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Integrated Water Resources Management in the Sandougou Catchment Area (Senegal): Going beyond Soil Defence and Restoration (SDR)

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Abstract: The Sandougou River is the last major right bank tributary of the Gambia River. It has a catchment area of 11,668 km² and is located in Senegalese territory. The flow in this sloping basin (1‰) is favoured by the conservation of soils and vegetation. Since 1970, global rainfall trends (below the average of 800 mm) have shown a drought affecting the whole basin with an average deficit of 100 mm per year. In addition, erosion phenomenon combined with high rainfall intensities explains the rapid run-off. This constitutes a considerable loss of water resources, up to 20% in the Sandougou basin. In this rural area where primary activities predominate, anthropogenic pressure is considerable. Indeed, overexploitation of firewood, resulting from the strong dependence of local populations on this resource, is at the origin of deforestation in the Sandougou basin. Such a situation contributes to environmental degradation and also has repercussions on soil erosion. Erosion affects the water retention capacity of the soil making it more susceptible to extreme conditions such as drought. The impact of soil erosion on more remote sites is not always as apparent as the impact of erosion on the site itself. Sediment reaching watercourses can accelerate slope erosion, silt up drainage ditches and streams, silt up reservoirs, cover spawning areas and reduce water quality. Fertilizers frequently transported with soil particles can contaminate or pollute water sources. To cope with this dynamic, soil defence and restoration (SDR) techniques have long been considered as the solution to the problems. However, the multifaceted nature of environmental problems and their persistence leads to the consideration of a more holistic approach. In the Sandougou catchment area, the application of article R50 of the Senegalese Forestry Code, the implementation of planning tools (AP-IWRM), institutional development in the framework of integrated water resources management (IWRM) prove the interest of such an approach for the protection of water resources.

Key words: Water resources, integrated water resources management, erosion, Sandougou, Senegal.

1. Introduction

The current climatic conditions and the strong pressure of populations and livestock are the major constraints on water resources in the Sandougou basin. They lead to, among other phenomena, water pollution, the early drying up of rivers, deforestation, silting and erosion. The persistence of these phenomena is increasingly reflected in changes in the dynamic morphodynamic plan and a limitation of agricultural and pastoral resources as well as a reduction in fish resources. Several interventions have been noted in the Sandougou basin. Their role is to mitigate the observed dynamics. These include soil conservation techniques implemented within the framework of Programme for the Sustainable and Participatory Management of Traditional and Substitute Energy (PROGEDE), the development of the Land Use and Development Plan, and the application of article R50 of the Senegalese Forestry Code.

The Sandougou has a watershed of 11,668 km^2 limited by latitudes 13°27′ and 14°36′ north and longitudes 12°42′ and 14°32′ west (Fig. 1). It is divided between Senegal, where it originates at an altitude of about 75 m, and the Gambia, where it flows

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into the Gambia River's maritime basin. The typical vegetation of the Sandougou basin is a savannah developed on the gravelly soils of the plateaus and the richer ferruginous soils of the valleys. Most of the basin is located in Senegalese territory. The Tambacounda region, in which Sandougou is located, is one of the most rainy regions in Senegal, with rainfall of up to 900 mm. However, observations made from 1940 to 2004 show a downward trend in water resources (rainfall, runoff, ground water). The decades 1971-1980, 1981-1990 and 1991-2000 were really fluctuating for all stations. Rainfall amounts dropped considerably during this period leading to extreme droughts in some stations like Koumpentoum [1].

The Sandougou basin has been the subject of several studies that have led to strong conclusions. Zade [2] has shown that surface water flows in the Sandougou are characterized by low modules (less than 1 m^3/s). Lele [3], in its analysis of water management, underlines the need to take into account the integration processes in the Sandougou basin, but also points out that the structural organization is not well organized.

This study presents the interest of an integrated water resources management (IWRM) approach in Sandougou where water resources are becoming increasingly scarce and where the environment is under increasing threat. While the region has a deficit of quality water resources, there is a growing demand for water for both livestock and humans. Indeed, access to water in the Sandougou basin is characterized by a multitude of uses such as cattle watering, fishing, crafts, market gardening and rice

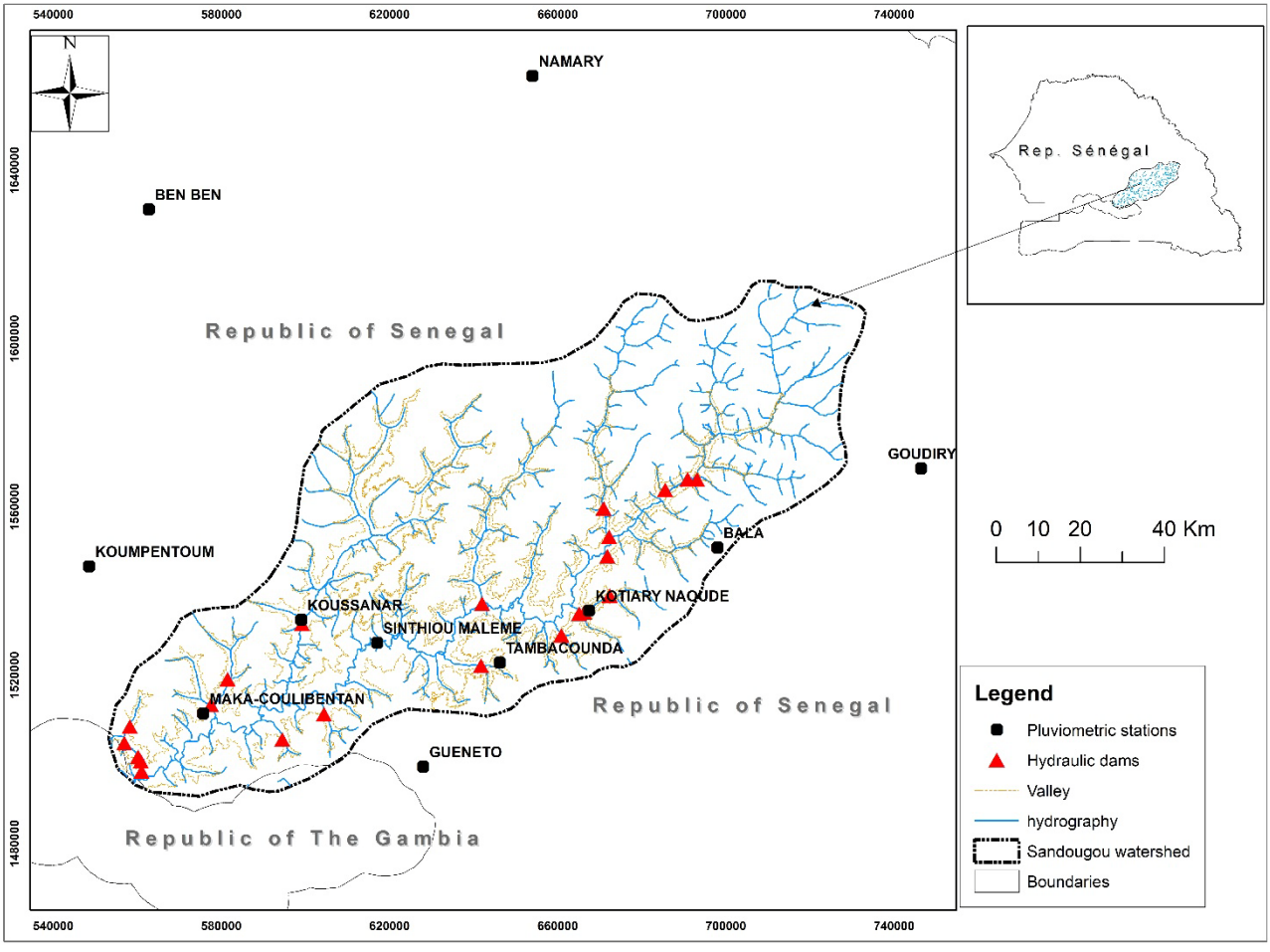

Fig. 1 Location map of the Sandougou basin.

cultivation. Household and livestock water sources are provided solely by traditional or modern wells. On the hydro-agricultural level, despite the presence of numerous lowlands with real edaphic potential, the exploitation of surface water by controlling it, even partially, remains almost non-existent. The rare forms of agricultural use of water are carried out by women in the traditional way in small areas.

2. Materials and Methods

2.1 Mapping of the Dynamics of Degradation and the Implication of the Law

In this study, the cartographic approach allowed the identification of the different hydraulic interventions in the Sandougou basin. Shuttle Radar Topography Mission (SRTM) data with a resolution of 30 m were used to obtain the hydrographic network of the basin. Land use mapping was carried out using data from the digitization of the images after verification with field elements.

In view of the geomorphology of the zone and its size, the Euclidean buffer zone method was used to highlight the areas preserved in the event of application of article R50 of the Senegalese Forestry Code. Buffer zones were created to define the protective rights-of-way around the hydrographic network with reference to the law. The result of the 30-m and 150-m buffer around the hydrographic network and the ponds was crossed with the current land use units which had already been digitized. This made it possible to generate a table showing the size of the areas that could be preserved according to the units considered.

2.2 Approach to Water Resource Variability as Indicators of Land Degradation

Taking into account the determinant character of the rainfall parameter on runoff, 11 rainfall stations were chosen for the rainfall analysis. However, these stations are poorly distributed within the basin (Fig. 1).

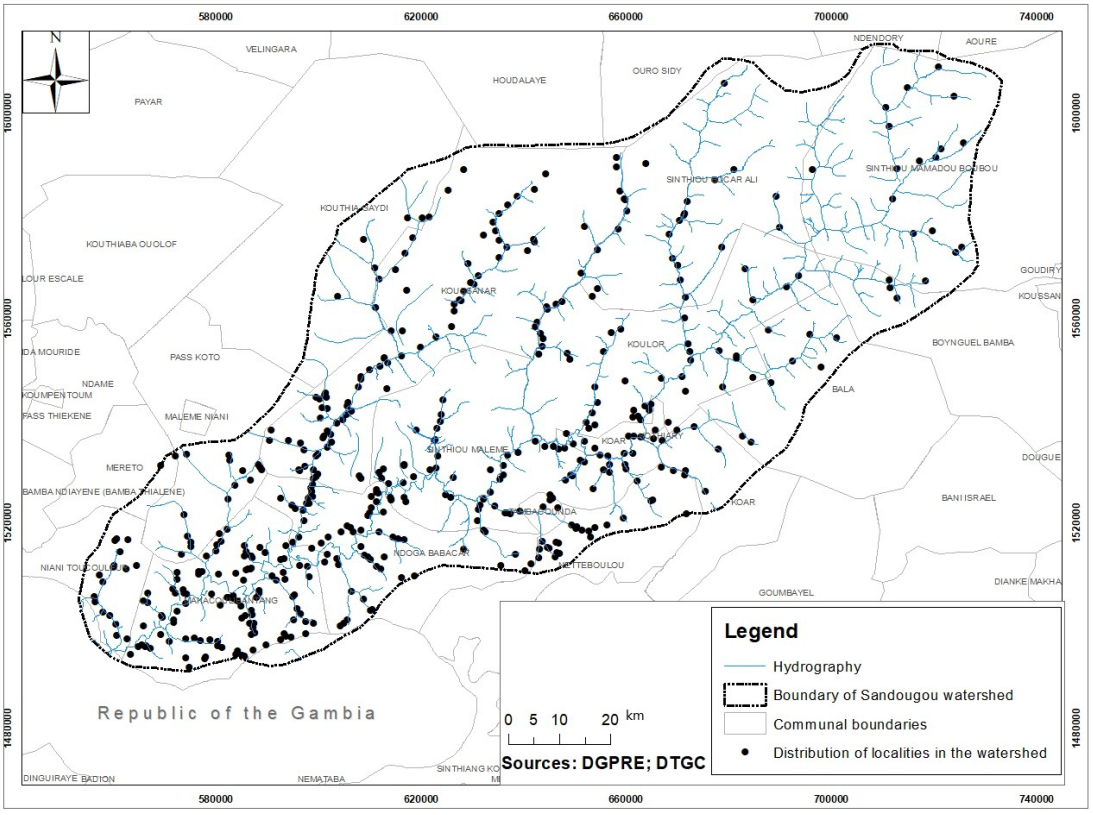

Fig. 2 **Distribution of villages in the basin.**

With the disparity of the observation periods between rainfall stations, the homogeneity of the data was controlled by the regional vector method [4]. It is therefore a chronological sequence of annual rainfall indices taking into account the effects of persistence, trend and pseudo-cycles in the climatic zone, but homogeneous overtime.

3. Results

3.1 Degradation of Water Resources, between Climate and Anthropogenic Impacts

3.1.1 Occupation of the Lowlands

In the Sandougou basin, most of the localities are located in the valleys not far from the rivers (Fig. 2). This distribution of villages in the basin is partly linked to the water crisis in the Sandougou basin. Indeed, to cope with the lack of water, the population tends to settle next to the rivers in order to have a water point. The network of human settlements revolves around two communes (Maka and Ndoga) which group together more than 193 villages. On the whole, the villages are quite scattered in relation to each other. The most populated villages are located in the commune of Maka Colibantan. In Ndoga, a single settlement exceeds 1,000 inhabitants, while 97% of the settlements have less than 500 inhabitants [5].

Economic activities in Sandougou are dominated by the primary sector in which rain-fed agriculture and livestock farming occupy more than 70% of rural households. Market gardening and logging mobilize nearly 30% of rural households [6]. Forest production is structured around wood fuels, the exploitation of which is intended to supply Dakar with domestic energy (firewood and charcoal).

3.1.2 Resource Variability

Decennial rainfall averages were calculated for all the stations in the basin. The downward trend, observed at the level of normal rainfall, was confirmed with some particularities:

(1) At the level of the basin, the decrease in rainfall began at the end of the 1960s. The 1940-1943 drought affected the average rainfall for the 1941-1950 decade.

(2) The timid recovery of precipitation during the 1991-2000 decade is noteworthy. In fact, this decade includes years with excess to very excess rainfall, such as 1994, 1995 and 1999, which contributed to raising the 10-year average (Fig. 3).

It should also be noted that rainfall is distributed between the months of June and October over an average period of 45 d. It constitutes the main water resource for rain-fed crops, which are the main activity of the area's populations. The mapping of the isohyets in the Sandougou basin shows a clear regression of the isohyets in a north-south direction (Fig. 4). This dynamic reflects a trend towards global drought in the basin, which favours evaporation and makes the soil more exposed to erosion.

3.1.3 Flow Deficit

The flows of the Sandougou basin are a direct response to rainfall impulses whose transfer can be subject to various modalities depending on the size, configuration, relief, geology and soils of the basin. The flow analysis is carried out with reference to the two functional stations of the Sandougou basin. These are the stations of Koussanar and Sinthiou Malem. The study of the annual availability reveals the weakness and the modicity of the flows of the Sandougou River both for the Sinthiou Malem station and for the Koussanar station. Thus, at Koussanar, the average annual volume does not reach 1×10^6 m^3 of water, while at Sinthiou Malem this volume is a little more important and tends towards 6×10^6 m^3 of water (Figs. 5 and 6). In addition, there is a great variability in the availability of water from one year to the next, reflecting the rainfall regime, which is the only source of water supply for the basin [6].

3.2 Development and Dynamics of a Catchment Area under Climatic Constraints

3.2.1 Persistence

Bioclimatic evolution, marked by water stress combined with anthropogenic actions, is causing

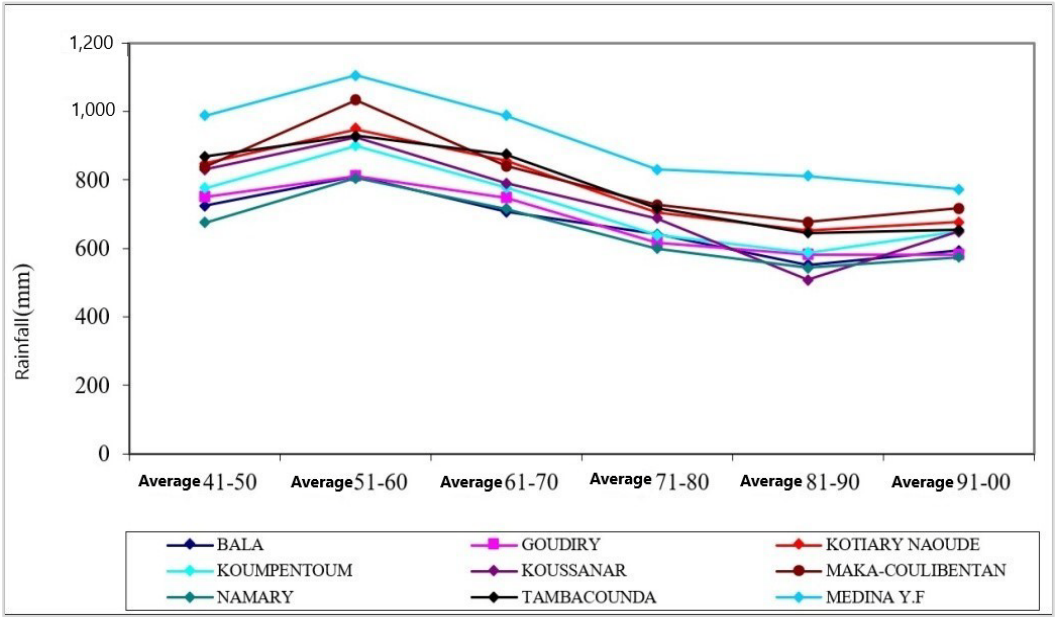

Fig. 3 Rainfall variation in the basin.

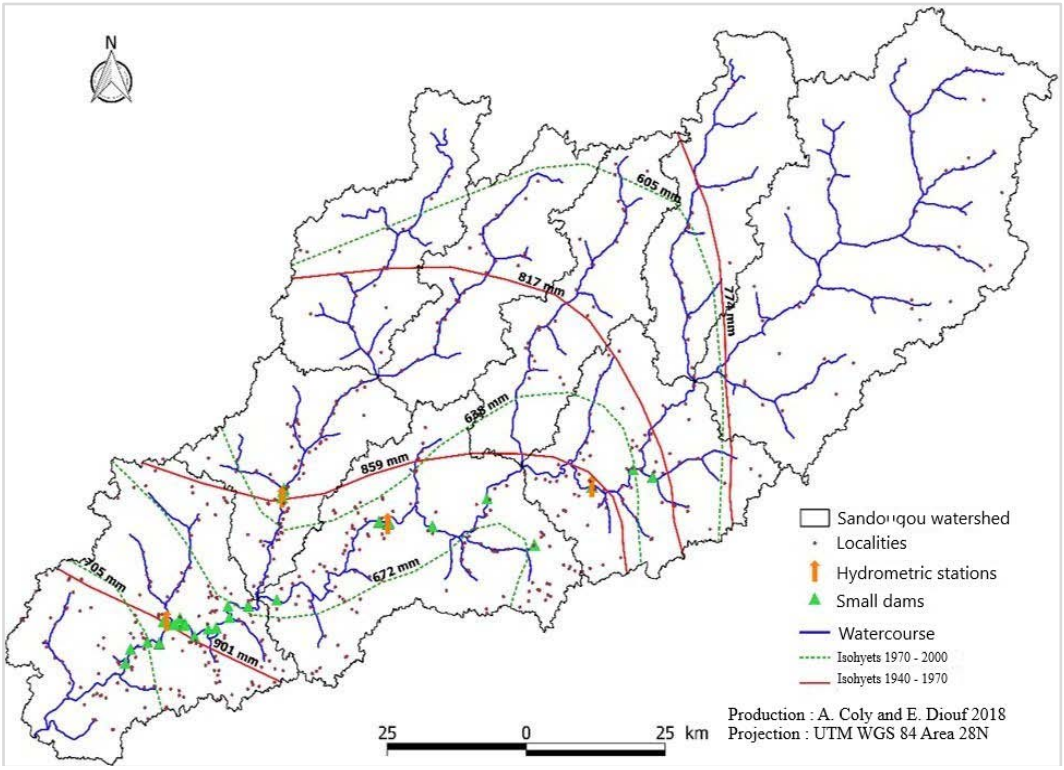

Fig. 4 Map of isohyets in Sandougou.

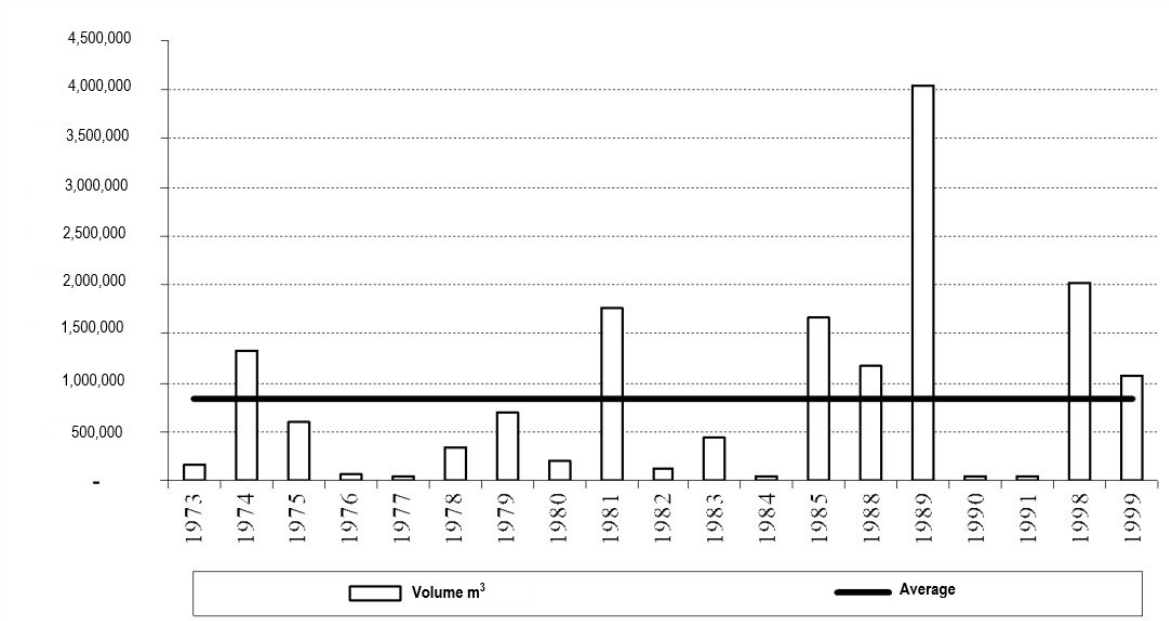

Fig. 5 Flow situation at Koussanar.

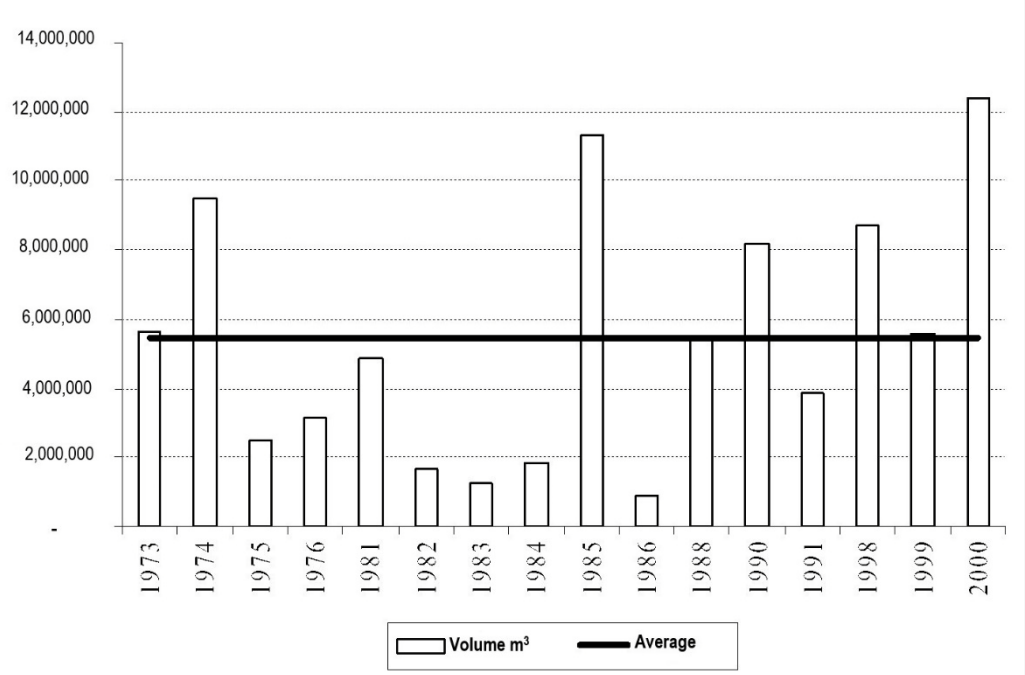

Fig. 6 Flow situation in Sinthiou Malem.

disruptions in biodiversity. Several species that were once abundant have disappeared or are in the process of disappearing. Indeed, these environments are increasingly being conquered by man. Excessive cutting of trees and overexploitation of resources (charcoal and firewood), especially bush fires, are the main factors in the degradation of these resources. The statistics on bush fire cases are revealing this situation. In 2005, 27,000 ha were burnt by early fires and 955 ha were ravaged by bushfires requiring the direct field intervention of the water and forestry services. Deforestation therefore remains very marked in the Sandougou valley. In addition, the intensity of the rains causes considerable damage in terms of loss of

soil fertility and gullying. The landscape of the Sandougou valley is strongly marked by gullying, which accentuates the transport of sandy sediments towards the hydraulic axes.

3.2.2 Facilities

The Sandougou basin has several hydraulic works. The layout of the localities in the hydrographic configuration shows that access to water remains the key factor in the establishment of villages, gites and hamlets. The works are mainly made up of equipped boreholes (about six), wells (about 205) and small dams, the most famous of which are the Sao dam located between the villages of Sao and Mboulembou and the Fadia dam (upstream of the Sao dam).

Taken as a whole, soil conservation increases water availability. In this respect, the strategy developed by PROGEDE in the Sandougou catchment area is a good example. Many local initiatives relating to the management of forest massifs, or even other aspects related to PROGEDE, have been taken, in particular the setting up of nurseries and reforestation. Several village committees are also starting up seedling production and planting operations. Even during the transitional period when PROGEDE did not have financial resources, nurseries were created almost everywhere in the intervention zone and reforested areas were also created on the initiative of the local people [7].

Indeed, PROGEDE's approach to forestry exploitation is fundamental to the protection of water resources. It is based on compliance with the provisions of the Senegalese Forestry Code. In a catchment area where the conditions are met for strong erosion with a high density of human occupation, the action of this programme reduces erosive phenomenon.

4. Discussion

4.1 The Law, an Opportunity for Soil Protection

Human activity in the Sandougou basin remains one of the main causes contributing to environmental degradation. The multitudes of economic activities carried out by rural households are dominated by the primary sector (rain-fed agriculture, livestock farming, market gardening, forestry, etc.). Occupation as well as anarchic exploitation clearly contributes to the acceleration of the phenomenon of erosion in the basin. The silting up of the main waterways has two direct effects: a reduction in the capacity of the reservoirs and an alteration in the quality of the water. The configuration of the units that make up the Sandougou basin on the one hand (presence of ponds and watercourses) and on the other hand the persistence of erosion, constitutes favourable conditions for the application of article R50. Taken from the Senegalese Forestry Code in its regulatory part, this article rigorously protects areas with characteristics such as those of the Sandougou. Indeed, the article stipulates that for land clearing, the discharge is mandatory if the clearing:

- is likely to compromise the stability of the land on the slopes and in the watersheds;
- is likely to cause erosion and silting of watercourses;
- does not respect a thirty-meter strip on the banks on both sides of the watercourses [8].

Independently of the soil defence and restoration measures carried out, the simple application of article R50 would significantly protect the environment of the Sandougou basin. Fig. 7 shows the units that would be preserved by applying the Forestry Code, i.e., by preserving sensitive areas along a buffer zone of 30-150 m.

The result of the cartographic treatment with the buffer method shows that the definition of the protection perimeters makes it possible to protect the environment of the basin. In fact, with a buffer zone of 30 m, 1% of cultivated area, 8% of meadows and 22% of vegetation are recovered and for a buffer zone of 150 m, the positive impact is even greater. It enables 11% of cultivated areas, 38% of grassland and 64% of vegetation to be recovered (Fig. 8).

The application of the law will thus reduce erosion because activities on the riverbank will be regulated. Bank bleaching is the real problem, and deforestation of gallery forests and trees on the beds of small streams has an impact on soil and water resource degradation.

In this region of bowe (indurated surfaces) and steep slopes, the impact on water resources will be real because the bed filling linked to the sediment supply will diminish and the flow speeds will decrease. The process thus slowed down and will favour water infiltration and a fairly beneficial transit for the soil and the ecosystem.

The application of this provision in watercourses favours the protection of the plateaux where the gullying of the palace will be low and infiltration will be highly favoured (Fig. 9). The area concerned in this region will be quite large.

All this shows that with the application of article R50 of the Senegalese Forestry Code in its regulatory part, therefore with few means, the areas defended will be significant and the effect sought with the soil defence and restoration will be better felt.

4.2 IWRM for a Resilient Society

Erosion control, and thus the reduction of sedimentation, is one of the objectives of integrated water management at the watershed level, as sediment can compromise water quality and water uses.

IWRM, through its integrated approach, is a relevant tool for taking into account the environmental issues of the Sandougou basin. Because of its characteristics,

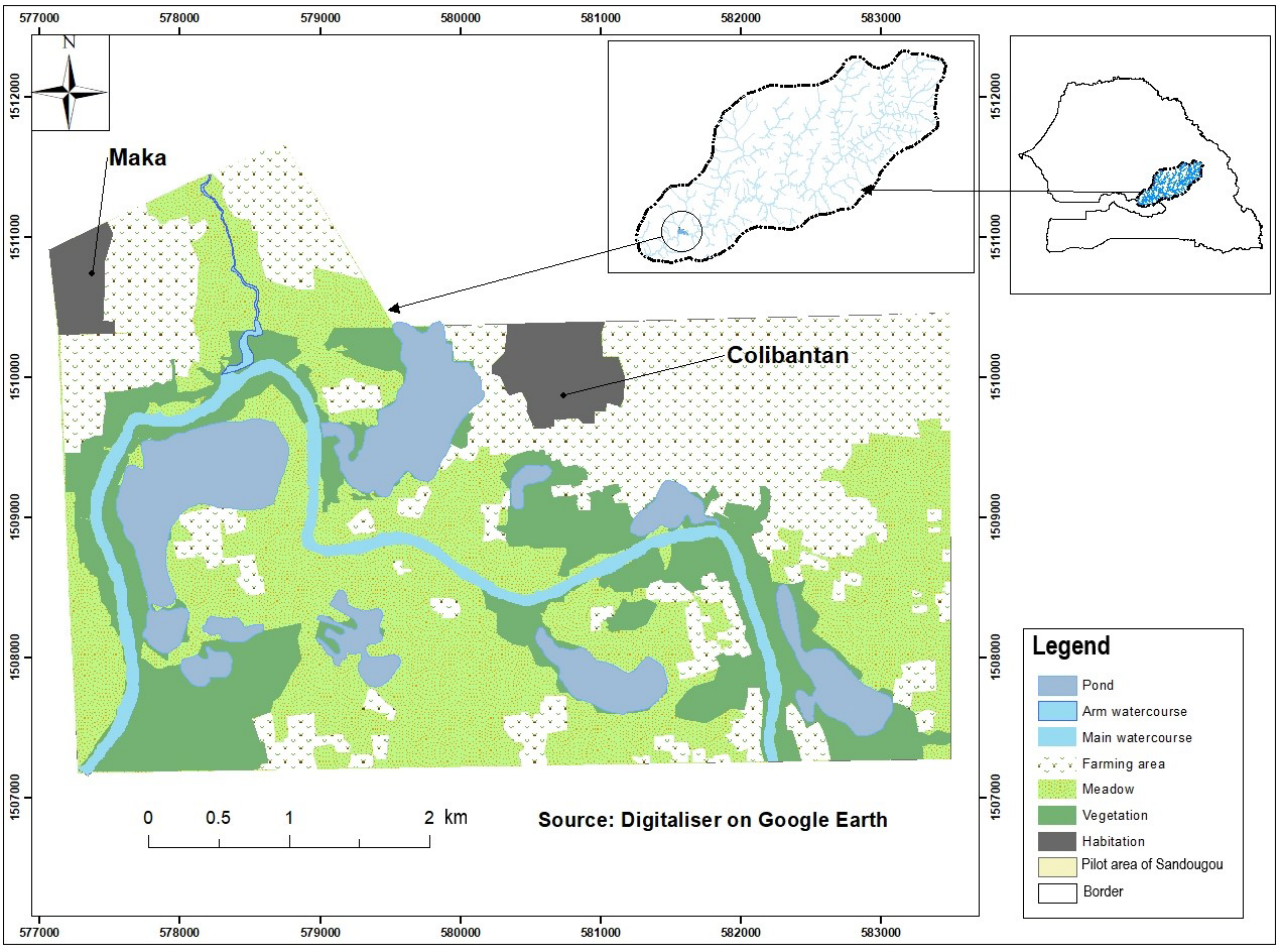

Fig. 7 Mapping of units to be preserved with the application of article R50.

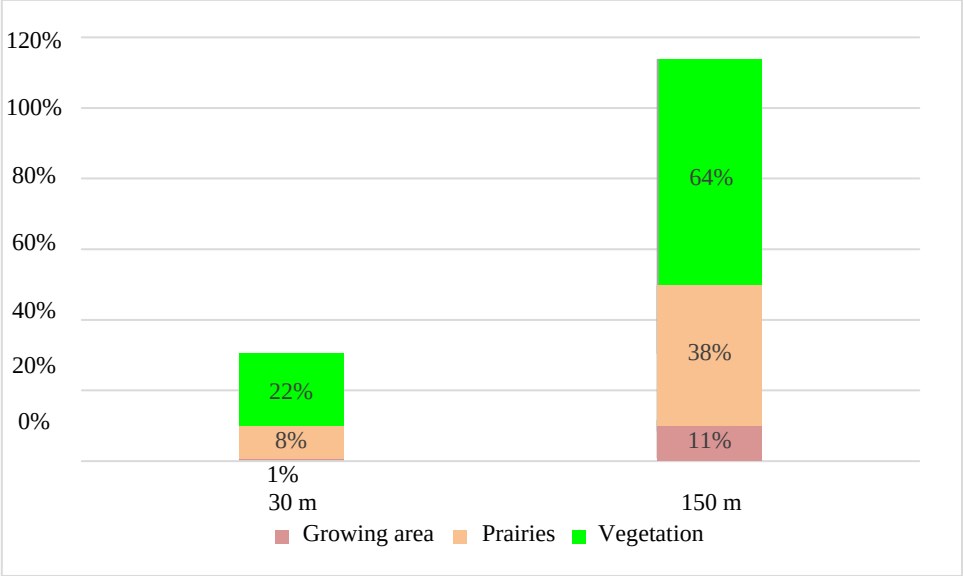

Fig. 8 Preserved areas with a buffer zone of 30 m and 150 m.

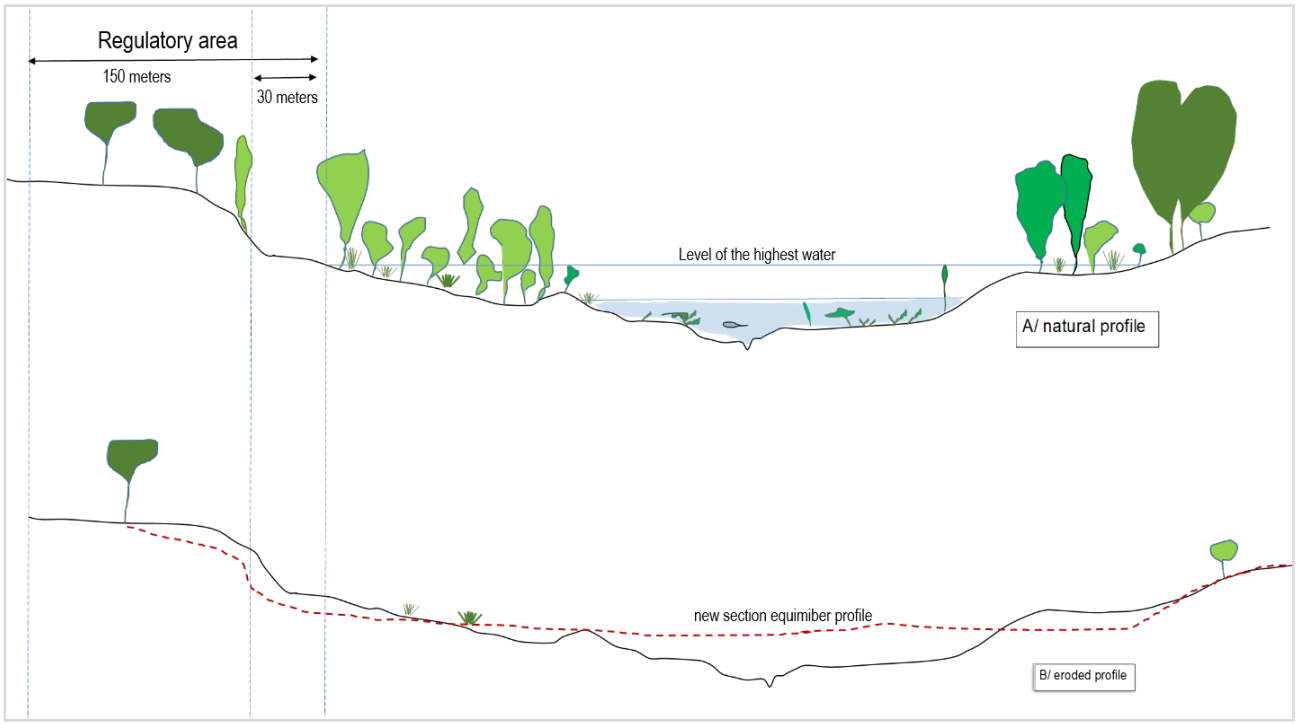

Fig. 9 Typical profile of the Sandougou, A: with application of the regulation, B: without application of the regulation.

IWRM can be particularly useful for land management. Many areas of natural resource management have stumbled over the issue of exercise space [9].

Soil management has tended to work on the slope and by extension strategies has been developed and extended to the catchment area, which is par excellence the relevant area for IWRM.

However, implications arise when in the analysis of the natural resources issue one realizes that the integration of different aspects introduces inconsistencies in the limits of each of them. Consequently, spatial inconsistencies arise on the different aspects taken into account, which IWRM has

resolved by taking into account the functional space in its implementation, which is common in the systems approach. The multifaceted nature of environmental problems and their persistence despite the actions of defence and restoration have led to research focusing on the scales and levels of analysis that allow for an understanding of the relationships to provide a management perspective.

The implementation of IWRM principles in Sandougou could also build on existing planning tools. These are mainly the action plan for IWRM (AP-IWRM) of Senegal, which was adopted in December 2007 and updated in 2017. Adapted to the local context (communal scale), AP-IWRM is a local IWRM action plan with the objectives of using, developing and protecting the quantity and quality of water resources.

5. Conclusions

Today, the Sandougou basin is a natural area with several challenges: economic, social and environmental. Anthropic actions (abusive exploitation of the forest) combined with unfavourable climatic parameters (reduced rainfall) have clearly favoured the degradation of the Sandougou's natural resources. Thus, faced with such a situation, the soil conservation strategy must move towards a more holistic approach as proposed by IWRM by following the process of exchange that takes place in the areas in question. The approach will have to be more territorial, which will in fact show the decision-making dimension that is the driving force behind water management projects in particular.

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