

# Chapter 12

## A Simplified Hydrological Method for Flood Risk Assessment at Sub-basin Level in Niger

Edoardo Fiorillo and Vieri Tarchiani

**Abstract** Flood events are increasing year by year in the Sahel, mainly caused by climate and land use changes. New strategies and tools are necessary to optimize flooding risk reduction plans. This paper presents a new hydrological method (FREM, Flooding Risk Evaluation Method), based on the curve number runoff estimation. The method can be adopted for small-medium basins and is based on the integration of remote sensing techniques with field surveys and participatory mapping. It consists of preliminary identification of the areas and sub-basins that most contribute to the flood risk; scenarios can then be developed in order to: (i) optimize the placement of traditional water retention structures in the elementary sub-basins that contribute most to the overall risk, (ii) assess the contribution of each hydraulic structure to reduce the total risk, (iii) give a priority ranking to these structures identifying those most urgent. The main advantages of this method are that it is easy to use and can be implemented using free available land cover, soil and morphology data and open-source GIS (Geographic Information System) software. A case study for the Ouro Gueladjo basin (Tillabery Region, Niger) is presented.

**Keywords** Sahel · Remote sensing · Flood risk assessment · Water retention measures · Adaptation

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## 12.1 Introduction

Western Africa Sahel is a region traditionally known for its droughts rather than its floods. After the droughts of the 1970s and 1980s, Sahelian countries are today also suffering from the effects of heavy rains and devastating floods. The authors investigated the Niger official database of flood damage (ANADIA NIGER DB) that has been compiled yearly since 1998 by the Niger government coordination unit “Système d’Alerte Précoce et Prévention des Catastrophes” (SAP). During the 1998–2014 period, more than 3600 localities and about 1.6 million people were affected by floods. The consequences of flooding don’t concern only damage to goods, agricultural systems and economic infrastructure (roads, bridges, dams destroyed), but also affect population resilience against food insecurity, particularly in the most vulnerable groups of people. In addition, recent years have seen an alarming increase in flooding, particularly in 2012. The problem is concentrated in the southwest of the country, but affects almost the entire country with 216 municipalities involved out of a national total of 263, among them 81 with more than 5000 people affected over the years.

The increased number of floods per year is mainly due to two factors: a higher frequency of extreme rainfall events and human induced land cover changes. Regarding the first aspect, Mouhamed et al. (2013) stated that during the 1960–2000 period, the cumulated rainfall of extremely wet days showed a positive trend in West African Sahel and that extreme rainfalls had become more frequent during the last decade of the 20th century, compared to the 1961–2000 period. Regarding the second factor, human pressure on the environment (significant increase in cropland and disappearance of natural bushes and landscapes, for example) has led to severe soil crusting and desertification. Higher runoff as a long-term consequence of land clearing and soil crusting was described at various scales in the Sahel, from small watersheds of a few tens of square kilometers (Albergel 1987) to larger catchments of up to 21,000 km<sup>2</sup> (Mahé et al. 2005). Leblanc et al. (2008) estimated that in a 50 km<sup>2</sup> study area, at a mean distance of 60 km east of Niamey, ~80% of the natural vegetation had been cleared between 1950 and 1992, firstly to open new areas for agriculture and secondly for firewood supply. As demonstrated by Albergel (1987), the increase of highly eroded areas with high runoff coefficients causes a reduction in the critical amount of rainfall that causes flooding. Descroix et al. (2012) pointed out that the exceptional flood that happened near the city of Niamey in 2010 was provoked by a rainfall that was only average with respect to the long-term record. These modifications, reducing the water amount needed for a critical rainfall, cause an increase in flood hazard frequency.

Moreover the Sahel area is characterized by one of the highest annual population growth rates and new settlements or urban expansion take place in flood prone zones where land is cheap or free. In several cases, houses destroyed by floods were built on valley bottoms or in the pathway of drainage channels exacerbating the damaging effects of rainfall and flooding. The causes of flood damage also include the human effects of inadequate drainage facilities and poor construction materials.

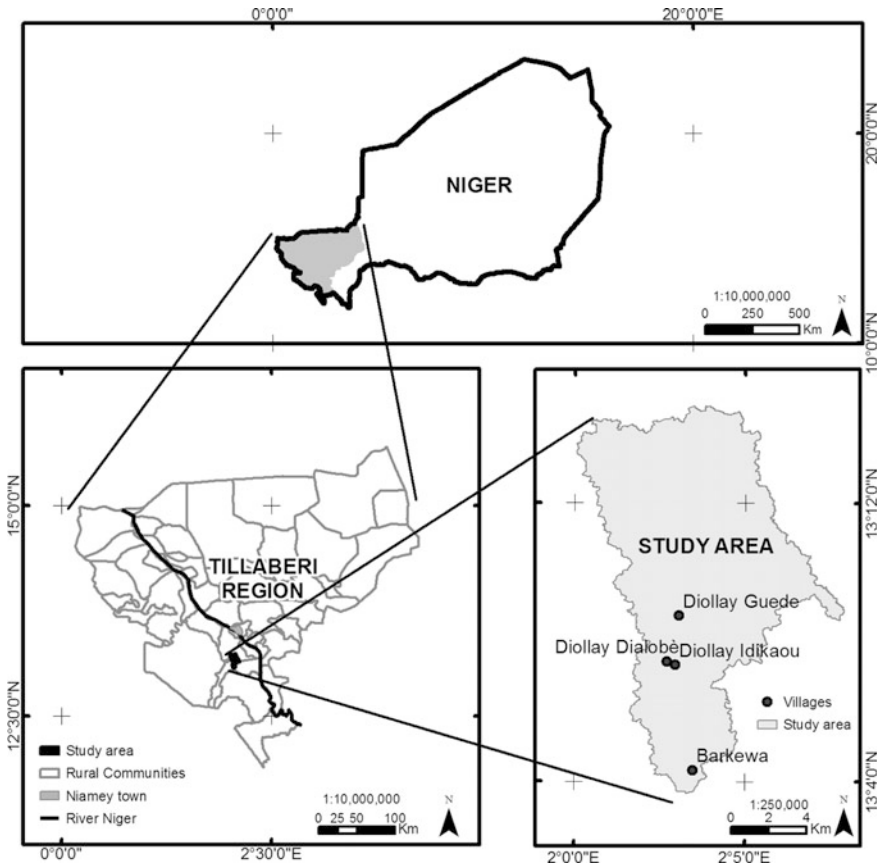
During the 1970s and 1980s many measures (including: grass strips, bench terraces, stone lines, half-moon micro catchments, zai-holes) were applied in order to increase water retention. Some of them, like zai-holes, are traditional water retention measures, while others were specifically developed considering the Sahel climatic and environmental characteristics. These techniques are helpful to rehabilitate degraded lands because on the one hand they slow down or stop surface runoff and consequently reduce soil erosion. On the other, they increase water infiltration that can be exploited for agricultural purposes or to induce natural revegetation. These water retention measures are also effective in reducing flood risk because, by reducing runoff, they increase the critical amount of rain that causes flooding. In the Niger Sahel environment, the appropriate positioning of these measures can be difficult due to the smooth morphology and scarce slopes that characterize the area. Considering the limited funds that are generally available for their realization, the placement optimization of these measures is a key factor. In order to do this, an important resource is provided by Geographic Information Systems (GIS) (Goodchild 2009). These systems, which can manage and analyze different types of spatial or geographical data, are very effective for environmental analysis. Until recently, their use for flood risk reduction plans in developing countries was limited by two main factors: the cost of software and necessary geographic layers (primarily the costs related to satellite imagery), and the technical and scientific skills required to run hydrological models that perform well analyzing the water cycle driver, but very complex to use. This article presents a new method (FREM-Flooding Risk Evaluation Method), based on the Curve Number (CN) runoff estimation method, which uses only free and open-source software and requires only basic-medium GIS skills. The FREM method has been developed in order to provide a simple tool to analyze the flood risk at basin and sub-basin level and to optimize strategies for risk reduction based on water retention measures. A case study is presented for the Ouro Gueladjo basin, located in the Tillabery Region of Niger.

## 12.2 Materials

### 12.2.1 Study Area

The study area (Fig. 12.1) is a 141 km<sup>2</sup> catchment located in southwest Niger in the Ouro Gueladjo Rural Community, on the right bank of the Niger River. Its elevation ranges from 185 to 270 m a.s.l. (ASTER DEM) and it is characterized by the following morphological units (Fig. 11.2): plateau, steep edge (talus), gently sloping glaciis and valley bottom.

Plateau and talus are composed of clayey sandstone called Continental Terminal (Machens 1967). The upper surface, locally covered by Aeolian sands, represents the remnant of a nearly horizontal laterite plateau. Two levels of cuirass layers are



**Fig. 12.1** Location of the study area

present in the study area: the higher level at about 260–270 a.s.l. and the lower at 230–225 m a.s.l. Gently sloping glacia is covered in the upper part by crusted bare soils and in the lower by sand layers; it is incised by a network of parallel gullies. In the sandy valley bottom, a large seasonal riverbed (“kori”), called Bukouroul, dug during wetter periods of the Holocene, holds a string of isolated ponds during the rainy season.

Regarding land cover in the study area (Fig. 12.2), the plateau is mainly covered by tiger bush or its remnants (*Combretum micranthum*, *Guiera senegalensis*, *Boscia* sp. dominate), a scattered woodland with alternating bare areas and vegetated strips. Due to firewood harvesting, vegetative cover on the plateau is generally degraded and has completely disappeared in some areas, generally near the edges. A few dispersed small millet and/or sorghum fields can be found where residual sand layers are formed and deep enough for cultivation.

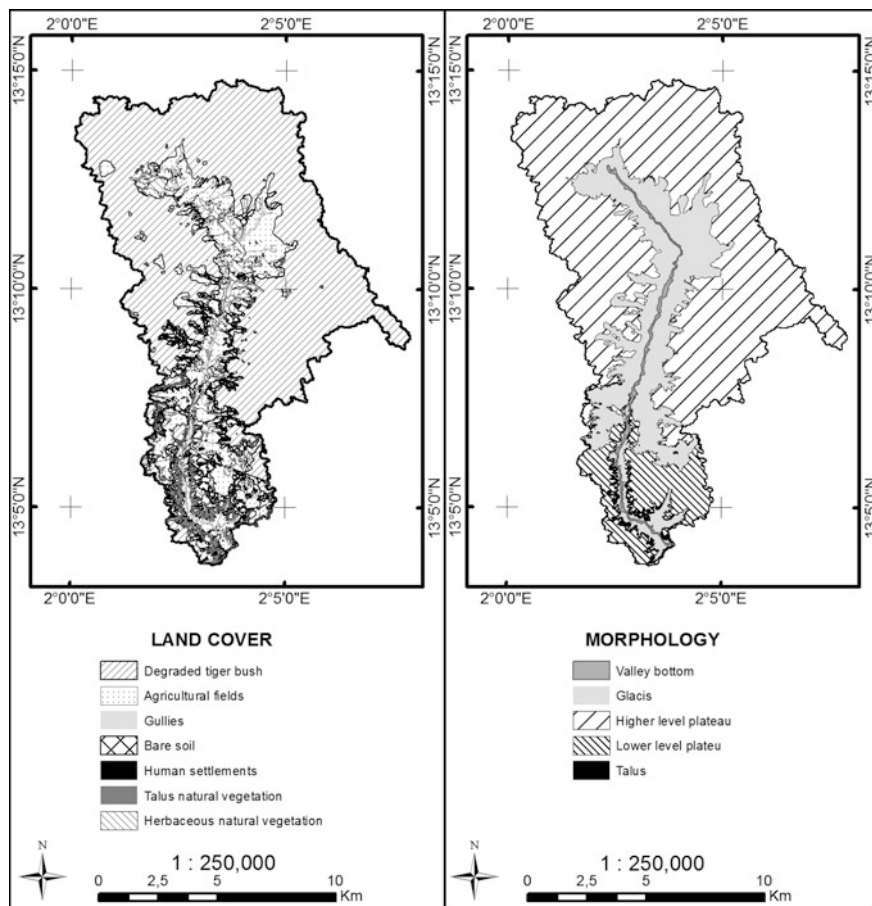


Fig. 12.2 Land cover (*left*) and morphology (*right*) of Ouro Gueladjo study area

Vegetation on talus slopes and upper parts of the glacis is scarce and dominated by *C. micranthum* and *G. senegalensis* (Chinen 1999). There are millet fields and remnants of fallow savannah on the glacis. The valley bottom is almost exclusively covered by agricultural fields. Soils are essentially of the tropical ferrallitic type, sandy and weakly structured (D'Herbès and Valentin 1997). On the generally hardly-cultivable laterite plateaus, thin acidic lithosols directly overlie the ferruginous iron pan. Hill slopes are covered by 0.5–8 m-thick sandy ferruginous soils, sometimes interlaid with other iron pan levels. Valley bottoms have weakly leached sandy ferruginous soils. All are rich in sesquioxides ( $\text{Al}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$ ), poor in organic matter (0.5–3%), and have little fertility (low nitrogen and phosphate content).

There are 4 small villages (Fig. 12.1) in the basin. Barkewa village (pop. 314) is the most exposed to flooding being near the catchment outlet on the right bank of the Boukouroul between the glacis and the valley bottom.

The other three villages (Diollay Dialobè, pop. 714; Diollay Guedel, pop. 484; Diollay Idakaou, pop. 340) are not directly threatened by flooding, but their fields located near the Boukouroul have been flooded repeatedly. This rural population lives mainly on rain fed agriculture and grazing. The study area has a typically semiarid climate, with an average annual temperature of 29.8 °C and annual rainfall of 517 mm (1980–2015 Niamey airport meteorological station data). At seasonal scale, 90% of the annual rainfall, mostly of convective origin, occurs from June to September.

### ***12.2.2 Satellite Images***

High-resolution satellite images provided by Google were used to detect land cover of the study area by photointerpretation that was subsequently used for FREM method implementation. Google imagery has already been used profitably in previous studies (Chang et al. 2009; Mering et al. 2010; Ploton et al. 2012; Taylor and Lovell 2012): it has the great advantage of providing free recent very high resolution true color images. For the study area, photointerpretation was performed on Digital Globe 50 cm resolution scenes acquired on November 9 2014. Moreover, 30 m resolution LANDSAT false color images were acquired from the Earth Explorer data gateway (<http://earthexplorer.usgs.gov/>) and used to facilitate discrimination of bare soil from vegetated areas using the near infrared band.

### ***12.2.3 Aster Dem Dataset***

Morphology, slopes and drainage were derived from ASTER DEM dataset. 30 by 30 m resolution grids were acquired free from ASTER GDEM data gateway (<http://gdem.ersdac.jspacesystems.or.jp/>). The ASTER Global Digital Elevation Model (ASTER GDEM) is a joint product developed and made available to the public by the Ministry of Economy, Trade and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). It is generated from data collected from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), a spaceborne earth observing optical instrument. Fujisada et al. (2005) stated that standard deviation is about 10 m, and so the vertical accuracy of DEM is about 20 m with 95% confidence. Hirano et al. (2003) assessed that ASTER DEM is suitable for a range of environmental mapping tasks in landform studies.

### ***12.2.4 Soter Soil Niger DB***

Soil data regarding the study area were derived from the SOTER (Soil and Terrain Digital Database) database that can be freely accessed on the internet ([https://www.unihohenheim.de/atlas308/b\\_niger/projects/b2\\_1\\_2/html/english/ntext\\_en\\_b2\\_1\\_2.htm](https://www.unihohenheim.de/atlas308/b_niger/projects/b2_1_2/html/english/ntext_en_b2_1_2.htm)). The South West Niger SOTER database (Oldeman and Van Engelen 1993; Graef et al. 1998) has been specifically developed for land evaluation and management purposes; it contains geomorphological and soil data in GIS or GIS compatible format and offers the possibility of relatively precise spatial estimations of terrain related factors such as soil types and soil factors.

### ***12.2.5 Rainfall Data and Critical Rain***

Daily rainfall data of the Torodi meteorological station, the nearest to the study area and located 23 km to the west, were acquired from the National Meteorological Service (DMN) of Niger, in order to detect the critical amount of rain that caused floods in the catchment.

Critical rain is considered as the minimum threshold of rain causing a flood, it is site specific and is identified by the study of rain/flood occurrences. Given that DMN collects daily rain data, the model cannot take into account the rain intensity or basin concentration time. The simplified model is based on a simple relationship between daily rainfall amount and probability of flooding, through the mediation of the structural features of the sub-basin. In the target area, the latest relevant flood was on August 23 2013 due to an 80 mm critical rainfall.

## **12.3 Method**

### ***12.3.1 Theoretical Basis***

The method is a simplified version of the Soil Water Assessment Tool (SWAT) (Gassman et al. 2007; Neitsch et al. 2011), the most widely used hydrological simulator. This method provides a simple tool to analyze flood risk at basin and sub-basin level and to optimize strategies for risk reduction. More specifically, the method allows: (i) the optimal placement of water retention structures in the elementary sub-basins that contribute most to the overall risk, (ii) the assessment of the contribution of each hydraulic structure to reduce the total risk, (iii) a priority ranking to be given to these structures identifying which are the most urgent.

The method is physically based, computationally efficient, and is based on Remote Sensing (RS) and GIS analysis integrated with field surveys. FREM methodology is shown in Fig. 12.3; it requires a preliminary watershed and

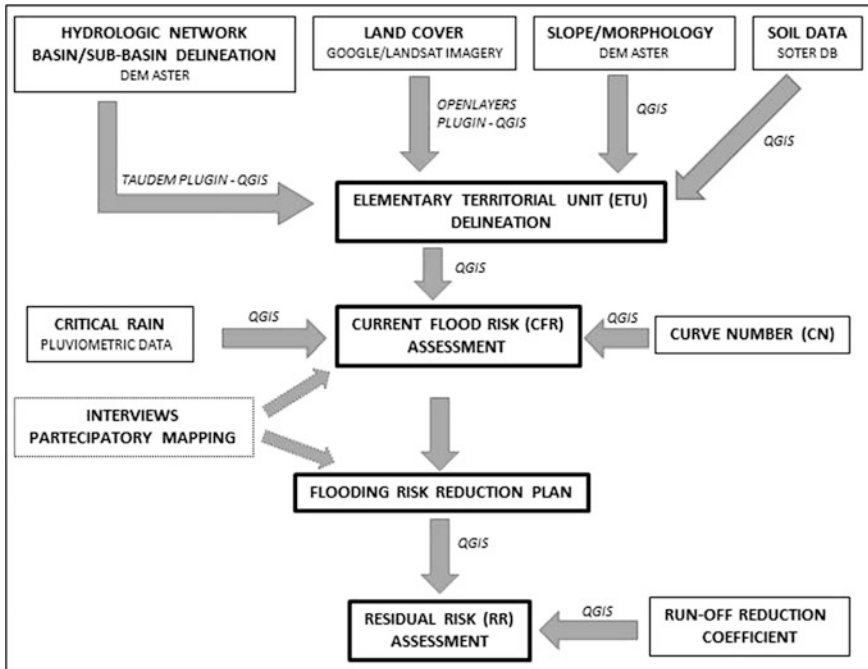


Fig. 12.3 FREM methodology

sub-basin delineation based on DEM data performed using QGIS software and TAUDEM plugin. Areas with the same slope, soil type and land cover form an Elementary Territorial Unit (ETU), a basic computational unit assumed to be homogeneous in hydrologic response to rains.

This preliminary analysis allows the assessment of the Current Flood Risk (CFR) in the study area. The risk is expressed as the amount of water that concentrates in the flooded areas after a critical rain, the minimum daily amount of rain that previously caused flooding in the study area. Therefore, knowing the impact of each area of the catchment, in terms of water that flows away and doesn't infiltrate, water retention measures can be planned. At this stage, two accessory types of maps can be derived to facilitate risk reduction planning. Runoff maps show the areas that have the highest runoff coefficients; priority maps, highlighting the units with higher runoff coefficients and dimensions, indicate the areas where it is more important to take action.

Finally, evaluating the runoff reduction coefficients of each water retention measure, the Residual Risk (RR) is calculated as the amount of water due to a critical rain that would concentrate in the flooded areas after implementation of the planned water retention measures. Areas with the same slope, soil type and land cover form an Elementary Territorial Unit (ETU), a basic computational unit assumed to be homogeneous in hydrologic response to rains.



### 12.3.2 *CN Runoff Estimation*

The curve number (CN) method (USDA 1986) allows surface runoff volumes of individual storm events to be estimated; it is widely used because of its simplicity and the limited number of parameters required for runoff prediction (e.g., Graf 1988; Ponce and Hawkins 1996; Bhuyan et al. 2003). It is used in a wide range of design situations and has been integrated into many hydrologic, erosion, and water-quality models such as CREAMS (Knisel 1980), SWRRB (Williams et al. 1985; Arnold et al. 1990), AGNPS (Young et al. 1989), EPIC (Sharpley and Williams 1990), PERFECT (Littleboy et al. 1992), WEPP (Risse et al. 1994) and SWAT.

The CN method is an empirically-based set of relationships between rainfall, land-surface conditions and runoff depth. The basic equations used in the CN method are:

$$R = (P - 0.25)^2 / (P + 0.85) \quad R = 0 \text{ for } P \leq 0.2S \quad (1)$$

$$S = (1000/CN) - 10 \quad (2)$$

where R = runoff depth (inches), P = precipitation depth (inches), S = potential maximum retention (inches), and CN is the Curve Number. The coefficients 0.2 and 0.8 in Eq. (1) arise from an assumption that the initial abstraction value ( $I_a$ ) S is equal to 0.2S.

CN is a function of soil type, land cover, slope and antecedent runoff condition. For each portion of the basin homogeneous in its hydrologic response to rains, a CN value, derived from specific tables, is conferred. CN has a range from 30 to 100; lower numbers indicate low runoff potential while higher numbers are for increasing runoff potential. CN are referred to units with 5% slope and average moisture conditions; specific formulas are provided for slope and moisture adjustments.

### 12.3.3 *Runoff Reduction Coefficients*

In order to estimate the impact of water retention measures in the risk reduction plan, runoff reduction coefficients were derived from the available literature and conferred to packages of water retention measures that are specific for land cover types (Table 12.1).

These runoff reduction coefficients, although indicative, are used to comparatively assess the effect of water retention measures on the different hydrological units. They can be used to develop scenarios that indicate the potential effects of risk reduction plans based on different runoff reduction techniques.

**Table 12.1** Runoff reduction coefficients of water retention measure packages

Land cover	Water retention measures	Runoff reduction coefficient
Natural vegetation	Stone lines/grass strips	0.6 <sup>a</sup>
Croplands	Field fencing with stone lines or grass strips, natural assisted regeneration of tree layers, contour lines ploughing.	0.25 <sup>b</sup>
Bare soil, degraded areas	Grass strips/contour bench terraces, reforestation, half-moon micro catchments	0.3 <sup>ab</sup>

<sup>a</sup>JGRC (2001)

<sup>b</sup>Roose and Bertrand (1971), Lamachère and Serpantié (1991), Nasri et al. (2004), Al Ali et al. (2008)

### 12.3.4 GIS Software

Method implementation was performed using QGIS, a free and open-source Geographic Information System software. QGIS was downloaded from the QGIS gateway (<http://www.qgis.org/en/site>); the software provides a plugin mechanism that can be used to add support for a new data source or to extend the functionality of the main program in a modular way. Watershed delineation and definition of its hydrologic network and sub-basins was performed with Terrain analysis using Digital Elevation Models (TauDEM) QGIS open-source plugin (Tarboton 2005), a set of tools for the extraction and analysis of hydrologic information from topography as represented by a DEM. Land cover photointerpretation was performed using the Open Layers Plugin, which allows a number of image services to be added, including the Google satellite images that were used in this study.

### 12.3.5 Interviews and Participatory Mapping

A few days of field surveys were conducted during November 2014 for ground truth validation of preliminary ETU delineation and to do a participatory mapping with village inhabitants. Participatory mapping and interviews were carried out in order to appreciate local perception of flood risk and to obtain information about aspects that cannot be recorded through remote sensing analysis. From this point of view, participatory mapping offers a tool to integrate GIS analysis and local perspective; it is a key to integrate top-down and bottom-up approaches and gives a voice to the most marginalized members of the community who are also the most likely to be affected by risk and climate and environmental changes.

### 12.4 Results

The FREM method allowed a flooding risk reduction plan to be conceived to a critical rain of 80 mm, equal to the amount that caused the last flood in the catchment during 2013; this plan has already been thoroughly explained in Tarchiani and Fiorillo (2016). The analysis indicated that the croplands of the Guellay villages, located on the glacia and in the bottom alluvial zones, are threatened by 42 small sub-basins (Fig. 12.4), covering an area of 112.1 km<sup>2</sup>, that discharged 4,413,992 m<sup>3</sup>. Most of these sub-basins, corresponding to 96.1 km<sup>2</sup>, are covered by degraded or highly degraded tiger bush formations on the plateau that are responsible for 82% of the amount of water that flows on the flooded areas. Barkewa, the village most exposed to floods, is threatened by 6 small sub-basins that surround the village on the south-western and north-eastern sides (Fig. 12.4).

These sub-basins, covering an area of 9.9 km<sup>2</sup>, in 2013 discharged 303,596 m<sup>3</sup> to the flooded Barkewa area. A classification of each sub-basin according to runoff coefficient allowed the prioritizing of areas to be treated. Priority areas were identified as large surfaces with high runoff rates, mainly bare soil or degraded bushes. Regarding the Diollay area (Table 12.2), due to the fact that most of the incoming water arrives from the plateau, the proposed measures involve mainly restoration and protection of tiger bush (8501 ha).

The plateau has been heavily exploited in the last decades for firewood harvesting and in the study area tiger bush is heavily degraded or has been totally cleared. On the glacia, proposed water retention measures involve mainly the restoration of marginal areas with natural vegetation by the implementation of

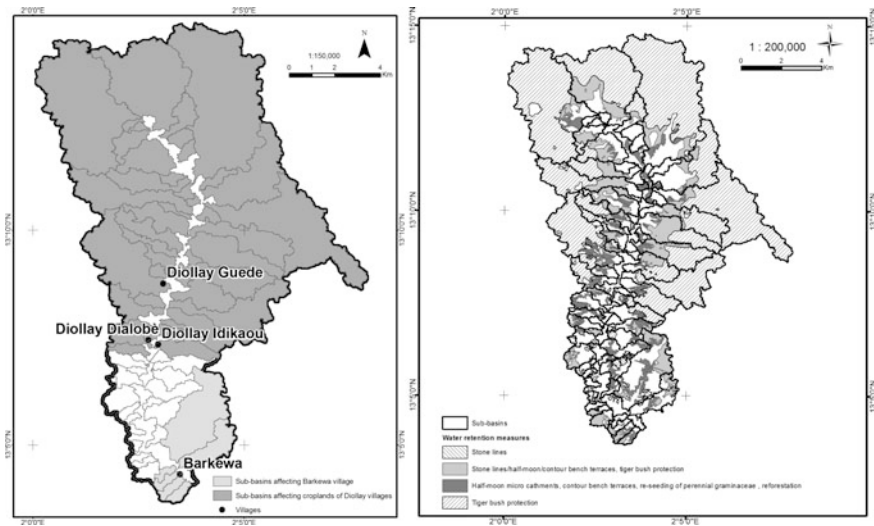


Fig. 12.4 Sub-basins affecting croplands of Diollay and Barkewa village (left) and Ouro Gueladjo study area flood risk reduction plan (right)

**Table 12.2** Flood risk reduction plan for the Ouro Gueladjo case study

Sub-basins	Morphology	Land cover	ha	Water retention measure
Affecting croplands of Diollay villages	Plateau	Degraded tiger bush	8048	Tiger bush protection measures
		Very degraded tiger bush	1453	Stone lines/half-moon micro catchments/bench terraces (according to the soil type), tiger bush protection
	Glacis	Marginal areas with natural vegetation	494	Half-moon micro catchments, bench terraces
		Lateritic cuirass	6	Stone lines
		Crusted bare soil	18	Half-moon micro catchments, bench terraces, reforestation
Affecting Barkewa village	Plateau	Degraded tiger bush	88	Tiger bush protection measures
		Very degraded tiger bush	147	Stone lines/half-moon micro catchments/bench terraces (according to the soil type), tiger bush protection
		Marginal areas with natural vegetation	15	Half-moon micro catchments, bench terraces, re-seeding of perennial grasses and herbaceous plants, reforestation
		Bare soil	41	Half-moon micro catchments, bench terraces, re-seeding of perennial grasses and herbaceous plants, reforestation
		Lateritic cuirass	66	Stone lines
	Glacis	Marginal areas	17	Half-moon micro catchments, bench terraces, re-seeding of perennial grasses and herbaceous plants, reforestation
		Bare soil	37	Half-moon micro catchments, bench terraces, re-seeding of perennial grasses and herbaceous plants, reforestation

half-moon micro catchments and bench terraces. For Barkewa, the flood risk reduction plan identified water retention measures for a 410 ha area (Fig. 12.4; Table 12.2), most (367 ha) located on the plateau.

On the glacis, the risk reduction plan requires actions on marginal and bare soil areas. The expected reduction in runoff water due to these actions for a critical rain analogous to that of 2013 has been calculated at about 26% for both croplands of Diollay villages and Barkewa village.

## 12.5 Discussion

The Ouro Gueladjo case study demonstrated that the method can be profitably applied in the Sahel environment providing a useful tool for environmental evaluation and to optimize flooding risk reduction plans. The method, compared to other more sophisticated hydrologic models, is much simpler and therefore requires only basic/medium GIS technical skills and can be performed just using QGIS software simply by applying the formulas presented in this paper. Models like SWAT are high-performing and allow many parameters like water, sediment, nutrient, pesticide, and fecal bacteria yields to be evaluated and determined at basin and sub-basin scale, but are much more difficult to implement and require many more data. FREM performs an evaluation focused only on risk reduction planning, but in a much more intuitive and direct way. Moreover it needs less data to be implemented. For example, regarding climatic and meteorological parameters, SWAT requires a large number of climatic inputs (daily precipitation, maximum and minimum temperature, solar radiation data, relative humidity, and wind speed), which complicates model parameterization and calibration, while FREM needs only the amount of critical rain that previously caused flooding in the study area.

The method has the great advantage of using only open-source software and data, a crucial factor for its applicability in developing countries. QGIS has already reached maturity; it is very stable, with high performances analogous to those of commercial software. TauDEM plugin has been demonstrated to be very effective in hydrologic network and basin delineation. The Openlayers plugin allows the very high resolution, and usually very recent free Google images in a real GIS environment to be used, overcoming the limited GIS possibilities provided by Google Earth. A limit that has emerged in the use of Google images is the lack of near infra-red bands, a key factor in environments like the Sahel, where crops and natural vegetation are not easily distinguishable from bare soil or highly degraded areas. This may be compensated by the integration of other free images like the LANDSAT scenes that have been used in this case, despite their limited spatial resolution. The recent availability of 10 m free high-resolution multispectral images provided by the latest generation of satellites, such as the Sentinel, should allow this limitation to be overcome.

However, the case study highlighted some limitations of free available ASTER DEM data. In the South West Niger Sahelian area there is a high presence of endorheic basins. Regarding the Ouro Gueladjo case study, field verifications indicated that Barkewa village is affected only by the 6 nearest surrounding sub-basins due to some ephemeral ponds that impede drainage from northern sub-basins. This aspect was not detected by the GIS hydrologic network analysis due to the not sufficient ASTER DEM spatial resolution, the highest actually available free for the study area, and vertical accuracy. However due to the endorheic nature of many watersheds in the region, the use of this methodology for flood risk assessment must be restricted to small-medium catchments and after field verifications. Moreover, the 30 m resolution is not enough to distinguish

micromorphology and in some cases to precisely delineate sub-basins. Therefore actual DEMs don't allow the physical and morphological aspects involved in the water cycle to be defined at a scale comparable to that provided by Google images for land cover delineation. This can reduce accuracy in flood risk reduction plans and must be kept into account.

Soil information is often a critical aspect in environmental studies due to the fact that it can only be detected at a high scale resolution by field surveys and only a few data are usually available free. In the present case study, the availability of the Niger SOTER database helped to overcome this problem. Anyway the CN method requires only one type of soil information, the infiltration capacity that is classified in just four classes. This aspect facilitates implementation of the CN method in the FREM methodology because in the Sahel environment rough infiltration rates, like those required, can easily be identified.

In the FREM model the impact of groundwater level was not considered because soil water balance in the Sahel is controlled more by surface than by deep soil conditions (Collinet and Valentin 1979, 1984; Hoogmoed and Stroosnijder 1984); therefore superficial hydrodynamics are mainly determined by surface conditions that are sufficient to explain significant infiltration (Casenave and Valentin 1992).

Finally, the Ouro Gueladjo case study highlighted that hydrologic modelling for risk reduction planning cannot be performed adequately without considering the opinions and needs of local inhabitants. Remote sensing and GIS are extremely powerful tools but some aspects that must be taken into account in risk reduction planning cannot and will never be understood and considered through them. In this study, a field campaign allowed remotely sensed data and local community perception, needs and knowledge of risk, to be integrated through the use of participatory mapping with the inhabitants of the villages located in the basin.

## 12.6 Conclusions

A real integration of hydrological risk reduction and adaptation to climate change does not exist, despite the many reports that pledge this integration. Climate change is currently affecting the water cycle and flood process by multiplying flash floods as well as river floods in some areas, (Bates et al. 2008). Since 2009, the World Meteorological Organization has been promoting an integrated approach to flood management: IFM (WMO 2009) that also aims at reducing the risks related to poor management of surface water and adaptation to climate change. At a local level, participatory methodologies for adaptation to climate change focus more on their suitability for the communities rather than appropriate planning of vast rural landscapes. The municipalities have no information on climate change in their territory or any analytical and climate prediction capacity. They therefore cannot set adaptation and risk reduction policies based on the results of robust analysis of local conditions.

There is thus a strong need for new and effective tools for flood related risk reduction planning. Floods are becoming one of the most common disasters even in

the Sahel and, due to climate change and environmental degradation, they are going to be increasingly frequent in the next decades. The method has been conceived for the Sahel environment but could also be applied in other environments with only slight changes, mainly related to specific runoff reduction coefficients for different water retention measures.

The application of the methodology in the Municipality of Ouro Gueladjo was actively used in the implementation of an action plan that was incorporated in the Municipal Development Plan in accordance with the resources the Municipal Council is planning to invest. The interest and participation of local stakeholders and populations confirms the importance of continuing and improving approaches integrating local and scientific knowledge to meet the real needs of communities and to ensure sustainable land management.

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