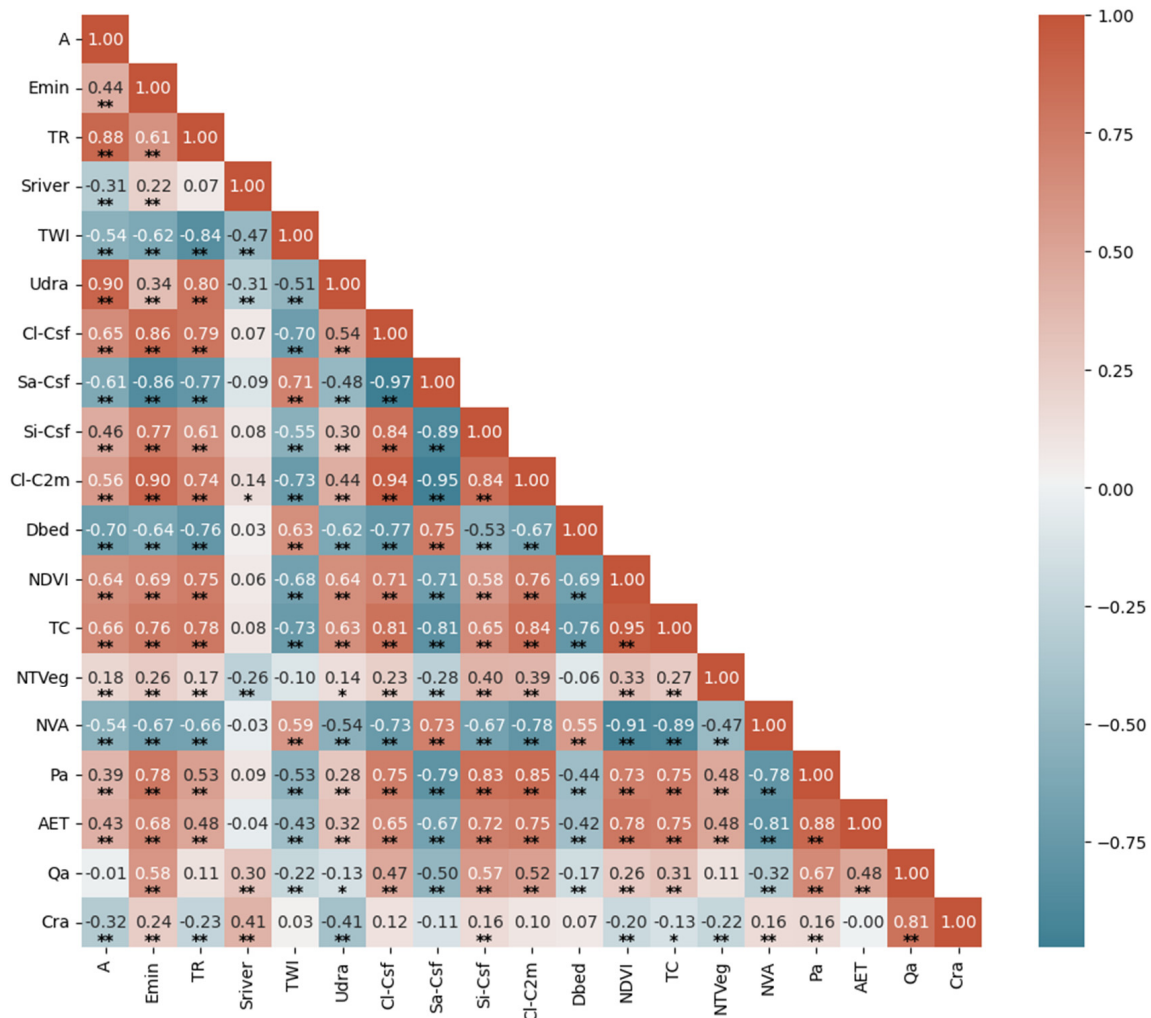


Figure 7. Correlation matrix between physical parameters and hydrological indices in inland valley areas at annual scale. Acronyms means: area (A), minimum elevation (Emin), total relief (TR), slope of flow axis (Sriver), topographic wetness index (TWI), percentage of upstream drainage area (Udra), mean clay content in catchment surface (Cl-Csf), mean sand content in catchment surface (Sa-Csf), mean silt content in catchment surface (Si-Csf), mean clay content in catchment at a depth of 2 m (Cl-C2m), average of absolute depth of bedrock in catchment (Dbed), annual normalized difference vegetation index (NDVI), tree cover (TC), non-tree vegetation area (NTVeg), non-vegetated area (NVA), annual rainfall (Pa), annual actual evapotranspiration (AET), annual total runoff (Qa), and annual total runoff coefficient (Cra). ** $p < 0.05$, * $p < 0.1$.

According to the observed correlations, we test a stepwise regression approach to determine a predictive equation of annual runoff using the most reliable physical parameters. The obtained equation based on rainfall (total precipitation measured over the year), average silt content in the soil (proportion of silt present in the soil composition), tree cover (percentage of catchment area covered by trees), and upstream drainage area (catchment area contributing to runoff downstream) provide reasonable prediction results in calibration but perform poorly in validation tests (Figure 10).

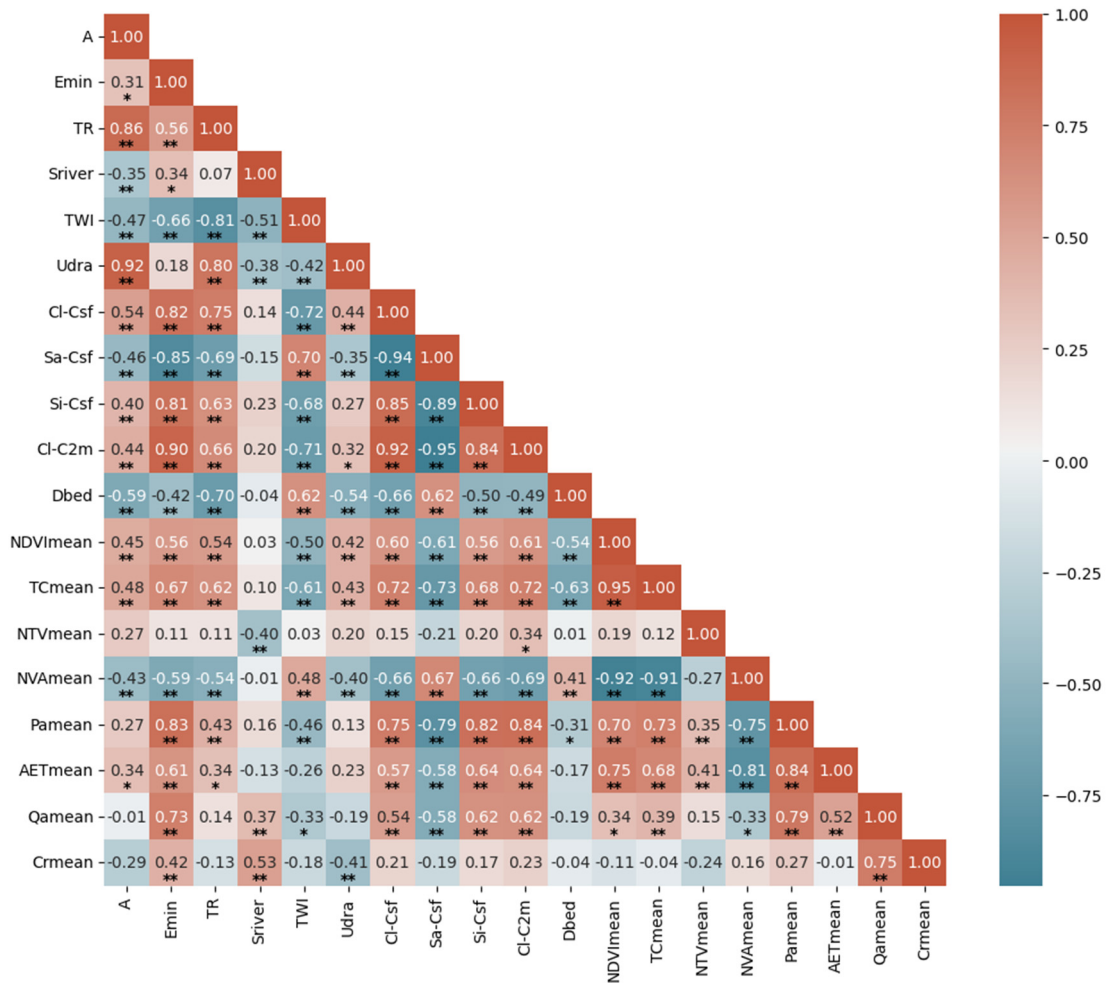


Figure 8. Correlation matrix between physical parameters and hydrological indices in inland valleys areas at multi-year scale. Acronyms means: area (A), minimum elevation (Emin), total relief (TR), slope of flow axis (Sriver), topographic wetness index (TWI), percentage of upstream drainage area (Udra), mean clay content in catchment surface (Cl-Csf), mean sand content in catchment surface (Sa-Csf), mean silt content in catchment surface (Si-Csf), mean clay content in catchment at a depth of 2 m (Cl-C2m), average of absolute depth of bedrock in catchment (Dbed), mean annual normalized difference vegetation index (NDVImean), mean tree cover (TCmean), non-tree vegetation area (NTVmean), non-vegetated Area (NVAmean), mean annual rainfall (Pamean), mean annual actual evapotranspiration (AETmean), mean total runoff (Qamean), mean runoff coefficient (Crmean). ** $p < 0.05$, * $p < 0.1$.

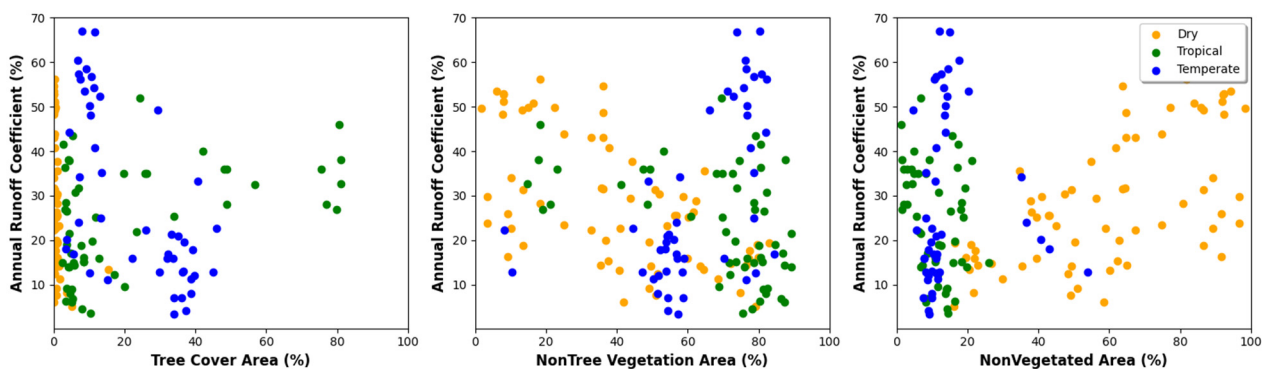


Figure 9. Scatter plots of runoff coefficients according to land cover factors in inland valleys at annual scale.

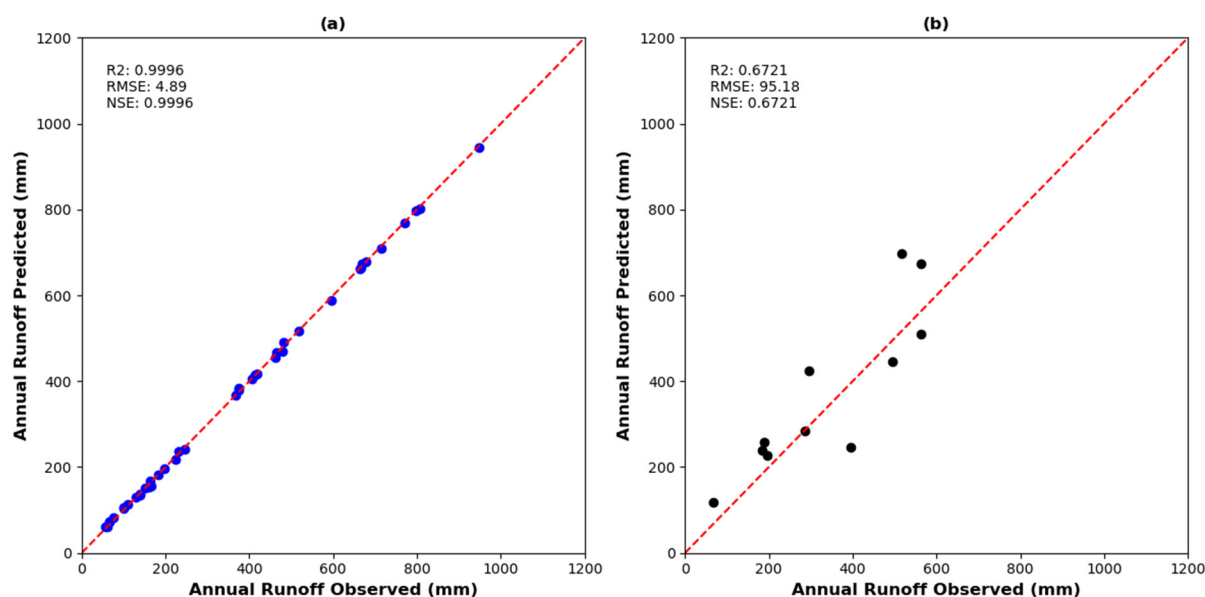


Figure 10. Annual runoff simulations with model based on physical characteristics of inland valleys (a) at calibration and (b) at validation.

3.4. Modeling the Hydrological Functioning of Inland Valleys

3.4.1. Process Reproduction

Two main objectives have been targeted by the different models of the hydrological functioning of inland valleys conducted in the literature: to verify certain hypotheses on the functioning of the system, and to predict modifications in its response subject to conditions set by possible changes. Following the first objective related to the verification of operating hypotheses, different hydrological models or plant growth simulations allowing for the reproduction of the hydrological processes observed in the inland valleys were used. Table A7 summarizes the types of models applied in the literature, as well as the performances observed in the simulations. The main simulated processes are the discharge at the outlet of the basin (total flow and flow components), soil moisture, and groundwater dynamics. Simulations are mainly conducted at a daily time scale, which is a critical scale of study for catchments, with response times typically less than 1 day.

According to [95], two questions need to be answered before a model can be deemed suitable for the simulation of hydrological processes. First, it is questioned whether the dominant processes are represented in a satisfactory manner by the model. Second, it is questioned whether the information required by the model is easily available at satisfactory temporal and spatial resolutions for the study area. In terms of representation of the main processes, most of the models used seem to be challenged by the reproduction of subsurface processes and transfer functions in the inland valleys, mainly in regard of the processes relating to fast flows. Surface and subsurface flows, which are the main components of runoff, are often poorly reproduced by most models. As a result, the flow simulations are generally mixed with error deviations that can be particularly significant in some cases (Figure 11). The results of modeling the dynamics of the water table and soil moisture, which also show unsatisfactory results [72,79], underline that significant efforts remain to be made on the part of the reproduction of water dynamics processes at the surface–soil–aquifer interface in inland valleys. Models with a flexible structure [96] could represent interesting options in this direction.

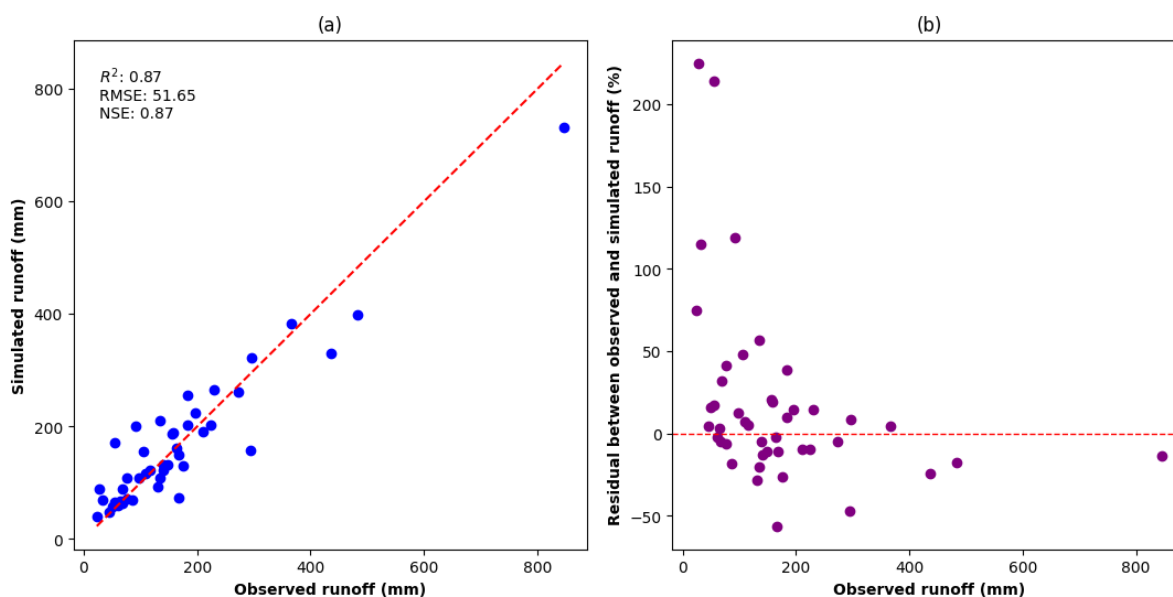


Figure 11. (a) Comparison between observed and simulated discharge at annual scale in inland valleys, (b) residual analysis of observed vs. simulated runoff according to modeling studies in inland valleys.

In terms of information required by models, the analysis of modeling works reveals that most of the sites face difficulties related to data availability. Ref. [97] recommend models that are relatively less demanding on input data for modeling inland valleys in Sub-Saharan Africa. This is in contrast of what actually has been used in modeling studies. Indeed, distributed or semi-distributed hydrological models have been widely used (Table A7). This kind of model requires high-resolution spatial and temporal data on physical parameters [98,99]. However, inland valleys as study areas are known to be data-scarce environments. We did not have enough studies, using lumped hydrological models to realize a comparative evaluation between lumped, semi-distributed, and distributed models' performance in this review. However, studies that realize this exercise in similar areas show that, despite being able to model the hydrologic processes in higher detail, distributed models do not necessarily provide better simulation results due to the large number of parameters involved in hydrological processes and the complexity of the catchment [99,100]. This is not a criticism of the use of distributed models, which can be very useful in understanding processes in inland valleys, especially on gauged sites. However, we would like to emphasize the importance of training—adapting lumped models based on local-scale process studies and testing them in these environments. In such a context, these models can be a good compromise for decision-making because, as highlighted by [98,99], they are transparent (for users and decision makers), robust (concerning data errors), and sensitive (with respect to a changing environment).

3.4.2. Predictive Impacts Assessments of Change in Drivers

Depending on the objective of forecasting changes in the hydrological response, two aspects are generally modeled on the inland valleys: changes in land use and climate change. This is explained by the fact that these aspects have considerably modified the conditions of tropical hydrology by impacting the regime and flow of the main rivers [101]. The importance of global changes in Sub-Saharan Africa has prompted considerable deliberation in recent years regarding the need to update hydrological standards in these regions [102,103]. Compared to large fluvial catchments, inland valleys have received limited attention in terms of specific studies assessing the impacts of climate and land-use

changes. Furthermore, we observed that the conducted studies have primarily focused on the effects on streamflows, while impacts on soil moisture and groundwater dynamics have been poorly documented.

Climate change scenarios in Africa for the coming decades are highly uncertain. Certainties are developing regarding the increase in temperatures (between 1.7 and 2.3%), but the evolution of precipitation dynamics is still poorly known [90]. The significant changes observed in the climatic parameters impact the hydrological functioning of inland valleys by acting simultaneously on all aspects of water balance processes. As main water inputs, precipitation amounts and variability are expected to affect hydrology in inland valleys. The variability in the precipitation change signal results in considerable uncertainty in the projected annual discharge and water balance [104]. In semi-arid areas, the main impacts of climate change on the hydrological functioning of inland valleys relate to an increase in runoff (24.5% to 46.7%), land loss by water erosion (31.1% to 54.7%), and water loss by evapotranspiration (+3.3% to +5%). In the Sahel, in particular, the runoff coefficients have increased to such an extent that the flows increase despite the decrease in precipitation [101]. The increase in runoff, despite a decrease in rainfall also called the “Sahelian hydrological paradox”, has been attributed to changes in LULC dynamics, which are prone to soil surface crusting and sealing [105]. But rainfall intensity changes also have a great impact on this phenomenon [106–108]. Paradoxically, an increase in groundwater recharge is reported for this region [109,110]. This observation is mainly attributed to the feedback effect of high-flow events on the formation of ponds, which have been identified as the main zones of deep infiltration in the Sahel [111]. For less arid climatic zones, large uncertainties are reported on the future dynamics of flows [112]. A mixed trend in the changes following the patterns in the variability of projected precipitation for the individual climate models is observed in discharge simulations [71]. More intuitively, studies established that discharges decreased during the drought periods and increase in humid periods. Refs. [57] and [113] report, respectively, a decrease and an increase in flows between 19.5% and 36.5% for areas with a rainfall greater than 1200 mm. Fast flow, which is the main cause of hydraulic infrastructure degradation and agricultural production loss, is the most sensitive to inter-annual rainfall variability [70]. Fast flow was also reported to exhibit the highest relative change compared to the other runoff components [112].

Related to land use and land cover, the literature reveals that deforestation for the benefit of agricultural development is the most observed land-use change in inland valley areas [109]. This change in land use is due to the increase in population and the impact of climate change on vegetation. Deforestation impacts the water balance at the inland valley scale by impacting evapotranspiration, which modifies vegetation characteristics such as albedo [112]. Ref. [114] shows the significant influence of land use on soil hydrological properties, suggesting that changes in land use, particularly agricultural and rangeland degradation and urban expansion, have led to reduced soil infiltration and increased flood risk in the area. As a result of the destructuring of the soil following deforestation in the inland valleys, the drainage networks have undergone spectacular changes in recent years, and the phenomena of erosion have considerably increased. This situation has led to an increase in runoff [112,115]. Studies report an increase in flows and risky flows in agricultural production areas [71]. The increase in flows, as related to a high peak flow, suggests (i) an increase in water resources that are not available for plant growth and human consumption and (ii) a change in flood risk for the population within and downstream of the watershed [115]. Recent papers have also shown that significant changes in land cover could lead to major transformations characterized by the reduction of bottom valleys areas [116]. Depending on the region, 30–90% of the world’s wetlands have already been destroyed or strongly modified in many countries, with no sign of abatement [117]. This

means an altered hydrological response affecting the timing and magnitude of runoff. Ref. [104] has observed that LULC and climate change individually will cause changes in the inland valley hydrological processes, but more pronounced changes are expected if the drivers are combined, although LULC changes will have a dominant influence. As an alternative, the authors recommend the adoption of land management and land-use strategies for conservation purposes to avoid increased sediment and nutrient fluxes downstream of the inland valleys. Planners should integrate these options, along with other nature-based solutions and climate-smart management practices, to enhance water management and agricultural production in inland valleys for years to come.

4. Discussion

The analysis of works on the hydrology of inland valleys has provided valuable insights into the current state of knowledge in this field. Bibliometric analysis and quantitative synthesis realized in this review shed light on the contributions made by recent research and highlight the most promising avenues for future investigations. Our study addresses a significant portion of the hypotheses concerning the factors determining the hydrological response at an annual scale in inland valleys. We mainly tried to answer two questions: (1) What are the physical parameters that govern the genesis and dynamics of runoff in inland valleys?; (2) What specific challenges does hydrological modeling currently face for simulating the inland valley hydrological system?

4.1. Physical Parameters That Govern the Genesis and Dynamics of Runoff in Inland Valleys

Based on the statistical analysis of information gathered from previous works, it has come to our attention that precipitation is the primary factor impacting runoff. We have observed different responses in the function of climatic zones. Runoff ratio means and magnitude are particularly important in dry and temperate regions. Our results confirm literature trends, which underlined the intense nature of runoff in the Sahelian zone due to soil crusting [118]. The increasing trend in extreme rainfall events reported by the scientific community [107,108], as well as the low soil coverage, undoubtedly contribute to this important runoff. Heterogeneity observed in the hydrological responses can be explained by the importance of other catchment features in the hydrological process.

Alongside morphological characteristics, altitude, axis flow slope, and upstream drainage area have a notable influence on the hydrological response in inland valleys. High-relief areas, characterized by steep slopes and significant elevation differences, often experience enhanced runoff due to the accelerated movement of water downslope. When rainfall occurs in such areas, the water quickly flows over the surface, resulting in increased surface runoff. Numerous studies have documented this effect of topography on runoff in African inland valleys [17,119].

The analysis of runoff coefficients according to soil texture has highlighted the discriminative nature of particle size composition on runoff. The presence of silt and/or clay in soils appears to strongly enhance runoff, while sandy soils, on the contrary, seem to attenuate it. This observation confirms the previous hypothesis and main reports on the subject [52]. Clay content in the soil directly affects the infiltration capacity and permeability of the soil, all of which play a significant role in determining the amount of runoff generated. Soil with high clay content tends to have smaller pore spaces and lower permeability, leading to reduced infiltration rates. As a result, when rainfall occurs on clay-rich soils, a larger portion of the water remains on the surface and contributes to runoff. The cohesive nature of clay particles also contributes to the formation of surface crusts or seals when exposed to rainfall. These crusts can further impede water infiltration and promote surface runoff, especially in areas with intense or prolonged rainfall events.

Our results also highlight the effect of land cover on annual runoff. We found that the tree cover notably demonstrates a threshold effect on the runoff coefficient mainly in temperate and tropical climates. It is generally accepted that vegetation intercepts rainfall, reducing the direct impact of raindrops on the soil surface and promoting water storage on plant canopies. This interception process delays the onset of runoff and allows for increased infiltration. Based on the collected dataset, land cover attributes appear to be an important predictor of baseflow (BFI) and also a good mitigation factor for quickflows. This shows a “conditional sponge effect capacity” of inland valleys when they are not fundamentally disturbed. In this study case, the “non-tree vegetation” land cover class appears to have a differentiated impact on runoff depending on the climatic zoning. This difference is explained by the applicability of the “non-tree vegetation area” concept to these different climatic zones. In tropical regions, non-forested vegetation comprises grasses, shrubs, and agricultural landscapes, offering extensive ground cover that helps reduce soil erosion, slow surface water runoff, and enhance infiltration, often supported by agricultural management practices. In arid zones, “non-tree vegetation areas” largely correspond to cultivated land. Runoff is mitigated here by agricultural practices that incorporate management strategies to a greater or lesser extent. Conversely, the “non-tree vegetation area” appears more as a proxy for the destruction of forested areas in favor of grazing or cultivated areas in temperate climates. This destruction of vegetation cover in favor of agricultural areas leads to an increase in runoff, even under management conditions. The effect of “non-tree vegetation areas” in inland valleys under a tropical climate is in accordance with the results of [10,88], which hypothesize that runoff volume and flood magnitude are accentuated by agricultural land use. They justify their observation by lower infiltration rates observed on agricultural land than on natural vegetation or fallow, which results in a higher surface runoff. In a practical way, these results underscore the importance of responsible land-use practices and conservation efforts in catchments’ management approach [120]. Differences in the impact of “non-tree vegetation area” among climate zones also shed light on the complexity of land cover interactions with the hydrological system, resulting in a debate within the scientific community. The factors influencing runoff at the watershed scale are complex, and the influence of some factors may be concealed [121], especially in analyses based on small sample sizes. We must mainly retain that in inland valleys, the soil cover acts as the differentiating factor, while precipitation serves as input to the production function [47]. By testing a quantitative approach to analyze the relationships between runoff and physical characteristics of inland valleys, this study established the feasibility of estimating the annual runoff based on rainfall, average silt content in the soil, tree cover, and upstream drainage area. The observed error margins attest to the complexity of the system. Although this model has a relatively low predictive accuracy, it lays a promising pathway for estimating, with few physical parameters, the patterns of annual runoff. It also offers simplicity to the predictions for practical uses, which are important for not-gauged catchments [122].

4.2. Challenges for Hydrological Modeling of Inland Valley Systems

Good data availability and the non-stationarity of processes are the main challenges that face hydrological modeling of inland valleys systems. In Section 3.2 of this review, we extensively discussed the gaps in hydrological data and analyzed possible solutions to address this situation.

Due to the significant impact of rainfall on surface runoff and the restricted capacity for on-site monitoring in the Sub-Saharan regions, we found it necessary to evaluate the suitability of using generic data for monitoring rainfall in studies of inland valleys. Further research on finer scales (daily and sub-daily) with integration of other gridded

precipitation datasets are desirable in this field to evaluate the potential of generic data for water management studies in inland valleys.

There remains an important need for research on classical rainfall–runoff hydrological modeling for engineering applications in water resources management, water supply infrastructure design, and flood and drought prediction processes. Studies must address the challenge of understanding hydrological responses at a sub-daily/event scale. Nevertheless, further research is also needed to understand the runoff component and factors that drive each component. Ref. [77] did the same observations and recommended more studies to prove the hypotheses related to interflow processes. Difficulties on the spatialization of information related to certain components of the water cycle, such as ground–water dynamics and soil moisture, seem to have limited the exploration of the river–soil moisture–groundwater interrelationships. This is particularly important as understanding these interactions is crucial for improving hydrological models and water management strategies in inland valleys. The integration of high-resolution satellite data and advanced interpolation techniques should help overcome this constraint. Understanding the relationships between runoff and its parameters could pave the way for incorporating site-specific parameters into modeling using flexible models such as Superflex [123]. Possibilities of assimilation of high-precision soil data into a hydrological model can improve the accuracy and reliability of predictions and help to address questions about the capacity of head water catchment to remember or anticipate his response to climate.

Soil moisture data assimilation, for instance, has found increased applicability in hydrology due to recently available remotely sensed soil moisture data [124]. The influence of physical parameters on runoff, and the heterogeneity of these parameters across contributing zones within the same catchment, underscores the need for fine-scale characterization of these parameters. Due to the importance of physical characteristics to predict flow metrics, and the fact that these features are not easily captured by catchment average values, some authors like [125] recommend more detailed catchment descriptors. Numerous studies have reported the deterioration of drainage networks in many inland valleys [126]. These changes are not detectable with freely available digital elevation models. Similarly, the properties of soils and aquifers need to be better characterized in order to gain a more detailed understanding of their interaction and their impact on water distribution within the catchment. On this question, Ref. [94] showed that streamflow simulation performances using freely available global soil datasets can be improved through the integration of locally measured soil information, and that availability of local soil information is critical for daily hydrologic model simulations. This is also critical for planning effective soil and water management practices at plot and field scales. In the same way, Ref. [127] found that, within recent advanced hydrogeological techniques, valuable “soft data” can be generated to reflect internal catchment structure and processes. Such hydrogeological soft data have a good potential for realistic calibrations of hydrological models, especially those conducted in inland valleys with limited hydrometric measurements. As an important boundary condition and input data for hydraulic modeling [39], topographic data with good resolution can allow better simulation with distributed models.

Significant changes have been observed in climatic parameters and land use, affecting hydrological processes in inland valleys and emphasizing the need for improved modeling approaches. Yet, the long-term impact of traditional or modern management schemes, implemented in inland valleys, is not well documented. At the same time, numerous cases of poorly managed schemes are reported and can be observed in many countries [7]. The effectiveness of the rapid pre-development diagnosis (DIARPA) [33] as a support tool for designing inland valley management systems in West Africa is increasingly being called into question in this context. It is suggested that the design of appropriate water

management systems for inland valleys should rather be based on validated dynamic modeling approaches.

Lastly, interdisciplinary research collaborations, including the involvement of stakeholders in data collection (Citizen Science), integration of advanced remote sensing techniques, and geospatial analysis, can enhance our understanding of inland valley hydrology. Combining local knowledge and hydrological expertise can lead to the gain of valuable insights into the complex processes governing water dynamics in these unique landscapes. By addressing these challenges, scientists, policymakers, and stakeholders can make informed decisions regarding sustainable water management practices, considering both environmental and socio-economic considerations. Nature-based solutions, such as reforestation and wetland restoration, should be integrated in management schemes to help reduce water risks to economies and society [128].

5. Conclusions

The synthesis exercise of knowledge relating to the hydrological functioning of inland valleys has allowed us to establish the relationships between hydrological responses at the annual scale and the physical parameters of the studied sites. Based on data extracted on the literature, we can conclude that rainfall is the primary input, and that soil-cover complex acts as a discriminating element. However, predicting runoff based on watershed characteristics performs poorly in validation tests, highlighting system complexity. This study provides valuable insights into the hydrological processes in inland valleys, contributing to the growing body of knowledge in the field of hydrology and offering practical implications for water resource management in these unique landscapes. However, despite the random nature of the sample used in this exercise, it should be noted that it cannot be considered sufficiently comprehensive to draw definitive conclusions. The uncertainties related to the data used, along with the unavailability of information that would have been important to consider (such as data on water management practices implemented on the sites), serve as notable constraints on the analyses conducted. Additional studies are of great interest to test the hypothesis proposed here. From a historical perspective, the field of inland valley hydrology is relatively young and rapidly growing. To address the enormous challenges in this field, greater collaborations are desired. We highly recommended the establishment of monitoring systems and instrumentation of pilot sites in understudied climatic regions. This will enable the availability of more extensive databases to better analyze the hydrological processes inherent to these environments. Effective low-cost monitoring systems open up new possibilities for exploration in this regard. Despite research efforts and recent advances in knowledge, many mechanisms associated with the spatio-temporal dynamics of water in these ecosystems still remain largely unexplained. Referring to the determinants of hydrological response at the event scale, surface runoff, groundwater dynamics, soil-moisture interactions, and the development of flexible models adapted to inland valleys, we note that the research fields are extensive. These research directions not only contribute to the advancement of hydrological science but also have practical implications for effective water resource management and agricultural production in Sub-Saharan Africa.

Author Contributions: A.M.T. contributions included: conceptualization, data curation, formal analysis, investigation, methodology, validation, visualization, and writing—original draft preparation and writing—review and editing. P.G.T. contributions included conceptualization, formal analysis, methodology, validation, visualization, and writing—review, editing, supervision, and project administration. P.B.I.A. and M.V. contributions included: conceptualization, formal analysis, methodology, validation, visualization, and writing—review, editing, funding acquisition, project administration, resources, and supervision. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: All data have been included in the manuscript.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. PRISMA 2020 Checklist for the study.

Section and Topic	Item #	Checklist Item	Location Where Item Is Reported
TITLE			
Title	1	Systematic synthesis of knowledge relating to the hydrological functioning of inland valleys in Sub-Saharan Africa	Page 1, Line 2–3
ABSTRACT			
Abstract	2	Inland valleys offer a unique opportunity to increase food security and the resilience of agriculture to climate change in Africa. However, their potential is constrained by a limited understanding of their hydrological functioning and inadequate water management. In order to synthesize knowledge on hydrological responses in inland valley areas, this work reviewed 275 studies from tropical Sub-Saharan Africa (SSA). Literature search data were extracted from Scopus™, ScienceDirect™, Web of Science™, Google Scholar™, and doctoral theses from ZEF, HAL, and Theses.fr, covering studies published from database inception through 31 May 2023. Our approach involved, firstly, a bibliometric analysis of all papers to gain insights into research trends and interests. Secondly, we performed a quantitative synthesis of results from 66 studies, examining stream flows in a set of 79 inland valleys to better understand factors that govern water dynamics in these environments. Correlative analyses and clustering methods were applied to identify potential links between runoff and watershed physical parameters. The findings highlight the varied responses of inland valleys over both time and space, influenced by a combination of catchment drivers. The correlation matrices between hydrological indices and physical parameters indicate a strong relationship among runoff and a range of parameters, of which the most significant are rainfall ($R^2 = 0.77$) and soil silt content ($R^2 = 0.68$). Challenges in accurately spatializing information related to potential determining components of the water cycle, such as groundwater dynamics and soil moisture, seem to have limited the exploration of interactions between river flow, soil moisture, and groundwater. Future works should prioritize the development of accurate hydrological models to enhance the understanding of inland valley behavior at fine scales and consolidate food security in Africa.	Page 1, Line 12–34
INTRODUCTION			
Rationale	3	Despite their immense potential, the productive capacity of inland valleys in tropical Africa remains largely underexploited [3,8,9]. Inland valleys are often neglected for agricultural development due to constraints linked to their exploitation such as difficult tillage, water control issues, and waterborne diseases. In particular, the complexity of the hydrological regime [10] is problematic for designing appropriate hydro-agricultural management infrastructure [7]. Due to their upstream position in the hydrographic network and their spatial distribution, inland valleys seem to exhibit “hydrological specificities”. Enhancing water resource management of inland valleys, therefore, needs a better understanding of their hydrological functioning. Accordingly, numerous studies have explored various aspects of the hydrological functioning of these unique wetlands over the past half-century. However, from the synthesis of knowledge obtained from these research works, little consensus has been reached regarding the processes governing water dynamics in these environments [11,12,14–17,68]. Ref. [17] explains this situation by a lack of comparable precise data between the inland valleys studied. Other sources underscore the difficulty of capturing fundamental hydrological processes to be generalized on the different sites [10]. Uncertainties persist regarding the mechanisms driving the spatio-temporal dynamics of water in these catchments. The ability to forecast hydrological characteristics, especially runoff, in ungauged inland valleys has gained even greater significance in the face of climate change impacts on tropical regions.	Page 2, Line 52–71

Table A1. Cont.

Section and Topic	Item #	Checklist Item	Location Where Item Is Reported
Objectives	4	Question 1: What are the physical parameters that govern the genesis and dynamics of runoff in inland valleys? Question 2: What specific challenges does hydrological modeling currently face in the inland valley systems?	Page 6, Line 191–194
METHODS			
Eligibility criteria	5	To ensure the relevance of the search results, a screening process was conducted to exclude duplicate documents. The remaining documents were then verified based on their titles and abstracts, with those deemed outside the scope of the study being excluded. Only documents written in French and English were considered for this study. In addition to scientific documentation, grey literature sources were explored, including project reports and existing documentation from various non-governmental organizations (NGOs) involved in inland valley management. This grey literature served as a valuable resource and supported the analysis and discussion in this study.	Page 4, Line 149–155, Figure 1
Information sources	6	Literature search data were extracted from Scopus TM , Science Direct TM , and Web of Science TM databases. The choice of its base is justified by the reliability of the peer-reviewed scientific publications provided therein [36]. Additionally, relevant documents from the Google Scholar TM database and the thesis dissertation (from ZEF, HAL, and Theses.fr doctoral theses) were also considered.	Page 4, Line 135–138
Search strategy	7	We applied “keyword search”, which offers the advantage of covering a wide range of articles compared to searching by title alone. The selected keywords focused on the hydrological functioning of inland valleys in Africa. The research equations incorporated three factors: (1°) the known names of the inland valleys ecosystems, (2°) the research object (hydrological functioning and water flow dynamics), and (3°) the geographical zoning (Africa and south of the Sahara). The types of documents considered are articles, book chapters, conference presentations, and doctoral thesis reports. To include all the documents produced on the subject, the terms presented in Table 1 were used in the field (title, abstract, and keywords). Additionally, a “citation hunting” strategy was employed by reviewing and selecting relevant references cited in the initially selected documents. A summary of the keyword combinations used to capture inland valley hydrology literature is provided in Table 1.	Page 4, Line 138–148
Selection process	8	Conceptualization of the manuscript was done by all the authors. The electronic search of relevant papers, filtration, and exclusion was conducted by A.M. Tidjani, who wrote the first draft. P.G. Tovihoudji and S. Petit were involved in confusion clarification, selection, and exclusion. The final manuscript was read and approved by all authors. To ensure the relevance of the search results, a screening process was conducted to exclude duplicate documents. The remaining documents were then verified based on their titles and abstracts, with those deemed outside the scope of the study being excluded. The exclusion criteria applied in this study were based on two factors: a non-compliant study subject (focusing on aspects of inland valleys other than hydrology) and a non-compliant study site (examining wetlands other than inland valleys).	Page 4, Line 149–151, Figure 1
Data collection process	9	Within this study, we initially assessed all the documents, having dealt with an aspect of the hydrological functioning of inland valleys. These documents were then divided into two main classes, namely the “primary documents”, which deal with the analysis of raw hydrological data and the “secondary documents”, which represent the literature review documents. Both the primary and secondary documents were used for the narrative analysis of the hydrological functioning. The data of the primary documents were collected and analyzed for a better understanding and the mapping of studies on the dynamics of water in inland valleys. These documents were also used to extract quantitative data to address the study’s objective, based on a data extraction form reports specifically developed and employed (see questions in the objective section). The form was piloted using 10 arbitrarily selected studies, with extracted data compared and inconsistencies resolved through feedback and discussions among the authors.	Page 4–6, Line 162–166, 181–196

Table A1. Cont.

Section and Topic	Item #	Checklist Item	Location Where Item Is Reported
Data items	10a	The full bibliometric data of the primary documents were collected and analyzed for a better understanding and mapping of studies on the dynamics of water in inland valleys (Table 2). To analyze the priority study topics covered in the literature, the primary studies were categorized based on the main aspects of the water cycle they address: surface water dynamics, soil water dynamics, and/or groundwater dynamics. By considering runoff as the reflection of the aggregate hydrological behavior of the system, we focused on the studies addressing the question of surface runoff at the outlet of inland valleys (Table 3).	Page 6–7, Line 169–205
	10b	The data collected are summarized in Tables 2 and 3	Page 6–7, Line 179–205
Study risk of bias assessment	11	The risk of bias assessment was conducted based on the authors' expertise, with a focus on the study design, data extraction, data analysis, and study report content. Additionally, automation tools, including WebPlotDigitizer software [45], were utilized to facilitate and streamline the initial data extraction process.	Page 9, Line 212–213
Effect measures	12	Specify for each outcome the effect measure(s) (e.g., risk ratio, mean difference) used in the synthesis or presentation of results.	N/A
Synthesis methods	13a	In this study, we used a mixed approach combining bibliometric analysis and statistical synthesis of previous studies to better understand the mechanisms governing water dynamics in inland valleys. These methodologies allow knowledge accumulation through a stronger focus on data extraction from available peer-reviewed articles and allow previous studies to be analyzed in a hydrologically meaningful way [19]. We initially assessed all the documents having dealt with an aspect of the hydrological functioning of inland valleys. These documents were then divided into two main classes, namely the "primary documents", which deal with the analysis of raw hydrological data and "secondary documents", which represent the literature review documents. Both the primary and secondary documents were used for the narrative analysis of the hydrological functioning. The full bibliometric data of the primary documents were collected and analyzed for a better understanding and the mapping of studies on the dynamics of water in inland valleys (Table 2). To analyze the priority study topics covered in the literature, the primary studies were categorized based on the main aspects of the water cycle they address: surface water dynamics, soil water dynamics, and/or groundwater dynamics. By considering runoff as the reflection of the aggregate hydrological behavior of the system, we focused on the studies addressing the question of surface runoff at the outlet of inland valleys. The methodological approaches applied to these documents are summarized in Table 2. Only experimental studies were considered in this section. The following documents were, therefore, excluded from this section: review of inland valley hydrology, study of certain aspects of hydrological functioning (soil moisture, aquifer dynamics) without addressing the question of surface runoff, and study of runoff based on generic data estimations or experimental data carried out on a plot scale.	Page 2, Line 80–84 Page 4, Line 162–167, Line Page 6, Line 182–193
	13b	The data preparation included using reading and/or WebPlotDigitizer to extract data from papers, followed by converting the physical, climatic, and hydrological data into standardized formats. The accuracy of the extracted data was validated through expert verification and comparison with established benchmarks.	Page 9, Line 208–259
	13c	Results from individual studies and syntheses were tabulated using descriptive statistics and pivot tables, with visual displays including graphs and charts to illustrate the spatio-temporal dynamics and key findings. Correlative analyses and clustering methods were applied to identify potential links between hydrological components and watershed physical parameters	Page 6, Line 170–179. Page 9, Line 208–259

Table A1. Cont.

Section and Topic	Item #	Checklist Item	Location Where Item Is Reported
Synthesis methods	13d	Results were synthesized using descriptive statistics, correlative analyses, and regression models to explore relationships between physical parameters and hydrological responses, complemented by K-means clustering for hydrological response classification; these methods were chosen to identify patterns and predictive factors effectively, and statistical analyses were performed using tools like QGIS, Google Earth Engine, and relevant bibliometric platforms.	Page 9, Line 208–259
	13e	Heterogeneity among study results was explored using subgroup analyses based on climatic zones, land cover types, and topographic characteristics, meta-regression to assess the influence of specific physical, climatic, and hydrological variables on runoff variability, and clustering tests to identify patterns and group studies with similar characteristics.	Page 9, Line 208–259
	13f	Sensitivity analyses were conducted by varying inclusion criteria, and testing alternative statistical models to assess the robustness of the synthesized results and identify the influence of specific data sources or methodological choices on overall findings.	N/A
Reporting bias assessment	14	The primary papers used in this study are peer-reviewed. Additionally, the authors assess selective reporting bias by analyzing the methodology and results of the published papers, while also applying their expertise in hydrology to evaluate the reliability of the findings	Page 9, Line 242–243
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	N/A
RESULTS			
Study selection	16a	This study incorporates findings from 275 publications that present results on the dynamics of water in inland valley areas in tropical Africa. The earliest paper dates back to 1973, but the bulk of the literature—77%—was published in the last twenty-three years (2000–2022). The analysis of the statistics in relation to the documentation used for narrative purposes in this study (188 documents) reveals a difference in the format of the rendering of the documents pre and post 2000.	Page 10, Line 262–266
	16b	It is crucial to note that some watersheds, similar to inland valleys in some points but fundamentally different regarding the longitudinal slopes of the main stream, have been observed in the eastern and southern zone of the continent and have not been considered in this study. Examples of these basins include Debre Mawi, Ene Chilala, Zenako-Argaka, Andit Tid, Maybar, Bekafa, Enkulal sub-catchments, Gomit in Ethiopia, Kwalei in Tanzania, Cathedral Peak Forestry Research Station, Two-stream research catchment, Bosboukloof-Langrivier in South Africa. Certain catchments were excluded due to a lack of the necessary elements to assess their nature, particularly regarding discriminatory physical criteria such as surface area, longitudinal slope of the flow axis, or soil type. These include the basins of Kromme (K90A and K90B), national gauging stations code A2H039 and A2H038 in South Africa, and Mpamadzi and Mpira river catchment in Malawi. Most of these wetlands are located in the steep slope regions of the eastern and southern parts of continent.	Page 11, Line 290–300
Study characteristics	17	Tables A2–A4 in the manuscript provides a list of the primary studies selected	Page 37–43
Risk of bias in studies	18	The review primarily focused on descriptive evidence of the results and did not include an evaluation of empirical findings of each study.	N/A

Table A1. Cont.

Section and Topic	Item #	Checklist Item	Location Where Item Is Reported
Results of individual studies	19	A quantitative synthesis of studies was performed to assess the global trends in research on the hydrological functioning of inland valleys in tropical Africa and the key driving factors of hydrological response in these valleys.	Page 10–14, Line 261–391
	20a	This study incorporates findings from 275 publications that present results on the dynamics of water in inland valley areas in tropical Africa. The earliest paper dates back to 1973, but the bulk of the literature—77%—was published in the last twenty-three years (2000–2022). The analysis of the statistics in relation to the documentation used for narrative purposes in this study (188 documents) reveals a difference in the format of the rendering of the documents pre- and post-2000. Documents from the first period, presented mainly in the form of reports, did not allow the exploitation of experimental data as desired here. For the post-2000 period, the average of eight publications per year highlights the substantial increase in scientific production (Figure 2). The scope of research has broadened, moving beyond the rain-runoff relationship to encompass other aspects of the hydrological cycle in inland valley areas, such as soil moisture and groundwater dynamics. The field is still growing however, most studies are mainly project-dependent, and this reality impacts publication trends. For example, there was a noticeable surge in publications in 2009 when a significant set of scientific advancements from the AMMA-CATCH observatory were presented in a special issue of the Journal of Hydrology [50]. Eighty-nine percent of the documentation used is in the form of a scientific article with ninety-six percent of the documents written in English, reflecting the predominant mode of scientific communication on the subject.	Page 10, Line 262–277
Results of syntheses	20b	The correlation matrices between hydrological indices at multiyear scale and physical parameters confirm the strong relationship between runoff and a panel of parameters (Figure 8). In disregarding parameters assessing potentially the same characteristics, the parameters exhibiting the highest correlations with runoff are rainfall ($R^2 = 0.77$) and soil texture ($R^2 = 0.68$ with silt content). Clay content (at a depth of 2 m and at the catchment surface) emerges as crucial discriminant factors, with clayey soils tending to exhibit higher runoff coefficients and high Baseflow Index (BFI). Topographic parameters like Upstream Drainage Area and Elevation factors present high correlations with a Mean Runoff Coefficient. Tree cover globally presents a threshold effect on the runoff and has a negative correlation with quick flows ($R^2 = -0.53$).	Page 18, Line 520–528
	20c	Relations between runoff coefficient and land cover factors at annual scale give a good illustration of impact of Tree Cover on runoff in studied sites (Figure 9). Land use appears to have a differentiated impact on runoff according to climatic zoning, particularly in relation to the Non-Tree Vegetation Area. In areas with high rainfall, there is like a threshold at which the effect of rain on runoff becomes negligible at annual scale. Given this observation, we hypothesize that land cover in general, and tree canopy in particular, through interception play a crucial role in this threshold effect by reducing the portion of rainfall that contributes to runoff. Annual tree cover (TC) relations with runoff coefficient tend to confirm this hypothesis.	Page 21, Line 543–550
	20d	According observed correlations, we test a regression approach to determine a predictive equation of annual runoff using most reliable physical parameters. Obtained equation based on rainfall, average silt content in the soil, tree cover and upstream drainage area give reasonable predictions results in calibration but performs poorly in validation tests (Figure 10).	Page 21, Line 553–556
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	N/A
Certainty of evidence	22	The study was strictly descriptive and highlight the varied responses of inland valleys over both time and space, influenced by a combination of catchment drivers. The correlation matrices between hydrological indices and physical parameters indicate a strong relationship among runoff and a range of parameters, of which the most significant are rainfall ($R^2 = 0.77$) and soil silt content ($R^2 = 0.68$).	Page 10–24

Table A1. Cont.

Section and Topic	Item #	Checklist Item	Location Where Item Is Reported
DISCUSSION			
Discussion	23a	<p>Based on the statistical analysis of information gathered from previous works, it has come to our attention that precipitation is the primary factors impacting runoff. We have observed different responses in function of climatic zones. Runoff ratio means and magnitude are particularly important in dry and temperate regions. Our results confirm literature trends which underlined the intense nature of runoff in the Sahelian zone due to soil crusting [118]. The increasing trend in extreme rainfall events reported by scientific community [107,108], as well as the low soil coverage, undoubtedly contribute to this important runoff. Heterogeneity observed in the hydrological responses can be explained by the importance of other catchment features in the hydrological process.</p> <p>Along morphological characteristics, altitude, axis flow slope and upstream drainage area have a notable influence on hydrological response in inland valleys. High relief areas, characterized by steep slopes and significant elevation differences, often experience enhanced runoff due to the accelerated movement of water downslope. When rainfall occurs in such areas, the water quickly flows over the surface, resulting in increased surface runoff. Numerous studies have documented this effect of topography on runoff in African inland valleys [17,119].</p> <p>The analysis of runoff coefficients according to soil texture has highlighted the discriminative nature of particle size composition on runoff. The presence of silt and/or clay in soils appears to strongly enhance runoff, while sandy soils, on the contrary, seem to attenuate it. This observation confirms previous hypothesis and main reports on the subject [52]. Clay content in the soil directly affects the infiltration capacity and permeability of the soil, all of which play a significant role in determining the amount of runoff generated. Soil with high clay content tends to have smaller pore spaces and lower permeability, leading to reduced infiltration rates. As a result, when rainfall occurs on clay-rich soils, a larger portion of the water remains on the surface and contributes to runoff. The cohesive nature of clay particles also contributes to the formation of surface crusts or seals when exposed to rainfall. These crusts can further impede water infiltration and promote surface runoff, especially in areas with intense or prolonged rainfall events.</p> <p>Our results also highlight the effect of land cover on annual runoff. We found that tree cover notably demonstrates a threshold effect on the runoff coefficient mainly in temperate and tropical climate. It is generally accepted that vegetation intercepts rainfall, reducing the direct impact of raindrops on the soil surface and promoting water storage on plant canopies. This interception process delays the onset of runoff and allows for increased infiltration. Based on the collected dataset, land cover attributes appear to be an important predictor of baseflow (BFI) and also a good mitigation factor for quickflows. This shows a 'conditional sponge effect capacity' of inland valleys when they are not fundamentally disturbed. In this study case, 'Non Tree Vegetation' land cover class appears to have a differentiated impact on runoff depending on the climatic zoning. This difference is explained by the applicability of the 'Non-Tree Vegetation Area' concept to these different climatic zones. In tropical regions, non-forested vegetation comprises grasses, shrubs, and agricultural landscapes, offering extensive ground cover that helps reduce soil erosion, slow surface water runoff, and enhance infiltration, often supported by agricultural management practices. In arid zones, 'Non-Tree Vegetation Areas' largely correspond to cultivated land. Runoff is mitigated here by agricultural practices that incorporate management strategies to a greater or lesser extent. Conversely, the 'Non-Tree Vegetation Area' appears more as a proxy for the destruction of forested areas in favor of grazing or cultivated areas in temperate climates. This destruction of vegetation cover in favor of agricultural areas leads to an increase in runoff even under management conditions. The effect of 'Non-Tree Vegetation Areas' in inland valleys under tropical climate is in accordance with results of [10,88] which hypothesize that runoff volume and flood magnitude are accentuated by agricultural land use. They justify their observation by lower infiltration rates observed on agricultural land than on natural vegetation or fallow which results in higher surface runoff. In a practical way, these results underscore the importance of responsible land use practices and conservation efforts in catchments management approach [120]. Differences in the impact of 'Non-Tree Vegetation Area' among climate zones also shed light on the complexity of land cover interactions with the hydrological system, resulting in a debate within the scientific community. The factors influencing runoff at the watershed scale are complex, and the influence of some factors may be concealed [121], especially in analysis based on small sample sizes. We must mainly retain that in inland valleys, the soil-cover acts as the differentiating factor while precipitation serves as input to the production function [47].</p>	Page 24–25, Line 682–743

Table A1. Cont.

Section and Topic	Item #	Checklist Item	Location Where Item Is Reported
	23b	The limited data set available for inland valleys in the existing literature restricts the generalizability of findings to a broader range of conditions. Further studies are crucial to validate the proposed hypothesis and explore the variability of hydrological responses across different geographical regions.	N/A
	23c	However, and despite the random nature of the sample used in this exercise, it should be noted that it cannot be considered sufficiently comprehensive to draw definitive conclusions. The uncertainties related to the data used, along with the unavailability of information that would have been important to consider (such as data on water management practices implemented on the sites), serve as notable constraints on the analyses conducted.	Page 27, Line 814–819
Discussion	23d	<p>Good data availability and the non-stationarity of processes are the main challenges that face hydrological modeling of inland valleys systems. In chapter 3.2 of this review, we extensively discussed the gaps in hydrological data and analyzed possible solutions to address this situation.</p> <p>Given the significant impact of rainfall on surface runoff, and the restricted capacity for on-site monitoring in the Sub-Saharan regions, we found it necessary to evaluate the suitability of using generic data for monitoring rainfall in studies of inland valleys. Further research on finer scales (daily and sub-daily) with integration of others gridded precipitation dataset are desirable in this field to evaluate the potential of generic data for water management studies in inland valleys. There remains an important need for research on classical rainfall–runoff hydrological modeling for engineering applications in water resources management, water supply infrastructure design, flood and drought prediction processes. Studies must address the challenge to understand hydrological response at sub-daily/event scale. Nevertheless, further research is also needed to understand runoff component and factor that drive each component. Ref. [77] did the same observations and recommend more studies to prove the hypotheses related to interflow processes. Difficulties on the spatialization of information related to certain components of the water cycle, such as groundwater dynamics and soil moisture, seem to have limited the exploration of the river-soil moisture-groundwater interrelationships. The integration of high-resolution satellite data and advanced interpolation techniques should help overcome this constraint. Understanding the relationships between runoff and its parameters could pave the way for incorporating site-specific parameters into modeling using flexible models such as Superflex [123]. Possibilities of assimilation of high precision soil data into a hydrological model can improve the accuracy and reliability of predictions and help to address question about capacity of head water catchment to remember or anticipate his response to climate.</p> <p>Soil moisture data assimilation for instance has found increased applicability in hydrology due to recently available remotely sensed soil moisture data [124]. The influence of physical parameters on runoff and the heterogeneity of these parameters across contributing zones within the same catchment underscore the need for fine-scale characterization of these parameters. Given the importance of physical characteristics to predict flow metrics and the fact that these features are not easily captured by catchment average values some authors like [125] recommend more detailed catchment descriptors. Numerous studies have reported the deterioration of drainage networks in many inland valleys [126]. These changes are not detectable with freely available Digital Elevation Models. Similarly, the properties of soils and aquifers need to be better characterized in order to gain a more detailed understanding of their interaction and their impact on water distribution within the catchment. On this question, ref. [94] showed that streamflow simulation performances using freely available global soil datasets can be improved through integration of locally measured soil information and that availability of local soil information is critical for daily hydrologic model simulations. This is also critical for planning effective soil and water management practices at plot and field scales. In the same way, ref. [127] found that within recent advanced hydrogeological techniques valuable ‘soft data’ can be generated to reflect internal catchment structure and processes. Such hydrogeological soft data have a good potential for realistic calibrations of hydrological models, especially those conducted in inland valleys with limited hydrometric measurements. As an important boundary condition and input data for hydraulic modeling [39], topographic data with good resolution can allow better simulation with distributed models.</p> <p>Significant changes have been observed in climatic parameters and land use, affecting hydrological processes in inland valleys and emphasizing the need for improved modeling approaches. Yet, long term impact of traditional or modern management schemes, implemented in inland valleys, are not well documented. At the same time, numerous cases of poorly managed schemes are reported and can be observed in many countries [7]. The effectiveness of the Rapid Pre-development Diagnosis (DIARPA) [33] as a support tool for designing inland valley management systems in West Africa is increasingly being called into question in this context. It is suggested that the design of appropriate water management systems for inland valleys should rather be based on validated dynamic modeling approaches. Lastly, interdisciplinary research collaborations including involvement of stakeholders in data collection (Citizen Science), integration of advanced remote sensing techniques and geospatial analysis can enhance our understanding of inland valley hydrology. Combining local knowledge and hydrological expertise can lead to the gain of valuable insights into the complex processes governing water dynamics in these unique landscapes. By addressing these challenges, scientist, policymakers and stakeholders can make informed decisions regarding sustainable water management practices, taking into account both environmental and socio-economic considerations. Nature-based solutions, such as reforestation and wetland restoration should be integrate in management schemes to help reduce water risks to economies and society [128].</p>	Page 26–27, Line 745–805

Table A1. Cont.

Section and Topic	Item #	Checklist Item	Location Where Item Is Reported
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	N/A
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	N/A
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	N/A
Support	25	This research was funded by Wallonie Bruxelles International (WBI) as part of the BAFONBE Project.	Page 28, Line 840
Competing interests	26	The authors declare no conflicts of interest.	Page 28, Line 850
Availability of data, code and other materials	27	All data and material are presented in the manuscript	N/A

Note(s): Adapted From: [37].

Table A2. Summary of studies used for rainfall-runoff analysis at event scale in inland valleys in Africa.

Continent Zone	Country	Climate	References	Sites Studied	Area (km ²)	Studied Period	Number of Events
West Africa	Senegal	Bsh	[129]	Ndiba	16.2	1983–1992	28
	Benin	Aw	[56]	Upper Aguima	3.2	2002	10
				Upper Niaou	3.5	2002	10
	Ivory Coast	Aw	[93]	Booro-Borotou	1.36	1984–1987	30
East Africa	Rwanda	Aw	[130]	Kansi	129.3	2010	08
	Tanzania	Aw	[131]	Mataini	0.3	2007–2008	10
				Bangalala	25.3		18
	Kenya	As	[132]	Gikuuri	5.7	2001–2003	07
				NF—Natural Forest	35.9	2007–2008	10
				TTP—Tea and Tree Plantations	33.3		09
				SHA—Small Holder Agriculture	27.2	10	
	Ethiopia	Cfb	[134]	Lagan	5.44	1958–1980	18
				Sambret	7.2		16
				Kasiry	3.99		2014–2015
Akusity				3.43	06		

Table A2. *Cont.*

Continent Zone	Country	Climate	References	Sites Studied	Area (km ²)	Studied Period	Number of Events
South Africa	Zimbabwe	Bsh	[136]	Zhulube	30	2007–2008	06
		Cwb	[87]	Grassland Research Station	3.33	1996	02
Final sample size (17 sites)							204

Note(s): Acronyms means: Hot semi-arid climate (Bsh), Tropical wet and dry winter climate (Aw), Tropical wet and dry summer climate (As), Tropical monsoon climate (Am), Tropical rainforest climate (Af), Subtropical highland climate (Cwb), Temperate oceanic climate (Cfb).

Table A3. Summary of the studies used for the analysis of the annual hydrological balance in inland valleys in Africa.

Continent Zone	Country	Climate	References	Sites Studied (Observations)	Area (km ²)	Studied Period
West Africa	Nigeria	Aw	[137]	Gidan Kwano	0.623	2009
	Ghana		[138]	Yepelugu	10.3	1993–1994
				Sidaribougou	24.8	1993–1994
	Mali		[139]	Dounfing	17.5	1994–1995
				Djitiko	103	
				Belekoni	120	
	Benin		[88] [56] [4]	Upper Niaou	3.5	2001–2003
				Upper Aguima	3.2	
				Lower Aguima	16.5	
				Ara	13	
				Donga-Kolokondé	105	
	Burkina-Faso		[90] [10] [72,140]	Nalohou	0.16	2009–2012
				Bankandi-North	09	2014–2016
Bankandi-Loffing		30				
Bankandi South		2.32		2015		
Mebar Low		7.85				
Mebar Up		4.66				
Fafo	11.3					

Table A3. Cont.

Continent Zone	Country	Climate	References	Sites Studied (Observations)	Area (km ²)	Studied Period					
West Africa	Burkina-Faso		[141] ^c	Tougou BV1	0.338	2010–2011 ^a 2010–2015 ^b 2004–2018 ^c					
			[142] ^a	Tougou BV2	0.338						
			[143] ^b								
			[144] ^b	Tougou	37						
			[105] ^c								
			Bsh	[145] [146] [147] [148]	Katchari	0.014	1998–2000				
				[126] [149]	Bazanga	0.35	1991–1993				
					Wankama	1.9	1992–1993				
					Sama Dey	6.3					
				Niger			[150]	Banizoumbou	C1 C2	0.047 0.111	1994
							[151] [152] [153] [111]	Tondi Kiboro	Tondi Kiboro Amont	0.047	1991–1994 2004–2011
	Tondi Kiboro Aval	0.064									
	Bodo	0.122									
	[111]	Wankama	Wankama Amont Wankama AMZE				0.03 0.032	2004–2008			
Central Africa	Congo	Af	[154]	Yoko	3.11	2019–2020					
		Cwa		Miombo	5.88						
	Cameroon	Aw	[155] [156]	Nsimi	0.6	1994–1999					
East Africa	Kenya	Aw	[5]	Tegu	2.3	2009–2011					
		Cfb	[157]	Sambret		1958–1973					
				Lagan							
		Am		Sous-bassin “Forêt Naturelle” du bassin de Sondu	35.9	2014–2018					
		Af	[133] [158]	Sous-bassin “Plantation de Tea” du bassin de Sondu	33.3						
		Aw		Sous-bassin “Parcelle Agricole” du bassin de Sondu	27.2						

Table A3. Cont.

Continent Zone	Country	Climate	References	Sites Studied (Observations)	Area (km ²)	Studied Period
East Africa	Kenya	Cfb	[93]	Sous-bassin Forêt du bassin de Kapchorwa	0.128	2007–2008
				Sous-bassin Conversion de 05 ans du bassin de Kapchorwa	0.144	
				Sous-bassin Conversion de 10 ans du bassin de Kapchorwa	0.0901	
				Sous-bassin Conversion de 50 ans du bassin de Kapchorwa	0.100	
	Ethiopia	Csb	[159]	Kecha	3.89	2015–2018
				Laguna	3.41	
		Csa	[160]	Kasiry	3.99	2014–2015
				Akusity	3.43	
		Cwa	[161]	Upper-tankwa	130	2006–2007
				Enda-selassie	121	
		Cwb	[162]	Dangishta/Brante	66	2015–2017
				Kilti	165	
		Cwa	[163]	Aynalem	72	2014–2018
Munyazi-Rwabuye	38.6					
Uganda	Aw	[164]	Mukura	41.6	2009	
			Akagera	32.2		
			Kansi	150		
			Namulongue	30		
South Africa	Zambia	Cwa	[28]	Kafue basin A	1.43	1967–1971
				Kafue basin B	1.13	
				Kafue basin G	0.95	
				Kafue basin J	1.28	
	Zimbabwe	[165]	Chizengeni catchment	2.74	1985–1986	
Marondera catchment			3.52			

Table A3. *Cont.*

Continent Zone	Country	Climate	References	Sites Studied (Observations)	Area (km ²)	Studied Period
South Africa	Zimbabwe	BSh	[166]	Romwe catchment	4.60	1995–1996
			[74]			1999–2001
		Cwb	[74]	Mutangui	5.9	1999–2001
			[167]			
South Africa	South Africa	Cwb	[166]	Grassland Research Station	3.33	1995–1996
			[87]			
		[67]				
		[65]				
		Cwb	[168]	Weatherley	1.5	1998–2001 2004
Cwb	[169]	Noordkaap X2H010	126	2004–2012		
Cwb	[170]	Queens X2H008	180	2004–2012		
Csb	[171]	Sandspruit	152	2008–2009		

Final sample size (71 sites)

Note(s): Acronyms means: Hot semi-arid climate (Bsh), Tropical wet and dry winter climate (Aw), Tropical wet and dry summer climate (As), Tropical monsoon climate (Am), Tropical rainforest climate (Af), Subtropical highland climate (Cwb), Temperate oceanic climate (Cfb). The letters a, b, and c in the table indicate the periods of study covered by the cited references.

Table A4. Summary of studies used to analyze the relationship between physical parameters and hydrological indices in inland valleys in Africa.

Continent Zone	Country	Climate	References	Sites Studied	Area (km ²)	Studied Period
Central Africa	Cameroun	Aw	[155] [156]	Nsimi	0.6	1994–1999
West Africa	Benin	Aw	[88]	Upper Niaou	3.5	2001–2003
			[56]	Upper Aguima	3.2	
			[4]	Lower Aguima	16.5	
			[87]	Ara	13	2003–2006
			[71]	Donga-Kolokondé	105	
			[90]	Nalohou	0,16	2007–2012
[10]						
[72]	Bankandi-North	09	2014–2016			
	Bankandi-Loffing	30				

Table A4. Cont.

Continent Zone	Country	Climate	References	Sites Studied	Area (km ²)	Studied Period	
West Africa	Benin	Bsh	[141] ^c	Tougou BV1	0.061	2010–2011 ^a	
			[142] ^a	Tougou BV2	0.338	2010–2015 ^b	
			[143] ^b	Tougou	37	2010–2011 ^a 2010–2015 ^b 2004–2018 ^c	
			[144] ^b				
			[106] ^c				
	[145] [146] [147] [148]	Katchari	0.014	1998–2000			
	Niger	Bsh	[126] [149]	Bazanga	0.35	1991–1993	
				Wankama	1.9		
				Sama Dey	6.3	1992–1993	
			[151] [152] [153] [111]	Tondi Kiboro Amont	0.047	1991–2011	
			Tondi Kiboro Aval	0.064			
			Bodo	0.122			
			Wankama Amont	0.03			
	Wankama AMZE	0.032	2004–2008				
East Africa	Ethiopia	Aw	[59]	Brante	66	2014–2018	
				Kilti	165	2014–2018	
	Kenya	Aw	[158]	Sous-bassin “Forêt Naturelle” du bassin de Sondu		35.9	2014–2018
		Am		Sous-bassin “Plantation de Tea” du bassin de Sondu		33.3	
Af	Sous-bassin “Parcelle Agricole” du bassin de Sondu			27.2			
South Africa	Zambia	Cwa	[28]	Kafue basin (A, B, G, J)	1.5	1967–1971	
	Zimbabwe	Aw	[87]	Grassland Research Station	3.33	1956–1995	
		BSh	[166] [74]	Romwe catchment	4.60	1995–1996 1999–2001	
	South Africa	Cwb	[168]	Weatherley	1.2	1998–2001	

Note(s): Acronyms means: Hot semi-arid climate (Bsh), Tropical wet and dry winter climate (Aw), Tropical wet and dry summer climate (As), Tropical monsoon climate (Am), Tropical rainforest climate (Af), Subtropical highland climate (Cwb), Temperate oceanic climate (Cfb). The letters a, b, and c in the table indicate the periods of study covered by the cited references.

Table A5. Experimental hydrological datasets available for inland valleys studied in Sub-Saharan Africa.

Site (Country)	Dataset—Parameters	DOI/Link Associated with the Dataset
Ndiba (Senegal)	Rainfall—Discharge	http://www.hydrosciences.fr/sierem/ (accessed on 15 November 2023)
Tondikiboro (Niger) Mele Hausa (Niger)	Rainfall	https://doi.org/10.17178/AMMA-CATCH.CE.RainD_Nct
	Discharge	https://doi.org/10.17178/AMMA-CATCH.CE.Run_Nct
	Soil moisture	https://doi.org/10.17178/AMMA-CATCH.CE.SW_Nc
Wankama (Niger)	Rainfall—Soil moisture	https://doi.org/10.17178/AMMA-CATCH.AE.H2OFlux_Ncw
	Discharge	https://doi.org/10.17178/AMMA-CATCH.CE.Run_Ncw
Banizoumbou (Niger)	Rainfall	https://doi.org/10.17178/AMMA-CATCH.CL.Rain_N
	Discharge	https://doi.org/10.17178/AMMA-CATCH.CE.Run_Ncw
	Soil moisture	https://doi.org/10.17178/AMMA-CATCH.AL.Met_Nc
Nalohou (Benin)	Rainfall	https://doi.org/10.17178/AMMA-CATCH.CL.Rain_Od
	Discharge	https://doi.org/10.17178/AMMA-CATCH.CE.Run_Odc
	Soil moisture at 10/50 cm	https://doi.org/10.17178/AMMA-CATCH.AE.H2OFlux_Odc
Ara (Benin)	Goudwater Level	https://doi.org/10.17178/AMMA-CATCH.CE.Gwat_Odc
	Rainfall	https://doi.org/10.17178/AMMA-CATCH.CL.Rain_Od
Kolokonde (Benin)	Discharge	https://doi.org/10.17178/AMMA-CATCH.CL.Run_O
	Rainfall	https://doi.org/10.17178/AMMA-CATCH.CL.Rain_Od
	Discharge	https://doi.org/10.17178/AMMA-CATCH.CL.Run_O
Aguima (Benin)	Groundwater Level	https://doi.org/10.17178/AMMA-CATCH.CL.GwatWell_O
	Rainfall	https://doi.pangaea.de/10.1594/PANGAEA.831192
	Discharge	https://doi.pangaea.de/10.1594/PANGAEA.831193
	Groundwater Level	https://doi.pangaea.de/10.1594/PANGAEA.831194
Nsimi (Cameroon)	Soil Moisture	https://doi.pangaea.de/10.1594/PANGAEA.831195
	Rainfall	https://doi.org/10.6096/bvet.cmr.meteo
	Discharge	https://doi.org/10.6096/bvet.cmr.hydro

Table A6. Parameters analyzed in studies on inland valleys hydrology.

Settings	Tools and Methods Used in Literature	Time and Spatial Accuracy	Ratio of Studies (Indicative Value Based on Analysed Studies)	Comments/Interesting Options (See [18] for More Options)
Morphology/Topography	Satellites data (SRTM, ASTER 30)	30 m	65%	Micro topography not taken into account
	SRTM 30 + DGPS (valley bottom)	5 m	25%	
Land Use Land Cover:	MODIS, LANDSAT ETM, RapidEye TerraSARX, SENTINEL 2	500 m to 05 m (1/2 days)	100%	The spatial resolution is interesting but characterization possibilities at a finer scale would be good
Pedology	Africa Soil Information Service (AfSIS) Harmonized World Soil Database (HWSD)	30–250 m	-	More on site studies in this area are recommended to improve generic sources
	On-site studies	Variable Spatial Ratio	35%	
Climatology: Rainfall, temperatures, insolation, evapotranspiration, etc.	Complete climate station + Rain gauges	Variable Spatial Ratio 5 min/1 day in time	100%	Recommendation of a station for 575 km ² (WMO, 2008) but no study has been carried out to determine the optimum density for inland valleys, Assessing the reliability of generic climatic data for this small's catchment is recommended.
	POWER database; CORDEX Africa; CRU TS 3.1 data set; African Rainfall Climatology Version 2	1 day/0.44°		
Hydrology: limnometry, piezometry, soil moisture	Manual reading	1 day–07 days	20%	Discharge are on situ study dependend Soil moisture and groundwater present difficulties in spatializing information on the basin at sub/daily scale. Assessing the reliability of generic climatic data is recommended
	Automatic device	05 min–06 h	80%	
	ASAR/ENVISAT data	(12.5 m × 12.5 m)/5 days		

Table A7. Models used to simulate the hydrological functioning of inland valleys.

Model	Temporal and Spatial Scale	Modeled Aspect	Country/Inland Valleys Studied	Model Performance Indices/Observations			References
				Performance	R ²	NSE	
SIMULAT-H	1 day/30 m	Discharge	Benin Aguima: Upper Niaou, Upper Aguima, Lower Aguima	Global trend (high), early season flow (poor), peak flows (high)	0.49–0.87	0.42–0.86	[4]
		Soil Moisture		Global trend high for the first soil horizons, but significant differences were observed for the deep soil horizons	0.54–0.95	0.25–0.86	[100] [99]
SWAT	SWAT	1 day—01 mois/2 mois	Ethiopia (Anjeni)	Global trend (high), early season flow (poor), peak flows (low)	0.57–0.96	0.45–0.95	[95]
		1 day/30 m	Benin (Ouriyori)	Global trend (high), peak flows (low)	0.82–0.88	0.82–0.88	[172]
		1 day/30 m	Ethiopia (Anjeni)	Global trend (high), peak flows (low)	0.75–0.84	0.66–0.8	[173]

Table A7. Cont.

Model	Temporal and Spatial Scale	Modeled Aspect	Country/Inland Valleys Studied	Model Performance Indices/Observations			References
				Performance	R ²	NSE	
ArcSWAT 2012	1 day/30 m	Discharge	Benin: Kounga Tossahou Kpandouga	Good trends simulations. Mixed results were observed across sites, particularly during the validation phase	0.39–0.74	0.3–0.73	[174]
	1 day/30 m	Discharge	Ouganda: Namulonge	Global trend (high), peak flows (low)	0.75–0.80	0.69–0.73	[72] [104]
	1 day/90 m	Discharge	Tanzania: Kilombero	Good fit of the daily discharge simulations. Underestimations can be observed at the transitions from the dry to the rainy seasons:	0.80–0.86	0.80–0.85	[175]
	1 day/10 m	Discharge	South Africa: Cathedral Peak research catchment	Good performance of model, especially in years with low to moderate rainfall. Performance was mixed in wet years, as it tended to overestimate the discharge	0.68		[176]
SWAT	1 day/30 m	Discharge	Benin: Kounga Tossahou Kpandouga	Good trends simulations. Mixed results were observed across sites, particularly during the validation phase	0.31–0.77	0.31–0.79	[174]
			Ouganda: Namulonge	Satisfactory results were obtained, although there was an overestimation of peak discharge:	0.69–0.80	0.50–0.51	[72]
SWAT +	1 day/30 m	Discharge	South Africa: Jukskei River catchment: A2H047	Satisfactory results in term of dynamic. Underestimation of base flow and overestimation of flood peaks	0.60–0.74	-	[177]
	1 day/30 m	Discharge	South Africa: Weatherley, W1 et W2	Good accuracy for both the upper and lower catchment. Overestimation of streamflow during rain season	0.82–0.86	0.80–0.85	[127]
	1 day/30 m	Soil Moisture	South Africa: Weatherley, W1 et W2	Soil water contents were simulated with varying degrees of accuracy ranging from very good to extremely poor. Underestimation of the water content for surface layers	0.35–0.50	-	
WaSIM	1 day/30 m	Discharge	Burkina-Faso: Bankandi-Loffing	Satisfactory results. Understimation of extreme events although most of the peak flows were well-captured	0.59–0.71	0.48–0.57	[112]
		Discharge	Burkina-Faso: Bankandi-Loffing;	High and low flows were well simulated at begin and end of of the rainy season. Under-estimation of some flood events at the peak season (July–August)	0.47–0.95	0.40–0.95	[73]
	Soil Moisture	Bankandi-north; Bankandi-south; Loffing	Temporal dynamics were well captured, some discrepancies can be observed in the rainy season	0.7	0.7		
	Groundwater Level		Unsatisfactory results with regard to R ² and NSE. However, in general, the temporal dynamics and the amplitudes of variations are acceptable	0.3	0.2		

Table A7. Cont.

Model	Temporal and Spatial Scale	Modeled Aspect	Country/Inland Valleys Studied	Model Performance Indices/Observations			References
				Performance	R ²	NSE	
WaSIM	1 day/30 m	Discharge	Benin: Ouriyori	High correlations between observed and simulated time series. Overestimation of floods values	0.74–0.78	0.674–0.76	[172]
		Soil Moisture		Good agreement between observations and simulations. Under-estimation of the soil moisture at the peak of the rainy season (June–August). Overestimation for deep layer at the beginning and end of the season	0.67–0.68	-	
	1 day/90 m	Discharge	Burkina-Faso (Dano, Batiara 1, Batiara 2)	Good agreement between simulated and observed discharges but underestimation of flood discharge during extreme events	0.7–0.9	0.6–0.9	[115]
		Soil Moisture	Batiara 2	Long term dynamic is well captured. Better simulation of the soil moisture dynamics at the surface (7 cm depth). Inaccuracy of simulations for deep soil layers in dry season	0.65–0.8	-	
		Groundwater Level	(Dano, Batiara 1, Batiara 2)	Good fit between observations and simulations. Overestimation of the groundwater level during the wet season	0.54–0.73	-	
HBV	1 day/30 m	Discharge	Burkina-Faso: Lofing	Good performance of indices of simulated discharge. Underestimation of peak flows	0.73–0.75	0.70–0.75	[178]
HBV light	1 day/30 m	Discharge	Burkina-Faso: Bakandi	Good fit between observations and simulations. Underestimation of peak flows	0.73–0.78	0.71–0.72	[7]
HBV _x	1 day/30 m	Discharge	Zimbabwe: Zhulube	Good reproduction of timing of discharge. Overestimation of discharge values at the beginning and end of the season. Model fail to simulate the two observed flow types differently (poor representation of Hortonian overland flow)	0.77	0.59	[136]
SHETRAN	1 h/90 m	Discharge	Burkina-Faso: Dano	Performance indices of simulated discharge are good. Main discrepancies were observed in low flow conditions and baseflow. Uncertainties tests also reveals large uncertainty bands during peak flows	0.7–0.72	0.65–0.7	[70] [113]
		Recharge	Ethiopia: Amen, Brante	Statistics are acceptable for both the calibration and validation periods	-	0.53–0.79	[179]
ParFlow-CLM	30 min/5 m	Discharge and flow components	Benin: Nalohou, V-shaped model	Satisfactory results although there were discrepancies observed in low flow conditions and at the beginning of the rainy season	0.28–0.92	-	[10]
PED Model	1 day	Discharge	Ethiopia: Anjeni	Good reproduction of timing of discharge. Underestimation of peak flow events	-	0.69–0.91	[180]
HEC-HMS	1 day/90 m	Discharge and water budget components	Rwanda: Munyazi-Rwabuye, Mukura, Akagera, Cyihene-Kansi	Model performed reasonably well over in calibration but due to the lack of sufficient and reliable data for longer periods, a model validation was not undertaken	-	0.65	[164]
TOPLATS	1 day/30 m	Discharge	Benin: Aguima, Upper Aguima, Lower Aguima	Good performance of the model at local scale (3–30 km ²). Performance decreases with increasing scale due to decreasing information density and increasing uncertainty in the procedure to determine the model parameters	0.51–0.56	-	[98]

Table A7. Cont.

Model	Temporal and Spatial Scale	Modeled Aspect	Country/Inland Valleys Studied	Model Performance Indices/Observations			References
				Performance	R ²	NSE	
UHP	1 day/ sub-basins	Discharge	Benin: Aguima, Upper Aguima, Lower Aguima	Good performance of the model at local and regional scales	0.62–0.70	-	[99]
REW-v4.0 model	1 day/30 m	Discharge	Benin: Ara, Bokpérou, Kolokondé	Good simulation of sub-catchments with a drainage area above 100 km ² . Poor results with small catchments, particularly at the beginning and end of the season	-	0.16–0.60	[181]
r.water.fea	1–5 min (event scale)/20 m	Discharge	Niger: Wankama	Satisfactory results. Potential for improvement through dynamic integration with a vegetation growth and energy balance model	0.59–0.90	-	[182] [183] [184]
MMS/PRMS Modular Modeling System	1 day/5–30 m	Discharge	South Africa: Weatherley	Good reproduction of timing and magnitude of discharge. Underestimation of peak flow events	0.61–0.94	0.81	[168] [185]
Variable Time Interval (VTI) model	1 day	Discharge (flow components)	South Africa: Sabie River 1, Diep River	Good results for the overall temporal dynamics. Less ability of model to reproduce recession characteristics and continuous low-flow spells	0.67–0.81	-	[186]
APSIM	01 day/Plot scale	Soil Moisture	Ouganda: National Crops Resources Research Institute	Satisfactory simulations of seasonal trends. Underestimation of values during the wet period and overestimation during the dry period	0.45–0.87	-	[187]
Hydrus-1D	01 day/Plot scale	Soil Moisture	Tanzania: Kilombero	Good agreement between measured and modeled time series. Simulation results less accurate during the dry season:	0.36–0.92	0.51–0.88	[188]
Environmental Policy Integrated Climate (EPIC)	01 day/Plot scale	Soil Moisture	Benin: Dogué	Satisfactory results for top soil layers in no bund plots of the inland valleys. Underestimation of values during the wet season and overestimation during the dry season for deep soil layers in the bund conditions:	0.48–0.68	-	[80]
ISBA land surface model	01 day/Plot scale	Soil Moisture	Niger: Wankama	Overestimation with standard model, good simulations after local calibration:	0.85–0.92	-	[189]

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