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Community and Impact Based Early Warning System for Flood Risk Preparedness: The Experience of the Sirba River in Niger

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Abstract: Floods have recently become a major hazard in West Africa (WA) in terms of both their magnitude and frequency. They affect livelihoods, infrastructure and production systems, hence impacting on Sustainable Development (SD). Early Warning Systems (EWS) for floods that properly address all four EWS components, while also being community and impact-based, do not yet exist in WA. Existing systems address only the main rivers, are conceived in a top-down manner and are hazard-centered. This study on the Sirba river in Niger aims to demonstrate that an operational community and impact-based EWS for floods can be set up by leveraging the existing tools, local stakeholders and knowledge. The main finding of the study is that bridging the gap between top-down and bottom-up approaches is possible by directly connecting the available technical capabilities with the local level through a participatory approach. This allows the beneficiaries to define the rules that will develop the whole system, strengthening their ability to understand the information and take action. Moreover, the integration of hydrological forecasts and observations with the community monitoring and preparedness system provides a lead time suitable for operational decision-making at national and local levels. The study points out the need for the commitment of governments to the transboundary sharing of flood information for EWS and SD.

Keywords: early warning; flood risk; hydrology; local communities; Niger river basin; rural development; Sahel

1. Introduction

As clearly stated by Ban Ki-moon, United Nations Secretary-General, on 1st September 2015: "The Sendai framework has important implications. It shifts the emphasis from disaster management to disaster risk management." This paradigm shift puts an emphasis on understanding the risks as the underpinning drivers for investing in resilience and preparedness, rather than in response and recovery.

Early Warning Systems (EWS) are a pillar of Disaster Risk Reduction (DRR) being "an integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events" [1]. EWS contribute in reducing vulnerability to floods in urban and rural areas, which can also affect Sustainable Development in the latter. The Sendai framework for Disaster Risk Reduction 2015–2030 recognized seven strategic targets including EWS. The framework also identified four priorities, the fourth of which embeds the concept of Climate Services (CS) as a powerful tool for more effective disaster preparedness and the 'build back better' principle. In this respect, the European research and innovation roadmap for Climate Services expands the contribution of CS, particularly "hydrometeorological services", to the Sendai framework and EWS, a building block of preparedness [2].

The scientific literature presents two main approaches for EWS: top-down and hazard-centered and bottom-up people-centered [3,4]. Kelman and Glantz [5] also categorized EWS by "First Mile" and "Last Mile" approaches, where the former involves communities from the beginning and the latter concentrates on technical solutions and include communities only at the end of the process. As is currently widely acknowledged, top-down or last-mile approaches concentrating on developing forecasts, methodologies and models show many limits in effectively reaching and engaging communities [6,7].

Experiences of bottom-up flood EWS can be retrieved from South Asia, particularly Nepal, India and Bangladesh, all of which practice flood EWS on different scales and use different approaches. Some trans-border flood EWS experience also exists between those countries [8]. In Asia, a strong emphasis on people-centered EWS was observed after the Third International Conference on EWS in Bonn in 2006 and is described as "a complete set of components that connects those who need to receive messages from others who compile and track the hazard information of which messages are composed" [9].

A new paradigm shift was achieved with the concept of Community-Based Early Warning Systems (CBEWS) supported by international non-governmental organizations. A CBEWS is "an early warning system (EWS) where communities are active participants in the design, monitoring and management of the EWS, not just passive recipients of warnings" [10]. The implementation of CBEWS is documented by many authors in developing countries, such as Malawi [11], Nepal [10,12], Indonesia [13], India [14] and Cambodia [15]. CBEWS have proved successful in saving lives, but are often limited in their forecasting time, reducing their suitability for saving assets or livelihoods [16]. Top-down and bottom-up approaches, therefore, need to be integrated: people-centered approaches have to be coupled with robust flood monitoring and forecasting systems.

Since 2015, and according to the recommendation of the World Meteorological Organization (WMO) [17], the need has arisen for EWS to be built on impact-based forecasting and warning services. The aim is to bridge the gap between hydrometeorological forecasts and the potential consequences of the forecasted hazard on specific sectors. This approach, linking forecast information to decision-relevant impact thresholds for users, improves uptake and effectiveness [18]. Although only recently introduced, best practices can be found in the national meteorological services of developed countries, such as the United Kingdom Met Office and National Weather Service of the United States, and are being tested in South Asia [19].

In West Africa, EWS have been conceived and implemented since the 1980s in the sector of food security, mainly addressing agricultural drought [20]. However, efforts surrounding flood management in West Africa have, for the most part, focused on rescue and relief during and after events, while scientific and technical attempts to simulate runoff and forecast flood behavior are limited due to the poor gauging of rainfall and discharge. In recent years, some international initiatives have addressed flood forecasting at global [21] continental [22] or river basin [23] levels to respond to the growing need for flood risk early warning. Despite this effort, none of the web-based systems that are used for ongoing transnational flood forecasting are connected to local EWS, even if they can provide valuable inputs for them. In West Africa, and probably across the whole continent, CBEWS for floods conceived through impact-based forecasts and warnings are not yet documented by the scientific or gray literature.

The objective of our research was to demonstrate that it is possible to set up a comprehensive Community and Impact Based EWS (CIBEWS), responding to the key points and indicators described in the literature, by enhancing existing tools, experience and knowledge in a remote rural area of a poor developing country, such as Niger. This paper describes the approach adopted by the Niger government, with the support of other technical partners, in the setting-up of a CIBEWS in Niger on a Sahelian tributary of the Niger river: the Sirba river. The Local Floods Early Warning System for Sirba, called SLAPIS (Système Locale d'Alerte Precoce contre les Inondations de la Sirba), has been set up within the ANADIA2 (Adaptation to Climate Change and Disaster Risk Reduction for Food Security—Phase 2) project by the National Directorate for Hydrology (DH, Niger) in collaboration with the National Directorate for Meteorology (DMN, Niger), the Interuniversity Department of Regional and Urban Studies and Planning (DIST) Politecnico and University of Turin (Italy) and the Institute for the BioEconomy of the National Research Council (IBE-CNR, Italy). The project was funded by the Italian Agency for Development Cooperation (AICS). The advantages of attaining the SLAPIS objectives are reducing the impacts of floods in both rural (contributing to Sustainable Development) and urban areas, namely that of Niamey, which is a few kilometers downstream of the Sirba–Niger confluence.

2. Materials and Methods

2.1. Study Area and the Hydrological Context

The area of interest is located in the Sirba river basin, the main tributary of the Niger river in the Middle Niger River Basin (MNRB). The Sirba river basin covers an area of approximately 39,000 km^2 across Burkina Faso (93% of the basin) and Niger in the central Sahel. The territory has a granitic substrate and a slight height variation between the upper level of 444 m a.s.l. and the lower of 181 m a.s.l.. The climate is semi-arid with a long dry season and a rainy season concentrated in 3 to 4 months, between June and September, and an annual rainfall between 400 and 700 mm [24]. The Sahelian climate is characterized by strong rainfall variability with persistent dry spells and extreme rainfall events [25]. Therefore, the hydrology of the Sirba river is determined by the monsoon season and its spatio-temporal variability. The flood magnitude is more influenced by surface runoff than by groundwater flow [26].

The Nigerien sector of the Sirba river was chosen as the study area. The reach covers 108 km, from the state border with Burkina Faso, a few kilometers downstream of the confluence of the three main tributaries (Yali, Faga and Koulouko rivers), to the confluence with the Niger river (Figure 1). According to the last census (2012), the Nigerien part of the Sirba basin has 171 villages with a total population of 88,863. The majority (97 settlements) are distributed in riverine areas, meaning that 61,703 people, belonging to 7732 households, live in potentially flood-prone zones.

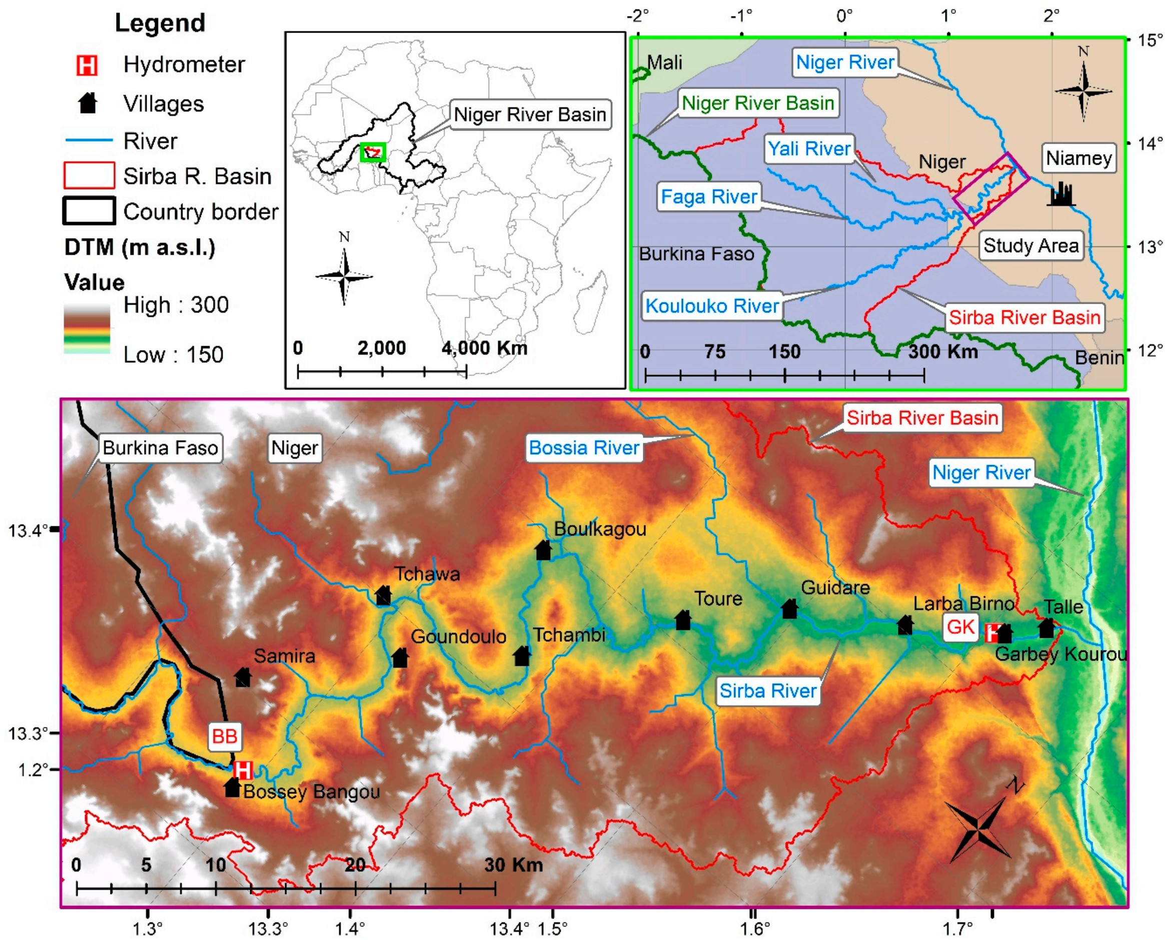

Figure 1. The geographical framework of the study area [27]. Bossey Bangou hydrometer (BB); Garbey Kourou hydrometer (GK).

Since the beginning of the century, as first highlighted by Tharule [28], extreme floods have been a crucial issue in the development of Sahelian countries. Indeed, an increasing number of flood events and flood-related impacts has been reported by many authors [29] and the frequency of flood events is particularly alarming in the MNRB [30–32]. These events often have disastrous consequences for the population, infrastructure, environment and economic sectors. During the last decade, the floods that struck Ouagadougou and Bobo Dioulasso (Burkina Faso) in 2009, the series of floods that hit Niamey (Niger) in 2010, 2012, 2017 and 2019 and those affecting Mopti and Bamako (Mali) in 2019 were particularly significant.

The high occurrence of these catastrophic events, despite the limited recovery of the climatic trends from the long drought that affected the region in the 1970s and 1980s, is referred to as the "Sahel Paradox" [33,34]. Hydrological studies conducted over the last 25 years clearly show two opposing phenomena: a runoff reduction in Sudano–Guinean catchments and an increase in Sahelian catchments [35–37]. Many researchers claim that, in the Sahel, besides the recent recovery of rainfall, which is still below the pre-1970 levels, and the increasing occurrence of extreme rainfall events, the main driver of floods is the strong land/vegetation degradation that has progressively reduced the water-holding capacity of the soil, leading to greater and faster runoff [33,38,39]. Indeed, even in the context of a so-called "regreening" of the Sahel, the recent increase in seasonal greenness at the Sahelian regional scale [40], investigations have highlighted that this vegetation evolution is not spatially uniform, and large areas remain affected by degradation, such as the northeast of Burkina Faso and the southwest of Niger.

The joint impact of land degradation and extreme rainfall increase produced an extension of the drainage network and the rupture of endorheic basins that caused a further discharge increase [39]. The right bank tributaries of the Niger river, and among these the Sirba river, show discharges 150% higher and runoff coefficients three times higher than those observed up to 50 years ago [31].

In Niger, the increase in flood events has been demonstrated to be country-wide by Fiorillo et al. [41], analyzing official data collected by the government on damages from 1998 to 2017. Regarding the regional and sub-regional impacts of floods, the southwestern areas of the country were confirmed to be the most exposed to flood risk. Over the last 20 years, the scientific literature has focused mainly on changes in Niger river flood magnitudes, trying to understand both the changes underway in regional hydrological characteristics and the main factors triggering the increase in floods in the area. However, Tiepolo et al. [42,43] demonstrated that the Niger river is just one of the causes of the flood risk, with other mechanisms and triggers being present.

2.2. Methods for System Set-Up

According to the United Nations International Strategy for Disasters Reduction (UNISDR), the four pillars of EWS, SLAPIS has been set up through a progressive process (Figure 2), addressing (1) risk knowledge, (2) risk monitoring and warning, (3) risk information dissemination and communication, and (4) the response capacity of communities and the authorities to respond to the risk information. Approaches, methods, data collected and analysis are described herein, according to each of the four pillars.

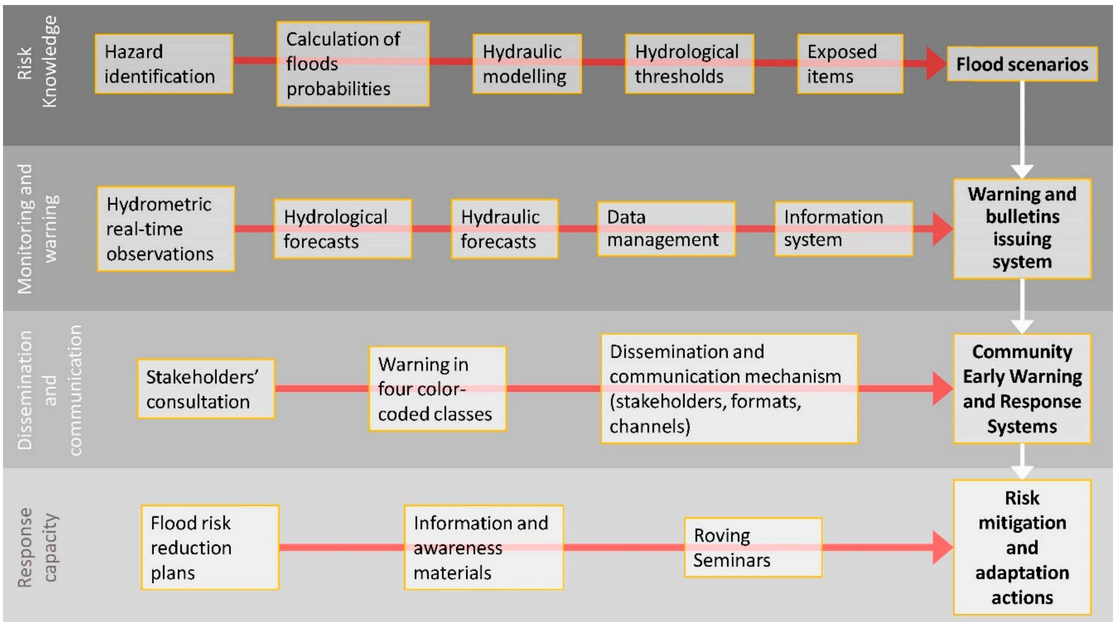

Figure 2. Conceptual framework of Système Locale d'Alerte Precoce contre les Inondations de la Sirba (SLAPIS) organized on the four pillars of EWS (United Nations International Strategy for Disasters Reduction).

2.2.1. Risk Knowledge: Risk Assessment at Local Level and Flood Scenarios

The risk assessment activities have been performed in the four main rural communities distributed along the last 40 km of the Sirba river: Tallé (population 2603 in 2012), Garbey Kourou (4634), Larba Birno (4713) and Touré (4065). The methodology adopted, as described by Tiepolo et al. [44], considers the risk (R) as "the probability of occurrence of hazardous events or trends multiplied by the consequences if these events occur" [45]. The potential damages have already been used as a component of the risk function in both Niger [46] and the developing countries of South Asia.

Risk assessment is conceived as a process starting from the understanding of the local risk governance framework including local planning processes, national guidelines and the literature. The second step is the identification, through meetings with each community, of the hydro-climatic threats, past catastrophic events, rainfall threshold, and flood level above which damages are registered and local resources mobilized by each community (capacity and assets) to address them. The last phase is the calculation of flood probabilities and the establishment of flood scenarios. Flood scenarios were calculated through the development of an ad-hoc hydraulic numerical model simulating the river behavior for each discharge threshold in the Hydrologic Engineering Center's River Analysis System (HEC-RAS) [47] environment. The hydraulic model was implemented on a topography based on a 10 m Digital Terrain Model (DTM) detailed with Geographical Positioning System (GPS) topographical surveys and calibrated with discharge and level observations, as described by Massazza et al. [27]. In order to take into account changes in the hydrological behavior of the Sirba river over time, as described by Tamagnone et al. [26], non-stationary analyses were conducted to identify the probability of occurrence of the assigned hazard thresholds [27,48,49]. The hazard thresholds, as already described by Massazza et al. [27], are shown in Table 1.

Table 1. Hazard thresholds for different flow conditions of the Sirba river [27]. Discharge (Q); Flow Duration Curves (FDC); Stationary Generalized Extreme Value (SGEV); Stationary Return Period (S-RT); Non-Stationary Generalized Extreme Value (NSGEV); Non-Stationary Return Period (NS-RT).

Color	Q max (m^3/s)	Index			Magnitude	Expected Damages
		FDC (Q_{XX})	S_{GEV} (S-RT_{XX})	NS_{GEV} (NS-RT_{XX})		
green	600	15	5	/	normal condition	/
yellow	800	5	10	2	frequent flood	fish nets, water pumps, livestock
orange	1500	/	30	5	severe flood	wells, boreholes, low-altitude houses, barns, and crops
red	2400	/	100	10	catastrophic flood	extended area at medium–low altitude (houses, barns, and crops)

Each threshold was simulated using the hydraulic model in order to define the area and relative hazard level to which riverine populations are subjected. Hydrological thresholds of flood scenarios were linked to field impacts, according to the national flood hazard classification [50] and international guidelines, such as the WMO Guidelines on Multi-Hazard Impact-Based Forecast and Warning Services [17]. Lastly, the risk level characterizing each scenario was obtained by matching together the information regarding the extent of flood-prone zones, the identification of exposed assets and their value [44].

2.2.2. Monitoring and Warning Service: Hydrological Observations and Forecasts, Data and Information Management

The monitoring component of the system relies on two automatic gauging stations at Bossey Bangou (upstream, at the Burkina Faso border) and Garbey Kourou (downstream, near the confluence with the Niger river). The Garbey Kourou hydrometer was installed in 1956 and is equipped with two water pressure measuring devices, one controlled by the Niger Basin Authority (NBA) and the other by the DH of the Republic of Niger, while the Bossey Bangou gauging station was installed in June 2018, in the framework of SLAPIS, and is managed by DH. The Bossey Bangou (2018–2019) and Garbey Kourou (1956–2019) updated discharge series and a set of 14 discharge measurements were used for hydrological and hydraulic modelling [26]. The headwater of the Sirba river in Burkina Faso is equipped only with hydrometric stations that are non-operational for the real-time monitoring of discharge and, therefore, are useless for the EWS.

Further information on water depth, maximum water levels and flooding extent were collected from local observations and field surveys made at the main localities along the Sirba river. Colored hydrometric staffs (ladders) were installed in May 2019 in five villages along the Sirba river: Touré, Larba Birno, Garbey Kourou and Tallé in the municipality of Gotheye and Larba Toulombo in the municipality of Namaro. The staffs are marked with the four different colored flood scenarios (green, yellow, orange and red). The levels of the colored staffs were defined thanks to fixed topographical points identified during the land surveys. A volunteer observer was appointed within the Community Early Warning and Response System (SCAP-RU) of the village and was trained.

Concerning forecasts, the system relies on two types: hydraulic model forecasts (related to observations of upstream hydrometric stations) and hydrological model predictions (derived from hydrological models acting on the Sirba basin). The first consists of the warning that should be conveyed to villages in the case of the river passing the hazard threshold at the upstream hydrometer. The hydraulic model allowed the flood propagation time to be calculated and, thus, the warning time for each village [44]. This type of forecast has a higher level of certainty but may give only a few hours or up to one day of notice to the riparian villages downstream.

Hydrological model forecasts have a major uncertainty but can give indications towards the evolution of the hydrology up to 10 days in advance. At present, the early warning system bases its forecasts on the global hydrological model GloFAS 2 [21]. Preliminary analysis shows that the gap between observed and forecasted discharge is quite significant. This suggested the post-processing of forecasts in order to decrease the bias and improve the EWS reliability. GloFAS forecasts are adjusted with corrective factors, improving their reliability according to historical series and real-time measured data. The optimization process was conducted through the linear regression method over homogeneous periods of the rainy season and was based on 10 years of simulations (2008–2018). The optimization allows quality improvement with an increase in Root Mean Square Error (RMSE) and the Probability of Detection (POD) of extreme events and, at the same time, reduces the False Alarm Rate (FAR), as described by Passerotti et al. [51]. A further improvement in the forecasting system is foreseen with the integration of a second model, Niger-HYPE [23].

Data management and services are ensured by a Spatial Data Infrastructure (SDI) based on interoperable and open source solutions and Open Geospatial Consortium (OGC) web services [52] for the management of observed and forecasted data and the establishment of a hydrological warning communication service. Methodologically, the implementation steps were the conceptual and formal data model design, the development of the SDI, the setting up of some Open Web Services (OWS) standards through the development of services and procedures for data flow management, the forecast data optimization and geoprocessing functions.

The SLAPIS client–server architecture (Figure 3) is based on open source technologies and software components which allow it to interact between data providers and end-users, including three main layers: data retrieval and storage, web services and user interface. All data are managed by a central open source geodatabase, which is the core of the SLAPIS server. Geoprocessing routines and data optimization procedures have been implemented on the data layer in order to ensure that the observed and forecasted data are uploaded into the system data model. Furthermore, Application Programming Interfaces (APIs) have been developed both to transfer forecast data from Niger-HYPE and GloFAS platforms and to foster the communication among the SDI components. For retrieving data from providers not equipped with standard and interoperable web services, we used the File Transfer Protocol (FTP).

For the front-end of the system, a customized Graphical User Interface (GUI) was designed and implemented for monitoring, in quasi-real-time, the observed and forecasted data and their visualization in graphic and tabular formats. The customized functions allow the users to retrieve (from the GUI) the entire data set for further analysis or applications. SLAPIS also has an open data portal which, using the Comprehensive Knowledge Archive Network (CKAN) [53] open source data catalogue, allows access to the available data, including raw and intermediate research data, as well as complementary studies on the area. Each dataset recorded in CKAN contains a description of the data and other useful information, such as available formats, the producer (if they are freely available) and the topic. Finally, a simple information box is available on the main page and it is automatically updated by the system with the current state of vigilance.

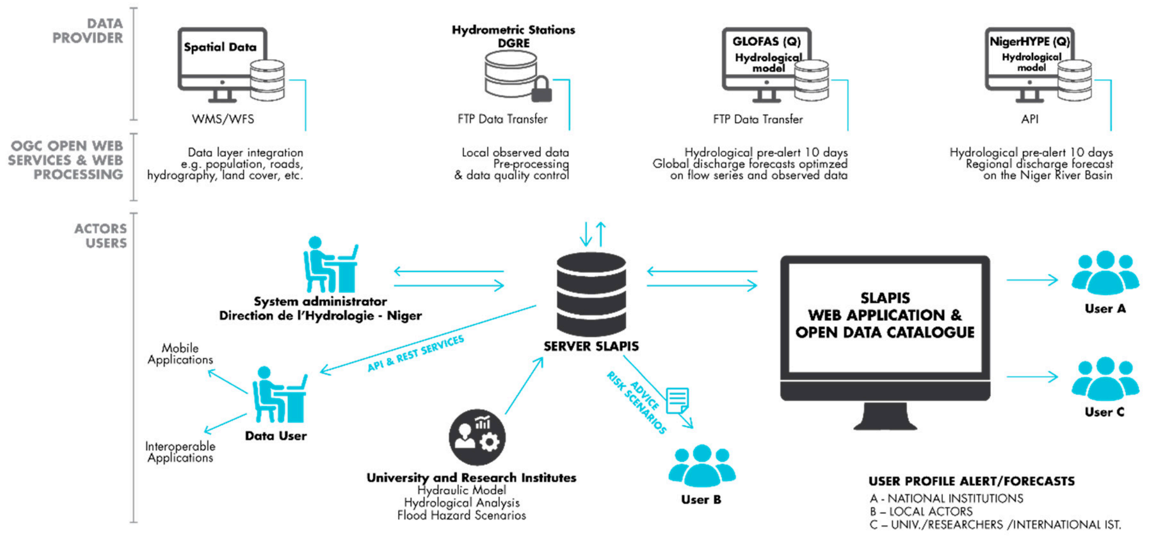

Figure 3. The SLAPIS information system architecture.

2.2.3. Dissemination and Communication: Stakeholders' Consultation

The dissemination and communication mechanism of SLAPIS was defined by a stakeholders' consultation and an analysis of the national alert mechanism. As indicated by the National Alert Code [54], the warning measures are disseminated by the decision of the Minister of Civil Protection at a national level, by Governors in the regions, Prefects in departments and Mayors in the municipalities (Article 5). Alert messages are prepared from information provided by technical institutions at different administrative levels.

An analysis of the needs of the actors in terms of information on the flood risk was performed through semi-structured interviews with national stakeholders, technical workshops with local administrations and focus groups with the communities involved. The result was the definition of the SLAPIS communication and information plan, stating that information produced by SLAPIS should be accessible to all stakeholders through specific tools and channels. Subsequently, information on the state of vigilance is transformed into alerts by the competent institutions according to the magnitude and amplitude of the forecasted flood risk.

Concerning the last-mile of communication, challenges include access to the information, the ability to understand the warning, and the ability to take action [55,56]. All these issues were dealt with via focus groups with local governments and community representatives. A set of actions were defined in order to create awareness at a community level about the flood scenarios and the actions to be taken in the case of a warning. Among different approaches, visualization is the one that has been preferred to aid the interpretation of flood scenarios [57]. In the context of SLAPIS, visualization includes the adoption of the four-color classification for scenarios. They are associated with warning content (the core of the message is the color), with the colored hydrometric staff gauges (qualitative gauging staffs) installed along the river, as well as information panels in the villages indicating priority actions to be taken. We adopted the four color-coded classes currently used by different countries (i.e., United Kingdom—the Met Office; EU—Meteoalarm, Philippine—Pegasa, Italy—Protezione Civile, India Meteorological Department) [19] and responding to the international standards (International Organization for Standardization - ISO 22324:2015). The classes are related to discharge, return periods and impacts on the main riverine settlements according to the classification, as described by Massazza et al. [27]—essentially, green stands for the normal condition, meaning a no-impact scenario, yellow (Stationary Return Period 10 years) stands for minor impacts, orange (Stationary Return Period 30 years) stands for significant impacts and red (Stationary Return Period 100 years) stands for severe impacts. Moreover, the installation of colored hydrometric staffs aims to increase awareness of the flood risk among communities by showing the levels of the hazard thresholds—the height that the flood can reach. Local hydrometric staffs also aim to establish a local communication system, building on the approach described by many authors in Asia [15,58], between upstream and downstream villages.

2.2.4. Response Capability: Communities Preparedness and Action

According to Girons Lopez [59], response capability was based on social preparedness for flood loss mitigation. Community flood risk reduction plans were prepared for the four main villages of Touré, Larba Birno, Garbey Kourou and Tallé in the municipality of Gotheye. The plans have the objective of associating the flood scenarios and the stakes to underline the specific criticalities of each village and propose measures to reduce potential damage. As described by Tiepolo et al. [44], the plans were drawn up with a multi-step methodology: participatory hazard identification, probability of flood occurrence, flood-prone areas, asset (mostly housing and crops) identification and risk reduction actions. The assets are identified in the flood zone by municipal technicians integrated using very high photointerpretation, as described by Belcore et al. [60]. Actions include both risk prevention and the preparedness actions known by the target communities, as well as best practices from the reference literature.

According to Fakhruddin et al. [61], the participatory development of flood risk reduction plans has the objective of enabling people to act, empowering communities with basic knowledge of the flood risks and of more urgent actions to be taken according to each scenario. Actions to reduce risk are associated with the flood scenario and the four color-coded classes of warnings. Therefore, the warnings embed both physical information (water depth and flood zones) and social information (such as community assets likely to be affected and community actions to be taken).

Community preparedness has also been strengthened by adopting and adapting the approach developed by Stitger et al. [62,63] for drought risk management through Roving Seminars on agrometeorology and agroclimatology. A new concept of Roving Seminars for flood risk management has been developed. The seminars take the form of a one-day meeting in a village, which the whole community is invited to attend. The objective is to make communities become more self-reliant in dealing with hydrometeorological issues related to floods that affect human life, habitats, assets, livestock and crops, and to increase the interaction between the community and the National Meteorological and Hydrological Services.

3. Results

The results are reported in the following sections, relating to each of the four pillars of EWS.

3.1. Risk Knowledge

The first main result in the definition of risk level was the assessment of flood scenarios. They were defined on the hazard thresholds, fixed on both the statistical analysis of discharge and impacts on the main riverine settlements according to the four color-coded classes. Flood hazard scenarios were mapped, showing the extension of flood-prone areas (Figure 4). The bulk of the assets are located on the left bank of the Sirba river (houses, community services, infrastructure, fields and vegetable gardens) while the assets on the right bank are essentially fields and orchards with few settlements.

The hydraulic numerical model was also used to calculate the conveyance time of the flood wave: the upstream hydrometer of Bossey Bangou provides notice of between 20 (Touré), 26 (Larba Birno) and 28 hours (Garbey Kourou and Tallé) [27]. Scenarios include the identification of exposed assets (houses, orchards, crops, pits, barns and wells) and their value, as described by Tiepolo et al [46]. Table 2 reports the value of the assets that could be damaged in the four main riverine villages by a flood event with a magnitude equal to the hazard threshold. Reported amounts should be considered, keeping in mind that the average annual GDP per capita in Niger is 430€ (2018) and the minimum wage is 46€ per month.

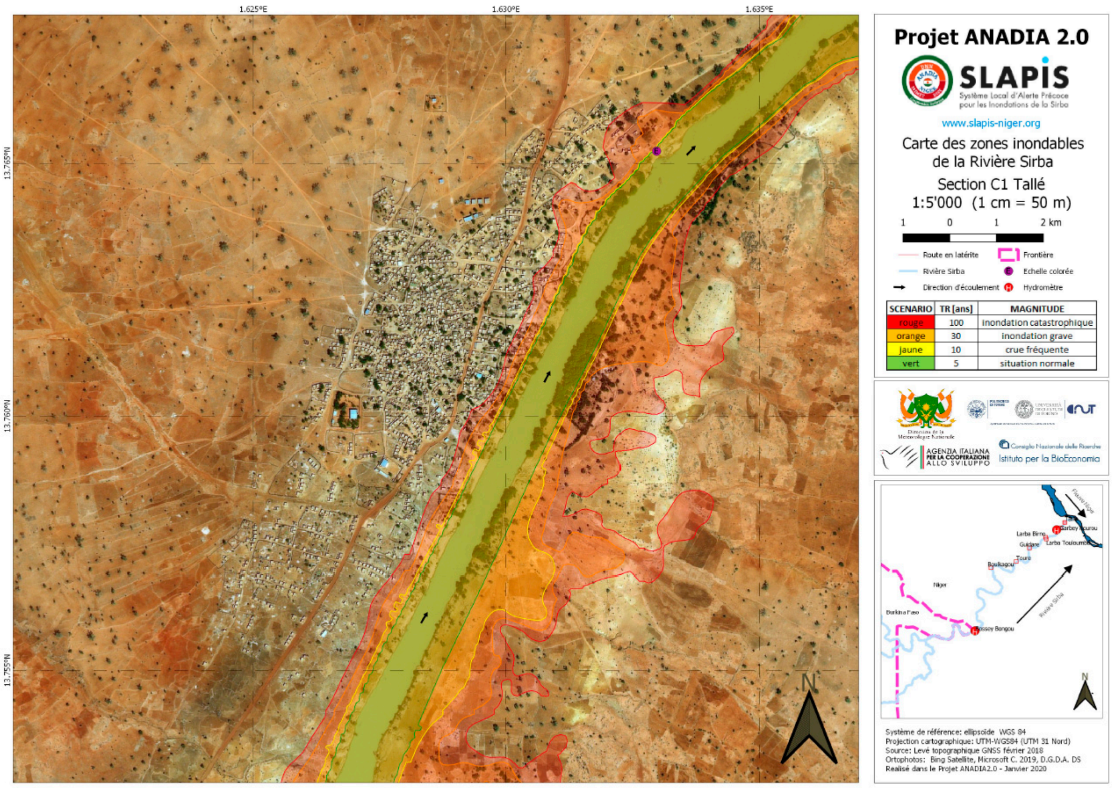

Figure 4. Atlas of flood-prone areas of the Sirba river. Tallé village (Gotheye municipality, Niger). This image reproduces the Table C1 of the Atlas which is in the official language of Niger (French). The Atlas is annexed as a Supplementary Material.

Table 2. Cumulative value (k€) of exposed assets in the four main villages along the Sirba river (adapted from Tiepolo et al. [44]).

Zone	Garbey Kourou	Larba Birno	Tallé	Touré	All
Yellow	0.2	1.3	13.0	0.3	14.8
Orange	8.4	5.4	19.9	1.6	35.3
Red	21.9	22.3	41.7	36.0	120.7

3.2. Monitoring and Warning Service

The observed and forecasted data are accessible by stakeholders using the SLAPIS web platform (www.slapis-niger.org), with specific characteristics that make it unique in the panorama of web tools developed for alerting at local level, because it integrates the following five levels (Figure 5):

1. Forecasts: the system downloads the daily forecasts from hydrological models (GloFAS and Niger-HYPE) and stores them in the central Postgres geodatabase. Data are postprocessed according to the optimization procedures and finally shown as the discharge in a graphic format (currently only GloFAS);
2. Observations: the system downloads real-time observations from hydrometric stations each hour and stores them in the Postgres geodatabase. Data are shown as the water height and discharge in both graphs and tables;
3. Levels of vigilance: levels of vigilance are set by the system once the thresholds are exceeded on observed data at the upstream station;

4. Flood scenarios: the system automatically displays on the map the flood scenario related to the exceeded vigilance threshold;
5. Vigilance bulletin: Exceedances in hazard thresholds activate a vigilance bulletin in the system and an automatic email message to the Directorate of Hydrology. The vigilance bulletins can be used as they are or can be edited to activate the alerting chain of national and local authorities, as defined by the National Alert Code.

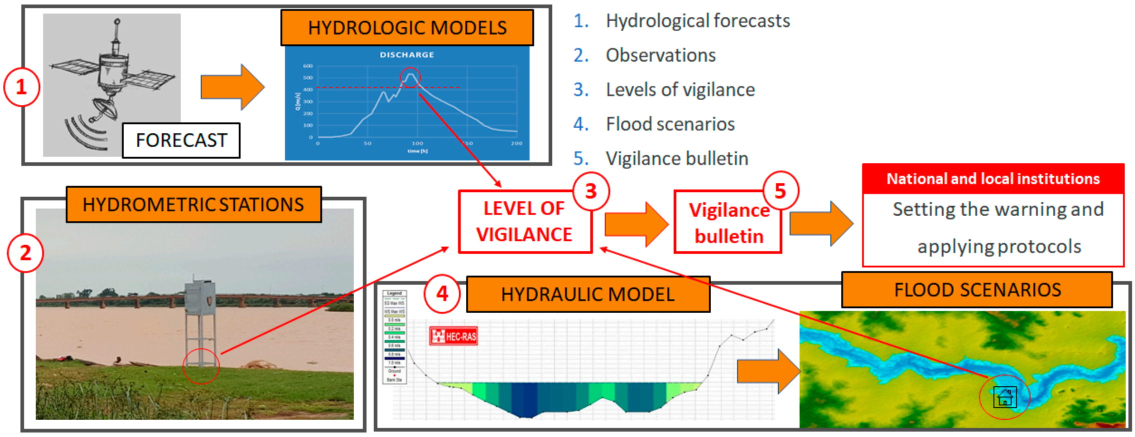

Figure 5. Structure of the SLAPIS monitoring and warning services.

The observed data are also accessible through the CKAN catalogue (http://sdicatalog.fi.ibimet.cnr.it:5003/fr/dataset?groups=slapis_prj), as well as other geographical data used by the system in different formats (SHP, GeoJSON, JSON and CSV).

The network of local observers is composed of two at the gauging stations and five village observers at the colored hydrometric staffs (Figure 6).

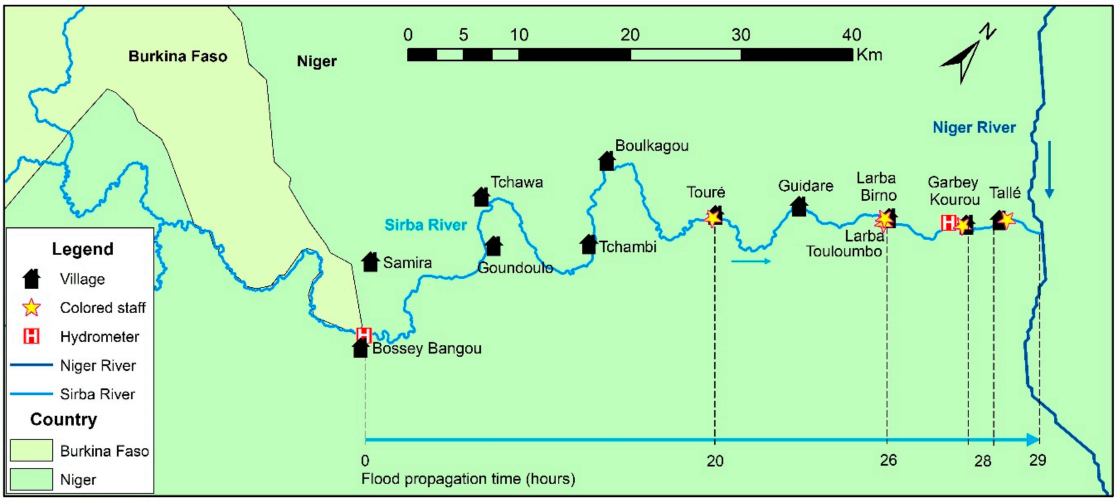

Figure 6. Map of the observation network and the flood propagation time.

In order to increase awareness of the flood risk among communities and integrate the observation network with additional local measures, colored hydrometric staffs (Figure 7) have been installed in five villages along the Sirba river with the objective of showing the levels of the hazard thresholds, the height that the flood can reach, to increase awareness of the danger of flooding and communicate the level of risk to villages downstream. The observers have been trained to read the scales and communicate any rise in the waters to the DH, the Vulnerability Monitoring Observatory (OSV) located in the municipality and the SCAP-RUs of the villages downstream, according to a specific observing protocol. In 2019, they used a WhatsApp group to send the information as a photo; however, in 2020, a system of visualization of the observed water levels at the colored staffs will be integrated into the SLAPIS platform.

Figure 7. Colored hydrometric staff at Garbey Kourou, Niger.

3.3. Dissemination and Communication

SLAPIS is integrated in the national alert system; indeed, its information mechanism was defined thanks to an analysis of the national alert mechanism and an analysis of the needs of the actors in terms of information on the flood risk. The communication and dissemination plan of SLAPIS defined that the flood scenarios produced in the framework of SLAPIS and the related warnings on the level of vigilance are accessible to all stakeholders with specific tools. Subsequently, the state of vigilance is transformed into an alert by the competent institutions. Figure 8 summarizes the SLAPIS information mechanism. In particular, it indicates the actors to whom the information is communicated directly, through which channel and in what format.

The information on the state of vigilance is then transformed into an alert by the competent institutions according to their protocol and communicated through institutional channels, as recommended by Rahman et al. [64]. According to Oktari et al. [65], the communication system is multi-channeled in order to ensure maximum outreach. Specific communication channels are established with different types of stakeholders. There are four main official information flows:

- To Civil Protection Directorate (DGPC) at a central level, that sends the alert to the Regional Directorate, then to the Departmental Directorate, which then communicates it to the Mayor;
- To the National Food Crisis Prevention and Management System (DNPGCA) at central level, that sends the alert to the Regional Committee (CRPGCA), then to the Departmental Committee (CSRPGCA), who communicates it to the Mayor;
- To the Ministry of Humanitarian Action and Disaster Management (MAH) which, not having any de-centered structure, transmits the alert via all the means of communication provided by the National Alert Code to all levels including the population.
- To the Mayor of affected municipalities who, once he has received the information concerning the level of vigilance, alerts:
    - The OSV through an emergency meeting. The OSV alerts sectoral infrastructure (schools, water supply, etc.);
    - Community Radio by telephone to dictate an alert release;
    - Chiefs of concerned villages by telephone. The village chief mobilizes all available means to alert the population (loudspeaker, town crier, etc.);

- o The Prefecture by telephone and/or SMS;
- o SCAP-RUs (through the OSV).

In addition to the information from the information system, SLAPIS integrates local observations made at the colored staffs installed in the main villages bordering the Sirba. The observer appointed within the SCAP-RU is responsible for communicating the possible rise in the water level to the OSV located in the municipality and to downstream villages using the color code of the flood scenarios (green, yellow, orange and red).

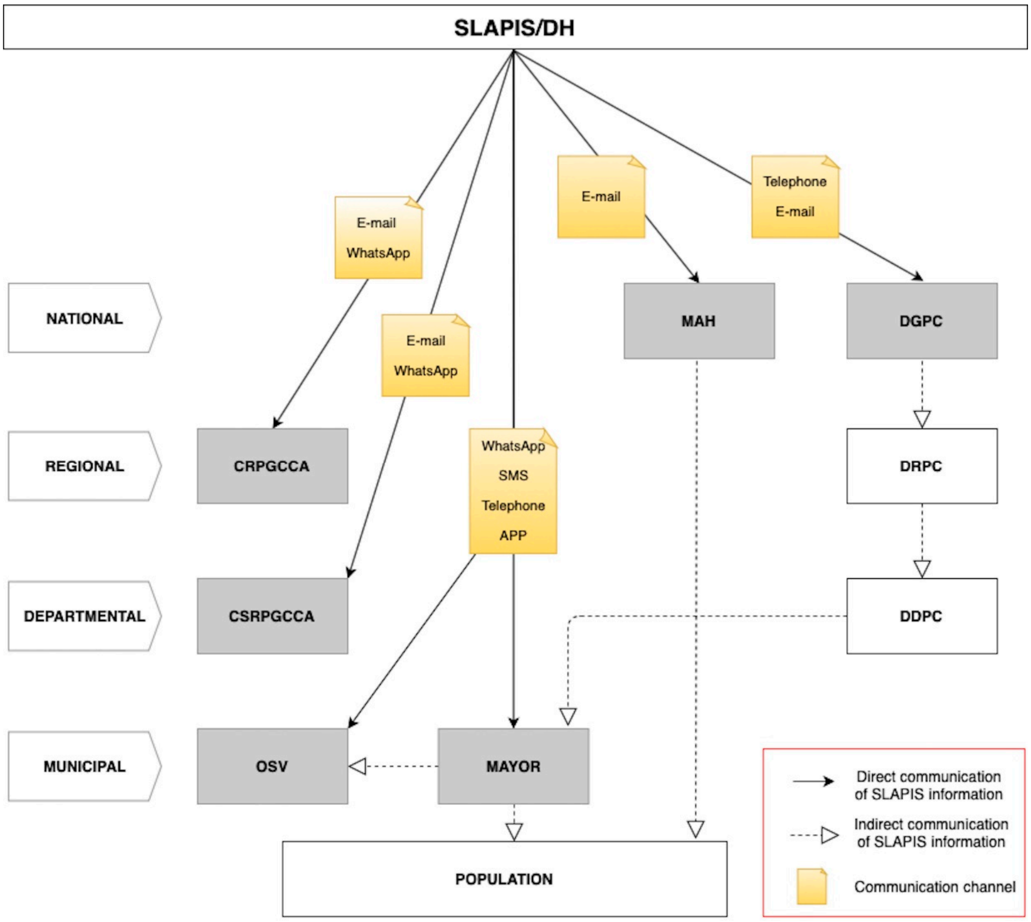

Figure 8. Information flow (Hydrology Directorate (DH); Ministry of Humanitarian Action and Disaster Management (MAH); Regional Committee of Food Crisis Prevention and Management System (CRPGCCA); Departmental Committee of Food Crisis Prevention and Management System (CSRPGCA); Vulnerability Monitoring Observatory (OSV); General Directorate for Civil Protection (DGPC); Regional Directorate for Civil Protection (DRPC); Department Directorate for Civil Protection (DDPC)).

3.4. Response Capability: Communities Preparedness and Action

Since 2006, the WMO has been promoting the organization of one-day Roving Seminars on weather and climate for farmers. We adapted the concept of Roving Seminars to the hydrological risks, with the main objective of strengthening communities' self-reliance in dealing with floods and other extreme hydrometeorological risks. Moreover, the seminars increase the interaction between the local communities and local staff of the National Meteorological and Hydrological Services, building trust and confidence. The seminars are organized in two parts. The first focuses on the weather, climate and hydrology of the region, particularly on the relationship between rainfall and discharge on the whole river basin and on local sub-basins. The aspects of change in land-use/land-cover and changes in hydrological processes are also well developed in order to promote a better comprehension of the dynamics, in which farmers are a key actor. The second part of the day focuses on the communities' perception of weather and hydrological information/alerts provided by SLAPIS. The main objective is to obtain feedback from the communities by a free and frank exchange of ideas and information. This part of the seminar is designed to engage all the participants in discussions and obtain suggestions on additional information and ways and means of improving future communication to facilitate effective operational decision making.

SCAP-RU are key actors in monitoring and coordinating actions in an emergency and in peacetime. SLAPIS invested in the empowerment of SCAP-RU, both technically and socially. From a technical point of view, SCAP-RU have been trained in risk assessment, monitoring and impact observation. Each SCAP-RU has been equipped with a smartphone and access to the internet to collect and transmit observations and receive information and alerts. SCAP-RU members have been charged with specific roles before, during and after emergencies, reinforcing their status and becoming a reference within the community.

In Niger, local plans to address hydro-climatic hazards are not required by law. Within SLAPIS, we developed local flood risk reduction plans for the main villages exposed to flood risk. The plans were coordinated with the communities and organized considering local capacities and assets. Even if the plans are very simple, they include a contingency part involving the setting up of an emergency committee, a map of the areas according to flooding probability and a map of exposed assets and basic emergency instructions. The plans also include structural prevention measures, such as the protection or displacement of boreholes, wells, fountains and photovoltaic plants [44]. The visualization of contingency actions in relation to risk levels was realized through local information panels, which report the main actions to be taken by communities in text and graphics.

Another result was the production of a Cartographic Atlas of flood-prone areas (published as a Supplementary Material to this paper) over the 108 km of the Nigerien reach of the Sirba river. Maps are compiled at large (1: 100,000) and detailed (1: 20,000) scales. The most exposed riverine villages of Tallé, Garbey Kourou, Larba Birno, Larba Toulombo, Guidare, Toure, Boulkagou and Bossey Bangou are also represented at greater detail (1: 5000).

4. Discussion

The results of the study are discussed herein according to the indicators identified by Sai et al. [19] for steering each of the four components of effective EWS (See Table A1 in Appendix A).

Concerning risk knowledge, the indicators identified in the literature are:

- Local risk assessment—interaction of vulnerability and hazard scenarios for determining the risk to the exposed elements with a detailed resolution [66]: this is a key element to connect top-down and bottom-up approaches. It was addressed through participatory local risk assessment for main localities along the river [44] and flood hazard scenarios, including hazard thresholds and flooding areas [27,44];
- Hazard mapping—hazard maps for different scenarios need to be developed to identify exposure to different hazard magnitudes [61,67]: flood hazard scenarios were mapped (www.slapis-niger.org) and an Atlas of flood-prone areas of the Sirba river produced (see Supplementary Materials);
- Vulnerability mapping—vulnerable elements and critical infrastructure need to be mapped, documented and periodically updated [68]: this point was addressed through the involvement of municipalities in listing, georeferencing and describing assets for each flood scenario in the main localities [44,60]; for future sustainability, the challenge is to keep the lists updated, which mostly depends on the willingness of the municipalities involved.

Concerning the monitoring and warning components, the indicators proposed by the literature are:

- Timely and accurate forecast—good quality data have to be collected and processed in real or quasi-real-time to produce meaningful, timely and accurate forecasts [3]: hydrological forecasts can ensure a lead time of 10 days, but their accuracy is lower than hydraulic forecasts based on the upstream hydrometer [27], which have a lead time of 28 hours. The accuracy of hydrological forecasts has been improved, assimilating real-time data observed at the gauging stations at Bossey Bangou and Garbey Kourou;

- Impact-based thresholds—warnings must be prepared and issued based on expected impacts severity, enabling end-users to take appropriate risk mitigation actions [17]: SLAPIS Hydrological warnings are based on four color-coded classes related to flood scenarios and assets at flood risk [27,44]. For citizens already used to that approach, the meaning is intuitive, but in a Sahelian rural area, the understanding is not evident. Indeed, many awareness-raising activities have been organized with local communities;
- Geographic-specific warnings—a dense monitoring network ensures a good coverage of the forecast, being more specific and issuing warnings to localized targets [65,67,69]: addressed by two automatic hydrometers on the Sirba river (108 km distance = ~ 28 hours. propagation time) at Bossey Bangou (13.73° N, 1.60° E) and Garbey Kourou (13.35° N, 1.29° E), real-time data collection in the online geo-database, real-time display of hydrological data (www.slapis-niger.org), real-time data available on CKAN at http://sdicatalog.fi.ibimet.cnr.it:5003/fr/dataset/bosse-bangou and some colored hydrological staffs installed between the stations for local observations (av. 35 km distance = ~ 8 hours. propagation time). The use of colored staffs for empowering communities in local warning is well documented in the literature and it also raises awareness about flood risk;
- Sector-specific warning—warning contents have been prepared and issued to different end-user groups with the same needs [3]: hydrological warnings are issued when a threshold is exceeded. The same information is sent to different groups of users with different format and communication channels according to users' needs and the preference expressed during the stakeholders' consultation.

Concerning dissemination and communication, the indicators collected by Sai et al. [19] are:

- Robust standing operating procedure—government policy establishes the warning dissemination pathway and the rules for defining specific impact-based warnings [64–66]: the main challenge is to involve all stakeholders, avoiding conflicts of mandate and responsibility. The National Alert Code is, theoretically, clear but practically different institutions claim the same mandate on flood risk management. Dissemination and communication plans have been developed according to the National Alert Code and the shared solution we found was to provide the same information to all stakeholders, leaving scope for the further dissemination to their own internal procedures. Therefore, all stakeholders in the alerting chain are involved through specific communication channels. The following alerting process reflects the chain of each stakeholder;
- Complete and timely dissemination—warnings must reach all exposed communities, including those in remote areas, in good time before the hazardous event occurs [64,65]: the pre-alert system based on forecasts has a lead time of 10 days, while the alert based on hydrological observation has a lead time between 6 to 28 hours. according to distance from the Bossey Bangou gauging station. The communication system for the last mile is mainly by mobile phone, now common even in more remote rural areas;
- Multiple dissemination channels—exposed communities must be warned via different media according to their ability/possibility of using them [65]: a communication system is in place to reach municipalities in multiple ways. At municipal level, Mayors can deploy multiple communication channels (Radio FM, Smartphone text and voice calls to village chiefs and SCAP-RU, public criers). At local level SCAP-RUs are equipped with colored hydrological staffs and smartphones (WhatsApp) to alert SCAP-RUs of downstream villages and OSV;
- End-user's dissemination and communication needs—message content, communication and dissemination means are tailored to end-user needs, ensuring higher warning understanding [61,64,67,69]: alerts rely on color-coded classes, associated with scenarios, impacts

and actions. Each SCAP-RU has knowledge of the scenarios associated with alert colors, flooding area maps, assets at risk and priority actions to be taken. Participatory meetings proved to be really useful in building trust.

Concerning response capability, the indicators addressed are:

- Information on impacts and advice—messages must contain information on the expected impacts and advice on how to implement risk mitigation actions [3,70]: Each SCAP-RU has knowledge of the color-coded classes scenarios. In each village information panels with infographics are displayed to report priority actions to be taken. Roving Seminars on flood risk proved to be very useful in raising awareness and building understanding of actions to be taken according to different scenarios.
- Community and volunteers education—volunteers must ensure coordination at local level, helping communities to effectively respond to alerts [66,69]: the SCAP-RU (composed of volunteers) are in charge of activity coordination at a local level (villages), local observations and exchanges with other villages, alert dissemination within the village, and the taking of urgent actions by the community.
- Preparedness and contingency plans—hazard and vulnerability maps are used as a management tool for improving the response and coordinating emergencies [66,71]: municipalities are empowered with flooding area maps at different scales, the list of assets at risk for each village and flood scenarios and the flood risk reduction plans for the main villages in their territory. The challenge for municipalities is to keep the lists of assets for each flood scenario updated.

Finally, some cross-cutting indicators are also addressed:

- Local community participation—end users can actively contribute to all four components of EWS [3,61,64,71]: communities are key actors in Participatory Local Risk assessment [44], discharge monitoring at a local level (SCAP-RU), communicating the observed levels of vigilance (SCAP-RU) and defining the contingency actions of risk reduction [46]. Furthermore, the technical architecture and GUI of the SLAPIS are designed to integrate (i) top-down and bottom-up approaches, (ii) hydrological forecasts and observations with local perception of populations and a lead time suitable for operational decision-making processes at national and local levels. According to many authors, involving communities and local stakeholders is the main challenge for achieving the purpose of the EWS and SLAPIS proved that it can be effectively achieved by appointing local observers, organizing meetings with communities, involving them in the risk knowledge phase and jointly defining communication and risk reduction plans.

5. Conclusions

According to Cools et al. [71], the key point to enhance the effectiveness of a flood EWS is: "a better match between the available risk information, the forecasting system and the response capability of authorities and the at-risk population". Cools et al. suggested, and the present study demonstrates, that "Engaging local communities and authorities in the EWS design can improve the effectiveness of the whole early warning process and hence results in a higher response to an alert warning".

The study proves that such key points can be operationally addressed, leveraging existing resources, local stakeholders and knowledge using simple but effective approaches and integrating state-of-the-art hydrologic-hydraulic scientific results in a decisional scheme for Sahelian rural areas. This mechanism will be replicable in each context, even if characterized by knowledge and structural deficits, creating a better capacity to exchange data and information and by directly connecting available technical capabilities with the local level. Beneficiaries are, therefore, able to define the rules that will develop the whole system, which, in any case, needs to be consistent with the legislation in force in the country and with internationally recognized best practices.

This study suggests that, instead of developing new forecasting tools, it can be preferable to enhance those already operating on the basin and calibrate them on the local scale by adding real-time observation control points and to connect discharge thresholds, field observations and hydrological forecasts with potential impacts through flood scenarios. This multidisciplinary approach ensures a greater level of suitability and sustainability. Indeed, it allows us to enhance the resonance of hydrological models already developed by the scientific community, which are not usually exploited by local technical structures and to concentrate efforts on: (1) the downscaling of forecasts, (2) topographical surveys and discharge measurements on-site, (3) the quality improvement of observations and (4) the implementation of hydraulic models to guide the planning of mitigation and adaptation strategies. The strength of simplicity also lies in not having to spread complex messages, but simply the reference risk scenario and, finally, its color-code (according to the international standards of ISO 22324:2015), which already embeds all of the other information.

The main limit of the study is that it focuses only on the Sirba reach in Niger. The absence of trans-border flood risk assessment and the lack of real-time hydrological monitoring upstream in Burkina Faso prevent the flood risk information being spatially extended upstream. Moreover, the limited lead time provided by the observation at the Bossey Bangou gauging station to the main downstream villages is a limitation of the EWS on the Sirba river.

The ongoing improvements of SLAPIS, already planned before the 2020 rainy season, include implementation of: (1) a second optimization based on real-time observed discharge and (2) the operational integration of the forecasting system of the regional hydrological model Niger-HYPE, ensuring more resilience and more accurate discharge forecast in the system. Further future developments of this study include the improvement and extension of the existing flood EWS to the whole Sirba basin. Naturally, this implies an urgent need for systematic flood monitoring and communication between the two countries (Burkina Faso and Niger), as well as a coherent flood risk assessment performed upstream of the boundary. In this respect, the respective governments' commitment to sharing of information and effectively disseminating it to flood-prone communities is necessary. At broader level, the study found that there is a need for institutionalizing and strengthening the existing practices of sharing of flood information between different countries for EWS purposes. The simple and integrated approach illustrated in this case study, bridging the gap between top-down and bottom-up approaches described by the literature, can inspire governments, local administrations and development partners to invest in the improvement of existing tools and knowledge in order to strengthen cooperation, collaboration and coordination, reduce hazard impacts and sustain the development of rural and urban areas.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/5/1802/s1, Atlas of flood-prone areas of the Sirba river (Atlas cartographique des zones inondables de la Rivière Sirba.

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Appendix A

Table A1. Indicators of effective EWS identified by Sai et al. [19] and the approach adopted to address them within SLAPIS.

EWS Component	Indicator	Description	References	SLAPIS
Risk knowledge	Local risk assessment	Interaction of vulnerability and hazard scenarios for determining risk to the exposed elements with a detailed resolution.	Scolobig et al. [66]	Participatory Local Risk Assessment for main localities along the river [46] Flood hazard scenarios, including hazard thresholds and flooding areas [27,46]
	Hazard mapping	Hazard maps for different scenarios need to be developed to identify exposure for different hazard magnitudes.	Fakhruddin et al. [61] Koks et al. [67]	Flood hazard scenarios mapping (www.slapis-niger.org) Flooding areas atlas of the Sirba (See Supplementary Materials)
	Vulnerability mapping	Vulnerable elements and critical infrastructures need to be mapped, documented and periodically updated.	Bhuiyan and Al Baky [68]	Listing, georeferencing and describing assets for each flood scenario [46,60]
Monitoring and warning	Timely and accurate forecast	Good quality data have to be collected and processed in a real or quasi-real-time to produce meaningful, timely and accurate forecasts.	Basher [3]	Use of two hydrological models (GLOFAS and Niger-HYPE) assimilating real-time data observed at the gauging stations of Bossey Bangou and at Garbey Kourou [27] and hydraulic forecasts
	Impact-based thresholds	Warnings must be prepared and issued based on expected impacts severity, enabling end user to take appropriate risk mitigation actions.	WMO [17]	Hydrological warnings based on four color-coded classes related to flood scenarios and assets at flood risk [27,46]
	Geographic-specific warnings	A dense monitoring network ensures a good coverage of the forecast being more specific, issuing warnings to localized targets.	Cumiskey et al. [69] Oktari et al. [65] Shah et al. [70]	2 automatic gauging stations on the Sirba river (100 km distance = ~ 28 hours. propagation time) at Bossey Bangou (lat° 13.73, lon° 1.60) and Garbey Kourou (lat° 13.35, 1.29 lon°) Real-time data collected in online geo-database SLAPIS Real-time display of hydrological data (www.slapis-niger.org) Real-time data available on CKAN at http://sdicatalog.fi.ibimet.cnr.it:5003/fr/dataset/bosse-bangou 5 colored hydrological staffs between the stations for local observations (av. 35 km distance = ~ 8 hours propagation time)
	Sector specific warning	Warning contents have been prepared and issued to different end users clusters with same needs.	Basher [3]	Hydrological warning issued when a threshold is exceeded. The same information is sent to different groups of users with different format and communication channel according to the preference expressed during the stakeholders' consultation.

Table A1. *Cont.*

EWS Component	Indicator	Description	References	SLAPIS
Dissemination and communication	Robust standing operating procedure	Government policy establishes the warning dissemination pathway and the roles for defining specific impact-based warnings.	Oktari et al. [65] Rahman et al. [64] Scolobig et al. [66]	Dissemination and communication plan developed according to the National Alert Code. All stakeholders in the alerting chain are involved. Specific communication channels established with different types of stakeholders. Alerting process reflects the chain of each stakeholder
	Complete and timely dissemination	Warnings must reach all exposed communities, including those in remote areas, in time before the hazardous event occurs.	Oktari et al. [65] Rahman et al. [64]	Pre-alert system based on forecasts has a lead time of 10 days, while the alert based on hydrological observation and hydraulic forecasts has a lead time between 6 to 28 hours. according to the distance from the upstream gauging station.
	Multiple dissemination channels	Exposed communities must be warned via different media according to their ability/possibility of using them.	Oktari et al. [65]	A communication system in place to reach municipalities in multiple ways. At municipal level, Mayors can deploy multiple communication channels (FM Radio, smartphone texts and voice call to village chiefs and SCAP-RU, public criers). At a local level, SCAP-RUs are empowered with colored hydrological staffs and smartphones (WhatsApp) to alert SCAP-RUs of downstream villages and OSV
	End user's dissemination and communication needs	Message content, communication and dissemination means are tailored on end user needs, ensuring higher warning understanding.	Cumiskey et al. [69] Koks et al. [67] Fakhruddin et al. [61] Rahman et al. [64]	Alerts rely on four color-coded classes, associated with scenarios, assets and actions. Each SCAP-RU has knowledge of scenarios associated with alert colors, flooding areas maps, assets at risk and priority actions to be taken.
Response capability	Information on impactsand advices	Messages must contain information on the expected impacts and the advices on how to implement risk mitigation actions.	Shah et al. [70] Basher [3]	Each SCAP-RU has knowledge of color-coded class scenarios. In each village, information panels with infographics are displayed to imply priority actions to be taken. Roving Seminars on flood risk to raise awareness and build trust and understanding
	Community and volunteers education	Volunteers must ensure the coordination at local level, helping communities to effectively respond to alerts.	Cumiskey et al. [69] Scolobig et al. [66]	SCAP-RU are charged with activity coordination at local level (villages): local observations and exchange with other villages, alert dissemination within the village, urgent actions by community
	Preparedness and contingency plans	Hazard and vulnerability maps are used as a management tool for improving response and coordinating emergencies.	Cools et al. [71] Scolobig et al. [66]	Municipalities are empowered with flooding area maps at different scales, the list of assets at risk for each village and flood scenarios and flood risk reduction plans for the main villages in the territory [46].

Table A1. *Cont.*

EWS Component	Indicator	Description	References	SLAPIS
Cross-cuttingcomponent	Local community participation	End users can actively contribute to all four EWS components	Cools et al. [71] Fakhruddin et al. [61] Rahman et al. [64] Basher [3]	Communities are key actors in: • Participatory local risk assessment [46] • Discharge monitoring at local level (SCAP-RU) • Communicating the observed levels of vigilance (SCAP-RU) • Defining the contingency actions of risk reduction [46] GUI of the SLAPIS are designed to integrate i) top-down and bottom-up approaches

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