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Groundwater: a matter of quality and quantity in Limpopo National Park

Stefania Vitale[1], Maurizio Barbieri[1]*, Angela Nigro[1], Giuseppe Sappa[2]

[1]Department of Earth Sciences, Sapienza University of Rome, Italy
[2]DICEA, Department of Civil and Environmental Engineering, Sapienza University of Rome, Italy

*Corresponding author: Prof. Maurizio Barbieri, Tel +39-0649914593; E-mail: maurizio.barbieri@uniroma1.it

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Abstract

Groundwater is a matter of quantity and quality, especially where groundwater is the primary source of water for people living in the SADC (Southern African Development Community) region, because it is used, extensively, for multiple purposes, covering a crucial role in supplying water for farming and domestic uses.
The large SADC area has limited surface and groundwater resources, because most of the water management areas are severely stressed and many people still do not have access to the accepted minimum supply of water. Increasing water demand, population growth, abstraction of surficial water and climate change are the main drivers on groundwater resources in SADC Region.
Water scarcity is becoming a limiting factor for economic development in the basin, as it is in many other basins located in developing countries with arid climates, lagging water infrastructure development, and rapidly increasing populations.
The first step for a sound water resources planning is the knowledge of the hydrogeological conceptual model in the area under study. Most rural communities in SADC are served by groundwater resources. Access to these resources is one and important critical factors. The lack of management of groundwater resources is also evident in community water supplies, where in some cases groundwater resources are developed in unsustainable way.
The aim of the present study is to design the water resources status quo, defining the hydrological conceptual model assessing the hydrogeochemical properties of groundwater in the Limpopo National Park, one of the jewels in the crown of Mozambique's protected areas, in order to quantify the water balance and to provide recommendations for a future correct management, focusing future research on this subject.

Keywords: *hydrological conceptual model, meteorological stations, hydrogeochemistry.*

Introduction

The present study is developed in the activity research of the SECOSUD Phase II project funded by the Italian Ministry of Foreign Affairs in the SADC [1]. The Limpopo National Park, in the Limpopo Basin, is the area of interest in the Mozambican part Limpopo River Basin (**Fig.1**).

The first step for a sound water resources planning is the knowledge of the hydrogeological conceptual model in the area under study and, on the second, the elaboration of analytical results to have a geochemical characterization of groundwater resources.

The Limpopo River Basin, located in Southern African Development Community, is an important agricultural area rich from a biodiversity point of view and with extraordinary mineral resources.

Groundwater management in Mozambique is poorly developed [2] and consequently current water uses in Mozambique are poorly monitored, it is not clear known how much water is really consumed, especially by the many small-scale users of surface and shallow alluvial groundwater [3].

Lack of management has already led to contamination and overexploitation of aquifers in some areas and could result in additional water supply problems, land subsidence and deterioration of groundwater dependent ecosystems [4].

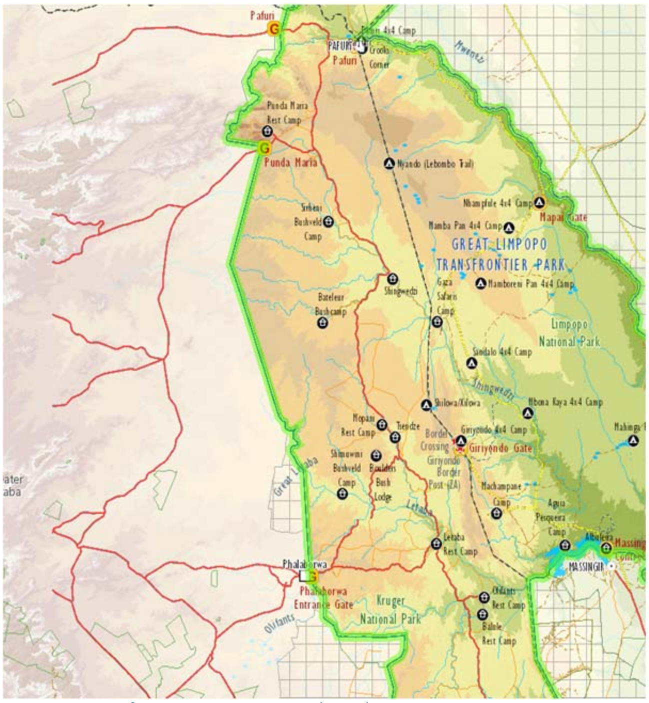

Fig.1 Map of Limpopo National Park

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Materials and Methods

The Limpopo National Park hasn't a sufficient coverage of rainfall records for his regional scale basin. Operative rainfall stations are mostly located on the East Southern part of Mozambique (**Fig.2**).

Fig. 2- Map of Mozambique Rainfall monitoring stations

According to INAM, Instituto Nacional de Meteorologia of Mozambique, the current monitoring rainfall network is made by the following gauge station (**Table 1**):

Meteorological Stations	Period of observations		Functionality
Massangena	1960	2015	Operative
Chicualacuala	1961	2003	Inoperative
Chigubo	1961	1978	Inoperative
Mabalane	no data	no data	Operative
Massingir	1961	2014	Operative
Funhalouro	1951/2003	1980/2007	Inoperative
Chibuto	1965	2014	Inoperative
Bilene-Macie	1965	2014	Operative
Xai-Xai	1951	2016	Operative
Panda	1951	2016	Operative
Massinga	1951/2003	1980/2016	Operative
Ndindiza	2006	2016	Operative

Table 1- Current rainfall monitoring network (after INAM 2016

In the meanwhile INAM send us historical series of meteorological data, referring to daily rainfalls, temperature and humidity, they were available the precipitations and temperature historical series, collected in 53 years of measurements, all over Mozambique.

These records data were collected in meteorological network stations in Mozambique, produced by the Climatic Research Unit (CRU) of University of East Anglia (UEA) and published on the bank world group, by Climate Change Knowledge Portal.

The main goals of the present study are to evaluate the total rainfall dropped on Mozambique territory to understand rainfall variability in time and to set up groundwater geochemical characterization, in the aim of addressing a correct management of water resources in the area of Limpopo National Park.

On the first the study aims to evaluate the total rainfall received at Mozambique to understand rainfall variability in time. Monthly precipitations historical series, referred to 53 years of observations were compared to the monthly precipitations historical series referred to 23 years of observations. The second step includes groundwater characterization, related to groundwater wells, in the Limpopo National Park buffer zone.

The hydrogeochemical characteristics of the buffer zone of Limpopo National Park are still poorly understood. The UNESCO defines buffer zone as "an area that should ensure an additional level of protection to areas recognized as a World Heritage sites" with an emphasis on the importance of these areas in the proper management of protected areas. In this framework this paper is aimed to preservation and conservation of biodiversity and to identify water quality assessment of the study area.

Groundwater resources were investigated in two different campaigns zone carried on in October 2016 and in March 2017, to analyze different properties, due to seasonal changes [5]. In these investigation campaigns, they have been visited 12 groundwater wells, and the present study shows the first results coming from their qualitative characterization. Here their geographical location is reported (**Fig. 3**).

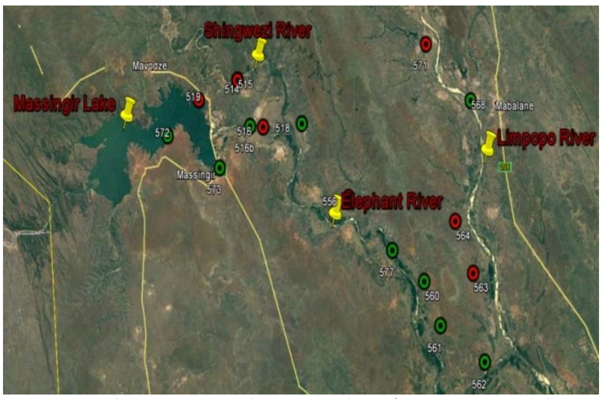

Fig. 3: Study area groundwater and surface water sampling

The study area: geological and hydrogeological features

The Limpopo National Park is spread on an area of about 11.433,156 km^2 (**Fig.4**).

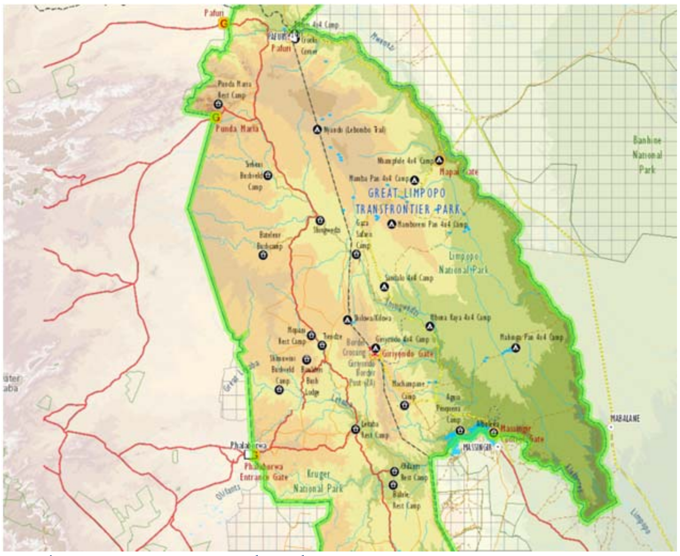

Fig.4 - Limpopo National Park area

The geographic position of Mozambique in the framework of Gondwana, makes the country a geologically important terrain particularly because it contains boundaries between cratonic and mobile belt terrains. The crystalline basement of Mozambique belongs to three major 'building blocks' or terranes, East, West and South Gondwana, that collided and amalgamated during the Pan-African orogeny to form the Gondwana Supercontinent [4].

In southern and middle Mozambique, the Phanerozoic cover can be divided into the Karoo Supergroup (Permian-Jurassic) followed by a succession of Cretaceous and younger sedimentary formations, partly associated with the development of the East Africa Rift System Phanerozoic sedimentary rocks of the Mozambique Basin occupy vast areas in southern Mozambique (**Fig. 5**).

Geologically Southern Mozambique, is poorly known due to the lack of more detailed maps [6]. The basin is floored by Jurassic volcanic and filled by Early to Middle Cretaceous and younger sedimentary rocks. Mapai formation occurring in the western part of the Gaza Province of southern Mozambique, is divided into 6 members that are characterized by calcareous siltstones, calcareous sandstones and calcareous conglomerates, locally calcified and oxidized. The Mapai rocks typically were deposited from both continental and coastal sedimentation environments, [7] and are locally good outcropping in the river bed of the Limpopo, dos Elefantes and Singuédzi Rivers. In the west, the lowermost limestones of the Mapai Formation overlie volcanic rocks of the Karoo age.

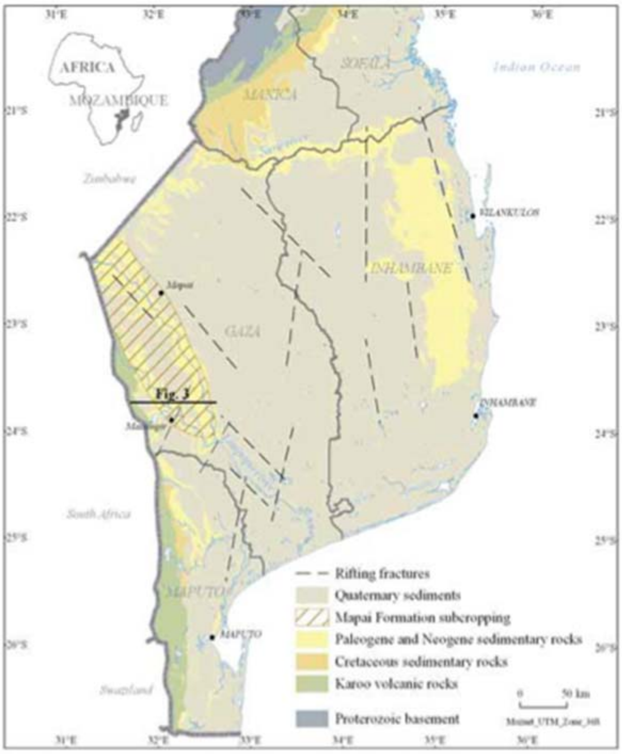

Fig. 5- Simplified geological map of southern Mozambique and the extension of the Mapai Formation. (modified after L.chelt 2004 and GTK Consortium 2006).

Fig.6 Mapai formation in the study area.

The hydrogeology of the basin is dominated by the Limpopo Mobile Belt, a metamorphic zone of high grade, that lies in the collision zone between theKaapVaal craton and the Zimbabwe craton, two Archeancontinental shield areas. Due to the metamorphic process, these rocks have very limited primary porosity or permeability and the groundwater occurrence is largely restricted to secondary features such as fault zones, joints, lithological contact zones [8].

The Karoo Volcanics of the Limpopo Basin in Mozambique are hydrogeologically quite similar to the crystalline rocks everywhere else in the Limpopo basin, where primary and secondary fractures are the most important water bearing features [9]. The water bearing formations of the Basement complex are low productive and discontinuous.

Material and Methods

The methodology of inverse Groundwater Budget Technique

The hydrogeological inverse budget [10] was applied to for the assessment of potential infiltration.
This methodology has been tested in over more 500 sites around the world [10].
First of all, meteorological data about Mozambique has been studied. Annual Average Precipitation (**Fig.** 7) and Annual Average Temperature (**Fig.8**) referred to observations data years 1960-2012 has been calculated ranging on the regional scale of Mozambique. Annual Average Precipitation is equal to 978,7 mm and Annual Average Temperature is 23,8 °C.

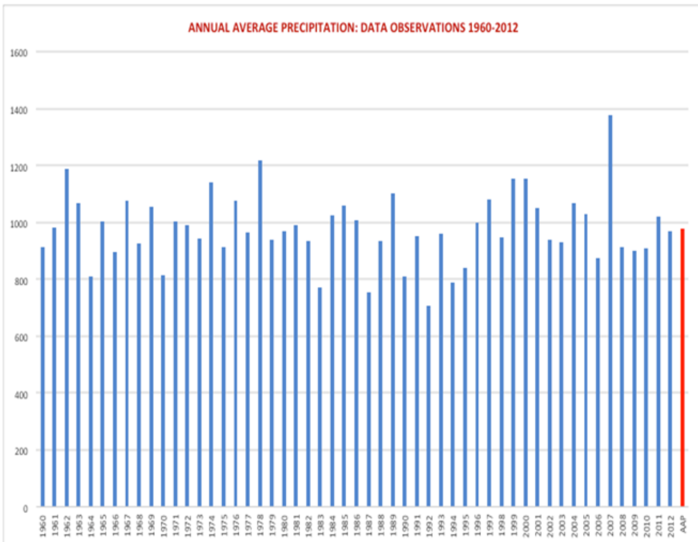

Fig. 7- Annual Average Precipitation observation years 1960-2012

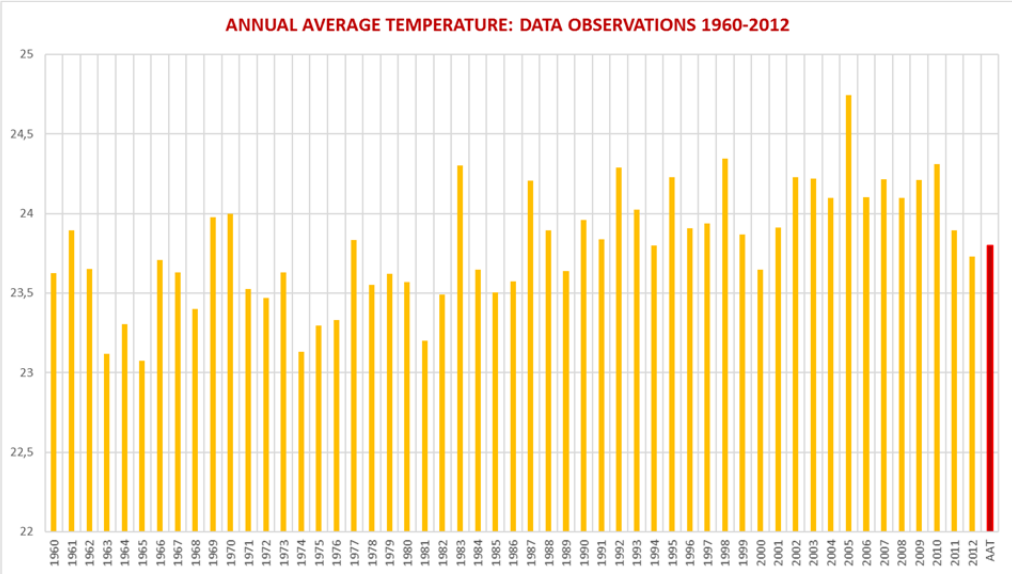

Fig. 8 - Annual Average Temperature observations years 1960-2012

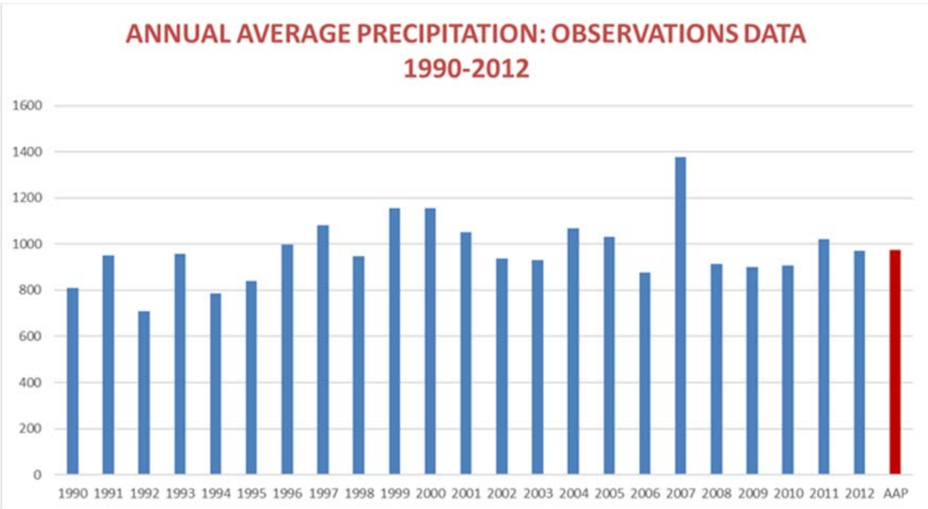

Fig. 9 - Annual Average Precipitation observations years 1990-2012

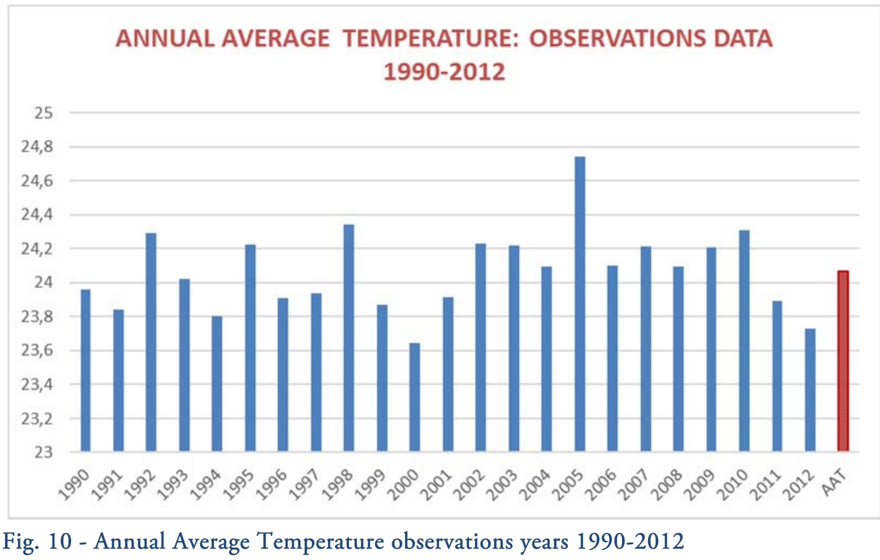

Fig. 10 - Annual Average Temperature observations years 1990-2012

As second step, Annual Average Precipitation, equal to 973,3 mm and Annual Average Temperature, equal to 24,7 °C referred to observations years 1990-2012 have been computed and represented in **Fig. 9** and **Fig. 10**.

These results suggest that there aren't sensitive modifications in precipitation regimes to identify a trend evolution in the annual average precipitation of the historical series considered, on the other hand the increase in Annual Average Temperature seems to be sensitive, as it is of 0.5 °C.

The present study is related to the application of the inverse water budget technique, in order to estimate the Effective Infiltration, evaluating the precipitation and temperature historical series referred to the period 1990-2012, ranging from the regional scale of Mozambique to the local scale of Limpopo National Park. Because of the lack of meteorological data about Limpopo National Parka area, the Mozambique rainfall data have been applied to the focus area.

This methodology gives us a general assessment of potential water resources in areas where there is a scarcity of data

The Effective Infiltration is assessed from the hydrological balance performed for the study area, taking in consideration the mean precipitation and thermometric data and the surficial lithology.

The basic information required to assess the effective infiltration are yearly average precipitation P, yearly average atmospheric temperature T, yearly average effective evapotranspiration Er which is estimated by Turcs' Formula and the infiltration coefficient χ, evaluated taking in consideration the conditions of outcropping rocks, from the Soil and Terrain database (SOTER) for Southern Africa [11], occurring in the area of Limpopo National Park (**Table 2**).

The Turc's formula is given below:

$$ETR(mm) = \frac{\overline{P}}{\sqrt{0.9 + \left(\frac{P^2}{L^2}\right)}}$$

where:

ETR = Annual Average Effective Evapotranspiration (mm)

P = Annual Average Precipitation (mm/y)

L = thermal indicator, defined by the equation L = 300 + 25Tc + 0.05Tc3

Standing on the Soil and terrain SOTER database, the Limpopo National Park rock outcropping include the following formations:

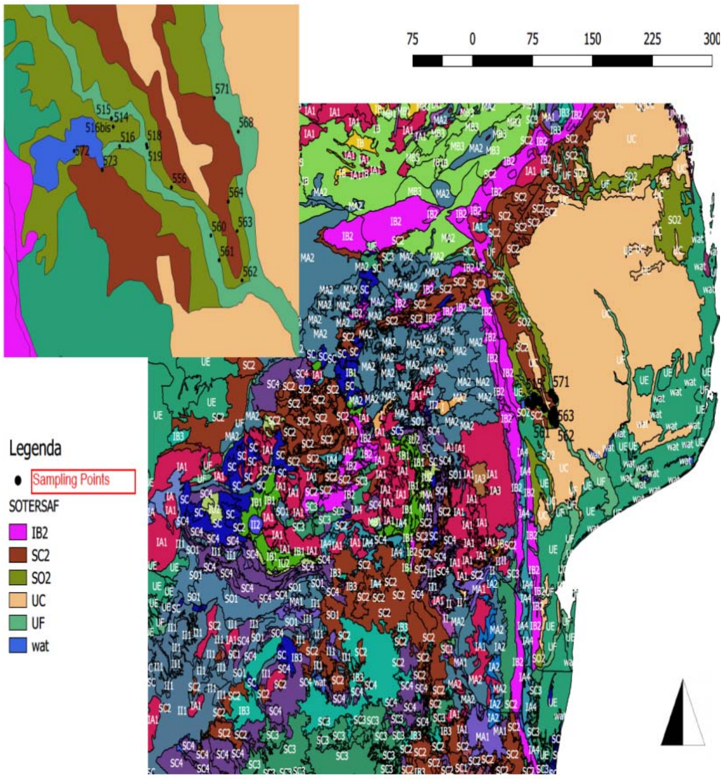

Fig.11- Lithological Map of Mozambique and Limpopo National Park.

Lithological description of Limpopo National Park (as Sotersaf)		
Major Class	**Group**	**Type**
Unconsolidated	UF	Fluvial: Sediment generally consisting of gravel and sand or silt and clay
	UC	Colluvial : Massive to moderately well stratified non sorted to poorly sorted sediments
	UE	Eolian: Sediment consisting of medium to fine sand and coarse silt particle sizes
Basic Igneous rock	IB2	Basalt
Clastic sediments	SC2	Sandstone, graywacke, arkose
	SO2	Marl and other mixtures

Table 2- Lithological description of Limpopo National Park.

The potential infiltration index χ varies between 0 and 1, depending on rock outcropping conditions, in the area under study (**Table 3**). The infiltration coefficient χ has been estimated on the basis of a range rating assessed on the basis of the hydrogeological conditions and surficial lithology [16].

Rock outcropping	Potential Infiltration Index
Group	χ
UF	0,15
UC	0,65
UE	0,15
IB2	0,75
SC2	0,3
SO2	0,1

Table 3 – Potential Infiltration Index

The average yearly effective precipitation is calculated as follows:

$$Q = P - Er(mm/y)$$

The obtained value multiplied by the infiltration coefficient χ gives the value of the effective Infiltration:

$$I = Q * \chi(mm/y)$$

Group	χ	Q (mm/y)	I (mm/y)
UF	0,15	109,81	16,5
UC	0,65	109,81	71,4
UE	0,15	109,81	16,5
IB2	0,75	109,81	82,4
SC2	0,3	109,81	32,9
SO2	0,1	109,81	11,0

Table 4 – Effective Infiltration related to any outcropping formation

The components in the water balance equation P= I+Etr+I are

P: Precipitations (mm/y)

Q: Effective Precipitation (mm/y) = P-ETR

I: Effective Infiltration = Q χ (mm/y)

R: Runoff = Q-I (mm/y)

Each component are so estimated:

Group		Q (mm/y)	I (mm/y)	ETR (mm/y)	R (mm/y)
UF	0,15	109,81	16,5	863,4839365	93,34
UC	0,65	109,81	71,4	863,4839365	38,43
UE	0,15	109,81	16,5	863,4839365	93,34
IB2	0,75	109,81	82,4	863,4839365	27,45
SC2	0,3	109,81	32,9	863,4839365	76,86
SO2	0,1	109,81	11,0	863,4839365	98,83

Table 5 - The Methodology of Hydrogeological Inverse Budget: applied to Limpopo National Park

Changes in rock outcropping influence the Effective Infiltration and the runoff, standing on the lithological conditions as it is represented in the following pictures.

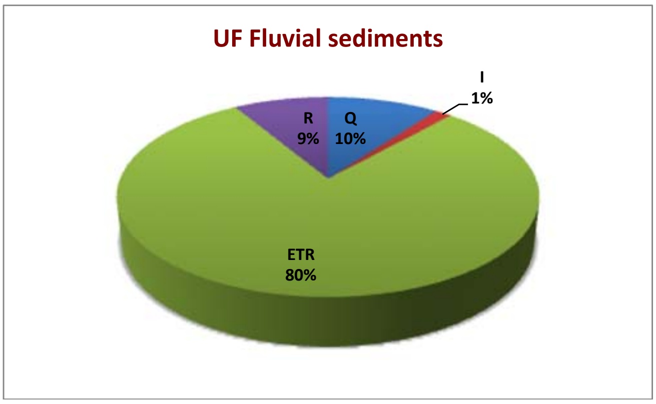

Fig.12- Hydrogeological Inverse Budget Components- UF Fluvial Sediments

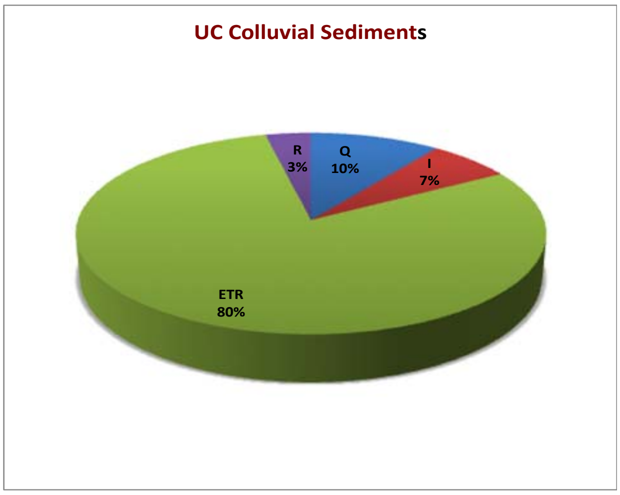

Fig. 13- Hydrogeological Inverse Budget Components-UC Colluvial Sediments

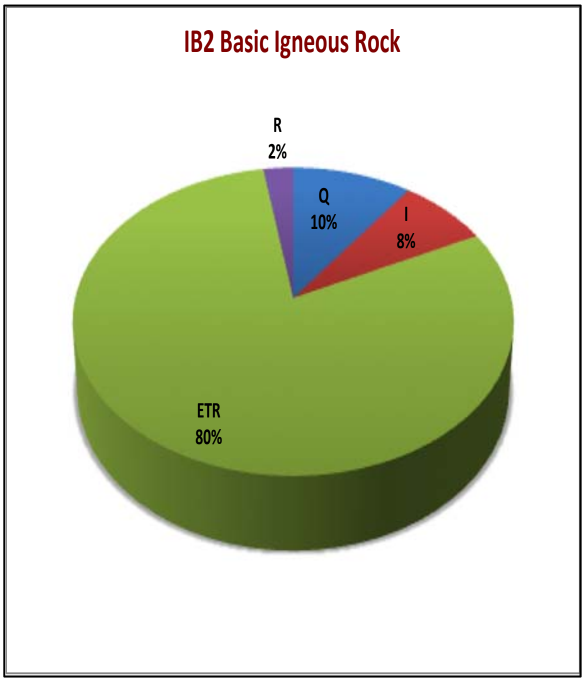

Fig.14- Hydrogeological Inverse Budget Components- UE Eolian Sediments

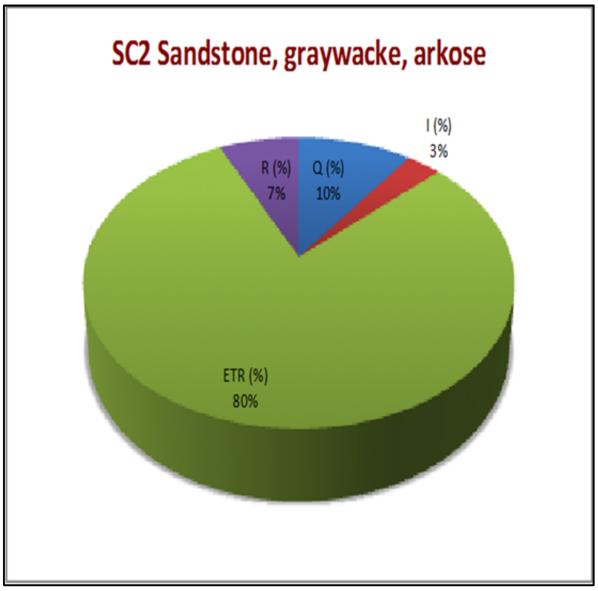

Fig.16- Hydrogeological Inverse Budget Components- SC2 Sandstone,graywacke,arkose

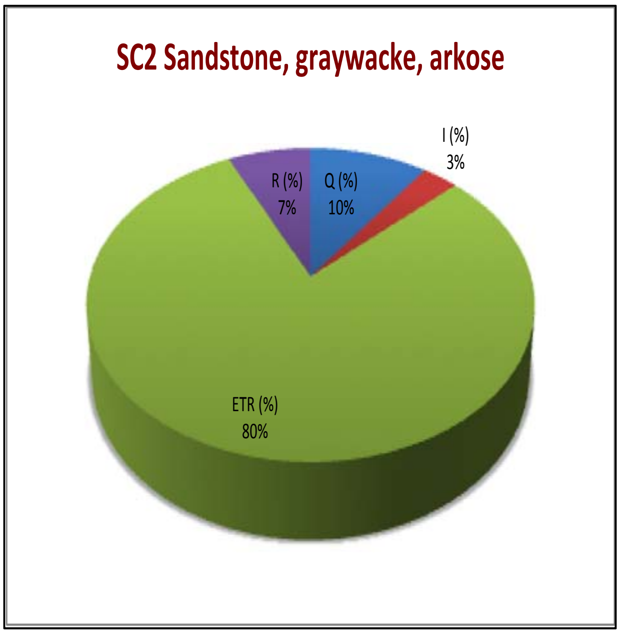

Fig.15- Hydrogeological Inverse Budget Components- IB2 Basic Igneous Rock

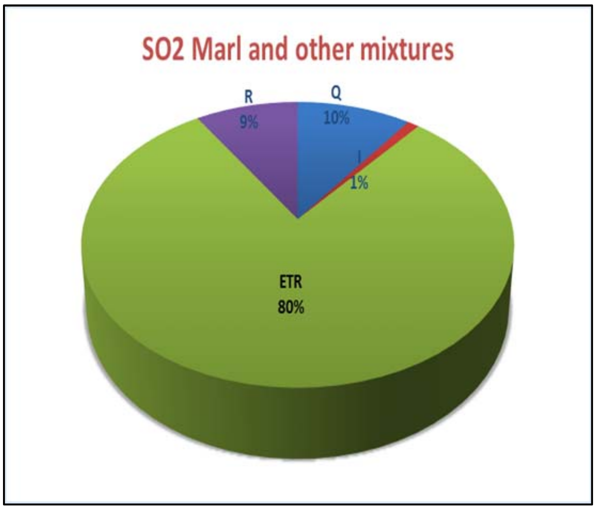

Fig.17- Hydrogeological Inverse Budget Components- SO2 Marl and other mixtures

Standing on these results, it comes out that infiltration in this area is very poor, due to high evapotranspiration coupled with the very low permeability of outcropping formations. As a matter of fact, the investigations carried on groundwater wells explored in the buffer zone around the Limpopo National Park looks like confirming this hypothesis.

Preliminary hydrogeochemical results of the buffer zone of Limpopo National Park

The hydrogeochemical characteristics of the buffer zone of Limpopo National Park are still poorly understood. The UNESCO defines buffer zone as "an area that should ensure an additional level of protection to areas recognized as a World Heritage sites" with an emphasis on the importance of these areas in the proper management of protected areas. In this contest, this manuscript is essential to preservation and conservation of biodiversity and to identify water quality assessment of the study area. To identify the geochemical characteristics of water of study were collected different water samples during two different field surveys. The first sampling event happened in October 2016 at the end of dry season, while the second field survey there was in March 2017 at the end of wet season. They were analysed groundwater collected from boreholes present in the villages of the area and some sample collected by surface water which: Limpopo River, Massingir Lake and Elephants River. During both sampling events principal chemical-physical parameters, major ions and trace elements were analysed to highlights: geochemical characteristics of water, elemental anomalies and difference between surface water and groundwater in relation to season (Wet and Dry) to evaluate importance of infiltration on the chemical characteristics of water.

Results of chemical physical parameters have been highlighted high values of electrical conductivity with reaches in groundwater a value of 5960 µS/cm during October 2016 and 3704 µS/cm during March 2017. The EC is a notable indicator of the amount of solids dissolved in water and the higher values obtained are indicative of high mineralization of groundwater of study area. The results of major ions were identifying as principal cation Na^+ and as principal anion Cl^-. Both these ions reach values that exceed 3000 mg/L during both sampling events. These results allowed to identify principal hydrogeochemical facies as $Na\text{-}Cl\text{-}SO_4$.

Waters of buffer zone of Limpopo National Park show high salinity. The results obtained from chemical physical parameters and major ions highlight the possible presence of brines or fossil water in the study area. These hypotheses are supported by the result obtained from trace elements. They are highlight high values of boron that reach values that exceed 1 mg/L (limit provided by European directive) in almost all sample. The relationship between this element and Cl^- concentration were used literature for identifying boron source in groundwater [12]. Figure 18 show the relationship between the samples in October 2016. The results show values similar or major of sea water highlight the possible presence of fossil water in the study area.

Furthermore the poor differences observed between the two sampling event in the geochemical characteristics of groundwater allowed to hypothesise poor circulation of these water.

These primary results highlight the poor quality of the groundwater of the buffer zone of Limpopo National Park. These waters do not seem to be suitable for drinking purposes and elevated salinity compromises their use even for agricultural purposes.

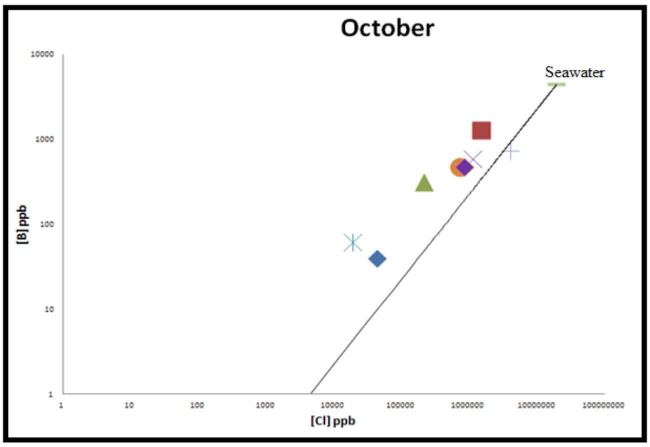

Fig.18- Relationship between boron and chloride in water of study area during October 2016.

Conclusions

This paper presents some preliminary results of the activity research. of SECOSUD Phase II, called "Conservation and equitable use of biological diversity in the SADC region (Southern African Development Community) a project supported by the Italian Ministry of Foreign Affairs in the SADC.

The overall objective of this researches is to design an integrated approach for Limpopo National Park groundwater characterization and management, based on a tiered and complex program, in order to preserve biodiversity.

In the area under study, the infiltration, coming from precipitation, is very low because of the rock formations, characterized by very low hydraulic conductivity and the hydrogeological nature of the outcropping formations.

On the other hand, the analytical results suggested water high mineralized. This means that above mentioned groundwater has ancient infiltration as they seem to have long residence time.

This study would be a first step which gives the picture of the background state of groundwater resources in this complex geological and hydrogeological scenario to focused the operative phase of the future activity.

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