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Exploring the Potential of Soil and Water Conservation Measures for Climate Resilience in Burkina Faso

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Abstract: Sahelian countries including Burkina Faso face multiple challenges related to climatic conditions. Setting up effective disaster management plans is essential for protecting livelihoods and promoting sustainable development. Soil and water conservation measures (SWCMs) are emerging as key components of such plans, particularly in Burkina Faso. However, there is an insufficiency of studies exploring their potential as green infrastructures in the Sahelian context and this research aims to contribute to filling this gap. We used national data, remote sensing, and GIS tools to assess SWCM adoption and the potential for climate resilience. Stone ribbons emerged as the most widely adopted SWCM, covering 2322.4 km^2 especially in the northern regions, while filtering dikes were the least widely adopted, at 126.4 km^2. Twenty years of NDVI analysis showed a notable vegetation increase in Yatenga (0.075), Oudalan (0.073), and provinces with a high prevalence of SWCM practices. There was also an apparent increase in SWCM percentages from 60% of land degradation. Stone ribbons could have led to a runoff reduction of 13.4% in Bam province, highlighting their effectiveness in climate resilience and flood risk mitigation. Overall, encouraging the adoption of SWCMs offers a sustainable approach to mitigating climate-related hazards and promoting resilience in Sahelian countries such as Burkina Faso.

Keywords: soil and water conservation measures; Burkina Faso; nature-based solutions; disaster risk mitigation; Sahel; climate resilience

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1. Introduction

Sahelian countries like Burkina Faso face multiple challenges due to climatic conditions [1]. The situation is worsened by the effects of climate change resulting in the occurrence and recurrence of natural hazards [2,3]. Establishing an effective and up-to-date disaster management plan is therefore crucial for protecting livelihoods and promoting sustainable development in these areas. Exploring local options seems reasonable as they will present benefits like quick adoption and easier implementation. In this context, soil and water conservation measures (SWCMs) appear as a potential key component to be considered in the plan, especially in the case of Burkina Faso.

Existing literature provides insights about SWCMs in relationship with agriculture and land rehabilitation, the main purposes for which they were traditionally implemented. Likely, Chen et al. have highlighted a significant reduction in soil erosion rates when SWCMs were applied [4,5]. Several researchers have documented that crop yields have increased under soil conservation techniques in comparison to non-treated fields [6,7]. Yields of sorghum increased by 109, 73, and 500% with, respectively, dry, normal, and wet types of rainfalls using stone bunds [8]. Similarly, an experimental study conducted by Zouré et al. has demonstrated that yields of millet are significantly higher on plots under SWCMs (2180 kg/ha) than on control plots (1070 kg/ha) [9].

While the majority of previous studies predominantly focus on the efficiency of these techniques on the agricultural and land management side [10,11], there remains an insufficiency of studies exploring the potential of SWCMs as green infrastructures in the Sahelian context. The importance of this research lies in exploring this alternative aspect, enlightening their potential role in climate action. This research aims not only to highlight sustainable water management practices already utilized in Burkina Faso but also to motivate their larger adoption as a means of enhancing climate resilience in the Sahelian areas. This study intends to contribute to filling the gap by investigating the usage and distribution of SWCMs in Burkina Faso on a provincial level, analyzing the SWCM presence in relationship with soil characteristics, and exploring the probable outcome that their implementation could lead to in terms of climate action.

2. Definition of SWCM

SWCMs can broadly be defined as a range of practices applied to preserve soil health, mitigate soil erosion, and manage runoff water predominantly to support agriculture. They serve several functions such as enhancing and maintaining soil fertility, improving soil structures, and retaining and conserving rainwater. SWCMs are typically categorized into three groups: physical, biological, and agronomic measures. In the case of Burkina Faso, SWCMs are extensively used by farmers to increase crop yields and promote agricultural resilience in environmentally challenging areas [11–13] (Figure 1). For this study, the focus was put on physical measures, specifically those primarily employed for managing stormwater runoff.

Figure 1. Common traditional SWCMs used in Burkina Faso. Source photograph (**a**): Fatoumata Diabate/OXFAM; Source photograph (**c**): Makan Sissoko/ESSOR; Source photographs (**b**,**d**–**f**): WOCAT [14].

2.1. Half-Moons

Half-moons consist of digging crescent-shaped holes with excavated soil placed downhill. They are positioned along slopes with their widest points at the same level [15]. Half-moons are typically 4 m in diameter and spaced 4 m apart in an alternate pattern [16]. This technique facilitates the collection of runoff water and promotes infiltration into the soil. Half-moons are effective but present some limitations. There is a risk of flooded crops reducing productivity. Anti-erosion structures such as stone barriers are then necessary for reinforcing their effectiveness. Half-moons require a significant labor effort and their efficacity can also be limited in areas with a low availability of organic matter.

2.2. Stone Ribbons

Stone rows, lines, ribbons, or bunds are barriers made of loose stones installed following rain contour lines. During the rainy season, these stones serve as small walls that limit the velocity of stormwater runoff, allowing sedimentation and water infiltration while mitigating erosion along agricultural fields [15]. They can be implemented independently but are also used in conjunction with other measures such as half-moons and zaï. Stone ribbons are suitable for gently sloping lands with most soil types, excluding flood-prone lowlands. The effectiveness of stone ribbons is often limited by factors such as the labor intensity, the availability of the stones, and the frequent maintenance required to keep the barriers effective.

2.3. Zaï

Also known as "water pockets", zaï is a traditional practice developed in the Northwestern area of Burkina Faso [17]. It consists of digging small pits during the dry season with diameters ranging from 0.15 to 0.20 m and depths of 0.10 to 0.15 m [15]. These pits would then be filled with organic matter waiting for rain events. Typically, zaï are densely spaced (12,000 to 15,000 holes per hectare) [5], depending on the selected crop. The specific characteristics necessary for establishing zaï are denudation and crusting. This technique aims to rehabilitate barren and highly degraded soils by enhancing water retention and promoting soil fertility [18]. Even though zaï implementation promotes better agricultural productivity, the pits can be easily flooded in the case of increased precipitation, thus harming the development of crops. They therefore require an additional measure to enhance their effectiveness, especially in areas with severe erosion. Similarly to half-moons, their effectiveness is strongly related to the presence of organic matter.

2.4. Filtering Dikes

Filtering dikes are small traditional dams constructed using loose stones, allowing water to flow freely through the structure. These stones act as filters, trapping sediment and facilitating water infiltration while diminishing peak discharges. They typically have an elevation between 0.4 and 0.6 m [19] and a triangular profile with a gentle downstream slope [15]. Filtering dikes are effective in managing runoff and enhancing soil moisture retention. They are adaptable to all soil types, focusing on areas with gullying. In contrast, they require a significant workforce and equipment and financial means to be implemented. An important quantity of stones is needed for this measure, making its adoption very difficult in areas with low availability in materials. The necessary calculations for effective filtering dikes can also be a source of difficulty for some farmers.

2.5. Grass Strips

Grass strips are vegetative barriers planted along contours or slopes near the edges of agricultural fields to reduce the velocity of water runoff, minimize soil erosion, and enhance infiltration [15]. They play similar roles as stone ribbons and stabilize soil particles. Effective against water and wind erosion, grass strips apply to most soil types except superficial hard soils. One limit of this measure is the increase in competition with crops for the use of resources such as water and nutrients.

2.6. Boulis

Boulis are traditional earthen retention basins built to collect stormwater during the short rainy season. These oval or circular structures are strategically placed within water channels to capture and store water for various purposes, including household use, irrigation, and livestock watering. Typically, 60 to 70 m long and 4 to 6 m deep, boulis are mini oases that attract diverse plant and animal species and can contribute to local biodiversity conservation efforts.

3. Materials and Methods

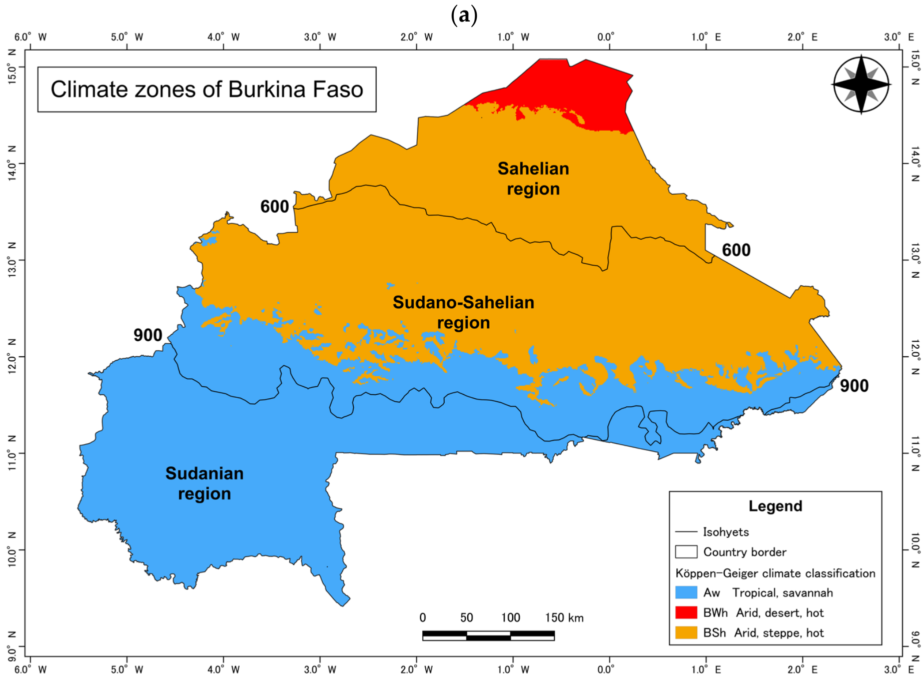
3.1. Study Area

The study was carried out in Burkina Faso, West Africa at a provincial level (Figure 2). The Sahelian country covers approximately 274,200 km^2 in size and is landlocked with six neighboring countries [14]. Burkina Faso is divided administratively into 13 regions covering 45 provinces, with the capital city Ouagadougou located within the Kadiogo Province. The country is characterized by a dry and a rainy season in alternance. The dry season lasts from October to April and the rainy season from Mai to September during which the country receives an annual average precipitation of about 815 mm. Burkina Faso is marked by three climatic regions from north to south with a predominantly dry tropical climate [20]: the Sahelian region in the north (receiving less than 600 mm of rainfall annually), the Sudano-Sahelian region in the center (between 600 and 900 mm), and the Sudanian region in the south (around 900 to 1200 mm of rainfall annually). The population was estimated at around 21 million as of 2019 [21], experiencing an annual demographic growth rate of 2.94% and a population density of 75.1 inhabitants/km^2.

For each climatic zone of the country, the dominant soil types can be found using the World Reference Base for Soil Resources (WRB) (Figure S1) [22,23]. In the Sahelian region, the predominant soils are Arenosols, characterized by sandy textures, low fertility, and high susceptibility to wind erosion. The vegetation in this area is sparse, consisting mainly of drought-resistant grasses and shrubs, with scattered trees, reflecting the low rainfall and low organic matter [24,25]. Lixisols and Plinthosols are the dominant soil types in the Sudano-Sahelian region. Lixisols, are moderately weathered soils with a clayey subsoil and are more fertile. Plinthosols have a clayey texture, are rich in iron, and may be prone to poor drainage due to their hard layers. The vegetation is more diverse, with savanna woodlands alongside various grasses. The Sudanian region is dominated by Luvisols, which are more fertile and have higher clay content. These soils are less prone to erosion in comparison to those in the northern and central regions. However, they can still suffer from erosion and loss of fertility because of intensive farming and deforestation, leading to significant soil degradation over time. The vegetation in this zone is denser and more diverse, with deciduous forests and savanna woodlands providing a rich habitat for a variety of plant species.

Burkina Faso's agricultural production is concentrated in the southern and central regions. The relatively more fertile soils allow the farming of subsistence crops (millet, sorghum, maize, etc.) and cash crops (cotton, groundnuts, sesame, etc.). As for the northern regions, the focus is primarily put on drought-resistant crops like millet and cowpeas. Farming methods practiced in the country include traditional subsistence farming, relying on manual labor and simple tools; and agro-pastoralism, combining crop farming with livestock rearing. These intensive agricultural practices often lead to overgrazing and deforestation, increasing soil erosion. Continuous cultivation and monocultures also lead to a depletion of nutrients and thereby result in a decline in soil fertility. In response, some farmers have adopted SWCMs to mitigate these challenges and sustain agricultural productivity.

(**a**)



(**b**)

Figure 2. Study area: (**a**) provinces of Burkina Faso; (**b**) climate zones Burkina following Köppen–Geiger classification [26], isohyets (mm/year), and climatic regions of Burkina Faso.

3.2. Datasets and Methodology

SWCM percentages were obtained from national reports from 2012 to 2021 in each province of Burkina Faso. The main report was the 2022 version of the agro-silvo-pastoral statistics directory, produced by the Ministry of Agriculture, Animal Resources, and Fisheries [27]. For each year, the total areas under SWCMs were calculated using percentage values from national reports from 2012 to 2021. A 10-year average was then calculated for each measure and mapped using GIS tools. Calculating the 10-year average helped smooth out the annual variations that can be significant in SWCM measures. This provides a more representative picture of the long-term trend. Mapping the 10-year averages also allows for better comparison of SWCM measures between different geographical areas.

SWCM impact factors were chosen from the literature and for each province; the potential runoff reduction and soil water-holding capacity improvement were estimated following the formulae below:

$$\text{Runoff Reduction}_{\text{province}} = P_{SWCM} \times R_r \quad (1)$$

$$\text{Soil Water-Holding Capacity Increase}_{\text{province}} = P_{SWCM} \times WHC_i \quad (2)$$

where:

P_{SWCM}: areal percentage under SWCM of interest;
R_r: runoff reduction factor from literature;
WHC_i: water-holding capacity increase factor.

In the case of the soil water-holding capacity, the increase was estimated taking the area and density of the pits into account in addition to the literature increase factor (Figures 3 and 4).

$$WHC_i = (Apit \times WHC_L + Anon\text{-}pit \times 1) - 1 \quad (3)$$

where:

Apit: fractional area of the pit;
Anon-pit: fractional area excluding the pit;
$WHC_{L:}$ water-holding capacity increase factor from literature;
−1: increment from the regional water-holding capacity baseline.

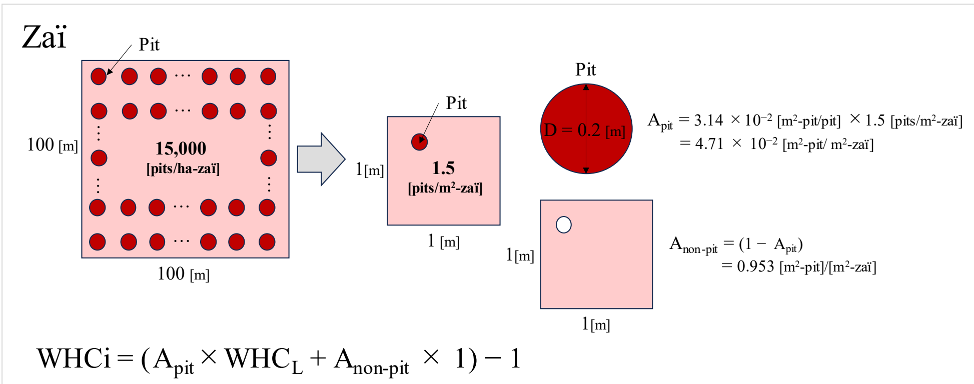


Figure 3. Estimation of water-holding capacity increase factor with zaï.

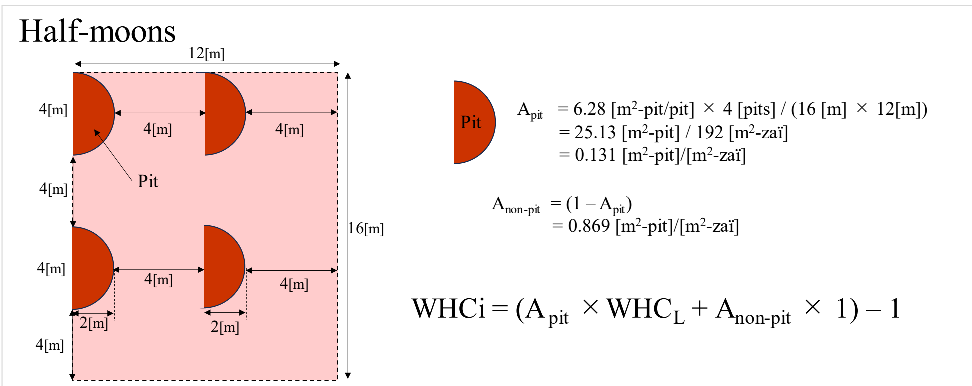


Figure 4. Estimation of water-holding capacity increase factor with half-moons.

Soil degradation data were extracted from the Global Assessment of Soil Degradation (GLASOD) to produce a map of the soil degradation state in the country. Conducted between 1988 and 1991 by the International Soil Reference and Information Centre (ISRIC), it produced the first global map of soil degradation at a scale of 1:10 million [28]. GLASOD map provides a comprehensive overview of human-induced soil degradation worldwide. It classifies soil degradation into four categories: water erosion, wind erosion, chemical degradation, and physical degradation, each further subdivided based on severity and impact. In addition, soil erosion values were extracted from the maps provided by European Soil Data Centre (ESDAC) (Figure S2) [29]. This dataset offers detailed spatial estimates of soil erosion risk using the Revised Universal Soil Loss Equation (RUSLE) and includes factors such as rainfall erosivity, soil erodibility, topography, and land cover. The 25 km resolution RUSLE maps are available for two years (2001 and 2012) and provide soil loss in ton/hectare/year (t/ha/year). In this study, the 2012 map was used to extract average soil loss values per provinces.

The Normalized Difference Vegetation Index (NDVI) quantifies vegetation amount and vigor. NDVI is calculated by comparing the reflectance of red and near-infrared light (NIR), which are absorbed and reflected differently by healthy vegetation [30]. It was used as a means to assess the potential impact of the traditional measures on vegetation in the country. NDVI was extracted from the collection MOD13Q1.061 Terra Vegetation Indices of Terra Moderate Resolution Imaging Spectroradiometer (MODIS). Vegetation indices of 250 m resolution are provided globally every 16 days with NDVI values at a per-pixel basis stored in the 'NDVI' band. The analysis was executed for a period of 20 years (2002 to 2021), and, for each year, all 23 scenes were considered. For one year, the 23 scenes were aggregated, clipped following Burkina Faso boundaries, and mean NDVI were extracted for each pixel (Figure S3). With the resulting rasters and province boundaries, zonal statistics were then performed using GIS software ArcGIS Desktop version 10.7.1. Maximum NDVI for one province was the maximum value among all pixels included in the specific province. The 20 years were divided into two and a 10-year average was calculated each time. The maximum NDVI change was then computed following this formula:

$$\text{Change} = (\text{B} - \text{A})/\text{A} \quad (4)$$

where:

A: 10-year average from 2002 to 2011 (Figure S4);
B: 10-year average from 2012 to 2021 (Figure S5).

Precipitation data were extracted from the Climate Hazards Group Infrared Precipitation with Station Data (CHIRPS) database [31], developed by the Climate Hazards Group at the University of California, Santa Barbara. It is a quasi-global rainfall dataset that combines satellite imagery, in situ station data, and atmospheric model outputs to provide high-resolution gridded precipitation estimates from 1981 to the present. This dataset is particularly valuable for studying climate variability and water resource management in regions where ground observations are scarce or unreliable. For this analysis, 20 years of daily precipitation data at a 0.25° resolution were extracted from 2002 to 2021. Precipitation change was calculated following the same steps as maximum NDVI change.

All demographic and socio-economic data of Burkina Faso were extracted from the 5th General Population and Housing Census (5th RGPH). It was conducted in 2019 by the National Institute of Statistics and Demography (INSD) of Burkina Faso. This decennial census provided critical insights into population size, distribution, and growth rates, as well as information on housing conditions, education, employment, and access to basic services. The final results of the 5th RGPH were published in 2022 [21].

4. Results and Discussion

4.1. Some Leading Causes of SWCM Implementation

4.1.1. SWCM Levels of Adoption

Figure 5 illustrates the spatial distribution and the level of adoption of each measure (average areas under SWCMs from 2012 to 2021). It is noticeable that SWCMs present different levels of adoption. The adoption of stone ribbons stands out as the most prevalent among SWCMs (2322.4 km^2). A possible explanation for this might be that they require relatively less maintenance once established and provide immediate benefits. Stone ribbons are commonly utilized both as standalone measures and also in combination with other techniques such as half-moons and zaï for enhanced anti-erosion protection. This result is supported by the correlation analysis presented in Figure 6. It points to the most common combinations between SWCM. The correlogram shows a meaningful positive linear relationship between stone ribbons and zaï (R = 0.64); and stone ribbons and half-moons (R = 0.53). The combination of grass strips and zaï appear to be the least common.

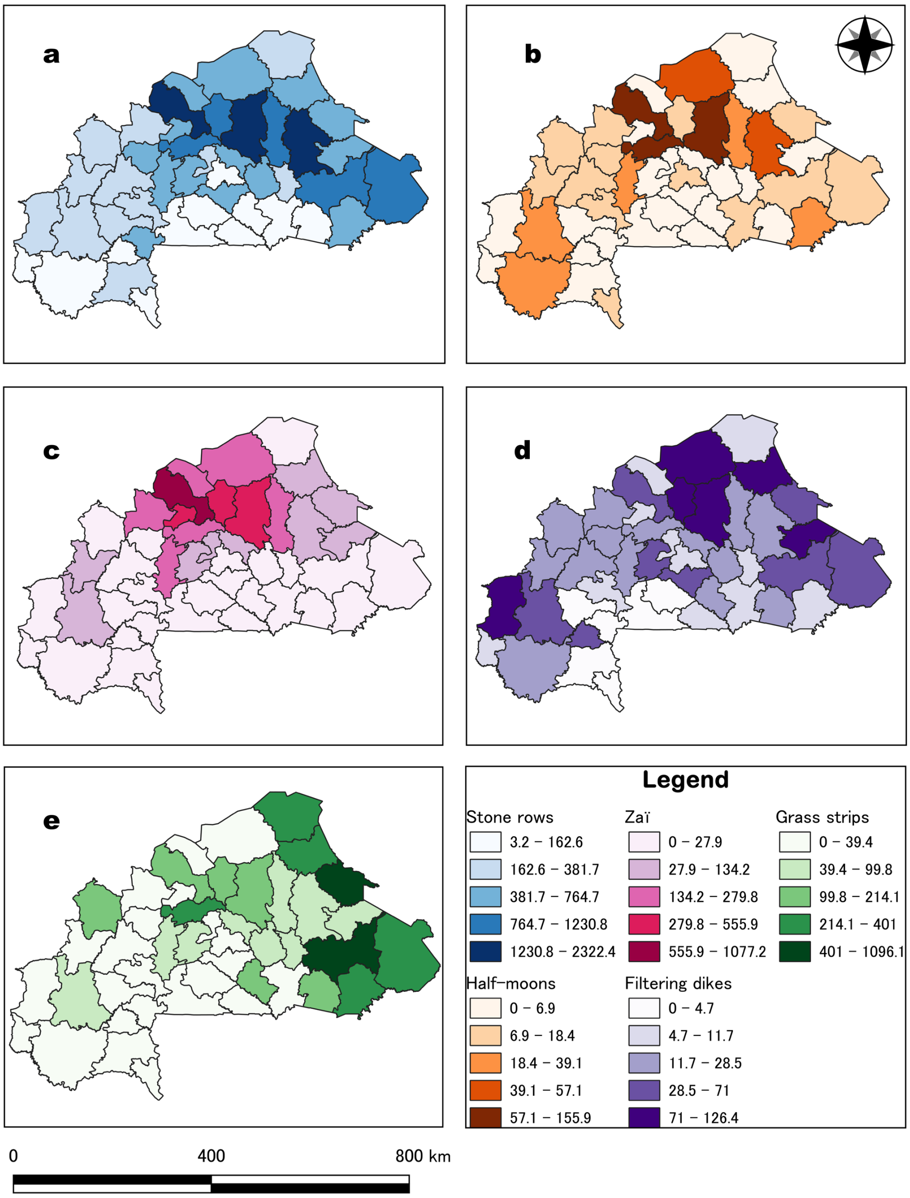


Figure 5. Average areas (km^2) under SWCM from 2012 to 2021: (**a**) stone rows; (**b**) half-moons; (**c**) zaï; (**d**) filtering dikes; and (**e**) grass strips.

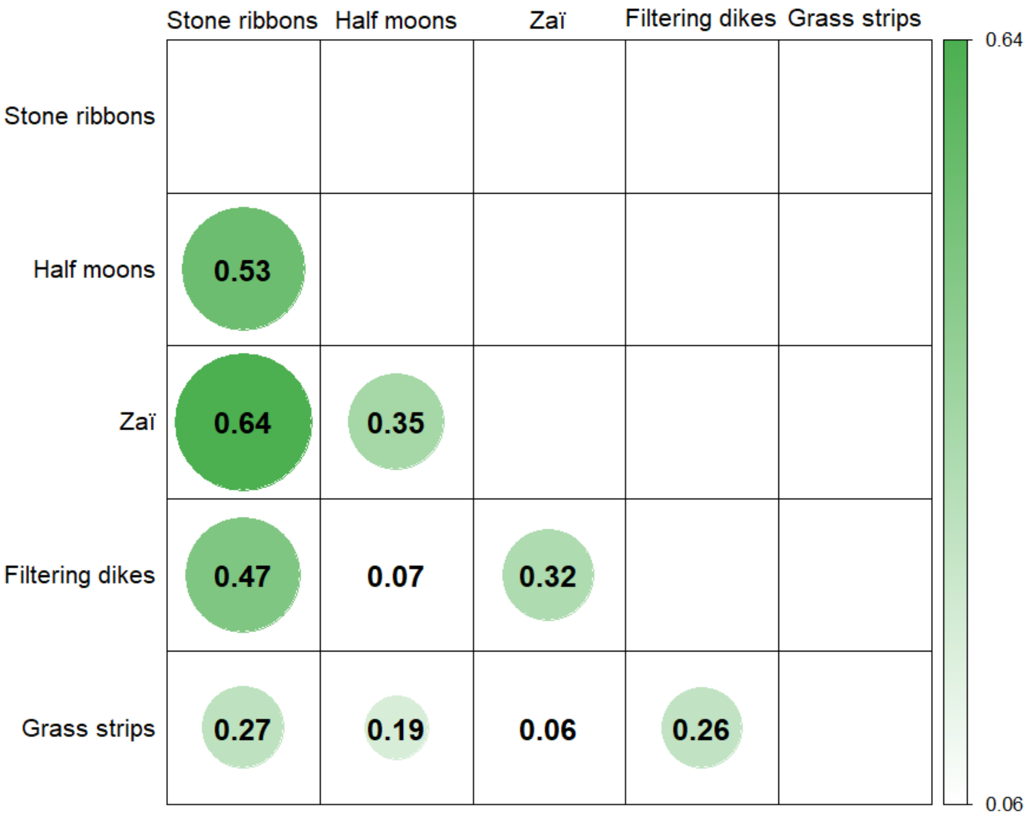


Figure 6. Correlogram illustrating the combinations among SWCM.

Zaï and grass strips are also reported to have high adoption rates, attributed respectively to the efficient results in a short lead time and the relatively lower requirements needed for their implementation. In contrast, half-moons require substantial labor intensity and more technical assistance, resulting in a lower adoption (155.9 km^2) when compared to other methods. Similarly, results show a limited adoption of filtering dikes (126.4 km^2).

4.1.2. Soil Conditions

As presented in Figure 5, the adoption of the mentioned SWCM is in the majority concentrated in the northern parts of the country (Yatenga, Zondoma, Bam, and Sanmatenga). The pattern is consistent with the soil degradation map (Figure 7) that highlights very high levels of water erosion in provinces throughout the North, Central Plateau, and Central regions as well as wind erosion across the Sahel region. It is also worth noticing that grass strips are well-adopted in the Sahel region (Oudalan, Seno, and Yagha) and play an important role in fighting against wind erosion.

The RUSLE soil loss per province indicates the estimated annual average soil loss due to water erosion, ranging from 1.01 to 11.71 t/ha/year in Burkina Faso (Figure S6). Areas with high soil loss are primarily located in the South-West region (11.71 t/ha/year in Ioba province) and also in the Central regions (8.32 t/ha/year in Ganzourgou province). The Sahel provinces, e.g., Yagha and Soum, present the lowest soil loss values following the ESDAC RUSLE map (respectively, 1.02 and 1.66 t/ha/year). This result can be related to the fact that the used dataset only presents water erosion. In the GLASOD map, wind is presented as the main erosion type and these provinces are categorized under very high severity. In addition, Northern provinces also present relatively low soil loss with ESDAC compared to GLASOD. This can be related to the inclusion of rainfall in the ESDAC data.

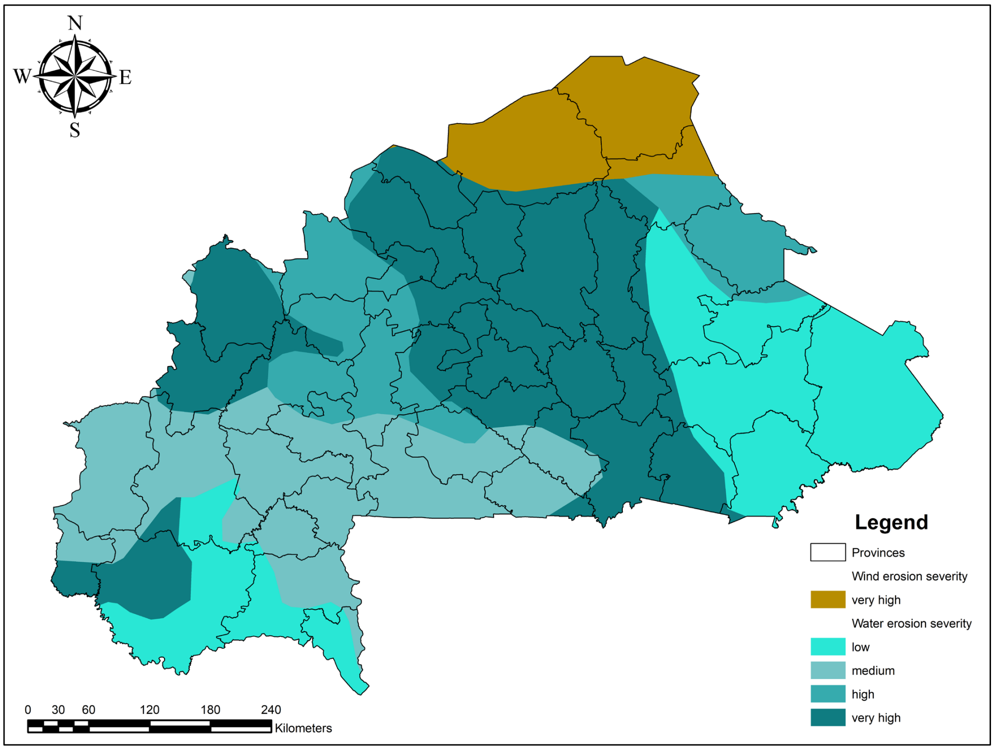


Figure 7. Soil degradation map of Burkina Faso.

Topsoil is lost as a major consequence of erosion and leads to soil impoverishment, reduced infiltration, and increased runoff [32–34]. It is understandable to assume that, in Burkina Faso, the spatial distribution of SWCMs is reflecting a strategic response to current environmental challenges, in particular, soil degradation due to water and wind erosion. Figure 8 illustrates, for each province, the areal proportion under each chosen conservation measure. The provinces are sorted from left to right by the percentage of land erosion under the GLASOD severity 4 or the category "very high" (Figure 7). There is an apparent increase in SWCM percentages in general once the land degradation percentage was 60% or more (starting from Passore province). Areas with serious soil degradation are more likely to adopt soil restoration measures. It is also noticeable that the adoption of zaï has increased around the same point. Zondoma, Bam, and Yatenga experience semi-arid conditions with less reliable rainfall. Subsistence farming in these provinces is more dependent on the immediate benefits of SWCM, such as zaï and stone ribbons, to maintain agricultural productivity.

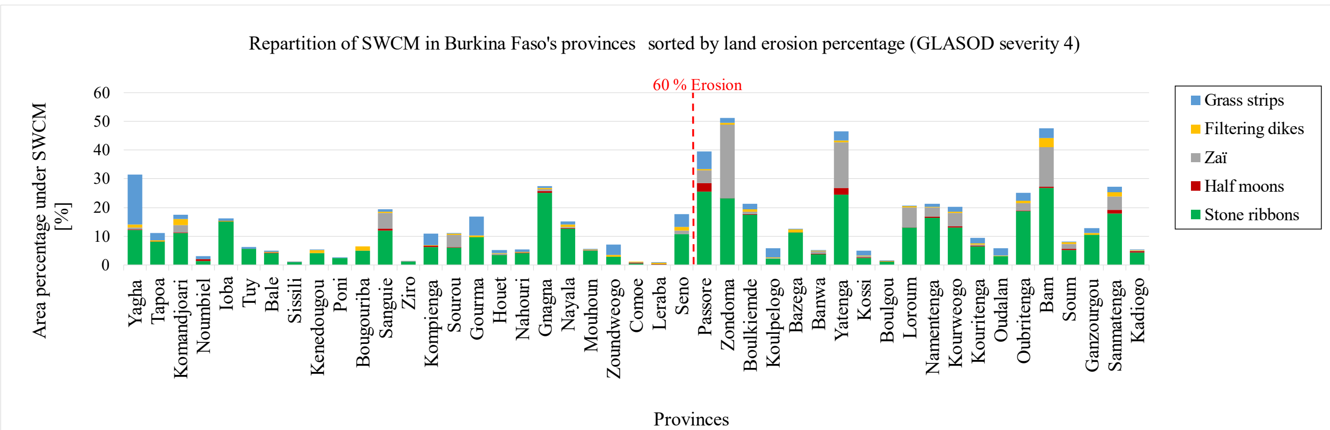


Figure 8. Repartition of SWCMs in provinces.

Some cases seem to be inconsistent with the previous findings. However, these cases can also be explained by the multifactorial nature of SWCM adoption factors. Kadiogo, for instance, hosts the capital city Ouagadougou which is highly urbanized. The pressure for residential, commercial, and industrial land use in urban and peri-urban areas may deprioritize agricultural activities and the adoption of SWCMs. Another example is Boulgou which is benefiting from a more favorable climate with higher and more reliable rainfall. This province has less immediate pressure to implement intensive SWCMs.

4.1.3. Socio-Economic Context

Income level plays a role in the choice of conservation measures by farmers and the extent of land to treat. Some of the SWCMs cost more than others (Table 1) and require more workforce and materials or periodic repairing. The cost per ha of filtering dikes was estimated to be around $296 against around $50 for zaï [16,35]. It can be an explanatory factor to the different levels of adoption of these measures (average of 1077.2 km^2 under zaï in comparison to 126.4 km^2 under filtering dikes).

Table 1. SWCM estimated cost and levels of adoption.

SWCM	Average Estimated Cost/ha [USD]	Level of Adoption [ha]
Zaï	50	107,720
Grass strips	57	109,610
Half-moons	82	15,590
Stone rows	188	232,240
Filtering dikes	296	12,640

In addition, areas with a high population density are more likely to experience land pressure and, therefore, more land degradation [36,37]. As shown in Figure 9, from Yatenga to Kourweogo, population densities vary from 68 to 169 inhabitants/km^2, besides Kadiogo provinces hosting the capital city (1014 inhabitants/km^2). One observation is that provinces with a high population density mostly follow the severe water erosion zones shown in Figure 7.

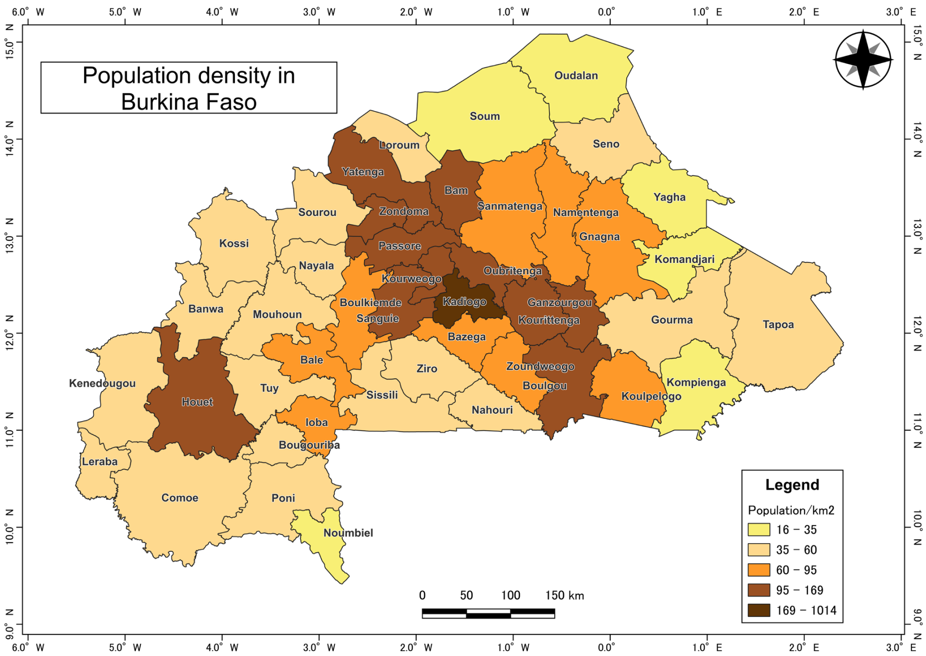


Figure 9. Population density per province in Burkina Faso.

Migration is another factor that is influencing the distribution of SWCMs by affecting the availability of the workforce. In the case of Burkina Faso, there is a migration pattern from rural provinces to cities in search of better living conditions [38]. In Burkina Faso, the economy relies significantly on agriculture and the sector employed approximately 80% of the workforce in 2022 [39]. Severe land degradation can lead to migration towards more fertile places [40]. Farmers who decide to rehabilitate their lands would then choose measures that are relatively easier and cost-effective to implement.

4.2. Potentialities Following SWCM Adoption

4.2.1. Impact on the Vegetation Cover

The NDVI provides a reliable indicator of vegetation dynamics and can be used to demonstrate the impact of SWCM implementation on efforts for vegetation restoration. Figure 10 shows the change in Max NDVI and precipitation for each province over a period of 20 years (2002 to 2021). For the vast majority of the provinces, an increase in the maximum NDVI values can be observed. Yatenga, Oudalan, and Passore provinces show the three highest values (respectively, 0.075, 0.073, and 0.071). Out of 45 provinces, 3 provinces are presenting a decrease in maximum NDVI values (Comoe, Ganzourgou, and Tapoa), and Houet is the only province that shows almost no change. In terms of precipitation, the change values are positive for 42 provinces out of 45. Only Kossi, Noumbiel, and Kompienga are presenting negative change values.

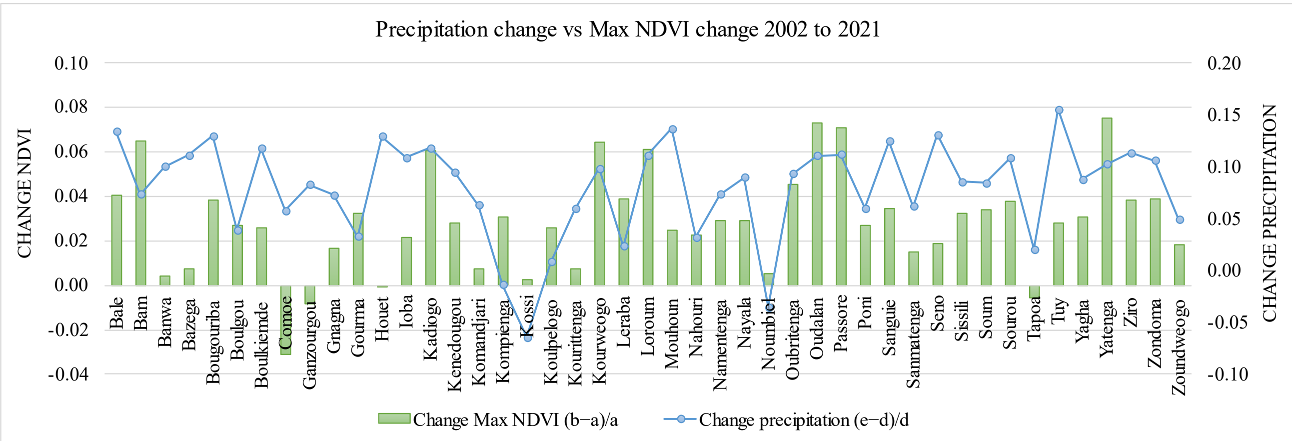


Figure 10. Precipitation change in comparison to NDVI change from 2002 to 2021.

According to many studies, there exists a positive correlation between precipitation and NDVI [41,42]. The assumption is that an increase in precipitation would improve the vegetation condition [43,44]. However, in some cases, we can observe a decrease in precipitation over the years and an increase in the NDVI values. This is the case for Kossi, Noumbiel, and Kompienga provinces. Moreover, the greatest precipitation change does not necessarily translate to the highest augmentation in NDVI. This has been seen in the Yatenga, Oudalan, and Passore provinces. Although these observations might seem contradictory, such results can be explained as other factors such as soil conservation practices enter into consideration.

The Yatenga, Oudalan, and Passore provinces are located in the Sahel and North regions, which fall under the Sahelian climatic zone in Burkina Faso. This zone receives less than 600 mm of yearly precipitation on average. These provinces also have very high percentages of degraded soils as a common characteristic (Figure 8). Under these conditions, the greening tendency may also be attributable to the local efforts on soil and water management. Kossi province can also be an example of the potential that SWCMs present for revegetation. The province was subject to the strongest decline in precipitation and still recorded a greening. A study by Salifou et al. presented that 78% of those surveyed in Kossi practice SWCMs [45]. The reclaiming of degraded lands has led to a decline of more than 40% in bare soil and an increase of between 2009 and 2019. SWCM implementation could play an important role in the development of greening trends. This is consistent with the findings of Nyamekye et al., supporting that approximately 81% of the sites under SWCMs have experienced an increase in NDVI [11].

4.2.2. SWCM for Climate RESILIENCE

Climate change poses a significant threat to sustainability, particularly in regions prone to arid and semi-arid conditions. Burkina Faso, located in the Sahel region of West Africa, is one such country where water scarcity and soil degradation are critical concerns. SWCMs represent a pivotal strategy in the broader context of climate change mitigation. Two general scenarios are often mentioned when predicting the climatic future: wetter and drier scenarios [46–48]. Like other green techniques well-experimented in other parts of the world, traditional practices from Sahel could also be considered because of their great potential. The advantage of using SWCMs lies in the fact that they could be useful in both scenarios.

In wetter scenarios characterized by increased precipitation, SWCMs could offer multiple benefits aimed at managing water resources more effectively. These measures can be used to retain stormwater and reduce runoff volumes, favoring flood risk mitigation in the watershed. Prior studies have already acknowledged the positive impact of SWCMs on runoff reduction. Wolka et al. mentioned a reduction of more than 50% using stone bunds in studies made in Burkina Faso, Ethiopia, and Kenya [49]. Paola et al. also conducted some research in the Sahel region and performed hydraulic simulations in Niger specifically. They concluded that half-moons installed in a staggered arrangement would lead to a runoff volume reduction of 70% at the field level and 8% at the basin level in case of extreme rainfall events [50]. Table 2 presents the percentage changes in erosion, runoff, and soil water-holding capacity observed by other researchers using SWCMs in experimental plots or selected areas within the Sahelian region. Using these percentage changes called impact factors here, it is possible to estimate the impact of some measures on a provincial level in Burkina Faso. The estimated impact values stored in Table 3 were made following the Equations (1)–(3). Bam province, for example, had an average of 26.7% of its area under stone ribbons from 2012 to 2021. This measure could have led to a reduction of around 13.4% in runoff volume with a chosen reduction factor of 50% or Rr = 0.5 (Table 3). If we scale the estimations to a regional level, the effects of SWCM inclusion in the disaster mitigation plan would be noteworthy. The North-Central region was found to be highly vulnerable to flooding events [51]. Considering that around 20.2% of the region was under stone ribbons from 2012 to 2021, the province could have recorded 10.1% less runoff on average with stone ribbons only. As shown previously, SWCMs are usually used in combination. The benefits in terms of water retention are more likely to be superior to these estimations. Moreover, there is a potential to exceed the estimations as some provinces have presented little to no installation of SWCMs during the period of interest. If the conservation measures are also implemented with a perspective of runoff reduction, it might be possible to increase their impact. With the projected increase in extreme rainfall events due to climate change [52], flooding events are expected to increase. It is worth trying the SWCMs as they could offer a cost-effective solution to mitigate these risks.

Table 2. Some impact factors of SWCMs on erosion, runoff, and soil water-holding capacity in the Sahel.

SWCM	Erosion Reduction Er [%]	Runoff Reduction Rr [%]	Soil Water-Holding Capacity Increase WHC_L [%]	References
Zaï	-	25 [1]	500	[53,54]
Stone ribbons	38; 60	50; 86	-	[49,55–57]
Half-moons	-	70	-	[50]
Grass strips	50; 79	42; 56	-	[49,56]

[1] 25% collection of runoff from 5 times zaï area.

Table 3. Potential impact of SWCMs on runoff and soil water-holding capacity with chosen impact factors.

Provinces	Stone Ribbons Rr = 0.5 [%]	Half-Moons Rr = 0.7 [%]	Zaï Rr = 0.25 [%]	Grass Strips Rr = 0.5 [%]	Zaï WHCi = 0.2 [%]
Bale	2.05	0.18	0.00	0.22	0.00
Bam	13.37	0.28	3.48	1.70	2.62
Banwa	1.84	0.16	0.21	0.11	0.16
Bazega	5.66	0.01	0.00	0.19	0.00
Bougouriba	2.50	0.00	0.00	0.00	0.00
Boulgou	0.54	0.09	0.00	0.04	0.00
Boulkiemde	8.77	0.03	0.24	0.89	0.18
Comoe	0.28	0.11	0.04	0.00	0.03
Ganzourgou	5.23	0.00	0.02	0.91	0.01
Gnagna	12.56	0.42	0.19	0.32	0.14
Gourma	4.80	0.06	0.00	3.38	0.00
Houet	1.68	0.13	0.09	0.44	0.06
Ioba	7.60	0.01	0.00	0.39	0.00
Kadiogo	2.13	0.27	0.07	0.08	0.05
Kenedougou	2.07	0.00	0.00	0.08	0.00
Komandjoari	5.57	0.09	0.66	0.83	0.50
Kompienga	3.05	0.39	0.00	2.11	0.00
Kossi	1.20	0.14	0.09	0.83	0.07
Koulpelogo	1.06	0.00	0.06	1.59	0.05
Kouritenga	3.26	0.11	0.11	0.97	0.09
Kourweogo	6.53	0.25	1.15	0.82	0.86
Leraba	0.05	0.13	0.00	0.15	0.00
Loroum	6.45	0.01	1.79	0.00	1.35
Mouhoun	2.43	0.09	0.03	0.07	0.02
Nahouri	2.09	0.02	0.03	0.39	0.02
Namentenga	8.25	0.29	0.77	0.51	0.58
Nayala	6.30	0.20	0.08	0.53	0.06
Noumbiel	0.70	0.43	0.00	0.51	0.00
Oubritenga	9.41	0.08	0.61	1.39	0.46
Oudalan	1.55	0.00	0.00	1.28	0.00
Passore	12.78	2.05	1.12	3.08	0.84
Poni	1.23	0.00	0.00	0.01	0.00
Sanguie	6.01	0.42	1.37	0.45	1.03
Sanmatenga	8.97	0.91	1.16	0.95	0.88
Seno	5.35	0.00	0.31	2.22	0.23
Sissili	0.46	0.00	0.00	0.11	0.00
Soum	2.58	0.32	0.39	0.04	0.30
Sourou	2.97	0.16	1.07	0.08	0.80
Tapoa	4.01	0.08	0.00	1.31	0.00
Tuy	2.76	0.00	0.02	0.31	0.02
Yagha	6.06	0.11	0.18	8.69	0.14
Yatenga	12.20	1.61	3.98	1.58	3.00
Ziro	0.54	0.00	0.00	0.06	0.00
Zondoma	11.58	0.09	6.42	0.85	4.84
Zoundweogo	1.45	0.00	0.00	1.72	0.00

In drier scenarios, SWCMs would demonstrate their adaptability by facilitating water retention and enhancing drought resilience. In the Sahel, where the annual rainfall is often less than 600 mm, these techniques are crucial. These measures promote infiltration and prolong the time of concentration, allowing water to percolate into the soil and recharge groundwater aquifers. This not only enhances the water availability but also contributes to the sustainability of ecosystems. Empirical evidence from the Sahel underscores the efficacy of SWCMs in enhancing the soil water-holding capacity. Studies have demonstrated that zaï, for instance, can increase soil moisture by up to 40% compared to untreated land [58]. Similarly, Danjuma and Mohammed mentioned that zaï pits with organic matter were able to hold water over 500% of the soil water-holding capacity [53]. Figures 3 and 4 detail how a 500% increase ($WHC_L = 5$) would be represented and how it would impact the value of the soil water-holding capacity in the field (increase of 20% or WHCi = 0.2). Following the same logic adopted previously, it is possible to estimate the capacities of SWCMs using calculated factors (Table 3). Zondoma province for example, located in Northern Burkina

Faso, potentially had an improvement of about 5% in water-holding capacity with zaï only. The implementation of SWCMs across various provinces can also have a cumulative impact on the national level. By increasing the overall soil water-holding capacity, Burkina Faso can enhance its resilience to climate variability, ensuring more stable agricultural outputs even in the face of adverse climatic conditions. This resilience is critical for the country's long-term development and stability.

Moreover, in regions prone to water scarcity, SWCMs provide additional means of capturing and storing rainwater, thereby supplementing conventional water sources and revitalizing the areas. Through their implementation, SWCMs are already contributing to the regreening efforts in arid regions. Their use enables farmers to sustainably manage water resources and maintain agricultural productivity even in arid conditions [5].

Another significant advantage of SWCM is their ability to enhance carbon sequestration in soils [59,60]. As outlined in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5 °C, soil management practices that increase organic matter have the potential to sequester substantial amounts of carbon dioxide from the atmosphere, thereby contributing to climate change mitigation efforts [61]. For rural producers, this presents a unique opportunity to participate in the carbon credit market. By adopting practices that increase soil organic carbon, producers can generate carbon credits that can be sold, providing an additional income stream. This economic incentive not only promotes the broader adoption of sustainable practices but also promotes financial viability for producers. In addition to carbon sequestration, SWCMs significantly improve soil properties, particularly water infiltration and retention. These improvements are crucial in the context of increasing climate variability and the growing incidence of extreme weather events. The IPCC report highlights that an enhanced soil structure and water-holding capacity can mitigate the adverse effects of drought, reducing the reliance on irrigation and stabilizing crop yields in the face of unpredictable weather patterns. This increased resilience is essential for maintaining the productivity and sustainability of agricultural systems in regions vulnerable to climate change. Moreover, the adoption of these techniques leads to substantial improvements in soil chemical and biological properties [62]. Increased organic matter content, resulting from practices such as mulching and cover cropping, enhances nutrient availability and soil fertility. These practices promote greater microbial activity, which is critical for maintaining soil functions such as organic matter decomposition and nutrient cycling. Additionally, cooperatives provide a platform for collective action. They enable small-scale farmers to access resources, training, and support for implementing these techniques. By pooling resources and sharing knowledge, cooperatives can help to overcome the barriers that individual farmers might face.

4.3. Recommendations and Future Directions

The benefits of SWCMs for land restoration and agricultural productivity have already been demonstrated. These measures could also be integrated into hydrological models to investigate their potential use for flood risk mitigation specifically. Such studies already exist and are documented in other regions of the world using green infrastructures like retention ponds, rain gardens, green roofs, permeable pavements, etc. Using SWCMs already known and implemented in Burkina Faso and other Sahelian countries for such studies could be beneficial and more adequate for local realities.

To consider SWCMs as stormwater management techniques and include them in the disaster risk reduction plan of Burkina Faso, the next step would be to deepen the impact assessment on the hydrological cycle as such. Further hydrological modeling studies including SWCMs alone and in combination would help to estimate the impact factors with more precision. There is also a necessity to measure and constitute runoff and soil properties datasets in the country. Such data would serve as a reference to quantify the actual volumes and visualize the impacts in terms of flood mitigation. More knowledge sharing and capacity building are recommended in collaboration with actors on the fields to enhance local expertise and facilitate the implementation of SWCMs. With the results of studies mentioned above, SWCMs could be modernized and more tailored to also address water disasters and related challenges in Sahelian countries.

5. Conclusions

SWCMs play an essential role in the pursuit of sustainable development and the battle against climate change due to the multiple advantages they present. The adoption of SWCMs in Burkina Faso is affected by multidimensional factors, the main ones being land use (mostly agriculture), soil conditions, precipitations, and the socio-economic status of populations. Stone ribbons are the most widely implemented SWCM, covering 2322.4 km^2, while filtering dikes are the least widely implemented, at 126.4 km^2. The NDVI analysis showed a notable vegetation increase in areas with a high prevalence of SWCMs from 2002 to 2021. Areas with more than 60% soil degradation are more likely to adopt SWCMs. It was also estimated that stone ribbons, for example, could have reduced potential runoff by up to 13.4%, highlighting their effectiveness in climate resilience and flood risk mitigation.

This study is limited by the absence of field measurements and detailed observed data. Some impacts were estimated following the results of previous studies from areas of interest. A natural progression of the work would be to conduct field experiments and surveys like previously recommended and also model the implementation of SWCMs for a more accurate impact assessment.

Overall, coordinated efforts are still needed to make full use of the potential these measures can offer. By enhancing water management efficiency, SWCMs have the potential to contribute to the disaster mitigation plans and the resilience of communities to climate-induced disasters would be strengthened as potential outcomes. Together, local and international stakeholders can make use of SWCMs to build a more resilient future by taking them into account in policy frameworks and projects, and investing in their widespread implementation.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16187995/s1, Figure S1. Soil types of Burkina Faso, WRB classification. Figure S2. Soil erosion map of Burkina Faso (ESDAC-RUSLE model). Figure S3. Mean NDVI map of Burkina Faso (2002 to 2021). Figure S4. Maximum NDVI per provinces in Burkina Faso (10 years average from 2002 to 2011). Figure S5. Maximum NDVI per provinces in Burkina Faso (10 years average from 2012 to 2021). Figure S6. Average soil loss by provinces in Burkina Faso.

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