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Vulnerability to Desertification in a Sub-Saharan Region: A First Local Assessment in Five Villages of Southern Region of Malawi

Riccardo Giuseppe Boschetto[*1], Rahma Mustafa Mohamed[2], Jacopo Arrigotti[3]

[1]*ISPRA – High Institute for the Environment Protection and Research, Via V. Brancati 48, 00144 Roma, Italy*
[2]*Consultant - Physical Chemical laboratory advisor Via C. Pavese 77, 00144 Roma, Italy*
[3]*RC – Research and Cooperation, Blantyre PO Box 5748, Malawi*

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Abstract

The study took place between July and September 2008 with the main objective to develop a first local environmental assessment suitable to obtain a general description of the agro-system environment of five villages in the Southern Region of Malawi. The research has been carried out in an administrative sub-division of the peri-urban area of the city of Blantyre, called Ntonda EPA (Extension Planning Area), where target villages had been previously identified for the overexploitation of their natural resource base and the mismanagement of their soils. This study attempts to illustrate the agro-ecosystem of the five villages in the area, their main features and the main anthropic factors, viewed as causes that could lead to desertification. As the matter of fact, the overexploitation of soils, which can be fairly considered as the one and only resource base endowment available in the area. The current farming system, heavily reliant on mere subsistence, is strictly interlinked with unsustainable fertilisation methods and a prevalent lack of socio-economic activities. Poorly planned and managed cropping systems yield low and erratic productions, despite government subsidised chemical fertilisation programmes; post-harvest management and storage are nearly inexistent and so are agricultural commodity exchanges with otherwise fairly accessible urban areas. As a result, agricultural investment (including on soil conservation) is minimal and local areas remain vulnerable to land degradation and ultimately to desertification. The baseline data collected with this research provide information on the main issues that determine the process of land degradation and desertification in the area. The study is based on the analysis of climate and soil parameters. This paper attempts to provide:

- a first assessment of vulnerability to desertification at local level, specifically at village level in the Southern Region of Malawi;
- an identification of the major causes and trends of agro-system degradation;
- a set of recommendations as to how to avoid further degradation of the agro-system before the desertification process becomes irreversible and untreatable.

Key-words: desertification, Malawi, local assessment, Sub-Saharan region.

Introduction

The present report has been produced in the framework of the project: “Improving Farmers Livelihoods and Incomes through Soil Re-fertilization in Blantyre District” promoted by the Italian NGO *Ricerca e Cooperazione* (RC) and co-financed by the European Commission under the Farm Income Diversification Programme, implemented by the Government of Malawi. The general objective of this study was to make an accurate diagnosis of the environment at local level, namely in five villages of the Ntonda Extension Planning Area (Ntonda EPA) in order to identify the most critical causes of land degradation and to examine the extent of exposure to the risk of desertification. According to the UNCCD definition, the desertification process is interlinked with various factors and multiple degradation processes at different time and space scale over different

* Corresponding Author: Tel. +39 06 50072566; Fax: +39 06 50072657. E-mail address: riccardo.boschetto@isprambiente.it.

kinds of environmental systems. In the last decades, the nature and extent of degradation processes have imposed the revision of the criteria to identify unleashing events, causes and mechanisms as well as the re-adjusting of critical thresholds. Although some natural processes lead to desertification, the problem is in most cases human induced, as overexploitation of natural resources, soil, water and vegetation under any eco-system – whether in arid, semi-arid or dry sub-humid domain – can initiate or worsen the desertification process.

On the grounds of the above background concepts, this study aims at providing insights on the state of the environment at local scale, particularly for what concerns agricultural land under a typical kind of subsistence production farming system.

For the purpose, the study looks into the following issues:

1. the main anthropic factors that represent a pressure on the agro-ecosystem;
2. the aridity condition of the areas targeted by the re-fertilisation project;
3. the current state of soils, which allows to modelise the loss of ecological resources in the agro-system and to plan future monitoring of the rate of change in biodiversity and in land degradation;
4. the current driving forces that could lead to desertification processes.

Materials and methods

The major problems affecting the agro-ecosystem in the target areas are similar to those affecting other semi-arid and dry sub-humid regions, such as low and erratic rainfall over fragile soils with declining fertility due to the impoverishment of physical, chemical and biological endowments. With low and unreliable agricultural production and dwindling natural resources, livelihoods of local people populations are under considerable pressure. Households are defined as subsistence farmers because they derive roughly a 90% of their income from farming activities, earning the rest from off-farm occupations mainly trading their own commodities (farm-products) to the local market or to middlemen. The main food in Ntonda EPA, as well as in the whole country, is the *nsima* (maize) a thick porridge made from maize (Zea mays) and eaten with a relish vegetables and supplemented with meat and wild fruits. Most of the people can not afford to buy meat, milk, vegetables, eggs and fruits other than mango and bananas produced locally. These conditions, that which in recent years led to several severe food shortages, are directly linked to the quality of soils.

Figure 1. Map of five villages.

Anthropic factors

The assessment study has been carried out in five villages of Ntonda EPA in Southern Region of Malawi (Fig. 1). Specifically the five villages are described in Table 1.

Table 1. Characteristics of the five villages.

Villages name	Average area	Families (beneficiaries)
Nsomba	20 ha	10
Maganga	10 ha	10
Malanga	10 ha	10
Kajiya	10 ha	10
Mboma	15 ha	10

Table 2. Agro-ecosystem of the five villages.

Villages plot	Coordinates	Main characteristics	Farming system
Nsomba = 2 plots	15° 51' 03'' S 35° 01' 30'' E	1. For the first plot we have chosen a steep slope field, terraced, frequent presence of stone, high exposition to the wind and sun, no trees around. 2. For the second plot we have chosen a gentle slope field, insignificant presence of stone, Bamboo trees on one side, nearness to water.	1. Maize 2. Maize, pigeon peas
Maganga = 1 plot	15° 52' 30'' S 35° 01' 01'' E	For the plot we have chosen flat, scarce presence of stone, nearness the main road, high exposition to the sun, no trees, no water nearby.	Maize, pigeon peas
Malanga = 1 plot	15° 52' 10'' S 35° 01' 13'' E	For the plot we have chosen gentle slope, scarce presence of stone, nearness the main road, high exposition to the sun, no trees, no water nearby	Maize, pigeon peas
Kajiya = 2 plot	15° 52' 47'' S 35° 01' 19'' E	1. For the plot we have chosen gentle slope, presence of a dambo area, common presence of stone, surfacing parental rock, presence of banana trees. 2. For the second plot we have chosen a f 3. lat field, scarce presence of stone, few precence of gricidia and acacia trees, high exposition to the sun.	1. Maize, cassava, beans 2. Maize
Mboma = 2 plot	15° 52' 02'' S 35° 00' 29'' E	1. For the first plot we have chosen a flat field, near to a Dambo, insignificant presence of stone, presence of palm trees, insignificant presence of stones 2. For the second plot we have chosen a gentle slope field, common presence of stone, quite near to the Dambo area, high exposition to t he sun no trees.	1. Irrigated farming, Maize, field peas, fresh vegetables, tomatoes 2. Maize, pigeon peas

Working on the assumption that problems with maintaining soil fertility will be more pronounced in densely populated areas, these villages were chosen on the basis of anthropic pressure on the fields, as well as for their agro-ecological characteristics and farming systems.

A participatory method, based on a social survey, was carried out in order to sample representative and accessible plots within each village that were characterized by a high anthropic factor. As we can see from the Table 2, the dominant farming system is based on rain-fed crop production, supplemented by varying degrees of chemical fertilisation, where water supplies permits (in the so called *dambo* areas) limited furrow irrigation. The main rain-fed crop are maize and rarely field beans and groundnuts, which are grown in monoculture or as mixed crops complemented by smaller areas of pigeon peas (*Cajanus Cajan)* and cassava. The few plots which are watered during the dry season, are dominated by horticultural crops, as fresh salad, chinese cabbage, onion, carrots and in high percentage by tomatoes. The only furrow irrigation system that we have met in one village (i.e. Mboma) is fed by the *dambo*[1].

Climate

A general comprehension of the climate at local scale has been obtained using secondary data from the national meteorological service, ei-

[1] A *dambo* is a natural ecosystem occupying a shallow, seasonally waterlogged depression at or near the head of a drainage network. *In situ* decomposition of the grass and sedge-dominated vegetation cover leads to a build up of organic matter and the creation of a hydromorphic, sometimes peaty, upper soil horizon. Hydrologically, a dambo catchment acts as a water store, releasing this as base flow to its headwater stream during the dry season. Because they retain moisture during the dry season, dambos support a vigorous growth of grasses when other forms of grazing are in short supply [Roberts 98].

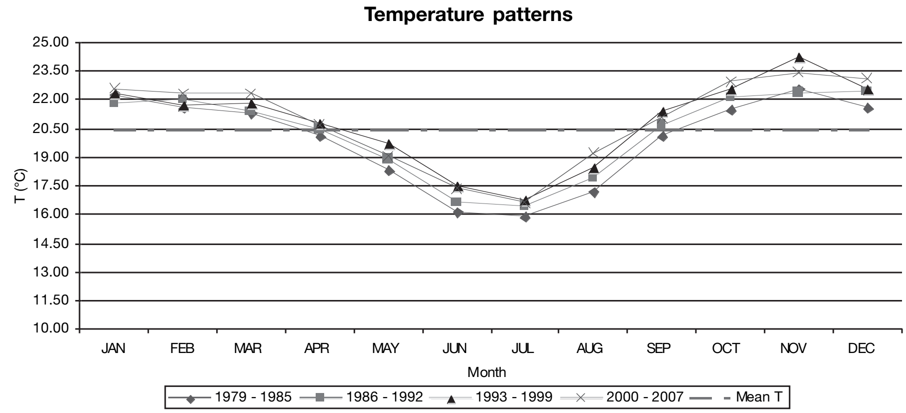

Figure 2. Temperature patterns variations.

ther because of the lack of simple meteo tools as rain gauges and temperature stations or because of the requirement to examine a wide range historical data. Hence, the study of the secondary climate data has encompassed more than 20 years, and was a crucial challenge either for the local farming system or to evaluate some climate parameters change. Changes in climate patterns have a reasonable impact on the length of growing season as well as crop growth, drought periods and carbon sequestration. It is widely understood that erratic precipitations followed by drought periods destroy the eco-system equilibrium and erode the few farmers' assets. In this framework we have analysed the climate, giving a clear idea of the type of the climate at local scale and developing some indicators suitable for the agriculture system such as the length of growing period (LGP) (IPCC, 2007).

Soil

The study of soil heavily depends on sampling strategy, including the location of observation sites, the timing of the investigation, the depth of a pit or dig (known as a soil profile), the techniques and tools of sample collection, the data analyses. This specific nature of soil makes the setting up of the sampling methodology a fundamental element of any evaluation study. Given this priority, the methodology was adopted in line with soil sampling protocol of the European Commission's Directorate General Joint Research Centre, that is the general requirements of the International Standard (ISO) and particularly the ISO 10381-4. The core of the methodology is to define a soil sampling scheme based on the so called "Area Frame Randomised Soil Sampling" (AFRSS). This is a randomised sampling template that is represented by a grid of 100 cells to be overlayed on the study area, thus allowing to carry out a modified random sample collection with a distance threshold. The numeration of the sampling cells is selected at random with particular care being placed to prevent a previously sampled cell being too close to subsequent ones, which can occur for pure random sampling plans (Stolbovoy et al., 2007).

Results

Anthropic factor results

From the social survey we have obtained these main results:

- the area is a high population density zone, which reflects a high agriculture mean density, that is over 70 plots per km^2;
- a low percentage (10%), of the selected plots is characterized by an efficient annual intercropping system able to enhance the agrosystem biodiversity;
- a widespread use of chemical fertiliser (99% of the plots) and the lack of knowledge about the benefits of organic amendments.

Climate results

The evaluation of climate at local scale encompassed temperature, rainfall, humidity parameters and affects land potentials trough drought, flooding and incipient desertification processes. The study has looked at the time series of temperature based on monthly data during thirty years ranging from 1997 to 2007. The analyses

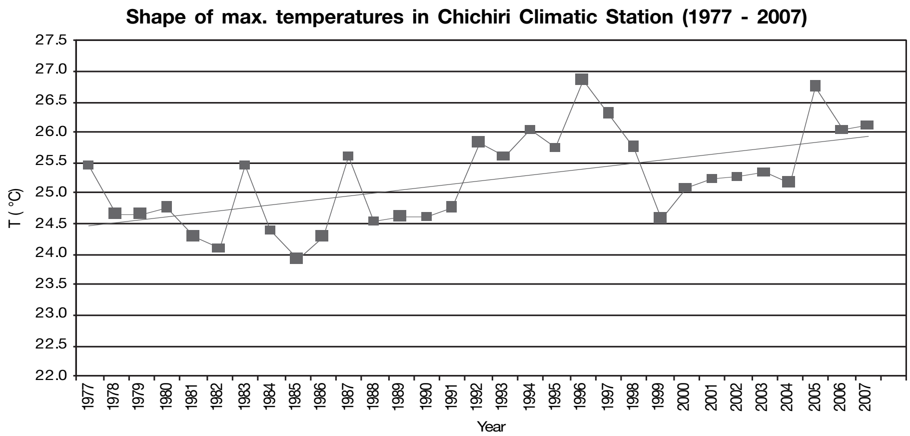

Figure 3. Historic series of maximum temperatures.

of secondary data has aimed at establishing a trend of temperature among last thirty years in order to evaluate all temperature patterns and to extrapolate some extreme events out of the ordinary shape temperature profile and anomalies respect on the mean value, that is 20,47 °C. In line with the IPCC methodology (IPCC, 2007) the study has aimed at looking into temperature patterns in order to understand some changes in temperature profiles. Thus, the range of values of secondary data has been categorised into four sets describing about seven years each and the variability has been analysed.

Temperature patterns have not changed during the period under observation, since we have ignored a fluctuation of less than 5%; but a deeper study is suggested for a longer period of years in order to calculate the climatic anomalies and the possible change in the curve shape during the last seven years. Last period, indeed, presents some warmer months especially during the so called rainy period. This fact is due to a general increase of the maximum temperatures as in the Figure 3 is sketched out.

Since it is true that the highest temperatures increase as underlined by the red trend line (Fig. 3), we can say it does not represent an anomaly for the climate. Namely temperature trend line has a positive linear slope and shows a 6% increase in temperature during the last thirty years and about 3,2% from mean value (25,2 °C).

Rainfall is considered, especially in Sub-Saharan regions, the most important source of water, that is essential to life and is an essential resource for nearly all human activities. It is intrinsically linked with climate trough a large number of connections and feedback cycles, so that any alteration in the climate system will induce changes in the hydrological cycle. Precipitation is the primary factor controlling the origin and persistence of drought condition, defined as sustained and extensive occurrence of

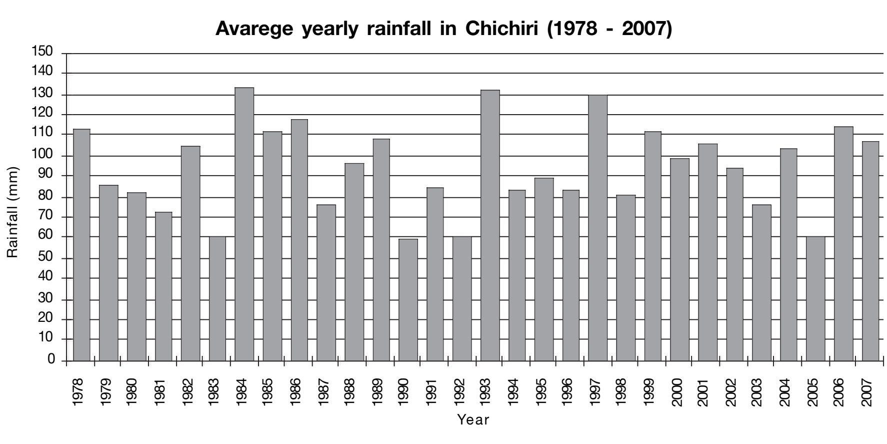

Figure 4. Average yearly rainfall distribution.

below-average water availability. Throughout the past thirty years, the average rainfall distribution is described in the picture 4, being the mean value 95 mm. The trend line (in red) indicates a very light increase in rainfall precipitation during the overall period considered of about 2%.

Although the positive linear slope of average yearly rainfall denotes a stable supply of water, it is necessary to highlight the variability of the rainfall distribution of one mean year across two equivalent short periods: 1987-1993, 1994-2000 and 2001-2007. This helps to understand the climate hazard occurrences, such as years of severe drought in 1992 and 2005 and partially in 1998. The comparison between the yearly mean rainfall distribution across two near periods of seven years has highlighted that, as we see in the graph below (Fig. 5), most remarkable variations in rainfall patters are during the so called dry season, namely ranging from May to June where water availability decreases respectively of 39.4% and of 25.8%, whereas during September temperature increases of about 69%.

The linear combination of the two most important climatic factors (rainfall and temperature) define the aridity conditions. Aridity is a critical environmental factor in determining the evolution of natural vegetation by considering water stress, which may occur reducing vegetation cover. Firstly, the analysis developed the bio-climatic index, the Bagnouls-Gaussen diagram, in order to quantify the length of dry period at local scale. The Bagnouls-Gaussen bioclimatic aridity index relates mean air temperature to precipitation on a monthly basis and provides a measure of water stress over vegetation. Vegetation cover increases with increasing soil depth and decreasing aridity. The Bagnouls-Gaussen bioclimatic aridity index represents the period and the comprehensive entity of hydric deficiency and it is calculated following this equation:

$$BGI = \sum_{i=1}^{i} (2T_i - R_i) \cdot k$$

where:

T_i is the temperature of the i month (°C);

R_i is the total monthly mean precipitation of the month i (mm);

k represents the frequency of the condition $2T_i$-$P_i > 0$ for the month i (%).

According to the graph (Fig. 6) a month is called arid when the value of rainfall is lower than the double value of the mean temperature, that is *P_ 2T*. As illustrated by the graph, the rainfall curve goes down the temperature in order to indicate the inversion of the hydric balance during the dry season; thus, at local scale, we estimated at least five full months of water deficiency from May to September.

An additional aridity index was considered during the baseline study, in order to classify the climate of the targeted areas and to establish the risk of desertification. The atmospheric conditions that characterise a desert climate are

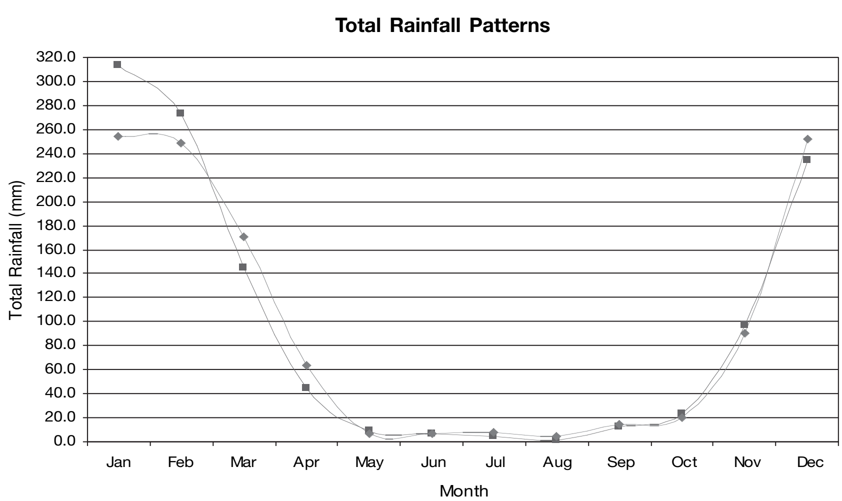

Figure 5. Comparison of two mean Rainfall distribution periods.

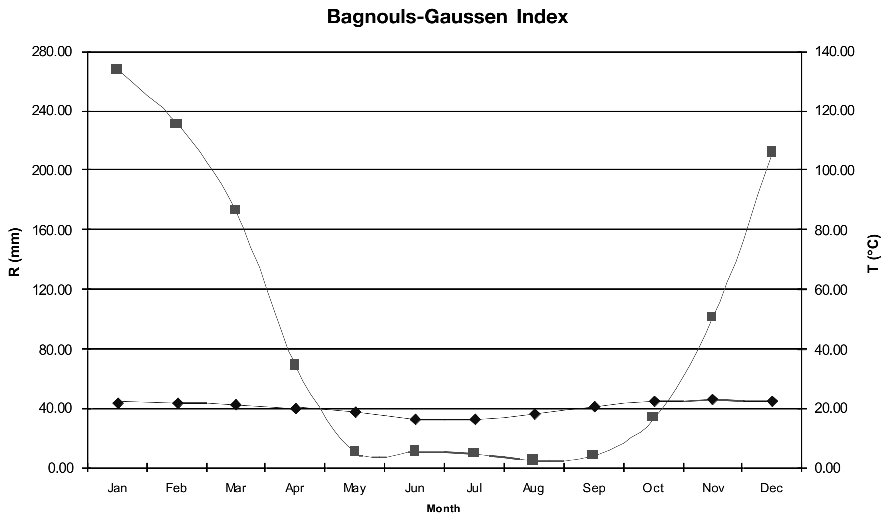

Figure 6. Bagnouls-Gaussen bio-climatic diagramme.

those that create a large water deficits, that is, potential evotraspiration (PET) much greater than precipitation (R). One of this is the FAO-UNEP bioclimatic index:

$$I_{UNEP} = \frac{R}{PET}$$

where:

R is the annual mean rainfall (mm)

PET is the mean annual potential evotraspiration (mm)

This index defines five climatic zones, assigning a specific score to each as described in the following Table 3. The quality of the indicator depends on the number and distribution of meteorological monitoring stations over an area. Since meteorological parameters are very variable in time and space, the stations have to be evenly distributed across an area covering the whole range of climatic conditions.

According to the UNCCD definition, an area which are sensitive to desertification can be divided into the three categories, namely arid, semi-arid, dry sub-humid. In line with this classification the study applied the mentioned categories to the target area.

Table 3. UNEP aridity index classification in climatic zones.

I_{UNEP}	*Climatic zones*
< 0.05	Hyper-arid
0.05-0.20	Arid
0.20-0.50	Semi-arid
0.50-0.75	Dry sub-humid
> 0.75	Humid

One area becomes naturally desertified when the ratio R/PET acquires values below a certain threshold, regardless other components. In contrast, when the ratio exceeds an upper threshold, desertification does not advance (FAO, 1977). The following scheme is proposed for the treat of desertification induced by the climate:

$$(\textit{No Risk of Desertification})\ 0.75 \le \frac{R}{PET} \le 0.05\ (\textit{Desertification})$$

At local scale we have found that 30% of events occurred across thirty years within the dry sub-humid zone treatable as at risk of desertification, but if we divided the long period considered into three equal periods we have obtained an average climate, at local scale, treatable as humid (Tab. 4).

Soil results

The main results achieved from the analyses of soil samples has aimed at identifying the current state of soils and the main constrains to sustainable development at farm level. The diagnostic processes started with participatory meetings to understand the use of soils at local

Table 4. UNEP aridity index values.

CHICHIRI Meteo-Station	1980-1986	1987-1993	1994-2000	2001-2007	1978-2007
Aridity index: I_{UNEP}	0.96 HUMID	0.84 HUMID	0.86 HUMID	0.88 HUMID	0.89 HUMID

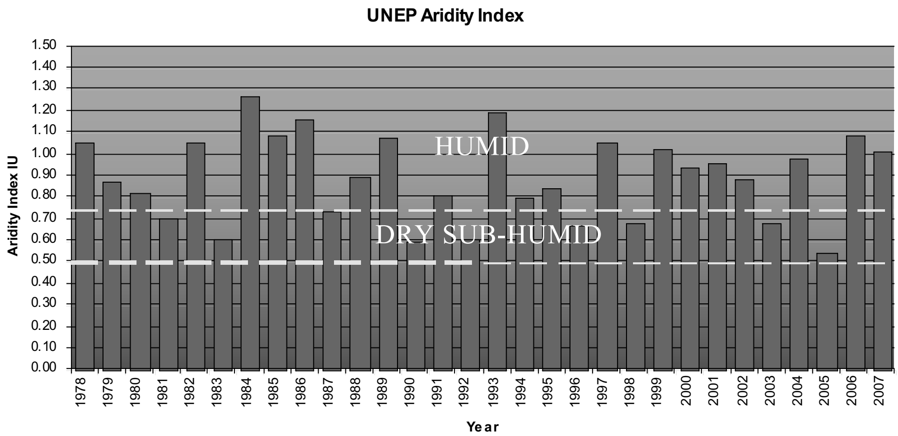

Figure 7. UNEP aridity Index.

level and proceeded with the collection of sample from eight representative plots as described in Table 2. On this type of soils a successful crop could depend on external nutrient supply, mainly provided by fertiliser applications based on Nitrogen and Phosphorus, more rarely on Potassium. To ameliorate the fertility of the soil (especially very acid soil, not in our case) and to improve the efficiency of the plant nutrient uptake, it is useful to keep an eye on the cation exchanges and the Ca/Mg ratio. The cation exchange of a soil mainly depends on type and amount of clay, organic matter and pH. Figures X Y Z represent the analysis results of soil samples took from the five villages.

The best pH for plant growth and good yields is between 5.5 and 7, that is from slightly alkaline to neutral conditions; mainly because within this range there are sufficient exchangeable Calcium and Magnesium, which means availability of nutrients (N, P),low presence of toxicity (Al) and also low water requirements. The samples from the target areas have presented common values in pH, every of them up to 6 till to 6.30, the low variations are represented in the distribution graph Figure 8.

The Ca/Mg ratio, which should be maintained between 2 and 7. High amount of Magnesium may cause Ca deficiency and possible presence of Al in reasonable toxicity levels (FAO, 2004). The graph shows that about 75% of the soils samples have a ratio around 2 and 2.50, while the others below 3. the variation of the ratio depends on the pH values, with increasing acidity, aluminium ions in the soil are mobilized, which are toxic to most plants and have harmful effects on aquatic environments (Fig. 9).

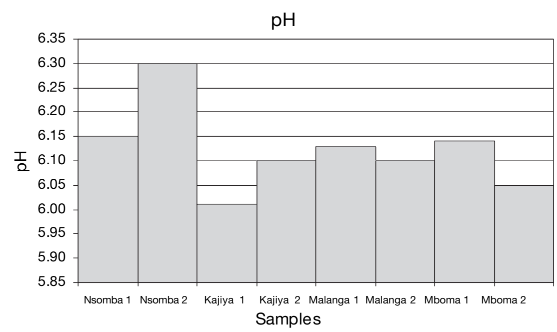

Figure 8. Distribution of pH in soil samples.

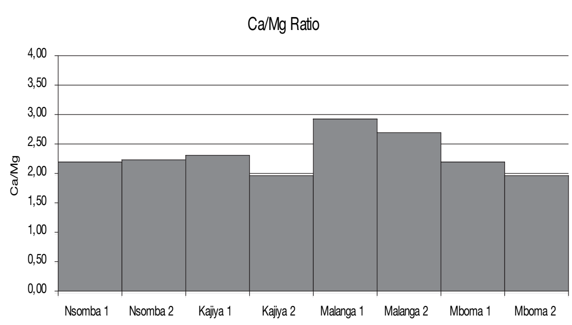

Figure 9. Distribution of Ca/Mg Ratio in soil samples.

Organic matter (OM) is a significant contributor to the overall nutrient demands of plants (N, P, and S.) particularly in zero or low external input systems. Before the widespread introduction of manufactured fertilisers, organic residues were the only means of supplementing many of the nutrients (such as nitrogen) to the soil. In non-cultivated soils it is likely that more than 95% of the Nitrogen and Sulphur is found in the soil organic matter, and possibly more than 25% of the Phosphorus; similar percentages are likely to be found in organically farmed soils. In the Figure 10 we note that the distribution of the overall OM values are below 2%, particularly more than 60% of the samples are below 1% of organic matter content. These values represent a low content of OM, which could mean an alarm bell if nobody is going to take corrective measures act in the short term; indeed, even if threshold values for soil organic matter content are not so clear, the loss of the OM and its low percentage in topsoil reduces soil fertility, degradates soil structure, facilitates the erosion and eventually leads to desertification.

As we have already seen, desertification is a complex phenomenon where both climate and soil are active drivers. In the process, OM is often considered a key factor either in soil degradation and in soil rehabilitation and may be suggested that qualitative threshold values above which the function of the soil may operate optimally be set from 1,5% of C content for aggregate stability and 2% of C content for desertification. So, strictly looking at the soil factor, our target villages may be subject to early desertification processes.

The carbon to nitrogen (C:N) ratio in agricultural soils has commonly been proposed as an indicator of overall nitrogen cycling, plot productivity, fertiliser use and nitrogen leaching in plant ecosystems. This ratio effectively integrates the effects of climate, plant cover type, and the role of soil carbon in nitrogen cycling. A healthy system, with a soil C:N ratio of approximately 12-15, will have high nitrogen uptake and high plant productivity (Harawa et al., 2006). In turn there will be low nitrogen leaching and little potential to overload aquatic ecosystems with nitrogen. This threshold depends of course on the type of crop and, above all, on the climate conditions in the target areas. In European climatic zones a good C to N ratio is around 20. The soil C:N ratio have been easily developed from samples analysed in the laboratory, and because it integrates climate and site variables, it is a reasonable proxy indicator of nitrogen cycling and plant (crop) health. All the samples analysed are above 10 but under 15, which represent a good value for the plants and the crop in tropical zones. Larger ratios tend to have low to no nitrate leaching, but with high rates of dissolved organic nitrogen or inorganic ammonium leaching. The samples values are representative of the high mineralisation of nitrogen respect to the presence of organic matter and underline the high pressure of the farmer behaviour to the state of the soil (Fig. 11).

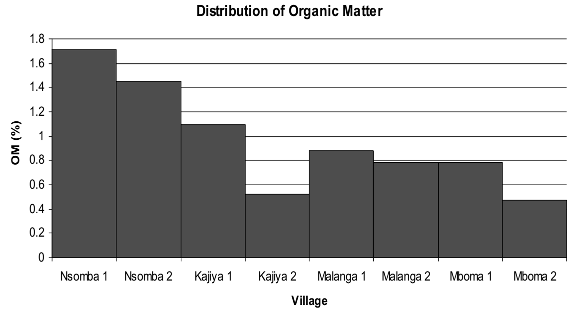

Figure 10. Soil organic matter content in study target villages.

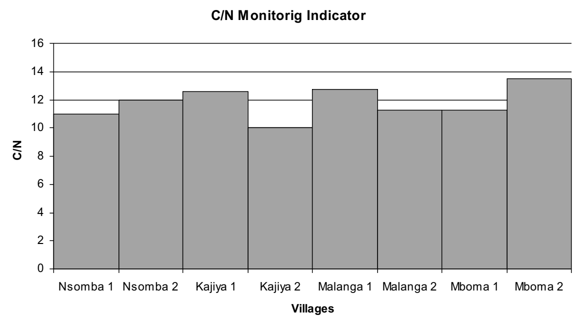

Figure 11. Carbon to Nitrogen ratio in the target villages.

Conclusions and discussion

A general picture of the state of the agroecosystem constraining the development of the farming system in five villages of Ntonda EPA was obtained through technical inspections, *in situ* sample collection and sample data analyses, paying attention to the participatory method with the involvement of local stakeholders, particularly the people around the farming system of the villages. The main conclusions are summarised in the list below.

- Climate: it was a crucial factor to evaluate the aridity condition that leads to the development of an indicator to establish that our target area, under the climatic point of view, is not at risk of desertification. Climate is also a fundamental concern for soil formation and it has, mainly trough the influence of temperature, a critical influence on C mineralisation and accumulation rate. The shape of maximum temperatures do not represent a high concern in the C sequestration rate.
- A risk of over-exploitation of the soil resource: the widespread use of inorganic fertiliser and the lack of organic matter in the topsoil, plus an inadequate management of the soil resource could increase the number of depleted areas prone to desertification.
- Low ratio of Carbon to Nitrogen tends to result in faster rates of release from organic sources and high mineralisation of nitrogen.
- The low percentage of the intercropping system in agricultural practices, especially with legumes plants (pigeon peas, beans), is not sufficient to enhance the performance of soils in acquiring biodiversity and organic carbon from crops variations.
- Continuous cultivation of the same land without adding organic amendments, such as manure, could degenerate the plough layers until desertification.
- Lack of a correct and sustainable management of soils can be a factor affecting household food security.

The results described in the above chapters, allow us to define some preliminary recommendations concerning the following main aspects:

- soil fertility in our target villages, and generally in Malawi agro-environment, occurs mainly in the top soil and largely depends on soil organic matter content. Although crop yields are not directly correlated to the amount of organic matter in the soil, the lack of it will cause the breakdown of soil structure, increased runoff, accelerated erosion and increased soil compaction, which in turn will prevent the development of a healthy root system and cause a reduction in nutrient and water availability to the plant population. Thus, for a soil to be productive, it must be properly managed to ensure that the physical properties do not deteriorate and that organic matter and nutrients are not lost;
- the most effective ways to increase levels of Soil C are to change the land use promoting afforestation or the establishment of grasslands, either permanent or temporary, which will generally result in an increase of soil C sequestration. Other solutions are to encourage practices which protect the soil, decrease the losses and increase the inputs of organic matter like the introduction of organic amendments in the topsoil as manure and slurries;
- besides, it is important to note that the organic matter from the crop residues the, and nutrients they contain, can be used to improve the soil structure and fertility and should not be lost. Indeed, under the current situation, farmers lose this source of nutrients as they burn large amounts of agricultural refuse;
- the water resource should be maintained and conserved where it falls, planning its careful utilisation in order to either prevent natural hazards, like run-off for agricultural land and flood, or to be stored for human utilisation as vital resource for food security;
- intercropping and/or crop rotation are strictly recommended in order to ease pressure on the topsoil and to prevent a loss of biodiversity in the soil depth.

In summary, there is sound need to rehabilitate degradated ecosystems, vulnerable lands needs appropriate planning programs and farseeing policies. At this purpose, it is useful and interesting to think that in the context of our target villages based on rainfed agro-ecosystem, inappropriate patterns of management may lead to a downward spiral of ecosystem degradation, as illustrated in Figure 12, whereas appropriate measures of soil and water conservation hold the promise of sustainable development (Hillel and Rosenzweig, 2002).

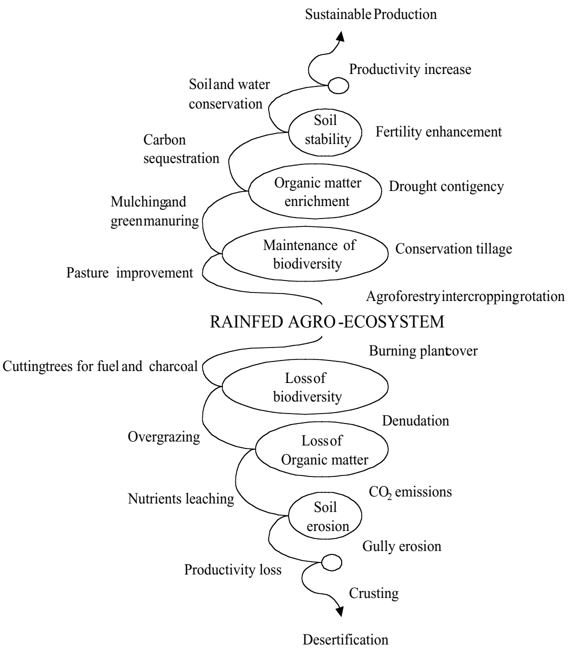

Figure 12. The upward and downward spirals of sustainable versus unsustainable rainfed agro-ecosystem.

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