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ASSESSMENT OF LAND USE DYNAMICS OF THE N'DJILI CATCHMENT IN DR CONGO: IMPLICATION FOR CATCHMENT PLANNING

Steve LEMBA DIETO

MSc. THESIS IN IWRM

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In collaboration with

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Integrated Water Resources Management of the University of Zimbabwe

HARARE, DECEMBER 2013

DECLARATION

I, Steve LEMBA DIETO, declare that this research report is my own work. It is being submitted for the degree of Master of Science in Integrated Water Resources Management (IWRM) at the University of Zimbabwe. It has not been submitted before for any degree of examination in any other University.

Date: ____________________

Signature: ____________________

The findings, interpretations and conclusions expressed in this study do neither reflect the views of the University of Zimbabwe, Department of Civil Engineering nor of the individual members of the MSc Examination Committee, nor of their respective employers.

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LIST OF SYMBOLS AND ABREVIATIONS

AGNPS	Agricultural Non-Point Source Pollution Model
ANOVA	Analyses of Variance
ANSWERS	Areal Nonpoint Source Watershed Environment Response Simulation
Aquater	Research project funded by Italian Ministry of Agriculture, Food and Forestry policies
AS	Aluminium Sulfate
BMP	Best Management Practices
CMP	Catchment Management Plan
CREN-K/CAEC	Congo Atomic Energy Commission – Kinshasa
DEMs	Digital Elevation Models
DRC	Democratic Republic of Congo
ERDAS	Earth Resources Data Analysis System
ESRI	Environmental Systems Research Institute
EUROSEM	EUROpean Soil Erosion Model
FAO	Food Agricultural Organisation
GIS	Geographic Information System
HRUs	Hydrologic Response Units
HSPF	Hydrologic Simulation Program Fortran
HydroSHEDS	Hydrological Data And Maps Based On Shuttle Elevation Derivatives At Multiple Scales
IHDP	International Human Dimensions Program
ISRIC-UGent	International Soil Reference and Information Centre – University of Gent
LH	Latin Hypercube
LISEM	LImbourg Soil Erosion Model
LULC & LULCC	Land Use And Land Cover & Land Use And Land Cover Changes
M.A.R	Mean Annual Rainfall
MENCT	Ministry of Environment, Nature Conservation and Tourism
MIKE SHE	Integrated Hydrological Modelling System
NASA	National American Security Agency
NBCBN	Nile Basin Capacity Building Network
NSE	Nash-Sutcliffe Efficiency
NTU	Nephelometric Turbidity Unit

OAT	One-Factor-At-a-Time
OSFAC	Observatoire Satellitaire des Forêts d'Afrique Centrale/Satellite Observatory of Central African Forest
OXFAM/QUEBEC	Oxford Committee for Famine Relief/QUEBEC
PBIAS	Percent Bias
REGIDESO	Regie des Traitements et de Distribution d'eau /Water Supply Authority
ROI	Region of interest
RSI-ENVI	Research Software Institute- The ENvironment for Visualizing Images
RSR	RMSE-Observations Standard Deviation Ratio
SHETRAN	Systeme Hydrologique Europeen-TRANsport
SNHT	Standard Normal Homogeneity Test
SOTERCAF	Soil Terrain Of Central Africa
SPSS	Statistical Package for Social Sciences
SRTM	Shuttle Radar Topography Mission
SWAT	Soil Water Assessment Tool
SWIM	Soil and Water Integrated Model
SWRRB	Simulator for Water Resources in Rural Basins
TSS	Total Suspended Sediment
UNEP	United Nations Environmental Programme
USDA-ARS	US Department Of Agriculture, Agricultural Research Service
UTM	Universal Transverse Mercator
WEPP	Water Erosion Prediction Project Model
WRA	Water Resources Assessments
WRMP	Water Resources Master Plan
WWF	Conservation Science Program of World Wildlife Fund
XLSTAT	Leading data analysis and statistical solution for Microsoft Excel

DEDICATION

I dedicate my dissertation to my all family. A special feeling of gratitude to my loving brothers and sisters, nephews and nieces whose words of encouragement and push for tenacity ring in my ears.

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God bless you all.

ABSTRACT

The lack of the basic data in both ungauged and poorly gauged catchments make the tasks of water resources management and planning challenging in these areas. This leads to ineffectiveness and improper assessment of water resources in most of the poorly gauged catchments. Thus, this study reports on three approaches that assess temporally and spatially the land use of the N'djili Catchment in relation to water resources management. The N'djili Catchment whose principal tributary is the N'djili river falls in the lower drainage basin of the Congo River. With daily average of 22.3 m^3/s, the N'djili river contributes to water supply of closely two-third of the population in the suburbs as well as private connections of Kinshasa with an estimated 330,000 m^3 of drinking water per day. Using four variables from meteorological, water quality and hydrological parameters, as well as daily sediment loads and daily discharge respectively generated from turbidity and water level measurements were processed. Variables such as sediments, discharge, rainfall and potential evapotranspiration were tested successively for homogeneity (Pettit test), time series and double cumulative curves analysis after performing the normality test. These trends analyses revealed significantly poor long-term correlation between meteorological and other group of parameters. The land use classification was done through unsupervised classification followed by Sieve and Clump post-classification methods for the following years 1987, 1995, 2001 and 2012. The confusion matrix was used and the average overall accuracy obtained for all the land use classification were 79.03% and Kappa coefficient accuracy ranged from 0.56 to 0.79. The analysis of variance revealed a significant (p-value <0.05) change occurred within land use classes. Hence, SWAT model was then used to simulate sediment loads based on the land use scenarios and the outputs revealed a progressive increase in sediment pattern as the changes occurred in land use. The model performance was evaluated using the following indices: Nash-Sutcliffe Efficiency (NSE), Percent bias (PBIAS), Root square mean error to the standard deviation (RSR), Pearson's correlation coefficient (r) and coefficient of determination (R^2). The dimensionless indices indicated that satisfactory to very good results were achieved from the simulations of the sediment loads. Finally, two regression models were used to predict the extent to which sediment loads and turbidity affect the water treatment cost of the N'djili river. Non-linear and multi-linear regression analyses were performed. The coefficient of determination (R^2 =0.82) from non-linear regression indicated that the amount of chemical used increases as the turbidity loads increase reaching a saturation level. On the other hand, the multi-linear regression model was built based on thirteen most sensitive parameter sets from the SWAT sensitivity analysis. The model showed that significant (p-value 0.04) and satisfactory prediction of sediment loads was achieved by considering only the Pearson's correlation coefficient (r = 0.63) while the coefficient of determination (R^2) only indicated a value of 0.40. This study reveals that the change in loads sediment identified through the analyses is a result of landuse practices rather than changes in meteorological variables and these results call for appropriate measures in terms of landuse activities and management as these lead to an increase in the costs of treatment of water supply for the city of Kinshasa.

Key words : *N'djili, trend analyses, land use/cover, SWAT model, regression analysis*

CHAPTER 1: INTRODUCTION

1.1. Background

River basins provide vital goods and services though it is always difficult to manage these resources in an uncontrolled environment (Walling, 2009). The world comprises several climatic and hydrological regions. One anticipates to experience different impacts from climate change. Climate change is just one of the additional aspects that water managers need to take into account for water resources planning and management.

On the other hand, land use and land cover (LULC) are considered as one of the most significant constituents of the terrestrial environment system (Lin *et al*., 2009). Modifications in LULC reflect the intensity of human activities on the global environment. In line with Munoz-Villers and Lopez-Blanco (2008) who stipulated that at the macro scale these modifications are known as to infer impacts on continental and global atmospheric circulation resulting to even greater effects on regional and continental climate.

Several studies have explored the composite interactions between land surface and other components at the local and macro climate, describing the degree of the shift in land surface in diverse geographic localities around the world (Lin *et al*., 2009). Based on these studies, there is evidence as earlier reported by Pielke *et al*. (2002) and as supported later by Liu *et al*. (2010) that macro-scale LULC changes, mostly in the tropic regions, cause remote climatic effects of global extent distant from where the area has been directly affected by land-cover changes .

According to the latest assessments over 80% of the world's agricultural land suffers from moderate to severe erosion which causes loss of productivity (Ritchie *et al*., 2009). Furthermore, it is argued that the increased mobilization rate of sediment and its delivery to rivers tend to increase reservoir sedimentation, water pollution and degradation of aquatic habitats, as a result of human pressure on the environment.

Moreover, the dispersed lands in watersheds are implicitly considered as potential source of sediment, a systematic rating of their potential for erosion would be useful in soil conservation planning. Most importantly, mapping and assessment of erosion prone areas enhances soil conservation and watershed management (Minella *et al*., 2007).

To date measurement techniques and tools to provide information on the spatial and temporal distributed patterns on the environment especially, for soil and water degradation across the N'djili catchment constrain the ability to develop cost-effective land management strategies. However, the capability results from the hydrological models coupled with the application of remote sensing and geographic information system (GIS) can provide a framework of management and planning in the environment where tools and data are limited.

In spite of the referenced above limitations in this meso-scale catchment, the worldwide application of Soil Water Assessment Tool (SWAT) as a distributed hydrological model has revealed that it is a versatile tool which can be used to integrate multiple environmental processes(Moriasi et al., 2007). This flexibility of SWAT to support more effective catchment management and its development could lead to better-informed policy decision makers. Furthermore, the model allows prediction of the impacts of landuse practices on water quality, sediment yield, and agricultural chemicals yield in ungauged watersheds (Ashagre, 2009). This capability of the SWAT model can be useful as a support tool for the management and planning of the water resources in N'djili catchment.

In view of the above, this study seeks to assess as reported both spatially and temporally land use dynamics of a meso-scale Catchment. N'djili catchment (~2291.9 km^2), is located in DR of Congo has been undergoing both land use and land cover (LULC) changes that are expected to have impact on the water quality and the hydrology of the N'djili river. Such changes have been documented in the other regions of the world such as the case of the Lake Naivasha catchment in Kenya by Becht and Harper (2002), land use changes in a coastal watershed in North Carolina by Qi *et al*. (2009),land use and climate change impacts on the hydrology of upper Mara River in Kenya by Mango *et al.*(2011). According to Defries and Eshleman (2004), the impacts of LULC changes on sediment generation at the meso-scale as phenomena is yet to be fully understood and documented by hydrologists and water resources managers. Therefore, the current study intends to better understand these impacts of LULC changes on sediment generation at the N'djili Catchment using SWAT model.

1.2. Problem statement

The N'djili catchment covers an area of about 2291.9 km^2. In the 1970s, this catchment was natural and mostly shielded with mixed-forest. However, the advent of the human pressure and activities in the last three decades has led the change of the natural pattern in the N'djili Catchment.

The uncontrolled agricultural practices and development of informal urban settlements have exposed the fragile soils to heavy rainstorms, resulting to considerably enhanced soil erosion rates and increased downstream flooding due to low hydraulic roughness of the current land cover. Based on the output of Soil Terrain Of Central Africa (SOTERCAF) as reported by Batjes (2007), the N'djili Catchment has mainly sandy soils and steep topography rendering it susceptible to erosion.

A relevant fact demonstrating the societal cost of water pollution is the increase in the water treatment cost of the N'djili river. Based on recorded data by DRC-Water Supply Authority (REGIDESO), the previous turbidity levels of the N'djili river in the years before 1990s were typically less than 15 Nephelometric Turbidity Unit (NTU), reaching more than 30 NTU during rainstorms as opposed to the current one whose hourly turbidity measurements range from 100 to 400 NTU(*Personal investigation*). Moreover, in some heavy rainfall events which usually occur at the last three months of the year up to later May of the next year, this range can be multiplied by 15 to 30. UNEP (2011) indicated that beyond the 1,000 NTU considered as threshold value, water treatment schemes are generally forced to stop their operations.

Considering the fact that the N'djili Catchment has got a water treatment plant which supplies about two-third the population in the suburbs as well as private connections of Kinshasa with an estimated 330,000 m^3 of drinking water per day (UNEP, 2011) .The question is now to find out to which extent the water treatment cost from the N'djili river is being currently affected by these changes?

Previous studies done on the N'djili Catchment have highlighted the impact of the human activities consisting in forest clearance, rapid expansion of agriculture and informal settlements Ndembo (2009), and population expansion Nsiala (2012) as causal factors. Formerly situated in a protected vegetated zone, N'djili water intake is currently surrounded by vegetable gardens and informal housing settlements. As a result, these have led to exponential increase in the N'djili river's turbidity loads over the past three decades. Furthermore, adequate knowledge on the links between land use/cover and water is limited in order to provide sound management and planning measure for the N'djili Catchment.

1.3. The rationale

The rationale of this study is two folds:

- ✓ Scientifically, is to provide an understanding of the relationship between LULC and water resources through modelling coupled with remote sensing and GIS tools.
- ✓ Socio-economically is to measure the effect of the increase of turbidity loads on the water treatment cost in order to provide some economic evidence on the importance of water resources management while protecting water infrastructure as well as to serve as basis to the town city council for the catchment management and planning.

1.4. The objectives and research questions of the study

1.4.1. The objectives of the study

The overall objective of this study is to assess the impact of landuse/cover change on water quality and hydrology (sediments, discharge, rainfall and evapotranspiration) in the N'djili Catchment.

The specific objectives are:

- ➢ To detect long-term changes in water quality and hydrological parameters resulting from LULCC
- ➢ To assess spatially and temporally the land use/ cover in the N'djili Catchment
- ➢ To assess the suitability of SWAT model in simulating total suspended sediment of the N'djili Catchment based on the land use/ cover changes
- ➢ To predict the extent to which sediment loads and turbidity affect the treatment cost of the water supply at the abstraction point of the N'djili river

1.4.2. The research questions

- ➢ Can the long-term trends and abrupt changes in water quality and hydrological parameters be linked from land use/cover changes?
- ➢ How significant are changes in land use/cover of the N'djili Catchment?
- ➢ Is SWAT model accurate and adequate in simulating the sediment loads of the N'djili river based on the land use/cover changes?
- ➢ To which extent sediment loads and turbidity affect the treatment cost of the water supply at the abstraction point of the N'djili river?

1.5 Scope and limitations

The study covers the assessment of land use dynamics of the N'djili Catchment in DR Congo. The catchment comprises the rural and peri-urban areas that fall in Bas-Congo and Kinshasa provinces of DR Congo. Five major land use/cover classes were distinguished as bare land, cropland, grassland and shrubs, settlements and water. Changes in these components have led to significant related impacts mainly on the water treatment cost of the N'djili river. Historical data and satellite imagery were the form of data used in this study. The study did not make any attempt in determining the water balance of the catchment over time, neither quantify selectively the loads in sediments in relation to the decrease of the vegetation cover nor address the issues related to any economic valuation methods, but still the findings can be inferred to them; or impacts of the sediment loads to public health.

1.6 Structure of the thesis

The study consists of six chapters organised as follows: Chapter One articulates the introduction and provides general background on the land use /cover changes, its interaction with the environment as well as its consequences to the water resources. It states the aim of the study, justification, scope and the limitations and its structure as well. Chapter Two postulates and reviews different literature undertaken in the field of land use dynamic and modelling. Chapter Three describes comprehensively the study area. Chapter four details extensively the materials and methodology used for data gathering, data processing, data analysis as well as modelling. Chapter Five presents and discusses the results for trend analyses, spatial and temporal analyses and modelling, respectively. Finally, chapter Six draws the conclusions and recommendations from the findings based on the study objectives.

CHAPTER 2: LITERATURE REVIEW

2.0. Introduction

This chapter provides a holistic and comprehensive overview of previous researches undertaken in the area of land use dynamic and modelling. The process of gathering this literature was carried out diligently throughout the course of the study.

2.1. Existing knowledge of the assessment of land use and land cover changes

Ever since, humans utilise land to meet their various needs. By doing so, they are modifying land resources in different ways. Normally, these modifications occur with harmful effects on both environment and human well-being. The change in land cover is a result of change in biophysical conditions but, mainly that one is more anthropogenic (Briassoulis, 2000).

As reported by several authors, (Briassoulis, 2000) stipulated that changes in Earth's natural land cover have taken place ever since and mostly reported as human-induced. The adverse impacts on people and the environment are considered as results of these changes (Liu *et al*., 2010).

In this process, the acknowledgement of the importance of land-use and land-cover change in the perspective of global environmental change and sustainable development is perhaps best reflected in the launching, in 1993, of the Land Use and Land Cover Change (LULCC) Core Project/Research Program and the International Human Dimensions Program (IHDP) as outlined by (Briassoulis, 2000).

2.2. Definitions and concepts related to the assessment of LULCC

Land cover is defined as the biophysical state of Earth's surface and immediate subsurface (Turner *et al*., 1995). Land use, according to these authors, involves both the manner in which the biophysical attributes of the land are manipulated and the intent underlying that manipulation, as the purpose for which land is used. On the other hand FAO (1995), explicitly defined land use as the function or purpose for which land is assigned by the population.

Both definitions of land use are convergent and evoking the terms: purpose, manipulation of land and people. Ideally, the human activities on a given land lead to impact directly or indirectly that portion of the land.

Earlier Meyer and Turner (1994), discussed on the distinction between "land use" and "land cover". They argued land cover articulates the physical, chemical, or biological categorization of the terrestrial surface whereas land use refers to purposes associated with that cover. In fact, land use relates to land cover in various ways and affects it with various implications and practically making a distinction between these two concepts is not straightforward because most frequently the source of data does not separate them clearly (Briassoulis, 2000).

In most literature researchers such as Briassoulis (2000), Pielke *et al*. (2002), Lin *et al*. (2009), Liu *et al*. (2010) documented land-use and land-cover changes concepts. The definition of these concepts converges to quantitative changes in the aerial extent (increases or decreases) of a given type of land use or land cover, respectively. However, the changes in land cover may refer either from land conversion (a change from one cover type to another), or land modification (alterations of structure or function without a wholesale change from one type to another), or even maintenance of land in its actual condition against agents of change (Bosch and Sheridan, 2006).

Similarly, land use and land cover change are strongly linked; the environmental impacts of land use change and their contribution to global change occur through physical process associated with land cover change as underlined by Brian *et al*. (2004). Furthermore, the same source stipulated that the detection, measurement, and explanation of land use and land cover changes rely mainly on the spatial and the temporal level of analysis. This allows one to anticipate that small changes cannot be detected at high levels of spatial and temporal detail as well as long term trends of land use and land cover change cannot be distinguished within short time horizons and small spatial units. The same author further reported on the description of the spatial and temporal levels of detail as decisive as it guides the choice of the types of land use/cover and fixes the factors influencing the types, processes, and impacts of land-use/cover change within particular spatial or temporal frames.

The study conducted by Bouman and Nieuwenhuyse (1999) indicated earlier that intervention in the dynamics of land use patterns has to be considered as impossible or even unrealistic without a proper understanding of the driving factors in these patterns.

2.3. Catchment Management and Planning

2.3.1. Land management

2.3.1.1. Consequences and Driving forces of land use and cover changes

As reported by Ellis (2010) and cited by Misana *et al.*(2012) that extents and intensities of land use and cover change, although are considered as far greater than ever in the history, driving exceptional changes in ecosystems and environmental processes at local, regional and global levels.

Thus, modifications in land use and cover have intended and unintended consequences and affect the environment. When mismanaged, these drivers may lead to increased vulnerability of the ecosystems and people as reported by Misana *et al.*(2012).

The so called driving forces comprise interactions of social, political, economic, demographic, technological, cultural and biophysical variables in order to establish structural conditions in the relationship between human and the environment as mentioned in Geist *et al*.(2006) and Ellis (2010) as reported by Misana *et al*.(2012).

Moreover, a study conducted by Mueller *et al*.(2008) as reported by Misana *et al*.(2012) established that slope gradient, soil properties and poor management of land resources coupled with climatic components, are more likely to be the key factors which predispose lands to soil erosion. As a result, this situation leads to sediment generation in the catchment.

2.3.1.2. Catchment sediment sources

The understanding of the spatial and temporal dynamics of the key drivers in sediment generation within the catchment requires an integrated management of sediment as reported in Collins *et al*.(2001) and reported by Zhang *et al*.(2012).

From previous works Zhang *et al*.(2012) stressed that sediment refers to substantial vector contributing to the transfer and fate of various substances, counting organic carbon, agricultural chemicals and industrial toxic contaminants. Hence, the same source articulated that the increased sediment loads are amongst other responsible for degrading freshwater habitats, detrimentally affecting aquatic biota and contributing to health risks associated with bacterial pulses.

In addition, Collins and Walling (2004) postulated that sediment generation and delivery at the drainage basin scale displays complex spatial and temporal variability; hence, consistent identification of key drivers of sediment sources has to be emphasized as an indispensable precondition for designing targeted remedial programmes in the context of limited budgets and resources.

2.3.2. Application of Soil Erosion Modelling and GIS

Schmidt *et al*. (2000) articulated that the representation of elevation in terms of topographic surfaces is supported by geomorphological analyses. Hence, the importance of representing topography using digital elevation models (DEMs) is key. Furthermore, this author reported on the distribution of soil changes over time as well as the capability linking sediment transfer to DEM. On the other hand, Brooks and McDonnell (2000) indicated that the redistribution of sediment and the long-term changes in landscape, which then, substantially affect the hydrological processes acting within and upon distinct hillslopes.

The spatial heterogeneity in topography, vegetation, soil properties, and land use are among important factors which are influencing soil erosion. However, predictive soil erosion models do not integrate the problem in a spatial context (ESRI, 1994). This has led to make use of a valuable tool such as Geographical Information System (GIS) as reported by (ESRI, 1994).
According to (ESRI, 1994), the advantages of linking soil erosion models with a GIS include the following:

- The ability of promptly producing input data to simulate different scenarios in developing the model input data at various spatial scales (Sharma *et al*., 1996).
- The capability to use very large catchments, so the catchment can be simulated with more details (De Roo, 1996).
- The facility of exhibiting the model outputs (Tim, 1996).

ESRI (1994) indicated that there are different ways for linking distributed hydrological erosion models with GIS, and Pullar and Springer (2000) categorised three levels of ranging from loosely coupled to tightly coupled arrangements:

- Loose coupling: the GIS system and the erosion model are separated, and the files must be transferred back and forth externally between the GIS and the model.
- Tight coupling: the GIS (typically) provides the shared interface to move the spatial data between the GIS and the separated modelling program.

- Fully integrated: the model is fully integrated as a component in the host GIS application.

2.3.3. Implications for Catchment Management and Planning

2.3.3.1. In ungauged or poorly gauged catchment

Most of the catchments in developing world are either ungauged or poorly gauged. Therefore, the need for a Water Resources Master Plan (WRMP) is still relevant *(Shrestha et al.*, 2004). The lack of the basic data makes these tasks comparatively more challenging in these regions. As a result, Water Resources Assessments (WRA) are either not done or done inadequately in most of the poorly gauged catchments *(Littlewood et al.*, 2003).

Consistent and accurate estimates of hydrological attributes are not only imperative for water resources planning and management but are also increasingly pertinent to environmental researches as reported by Schröder (2006) as reported by Kileshye-Onema *et al*.(2012). Several researchers such as Uhlenbrook and Siebert (2005); Koutsoyiannis (2005); Zhang *et al*.(2008) as reported by Kileshye-Onema *et al*.(2012) have documented the reduction of uncertainty related with hydrological predictions in ungauged or poorly gauged. While highlighting the case of Semliki watershed, Kileshye-Onema and Taigbenu (2011) and Kileshye-Onema *et al*. (2012) indicated that the use of sensitivity analyses of both linear and non-linear predicative tools can allow water practitioners and planners to evaluate the impact of physiographic catchment attributes for preliminary assessment of the water resources of an ungauged or poorly gauged catchment.

2.3.3.2. Need of Distributed Hydrological Models for Best Management Practices (BMP)

Xu *et al*.(2009) articulated that the hydrological cycle in a catchment is influenced by variations of climate as well as land uses. Physically based distributed hydrological models, are described as to have a physical representation for the spatial variability of hydrological processes. Their ability to simulate the impact of climate change and human activities on the hydrological cycle, has led them to be increasingly used from a simple to a complex water resource systems as reported by Xu *et al*.(2009). Hence, these authors mentioned that these models have got a potential to adequately estimate the surface runoff since it affects the transport of sediments and agricultural chemicals.

Tripathi *et al*.(2005) underlined that effective mechanisms of regulating water and soil losses oblige implementation of the best management practices in erosion-prone areas of the catchment. Considering the rapid urbanisation and economic development, water scarcity and deterioration of water quality have become increasingly severe in many river basins around the world (Zhang and Liu, 2006). The use of physically based distributed hydrological models and techniques such as remote sensing and GIS can assist water authorities to undertake effective water management strategies for the sake of sustainability of economic development to meet the water demand for the growing population.

The study conducted by Mishra *et al*.(2007) introduced several hydrological models such as ANSWERS, AGNPS, HSPF, MIKE SHE, SWRRB, SWIM, SWAT and WEPP which are commonly used nowadays to simulate hydrological processes.

Amongst this set of hydrological models, the Soil and Water Assessment Tool (SWAT) is reputed as largely applied to ungauged basins as documented extensively by Arnold and Allen (1996) and Arnold *et al*.(1998). It was developed by the US Department of Agriculture, Agricultural Research Service (USDA-ARS) and it is a process-based hydrological model with major components including surface hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, groundwater and lateral flow.

2.3.4. Soil Water Assessment Tool (SWAT) Model

2.3.4.1. Brief description of SWAT model

Arnold *et al.* (1998) described SWAT as basin scale, continuous time model that functions on a daily time step and aimed for assessing the impact of human activities and climate on stream flow, sediment and agricultural chemical yields in large river basins. The same source articulated that the model focused on physical processes, computationally efficient, and enables to perform continuously simulation in long-term period.

NBCBN (2010) highlighted the main constituents of model comprising weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. In addition, the design of the SWAT model operates in such way that a single watershed is scattered into many subwatersheds, which then in turn subdivided into hydrologic response units (HRUs).

In fact, the HRUs consist of identical land use, management, and soil characteristics. Furthermore, these HRUs allow the model to simulate efficiently any process occurring within the subwatersheds. The insightful description of the model can be found in Arnold *et al.*(1995).

2.3.4.2. Comparisons of SWAT with Others Models

In literature, various researchers such as Refsgaard and Storm (1995); Bicknell *et al*. (1997), Borah *et al*.(2004); Saleh and Du (2004); El-Nasr *et al*.(2005); Singh *et al*.(2005); Srinivasan *et al*.(2005); Gassman *et al*.(2007) documented on SWAT model as reported by NBCBN (2010), have got in general a satisfactory appreciation on the performance of this model as compared to other distributed hydrological models.

Table 2.1 below gives a broader picture of some comprehensive sediment yield models which do not entail sediment delivery ratio (Arnold *et al*., 1995).

Table 2.1.Comparison of five recently developed physically-based erosion and sediment yield models as modified from Bathurst (2002) cited by Ndomba (2007) and NBCBN (2010)

Model features		**Models**				
		SHETRAN *(Buthurst,2002)*	**WEPP** *(Lane et al .,1992)*	**EUROSEM** *(Morgan et al.,1998)*	**LISEM** *(De Roo et al.,1996)*	**SWAT** *(Arnold et al.,1995)*
Simulation type	*Continuous*	Y	Y	N	N	Y
	Single event	Y	Y	Y	Y	N
Basin size		< $2000km^2$	< $2.6km^2$	Small basin	Small basin	Larger basin
Spatial distribution		Grid	Grid	Uniform slope planes	GIS raster	HRU
Overland flow	*Rainfall excess*	Y	Y	Y	Y	Y
	Upward saturation	Y	N	N	Y	Y
Erosion process	*Raindrop impact/overland flow*	Y	Y	Y	Y	Y
	Rilling	N	Y	Y	Y	Y
	Crusting	N	N	Y	Y	N
	Channel banks	Y	N	Y	N	Y
	gullying	Y	N	N	N	N
	Land sliding	Y	N	N	N	N
Output	*Time-varying sedigraph*	Y	N	Y	Y	Y
	Time-integrated yield	Y	Y	Y	Y	Y
	Erosion map	Y	Y	N	Y	Y
Land use		Most vegetation covers	Wide range of land use	Mainly agricultural	Mainly agricultural	Wide range of land use

Note: Y=Yes; N=No; Simulation type: Can the model simulate continuous periods or is it limited to single rainfall events? Basin size: what is the maximum basin size which can be simulated? Spatial variability represented? Overland flow: is overland flow (important for routing sediment) generated by rainfall excess over infiltration and by upward saturation of the soil column? Erosion process: What processes are included in the model? Output: does the model provide time-varying sediment discharge (sedigraph), time-integrated (bulk) yield and a spatially distributed erosion map? Land use: what sort of land covers can be simulated?

The above table reports that amongst the reviewed physically based erosion and sediment yield models, SWAT model is one of them which has got capability and flexibility of continuously simulating erosion processes and sediment loads to a larger extent basin as well as a wide range of land use based on the smallest catchment units so called as Hydrological Response Units (HRU). These HRUs allow to capture details relating to hydrological processes of any catchment (Di Luzio *et al.*, 2004).

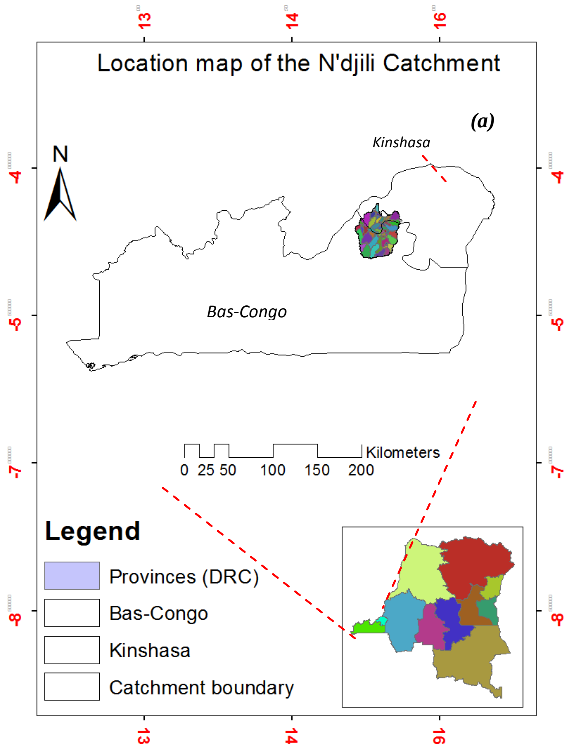
2.3.5. Application of the prediction of the impacts of land use change using SWAT model

Alibuyog *et a*l.(2009) reported that the performance of a predictive model for assessing the impacts of land use changes on runoff and sediment yield in watersheds has to be looked at with due importance. The same source underlined the significance of using the hydrological distributed model for the sake of the development of policy interventions as well as the watershed management programmes that ensure environmental and economic sustainability. Therefore, SWAT model is among the most widely used computer simulation modelling tools for predicting runoff and sediment yield as indicated earlier by Arnold *et al*.(1995) and reported later by Gassman *et al*. (2007).

To date, no applications of SWAT in the DRC which have been reported. However, numerous studies exist on the applications of SWAT in the assessment of the effects of land use change on soil erosion in Eastern African regions (Kimwaga *et al.*, 2012; Ndomba *et al.*, 2008).

CHAPTER 3: STUDY AREA

3.1. Location



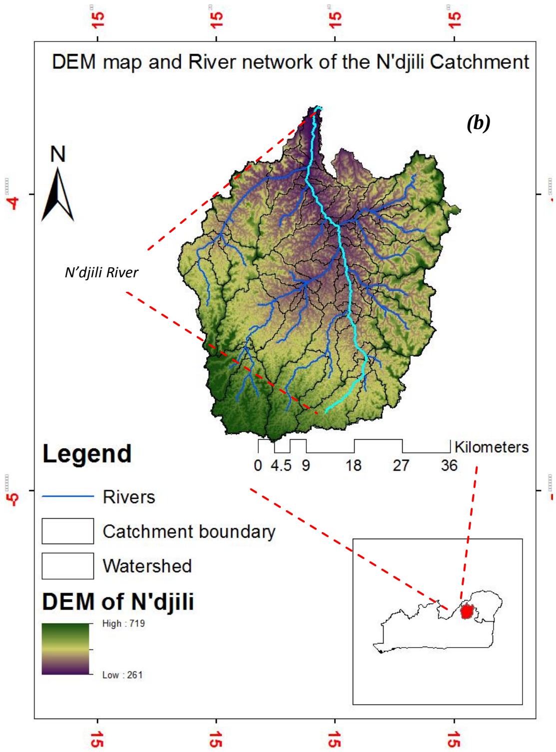


Figure 3.1a.Location of the study area

Figure 3.1b.DEM and River network of the N'djili Catchment

3.2. Description of the study area

N'djili catchment is located within two provinces of the DRC (Figure 3.1a). It is characterised by the following geographic coordinates: latitude S 4°19'36.69" to 4°55'10.69"S and longitude E15°07'52.31" to E15°36'44.31" (Figures 3.1a and 3.1b). The upper land is situated at 726 m above mean sea level and the lower land is found at the minimum of 263 m above mean sea level (Figure3.1b). The catchment is drained by a complex hydrographical network whose N'djili river (~ 61.2 km of length) constitutes the principal tributary (Figure3.1a). The catchment area is approximately 2291.9 km^2. Considering the position of the N'djili river, this catchment is more inhabited in its lower side as compared to its upstream side as shown below in the terra metric satellite image of 2013 (Figure3.2).

Figure 3.2.Overview of the occupation of the N'djili Catchment (extracted from Google earth 2013)

3.2.1. Population and Current Land use

N'djili Catchment is of great demographic importance (Nsiala, 2012). In 2004, the municipalities that are part of this catchment counted about 3,515,177 inhabitants which represented approximately 50.1% of the population of Kinshasa living within an area of 835.83 km^2 or 8.6% of the territory of this city as reported in the Monograph of the City of Kinshasa (2005) and cited by Nsiala (2012). However, this source did not include the statistics from the Bas-Congo province and which would have brought a real picture of the existing population of the N'djili Catchment. To date, these information need to be updated based on the current trend of Kinshasa's population which is above 10 millions of inhabitants (UNEP, 2011)

Some studies conducted in N'djili Catchment have indicated that agriculture, livestock, industry, mining, wildlife conservation, tourism, fishing, auto-repairs, commercial activities are the major land use and housing, schooling, transportation should also be included (Kashimba, 2008; Lemba, 2010; Nsiala, 2012).

3.2.2. Lithology and Soils

Figures 3.3a and 3.3b show the spatial distribution and properties of the lithology and soils of the N'djili Catchment derived from a digital database for Central Africa (SOTERCAF) produced in 2006-2007 in the frame of an ISRIC-UGent-FAO project as earlier reported by Van Engelen *et al*.(2006) and Goyens *et al*.(2007).

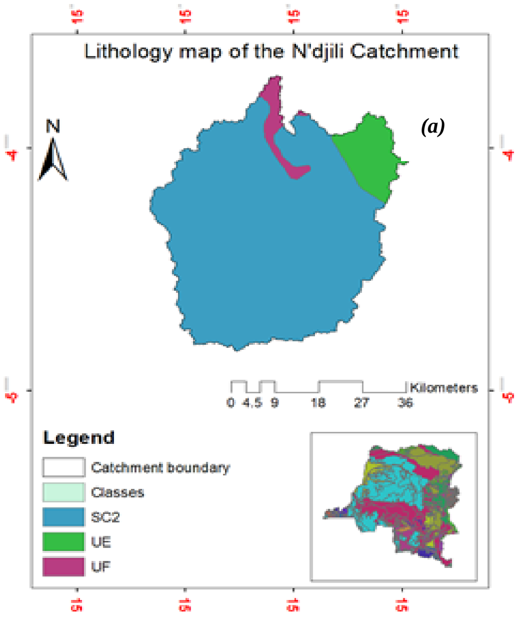


Figure 3.3a.Lithology map of the N'djili Catchment

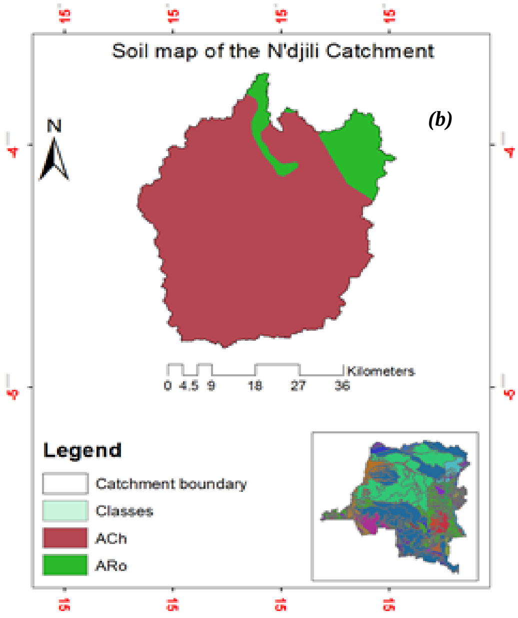


Figure3.3b. Soil map of the N'djili Catchment

Approximately 80% of soils belong to the *Haplic acrisols* (ACh) class type and to the SC_2 as lithology class type, then followed by the Ferralic arenosols (ARo) which soil class corresponds to UE lithology class-type (±13%). The Humic ferralsols (FRu) which fit to the UF lithology class-type and the water occupy respectively more or less than 7%. Table 3.1 gives the details about these class-types of the lithology of the N'djili Catchment.

Table 3. 1. Class-types of the lithology of the N'djili catchment

n°	Major class	Group	Type
1	S (sedimentary rock consolidated)	SC (clastic)	SC2(sandstone, greywacke, arkose)
2	U(sedimentary rock unconsolidated)	UE (aeolian)	UE 1 and 2 (loess α sands)
		UF (fluvial)	UF 1 and 2 (sand, gravel α clay, silt and loam)
3	Water	……	water

Source:(Van Engelen et al., 2006)

3.2.3. Geology and Groundwater potential

The geology of the N'djili watershed was formed since the Precambrian era, passing through the Cretaceous undifferentiated to Mesozoic- Cenozoic as indicated by Egoroff *et al*. (1962) and reported by Lemba (2010).

The same source articulated that the system formed in Precambrian is Schisto-sandstone whose Floor (II) is represented by the series of Inkisi" indurated sandstone", which is composed of two sub units including quartzites and shales of Luvumu, and arkoses of the Zongo.

Earlier on, Ndembo (2009) citing Egoroff (1955) specified that lower Cretaceous formations are found in the west and along the Congo River and the ocher sands of Neogene which mainly cover the watershed and extend to the whole Province of Kinshasa. Specifically, indurated sandstone at the Ndjili is found in the plain area, and the sedimentary basin extends eastward and filling is done over the long marked by absence of sedimentation (Ndembo, 2009).

On the other hand, information on the availability and hydrodynamic parameters of the aquifers of Kinshasa has been availed through series of projects conducted in the area respectively by Aquater in 1987 and OXFAM/QUEBEC in 2001 (Ndembo, 2009). The project implementation consisted of drilling wells and boreholes. According to this source, the N'djili watershed aquifer lies within the main aquifer which is Mount-Amba.

Furthermore, the same source documented that the exploitation flow rate values range from 30-60 m^3/h. Assuming that these rates corresponds to the maximum, they should logically increase progressively towards the east by increasing the aquifer height related to the deepening of the bedrock (sandstone Inkisi) as indicated by Ndembo (2009). The average values of some hydrodynamic parameters are given in Table 3.2:

Table 3.2. Hydrodynamic parameters of Mount Amba Aquifer from Ndembo (2009)

Hydrodynamic parameters	Value ranges	Units
Permeability	10^{-4} to 10^{-6}	m / s
Transmissivity	10^{-2} to 10^{-5}	m^2 / s
Specific flow rate	1 to 1.5	$m^3/h/m$

3.2.4. Climate

Climatic conditions in the N'djili Catchment are quite diverse due to considerable differences in the altitude and topography. The climate type is described as AW_4 from Köpen classification as reported by Ntombi (1998) cited by Kabuya (2005). The annual temperature ranges from 20.8°C to 31.7 °C.

The rainfall regime within the catchment is influenced by local topography within the catchment ranging from the valley floor to the medium gradient hill. The catchment experiences two main seasons which are the rainy and dry season. The rainy season lasts for about 9 months and the remaining 3 months form the dry season.

Long rains occur later at the end of the month of September to the month of January of the next year. In contrast, the short rains are experienced toward the ends of February and in the middle of May. Then, the rest of the months are considered as dry period. The N'djili catchment experiences an average annual rainfall of more less than 1400 mm/year but can receive up to maximum of more less than 1964 mm a year.

According to the daily rainfall data recorded from 1961 to 2007 at the N'djili weather station whose geographic location is given in Table 3.4, it is revealed 107 days of rains contribute to the mean annual rainfall of 1487 mm/year for a normal year. However, the year 1972 has been below (1000 mm) the average with the maximum of 1964 mm/year of rainfall recorded in 1997.

Furthermore, the analysis of trends of 5-year cycle showed variations of rainfall throughout the 46 year- period, and the projected mean annual rainfall would go above 1500 mm/year for the 10-year cycle. Additionally, the month of November receives generally more rainfall (with a M.A.R of 255mm) than any other months and it is followed by the month of April (222 mm/month of M.A.R). About 40% of rainfalls occur from October to December and the monthly rainfall average received during the dry season range from 2.8 mm/month to 36.7 mm/month.

The following Figures 3.4a and 3.4b illustrate respectively the variation of rainfall occurrence from 1961 to 2007 and the monthly variation of rainfall occurrence in a year.

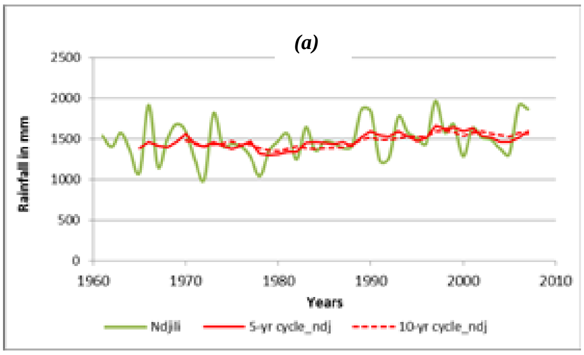


Figure 3.4a.Yearly variation of rainfall occurrence in the N'djili Catchment (1961 -2007)

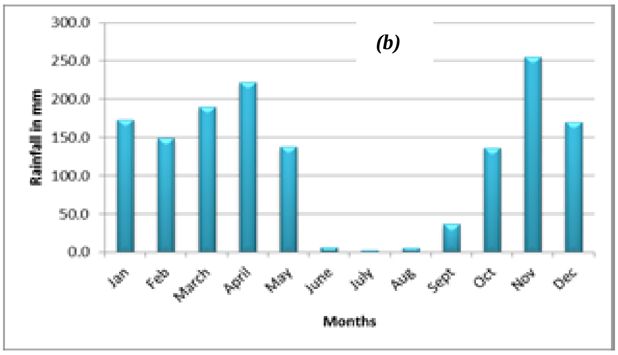


Figure 3.4b.Monthly variation of rainfall occurrence in the N'djili Catchment (1961 -2007)

3.3. Overview of existing data

3.3.1. Hydro-meteorological and Water quality Data

The references of meteorological, hydrological and water quality data are detailed in Table 3.4. Even though, some isolated measurements which have been undertaken into the N'djili river along the whole catchment, in general, the N'djili catchment is still an ungauged catchment. However, since the installation of an abstraction point for water supply on the N'djili river, the measurement of hourly turbidity has been recoded for a number of years. In the past, the catchment used to have substantial number of weather stations, but to date many of them are no longer functional. The geographic locations of weather stations in/or nearby the N'djili Catchment are shown in Table 3.3.

Table 3.3. Geographic locations of weather stations in/or nearby the N'djili catchment

Nº	Name of Station	Station type	Identity of Station	Latitude	Longitude	Altitude	Source of information
1	N'djili,	Weather	64210	S 04° 23'	E 15° 26'	311 m	Mettelsat
2	Ndolo	Weather	64211	S 04° 19'	E 15° 18'	279 m	Mettelsat
3	Mont- Amba (CREN-K)	Weather	------	S 04°24'	E 15°18'	433 m	CREN-K
4	Mbanza N. (Luzumu)	Weather	------	S 5° 15'	E 14° 51'	464 m	NASA
5	N'djili station 2	Gauging station	------	S 04°23'	E 15°21'	285 m	CREN-K
6	REGIDESO station	Abstraction point	------	S 04°23'11"	E 15°22'	278 m	REGIDESO

Table 3.4. References of meteorological, hydrological and water quality data

Data type	Number of stations	Name of stations	Source of Data	Data category	Time period	Time step Unit	Quantity (years)
Rainfall	4	N'djili, Ndolo, Mont-Amba and Mbanza-Ngungu	Mettelsat	Meteorological	1961 - 2007 2008-2012	Daily, Monthly	51
Temperature (Max, Min, Average)	4		Mettelsat	Meteorological	1961 - 2007 2008-2012	Daily, Monthly	51
Max rainfall half-hour	2	N'djili and Ndolo	Mettelsat	Meteorological	1987-2012	Monthly	23
Relative Humidity	3	N'djili, Ndolo, and Mbanza-Ngungu	Mettelsat	Meteorological	1964 - 2012	Daily, Monthly	48
Wind speed (2m)	3		Mettelsat	Meteorological	1964 - 2012	Daily, Monthly	48
Potential Evapotranspiration	2	N'djili, and Mbanza-Ngungu	Computed using modified Penman Modified equation Shuttleworth,1992	Meteorological	1983-2012	Daily, Monthly	29
Water levels	1		Hernandez,1967 & Kabuya,2005	Hydrological	1966-67, & 2005	Daily, Monthly	2
Discharges	1						
sediments	1		Kabuya,2005	Water quality	2005	Daily	
Turbidity		N'djili 2					
Amount chemical used for Water Treatment	1		REGIDESO	Water quality	1985-2012	Hourly, Daily	27

3.3.2. Soil database

Soils data for N'djili basin exist from the spatial distribution and properties of the soils of DRC gathered since 1960.This database was aggregated in SOTER (SOil and TERrain) database (DRC, Rwanda, Burundi) available at http://www.isric.org/projects/soter-central-africa-sotercaf (Baert *et al*.,(2012). The present study extracted the details related to this particular area which is the N'djili Catchment. These details served as one of the major inputs to model undertaken in this study.

3.3.3. Satellite Data

A number of satellite data, fine and coarse resolution, exist which cover portions of the catchment for different years were acquired. These were identified, selected, downloaded and then, processed. Among them, Landsat imageries and DEM map were used in the current study.

3.3.3.1. Landsat Imagery

The Landsat scenes needed for the present study were obtained from the website: http://glovis.usgs.gov for the identification and the selection of the needed criteria. http://earthexplorer.usgs.gov was utilised for downloading Landsat products. These were done for different years and details are presented in Table 3.5. The path and raw details for the study area as identified from http://landsat.org guided the acquisition of scenes for the catchment area.

Table 3.5.Landsat scenes characteristic

Nº	Period	% of clouds	Landsat Identity	Resolution
1	Rainy season (January 23,2012)	30	LE71820632012023ASN00	30 m
2	Rainy season (April 30,2001)	30	LE71820632001120EDC00	30 m
3	Rainy season (February 01,1995)	30	LT51820631995032XXX01	30 m
4	Rainy season (January 10,1987)	30	ETP182R63_5T19870110	30 m

All the Landsat scenes were processed in order to carry out the land use and cover changes for the whole catchment.

3.3.3.2. Digital Elevation Model (DEM)

The current study used DEM downloaded from Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales (HydroSHEDS) at http://hydrosheds.cr.usgs.gov/datadownload.php?reqdata=3demg. HydroSHEDS is a mapping product that provides hydrographic information for regional and global-scale applications in a consistent format. It provides high-resolution elevation data obtained during a Space Shuttle flight for NASA's Shuttle Radar Topography Mission (SRTM). This product was developed by the Conservation Science Program of World Wildlife Fund (WWF). Table 3.6 provides details of the DEM taken for the N'djili Catchment.

Table 3.6. DEM characteristics for the N'djili catchment

Nº	Period	References	Data format	Projection	Resolution	Values
1	December 2006	S05e015	Raster	Geographic referenced to WGS84 horizontal datum	3 arc-second (90m)	meters

3.3.4. Additional data

Required additional data for this study include data on potential evapotranspiration (Ep) and was computed using the Penman-Monteith equation as modified by Shuttleworth (1993). This equation (3.1) is described below as:

$$E_p = \frac{\Delta}{\Delta + \gamma}(R_n + A_h) + \frac{\gamma}{\Delta + \gamma}\left[\frac{6.43(1 + 0.536U_2)D}{\lambda}\right]$$

Equation 3.1

The description of parameters of this formula is detailed in Table 3.7.

Table 3.7. Description of different parameters evolving the Penman-Monteith equation as modified by Shuttleworth (1993)

Parameter	*Formula*	*Description*
Available energy, A_h	$A_h = R_n - G$	In (MJ/m^2/day), A_h = 0, when performing regional hydrological assessment. G, is sensible heat lost to ground and G = 0.
Vapour pressure deficit, D	$D = e_s - e_a$	In (kPa), e_s and e_a are defined below.
Gradient (slope) of saturated vapour pressure (Δ)	$\Delta = \frac{4098 * es}{(237.3 + T)^2}$	e_s is the saturated vapour pressure (in kPa) and T is the temperature (in °C).
Saturated vapour pressure (e_s)	$es = 0.6108 \exp\left(\frac{17.27T}{237.3 + T}\right)$	In (kPa)
Actual vapour pressure (e_a)	$e_a = 0.6108 \exp\left(\frac{17.27 * Td}{237.3 + Td}\right)$	In (kPa) and Td (dew point temperature in °C)
Psychrometric constant (γ)	$\gamma = 0.0016286 \frac{P}{\lambda}$	P is the atmospheric pressure (kPa) and λ is the latent heat of vaporization of water (MJ/kg)
Atmospheric pressure (P)	$P = 101.3\left(\frac{293 - 0.0065Z}{293}\right)^{5.256}$	Z is the elevation of the reference point in meter.
Latent heat (λ)	$\lambda = 2.501 - 0.002361\ Ts$	T_s is the surface temperature of the water in °C.
Net radiation (Rn)	$R_n = R_{ns} - R_{nl}$	In MJ/m^2/day
Net short-wave radiation (Rns)	$Rns = Rs(1 - \alpha)$	Rs is the solar radiation (MJ/m^2/day) and α is the short-wave radiation reflection coefficient (albedo). For a free surface, α= 0.23.
Net outgoing long-wave radiation (Rnl)	$Rnl = f\epsilon\sigma(T + 273.2)^4$	f is the adjustment for cloud cover, ϵ is the net emissivity between the atmosphere and the ground. 0.05≤ f ≤ 1.0 and σ is the Stefan-Boltzmann constant (4.903 x 10^{-9} $MJ/m^2/K^4$/day)
wind speed at 2m (U_2)		In (m/s)

CHAPTER 4: METHODOLOGY

4.1. Methodological design

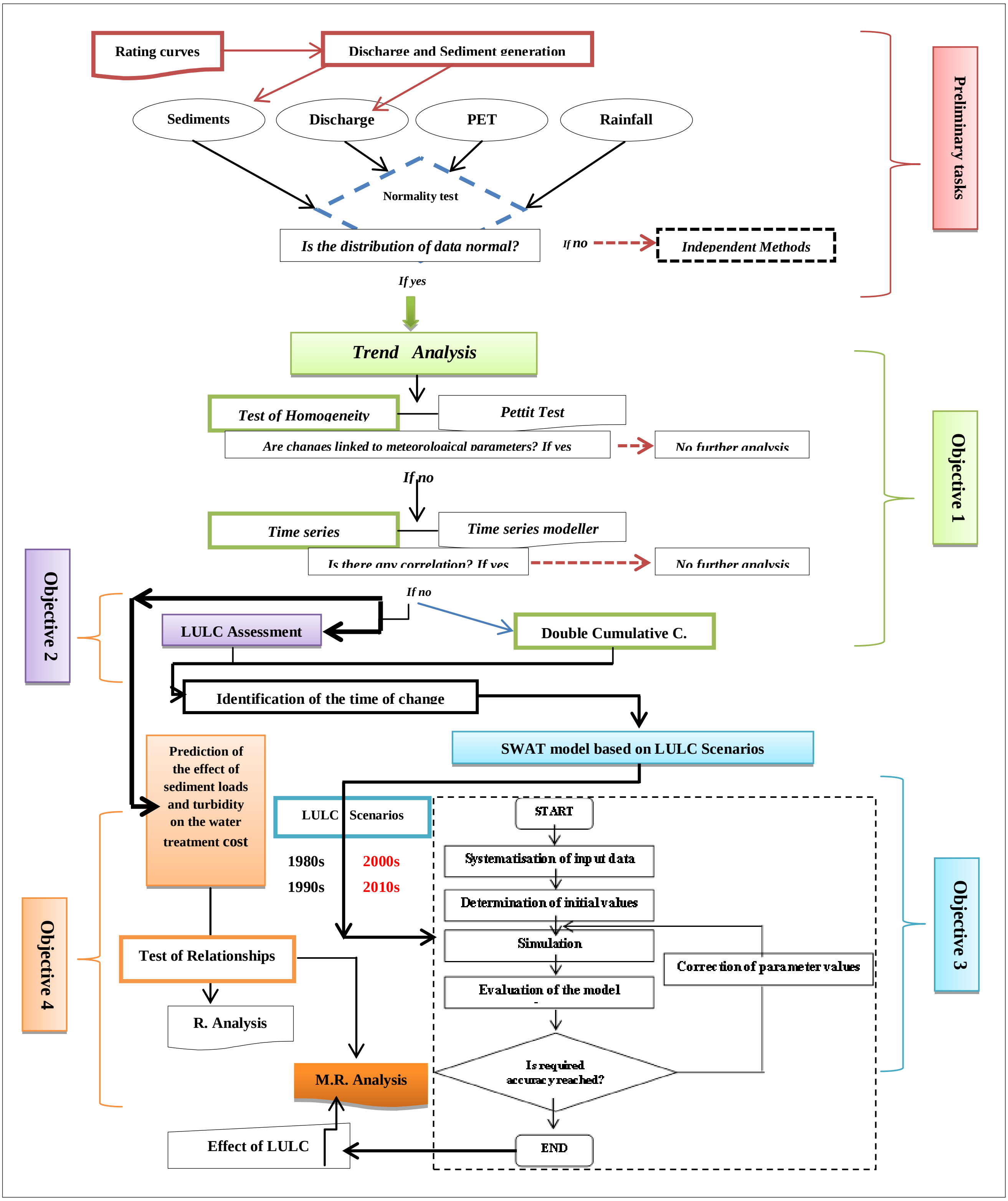


Figure 4.1.Methodological design of the study

4.2. Methods

4.2.1. Preliminary Tasks

4.2.1.1. Rating curves

The rating curves were performed for the water level and discharge, and turbidity and total suspended sediment in order to predict one variable using another. Dymond and Ross (1982) agreed with previous authors such as Carter and Anderson (1963); Dickson (1967 & 1972); Herschy (1978) that the rating function should have general form as follow:

$$Q = \alpha (H - H_0)^{\beta} \qquad \text{Equation 4.1}$$

Then,

$$Q = aX^{\beta} \qquad \text{Equation 4.2}$$

Where Q is discharge, H is water level relative to an arbitrary datum, Ho is water stage at zero discharge, and α and β are constants. X will be referred to as water stage from now on. So, the equation 4.2 becomes linear after natural log transformation:

$$\ln Q = \ln \alpha + \beta \ln X \qquad \text{Equation 4.3}$$

Similarly, (Holliday *et al.*, 2003) found a strong correlation between turbidity (NTU) and the total suspended sediment (TSS). They concluded that there is a power relationship between both parameters of the form:

$$NTU = a\,TSS^{b} \qquad \text{Equation 4.4}$$

Where **a** and **b** are regression-estimated coefficients.

The equation 4.4.was linearised in the same way as the equation 4.2, and it is expressed below as:

$$\ln TSS = \frac{1}{b} \ln NTU - \frac{1}{b} \ln a \qquad \text{Equation 4.5}$$

The linear transformation was used in order to allow a quick assessment of the correlation between the intended variables Schwarz (2013) .

In fact, this study opted for the use of turbidity measurement with nephelometric turbid meter as considered as good method to estimate sediment loads in rivers as earlier proposed by Lewis (1996) and later indicated by Pavanelli and Pagliarani (2002).

However, the pattern of the presumed relationship was roughly explained by Rasmussen (1995) as results of variations in sediment composition and stream energy.

4.2.1.2. Discharge and sediments generation

The above described rating curve analyses were used to transform the water level into discharge and the turbidity into suspended sediments respectively based on the fitness of their relationships. This technique served to characterize the flow regime and the sediment pattern of the N'djili river as suggested the study conducted by Rantz (1982).

4.2.1.3. Test of normality

The test of normality was carried out for the variable such as suspended sediment, discharge, potential evapotranspiration and rainfall. According to Hun Myoung (2008), the normality test is considered as critical in most of the statistical methods and its common assumption is that a random variable is normally distributed.

However, the same source further argued that when this assumption is violated, interpretation and inference may not be reliable or valid. In order to perform the test of normality, two ways are frequently used such as graphical and numerical methods (Hun Myoung, 2008). These methods are either descriptive or theory-driven.

This study opted for both methods in order to be statistically more rigorous whereas the Q-Q plots were adopted and the empirical assumption of Kolmogorov-Smirnov test was used to examine the normality of data. This test was carried out under SPSS (16^{th} version) as a statistical package.

4.2.2. Methodology of the Objectives

4.2.2.1. Methodology for Objective 1

Long-term trend analyses of water quality and hydrological parameters were compared to meteorological parameters in order to discern if the inherent patterns occurred in both water quality and hydrological parameters are linked to the ones for meteorological parameters or a further investigation has to be made elsewhere.

To do this, the starting point was the test of homogeneity which helped to depict abrupt change points then, followed by time series analyses which served to examine the long-term correlation trends between meteorological, water quality and hydrological data and finally, the double cumulative curves analysis was performed to ideally identify the time of changes.

4.2.2.1.1. Test of Homogeneity for abrupt changes

The meteorological, water quality and hydrological data were then subjected to homogeneity test after being tested for normality. This test allows identification of possible error sources of measurements and environmental changes (Biggs *et al.*, 2010). In literature, a lot of methods were proposed for testing the homogeneity of meteorological variables like precipitation and temperature (Ducr'e-Rubitaille *et al.*, 2003; Klingbjer and Moberg, 2003; Modarres, 2008; Staudt *et al.*, 2007; Tomozeiu *et al.*, 2005). Wijngaard *et al.*,(2003) used the standard normal homogeneity test method (SNHT), Buishand test, Pettitt test and Von Neumann tests for testing the homogeneity of daily precipitation and temperature series.

Ultimately, the non-parametric Pettitt test was adopted for this purpose. This test is reputed as a rank-based test for detecting significant changes in the mean of time series data when the exact time of change is unknown (Pettit, 1979). The test is considered as vigorous to changes in distributional form of time series and relatively powerful as compared to Wilcoxon-Mann-Whitney test, CUSUM and cumulative deviations (Kundzewicz and Robson, 2004). Furthermore, Pettitt test has been widely adopted to detect changes in climatic and hydrological time series data (Ma *et al.*, 2008; Moraes *et al.*, 1998; Zhang and Lu, 2009).

The present study used the simulations of Monte Carlo under XLSTAT.2013.2.07 as statistical package in order to carry out the homogeneity test (Pettitt test).

4.2.2.1.2. Time series analysis

The time series analysis was performed concomitantly for the meteorological data against the water quality and hydrological data in order to assess if the pattern of the meteorological data is correlated to the long-term pattern of both water quality and hydrological data.

This analysis was carried out using two methods. One based on the polynomial transformation for the long-term time series which was performed under XLSTAT.2013.2.07 statistical package and on the other hand, the correlation analysis (Pearson test performed under SPSS statistical package) was carried out as well to assess the link in the pattern of these three groups of variables.

4.2.2.1.3. Double cumulative curves analysis

Double cumulative was applied for instance to check the consistency (Searcy and Hardison, 1960) and long-term trend of the meteorological and the water quality data in order to infer any breaks in the slope of the curve to a corresponding shift whether occurring naturally or human-induced at a corresponding time as well.

4.2.2.2. Methodology for Objective 2

The spatial and temporal assessment of LULC was carried out using Landsat images respectively for 1987, 1995, 2001 and 2012 whose details are provided in Table 3.5. Each one of then was subjected to land use/cover classification procedures and five major classes were chosen as basis of this classification. The referred land use classes are as followed: *bare land, cropland, grassland and shrubs, and water*. This process consisted on the following three consecutive steps: pre-processing, classification and accuracy assessment.

4.2.2.2.1. Pre-processing

This concerned the gap filling and calibration of the Landsat images.

a) Gap filling

The Landsat image (Landsat 7 Enhanced Thematic Mapper Plus) for 2012 was subjected to gap filling process which was carried out under ERDAS Imagine 8.4 using focal analysis. The completion was obtained after five runs of this analysis.

b) TM Calibration

All the Landsat images were subjected to calibration. This process required parameters such as Landsat satellite, date of acquisition, sun elevation (degree), calibration type (reflectance was used), and was performed under ENVI 4.2 as described by (Krimmer, 2008).

4.2.2.2.2. Classification and Post-Classification

All the Landsat images were subjected to ISODATA unsupervised classification under ENVI 4.2. This particular technique was selected because of its ability to deal with shadow masks which frequently occur during the year in the region whereby the present study area is located, and provides a wide range of results with 73% to 87 % overall accuracy for images from 2000, but 18% to 92 % below 2000 (Helmer and Ruefenacht, 2005).

Moreover, this method calculates class means evenly distributed in the data space then iteratively clusters the remaining pixels using minimum distance techniques (RSI-ENVI, 2005).
Each iteration recalculates means and reclassifies pixels with respect to the new means and the process will continue until the number of pixels in each class changes by less than the specific pixel change threshold or the maximum number of iterations is reached.

A further classification was carried out after completing the previous stage. This concerned the post-classification using Sieve and Clump classification. According to RSI-ENVI (2005), Sieve is usually run first to remove isolated pixels based on a size (number of pixels) threshold, then Clump is run in order to add spatial consistency to existing classes by combining adjacent similar classified areas.

4.2.2.2.3. Accuracy Assessment

This assessment was completed using a confusion matrix function performed for each Landsat image. This function allows comparison of two classified images (the classification and the "truth" image), or a classified image and regions of interest (ROIs). RSI-ENVI (2005) argued that the truth image can be another classified image, or an image created from actual ground truth measurements. So, the current study used the outputs from IsoData classification to match with the outputs from the post-classification in order to carry out the accuracy assessment. The compiled works from MENCT (2008), DRC-Ministry of Environment, Nature Conservation and Tourism and the one from OSFAC (Satellite Observatory of Central African Forest) at *http://osfac.net/index.php?lang=en&Itemid=135* and *ftp://congo.iluci.org/FACET/DRC/* were used as reference information in order to assist the image classification process.

The indexes such overall accuracy and Kappa coefficient were used to determine the accuracy level for each land use/cover classification. These indexes are expressed as followed:

$$\boldsymbol{Overall\ accuracy} = \frac{\boldsymbol{Number\ of\ classied\ pixels}}{\boldsymbol{Total\ number\ of\ pixels\ of\ the\ area}}$$

Equation 4.6

and,

$$\boldsymbol{Kappa\ coefficient} = \frac{\boldsymbol{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} * x_{+i})}}{\boldsymbol{N^2 - \sum_{i=1}^{r}(x_{i+} * x_{+i})}}$$

Equation 4.7

Where N is the total number of sites in the matrix, r is the number of rows in the matrix, x_{ii} is the number in row i and column i, x_{+i} is the total for row i, and x_{i+} is the total for column i (Jensen, 1996).

Moreover, the statistics from land use/ cover classes were then subjected to an analysis of the variance to examine the level of the significance in changes. In turn, all the land use/cover maps were taken as inputs to the SWAT model to serve as major part of the scenarios.

4.2.2.3. Methodology for Objective 3

The simulation of sediment loads was performed using SWAT model and having land use/cover as basis of scenarios. The version of SWAT used was SWAT2009 which is close and tight coupling with Arc View 10.01 as indicated by Di Luzio *et al*. (2004). The modelling process consisted the following four steps.

4.2.2.3.1. Systematisation of the Input data

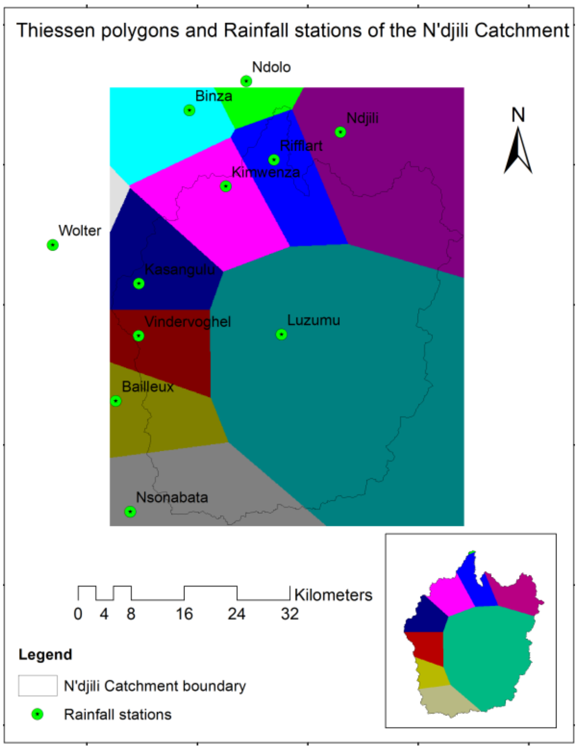
a) Spatial data

The spatial data required by the model included a digital elevation model (DEM) whose details are given in table 3.6; land use map (see objective 2) and soil map. The DEM was projected in Universal Transverse Mercator (UTM) and the landuse map for each year was generated using Landsat images of 30 m x 30m of resolution, and then the soil map and soil properties were respectively extracted and derived from the soil map of DR Congo obtained from SOTERCAF.

b) Weather parameters

Time series of meteorological parameters such as rainfall, temperature (max and min), solar radiation, wind-speed and rainfall max half hour were compiled into proper format required by SWAT model from three weather stations as follow: N'djili, N'dolo and Mbanza- Ngungu (Luzumu). These weather stations were chosen according to the data availability and the aerial percentage of influence and the proximity from the catchment outlet.

The Thiessen polygons of the Catchment were generated in order determine the percentage of influence of each weather station (figure 4.2).



Area of influence

Rainfall stations used	%	Label
Ndolo	0.18	
N'djili	9.31	
Mbanza (Luzumu)	48.86	

Figure 4.2. Thiessen polygons of the N'djili Catchment

Finally, all the above weather parameters were fed into SWAT weather generator macro to simulate the secondary weather data. The combined primary and secondary data allowed the model to predict climatic and hydrological conditions over the whole catchment for a long-term period. Lastly, V4 Test database generated from this process was exported into Arc View, and then appended into the SWAT user weather generator database.

4.2.2.3.2. Determination of the Initial Values

Based on the spatial data, the model was able to generate statistics on the topographic conditions, Hydrological Response Units (HRU) and distribution statistics for land use and soil classes within the sub basins of the whole Catchment.

4.2.2.3.3. Simulations

a) Sensitivity analysis

This analysis reveals the influence that change to an individual input parameter has on the model response and can be performed using various methods (Veith and Ghebremichael, 2009). The method in the Arc SWAT interface combines the Latin Hypercube (LH) and One-factor-At-a-Time (OAT) sampling (Van Griensven and Srinivasan, 2005).

In order to investigate the most sensitive parameter set ranking, two runs of sensitivity analyses were performed of which one as first run was done without observed data and the second run used the observed data.

The sum of squares residual ranked was then chosen as objective function. The observed data used was a dataset of monthly sediments for 1987, 1995, 2001, and 2012.

b) Calibration and Uncertainty analysis

Following the sensitivity analysis outcomes, the auto-calibration was run for only the sensitive parameters to acquire the optimum values for the modelled sediments. The calibration and uncertainty analysis were carried out by performing *SUNGLASSES* method. The manual adjustment was then made to match the modelled sediments to the observed (Van Liew *et al*., 2005).

c) Validation

The validation of the model was performed using an independent dataset of 2006 from the N'djili Catchment. While relating on the calibration and validation techniques (Arnold *et al*., 2012) exposed some tactics on how to manage observed data in such way that it can be split into two datasets: one for calibration and another for validation, or else to use calibrated data from watershed with approximately similar climatic, soils, and land use conditions.

4.2.2.3.4. Evaluation of the model performance

Both statistical and graphical model evaluation techniques were reviewed and are commonly being used (Moriasi *et al*., 2007). For instance, the present study undertook only the statistical technique for the evaluation of the model performance.

The same source suggested that the recommended statistical model evaluation techniques must be selected based on the following criteria: (1) robustness in terms of applicability to various constituents, models, and climatic conditions; (2) commonly used, accepted, and recommended in published literature; and (3) identified strengths in model evaluation. Additionally as proposed Boyle *et al*. (2000), the trade-off between long-term bias and residual variance should also be accounted in the evaluation of the model performance.

Based on the criteria exposed at the above, this study adopted the following techniques:

a) Pearson's correlation coefficient (r) and coefficient of determination (R^2)

Pearson's correlation coefficient (r) and coefficient of determination (R^2) describe the degree of collinearity between simulated and measured data. The correlation coefficient, which ranges from −1 to 1, is an index of the degree of linear relationship between observed and simulated data. If r = 0, no linear relationship exists. If r = 1 or −1, a perfect positive or negative linear relationship exists.

Similarly, R^2 describes the proportion of the variance in measured data explained by the model as earlier reported by Legates and McCabe (1999) and as cited later by Moriasi *et al*.(2007).

R^2 ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable. Although r and R^2 have been widely used for model evaluation, these statistics are oversensitive to high extreme values (outliers) and insensitive to additive and proportional differences between model predictions and measured data as reported by Legates and McCabe (1999) and cited by Moriasi *et al*.(2007).

b) Nash-Sutcliffe efficiency (NSE)

The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance (Moriasi *et al*., 2007).

NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed as shown in equation 4.8:

$$\boldsymbol{NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=0}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right]}$$

Equation 4.8

Where,

Y_i^{obs} is the *i* the observation for the constituent being evaluated, Y_i^{sim} is the *i* the simulated value for the constituent being evaluated, Y^{mean} is the mean of observed data for the constituent being evaluated and *n* is the total number of observations.

NSE ranges between −∞ and 1.0 (1 inclusive), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance.

c) Percent bias (PBIAS)

According to Gupta *et al.(1999)* Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. The same source suggested that positive values indicate model underestimation bias, and negative values indicate model overestimation bias. PBIAS is calculated as in equation 4.9:

$$\mathbf{PBIAS} = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right) * 100}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right]$$

Equation 4.9

Where PBIAS is the deviation of data being evaluated, expressed as a percentage.

d) RMSE-observations standard deviation ratio (RSR)

RMSE is one of the commonly used error index statistics (Moriasi et al., 2007). Based on the recommendation made by Singh *et al*. (2004) and as reported later by Moriasi *et al.(2007)*, a model evaluation statistic, named the RMSE-observations standard deviation ratio (RSR), was developed. RSR standardizes RMSE using the observations standard deviation, and it combines both an error index and the additional information as recommended by Legates and McCabe (1999) and as indicated by Moriasi *et al*. *(2007)*. RSR is calculated as the ratio of the RMSE and standard deviation of measured data, as shown in equation 4.10:

$$\mathbf{RSR} = \frac{\mathbf{RMSE}}{\mathbf{STDEV}}\frac{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right]}$$

Equation 4.10

RSR incorporates the benefits of error index statistics and includes a scaling/normalization factor, so that the resulting statistic and reported values can apply to various constituents. RSR varies from the optimal value of 0, which indicates zero RMSE or residual variation and therefore perfect model simulation, to a large positive value. The lower RSR, the lower the RMSE, and the better the model simulation performance.

4.2.2.4. Methodology for Objective 4

4.2.2.4.1. Non-linear regression analysis

The prediction of the effect of sediment loads and turbidity on the water treatment cost was performed using non-linear regression analysis. To do this, XLSTAT was used as statistical package.

4.2.2.4.2. Multi-linear regression analysis

A multi-linear regression model was built based on the selection of thirteen parameter sets found as the most sensitive from SWAT sensitivity analysis outputs in order to identify the ones which sensibly affect the observed sediment loads from the N'djili river. Data analysis tools from MS Excel were used to build a multi-linear regression model.

CHAPTER 5: RESULTS AND DISCUSSION

5.0. Introduction

This chapter presents the research findings from the statistical, spatial analyses and modelling performed in the current study as described in the methodological design (Figure 4.1).

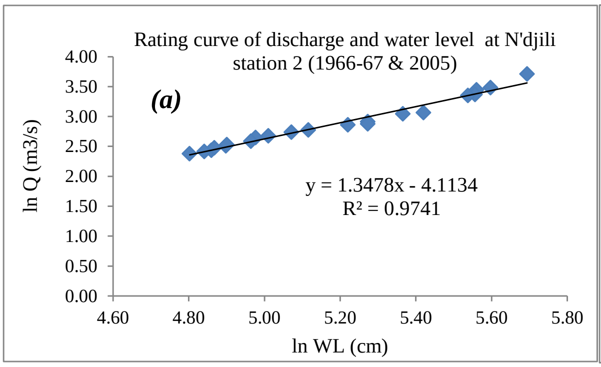
The results are partitioned into five sections. The first section introduces the preliminary tasks referring to the ratings curves, discharge and sediment generation, and normality test. The second section deals with the trend analysis of meteorological, water quality and hydrological parameters. The third section addresses the spatial and temporal assessment of land use/cover in the N'djili Catchment. The fourth section presents the outputs of the SWAT model based on four land use/cover scenarios. Lastly, the fifth section shows the prediction of the effect of sediment loads slash turbidity on the water treatment cost of the N'djili catchment.

5.1. Preliminary Tasks

As indicated earlier, these preliminary tasks consisted in rating curves, generation of discharge and sediments, and test of normality.

5.1.1. Ratings Curves

Figures 5.1a and 5.1b show the rating curves of the N'djili river based on the discharge Q (m^3/s) and water level WL (cm), and turbidity (NTU) and total suspended sediment TSS(mg/L).The statistics from Pearson correlations are given in Tables 5.1a and 5.1b. The data acquired for this computation were recorded at the N'djili station2.



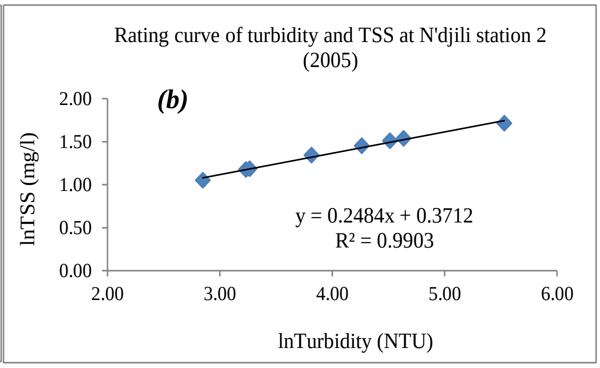


Figure 5.1a.Rating curve between Discharge and Water Level

Figure 5.1b.Rating curve between TSS and Turbidity

Table5.1a.Correlations between Water level and Discharge

		Discharge(m3/s)	Water level (cm)
Pearson Correlation	Discharge(m3/s)	1.000	.987
	Water level (cm)	.987	1.000
Sig. (1-tailed)	Discharge(m3/s)	.	.000
	Water level (cm)	.000	.
N	Discharge(m3/s)	21	21
	Water level (cm)	21	21

Table5.1b.Correlations between Turbidity and TSS

		Sediments(mg/L)	Turbidity (NTU)
Pearson Correlation	Sediments(mg/L)	1.000	.995
	Turbidity (NTU)	.995	1.000
Sig. (1-tailed)	Sediments(mg/L)	.	.000
	Turbidity (NTU)	.000	.
N	Sediments(mg/L)	8	8
	Turbidity (NTU)	8	8

Figures 5.1a and 5.1b reveal a strong relationship ($R^2 \geq 0.97$) and a very significant difference (*p-Value 0.000*) from the Pearson correlations (Tables 5.1a and 5.1b) respectively between the water level and discharge, and turbidity and sediments. This allows a further prediction of one variable using another, and *vice-versa*.

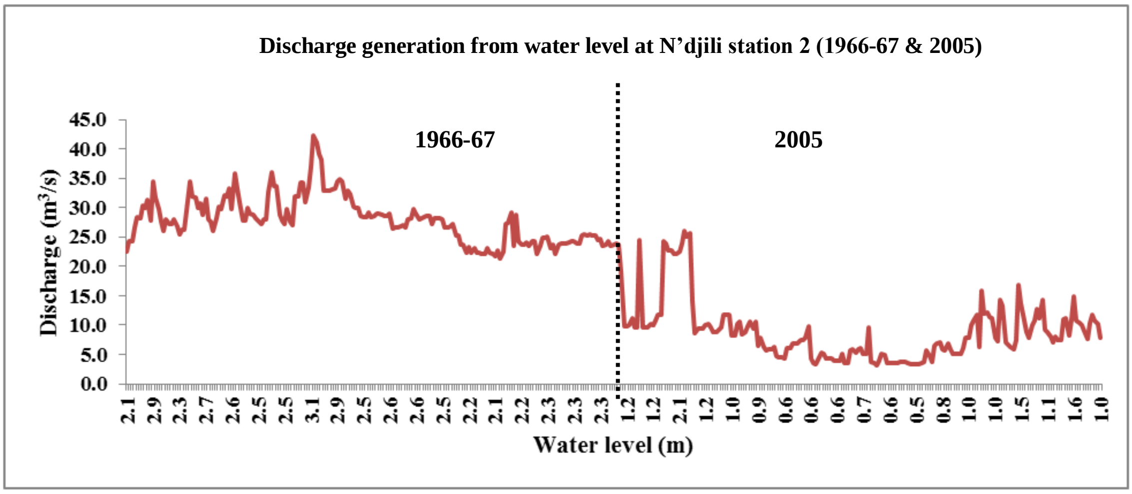
Although, the slopes of the curves (b=1.35 for Fig.5.1a, and b=0.25 for Fig.5.1b) are very different from each other in terms of their magnitude, of which one is even greater than the unity, indicate that the linear relationship is likely to be appropriate.

As discussed by Domeneghetti *et al.*(2012) that the rating curves' construction has to be calibrated with the discharge observation in the set together with the associated water level. Indeed, they discovered that the bias increases with the number event while using traditional approach of the rating curves' construction (Equation.4.1) mostly when dealing rivers whose discharge rates are greater than 6000 m^3/s. So, they advised to make use of the constrained approach which minimises the uncertainty.

Similarly, as argued by Rasmussen (1995) reported by Holliday *et al.*(2003) that the relationship between turbidity and suspended sediments is strongly linked to the spatial and temporal changes due to variations in sediment composition and stream energy.

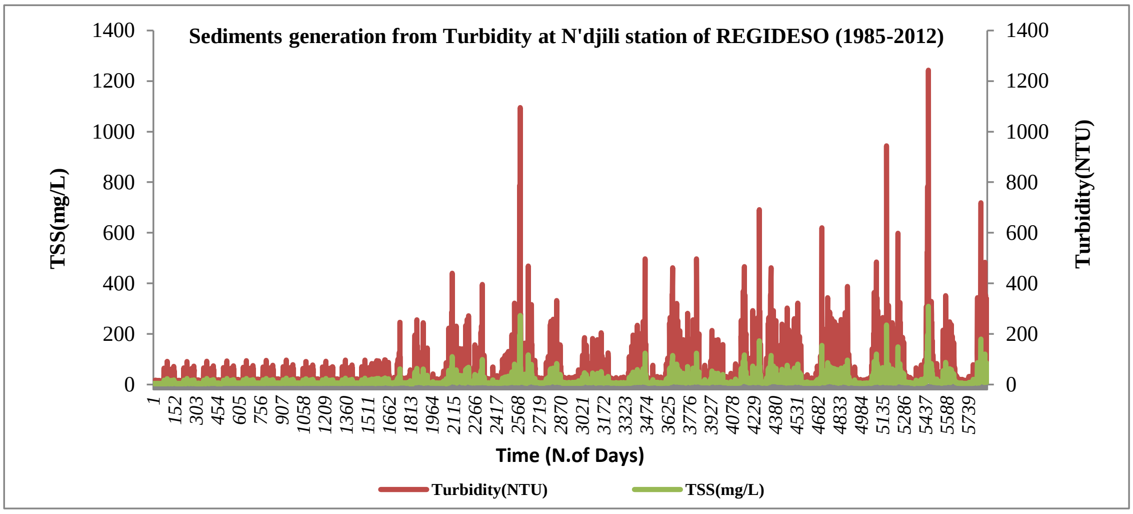
5.1.2. Discharge and Sediment Generation

Both discharge Q (m^3/s) and sediments(mg/L) are generated (Figures 5.2 and 5.3) based on the relationship resulted from the rating curve analysis and recorded data obtained from 1966 to 67 and 2005 for daily water level at N'djili station 2, and from 1985 to 2012 for daily measurements of turbidity (NTU) at N'djili station of REGIDESO.



Note: Measurements for 1966-67 comprised October to September and January to December for 2005

Figure 5.2. Discharge generation from Water Level, WL at N'djili station2 (1966-67 & 2005)



Figures 5.3.Sediments generation from daily measurements of Turbidity at N'djili station of REGIDESO (1985-2012)

As result of the rating curves' construction, Figures 5.2 and 5.3 show correspondingly higher discharges observed from 1966 to 1967 than it has been observed in 2005, and on the other hand, the contrary view can be perceived in the sediment loads pattern from 1985 to 2012.

Moreover, this general observation illustrated in Figures 5.2 and 5.3 can be attributed to the drastic change in the landscapes of the N'djili Catchment as supported by Paul and Meyer (2001), who earlier argued that the new development, and related various land activities, has led to have hostile effects on navigable waters and upstream tributaries by letting sediments to enter the natural ecosystem.

5.1.3. Test of Normality

Figure 5.4a-d illustrates respectively the graphical representation of the normality test performed for sediments, discharge, potential evapotranspiration (PET), and rainfall.

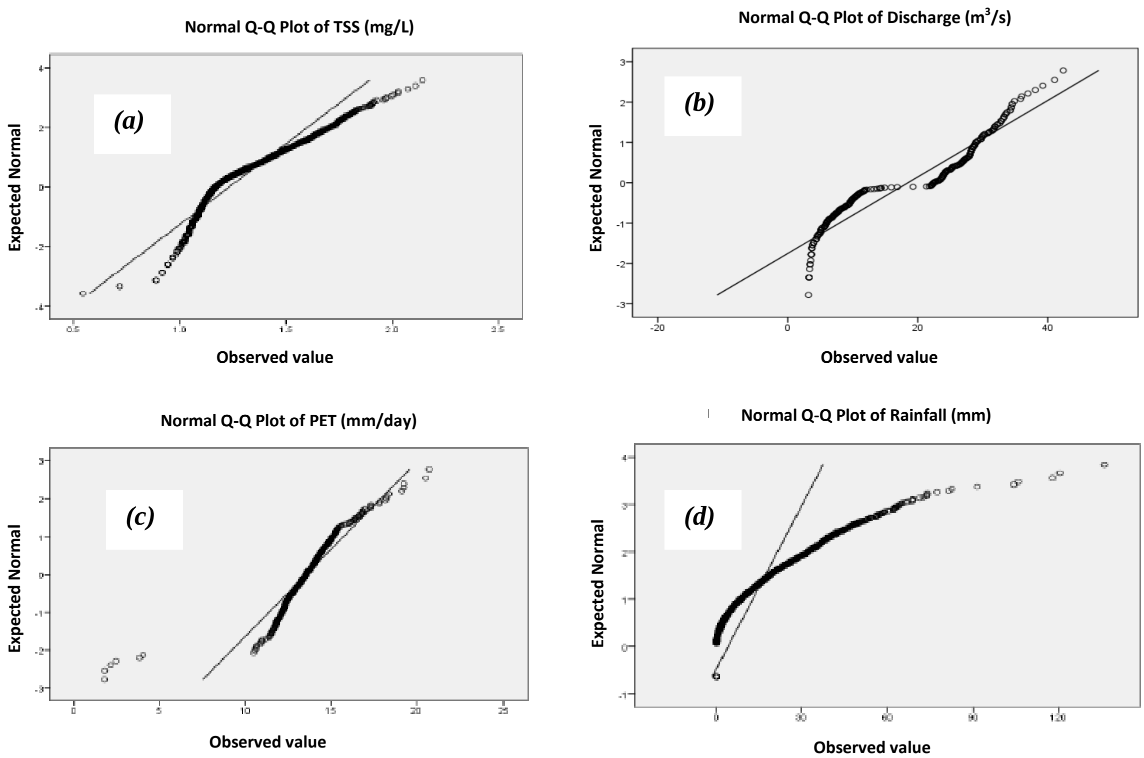


Figure 5.4a-d.Test of normality for sediments, discharge, PET and rainfall

The statistics results of the normality test are provided in Table 5.2.

Table 5.2. Statistics of Normality test for sediments, discharge, PET, and rainfall

			Skewness			***Kurtosis***			***K-S[a] with Lilliefors Correction Test***		
Param.	*Mean±SD[a]*	*Mean±SEM[a]*	*Stat.*	*SE*	*z*	*Stat.*	*SE*	*z*	*Stat.*	*Df[a]*	*Sig.*
TSS (mg/L)	3.5±0.1	3.5±0.01	1.72	0.03	53.66	3.65	0.06	56.95	0.146	5872	0.000
Disch. (m3/s)	18.5±10.5	18.4±0.5	-0.03	0.13	-0.22	-1.50	0.25	-5.92	0.166	371	0.000
PET (mm/day)	2.5±0.3	2.5±0.00	-2.47	0.02	-107.48	9.33	0.05	198.49	0.121	10897	0.000
Rainfall (mm)	4.0±8.7	4.0±0.1	3.68	0.02	193.58	20.81	0.04	547.68	0.322	160404	0.000

[a]*Abbreviations: Df, Degree of freedom; K-S, Kolmogorov-Smirnov; SD, Standard deviation; SEM, Standard error of mean*

K-S'test ($\alpha=0.05$) reported in Table 5.2 and a visual inspection of the normal Q-Q plots (Figure5.4a-d) revealed that only discharge data were approximately normally distributed, with a skewness of -0.03(SE=0.13) and a kurtosis of -1.50(SE=0.25) .According to Ghasemi and Zahediasl (2012), large samples (200 or more) with small standard errors, the z-criterion should be compared to the value of ±2.58. However, sediments, potential evapotranspiration and rainfall data were not normally distributed regarding their respective skewness and kurtosis scores (Doane and Seward, 2011). Furthermore, all the four referred variables were differed very significantly (*p-Value 0.000*) from the normality.

Moreover, according to Hun Myoung (2008) who postulated that most of the statistical analyses use one common assumption which is a random variable is normally distributed. In the further discussion, the same source related that normality is usually appropriately assumed deprived of any empirical evidence or test. However, it is perceived has to be more critical in many statistical analyses and when this assumption is violated, interpretation and inference may not be reliable or valid. This implies that non-parametric tests will be the most appropriate to perform.

5.2. Results for Objective 1

These refer to the trend analyses focused on the homogeneity test, time series, and double cumulative curves.

5.2.1. Homogeneity test (Pettitt test)

The results related to Pettitt's test of homogeneity are shown in Figure 5.5a-d and the referenced statistics are provided in Table 5.3. These results concern parameters such as average daily sediments from 1985 to 2012; daily discharge from 1966 to 1967 and 2005; potential evapotranspiration from 1983 to 2012; and rainfall from 1961 to 2012. The designated parameters were respectively measured at the N'djili station of REGIDESO for the sediments and others at the N'djili station 2 and N'djili station whose details are given in Table 3.4.

Figure 5.5a-d shows the shift occurred in the mean of the time series of data with respect of their period of the observation. Indeed, the comparison of the mean1 and mean2 as shown in the designated figure is made by investigating the magnitude of the ratio between the two means for each variable. While assessing the degree of change between mean1 over mean2, the ratios reveal that mean1 is 0.88, 3.15, 0.82, and 0.91 times than mean2 for respectively sediments, discharge, potential evapotranspiration and rainfall. The inverse case is that the mean2 is 1.14, 0.32, 1.21, and 1.10 times than mean1. This quick assessment sticks to postulate that out of the four variables used only the rainfall pattern (difference of ratio2 and ratio1=0.19) has not changed sensibly as compared with the three others.

Hence, the statistical analyses of Pettitt's test of homogeneity given in Table 5.3 indicated a very significant difference (*p-Value <0.0001*) for all the variables. The argument above used by Paul and Meyer (2001) can be applied to explain the statistical significance resulted from the test of homogeneity.

As confirmed by Firat *et al.*(2010) that the Pettitt's test of homogeneity was found as the most robust test to detect the non-homogeneity at 95 % of interval confidence level in the rainfall data series in Bandirma and Gönen stations in Turkey.

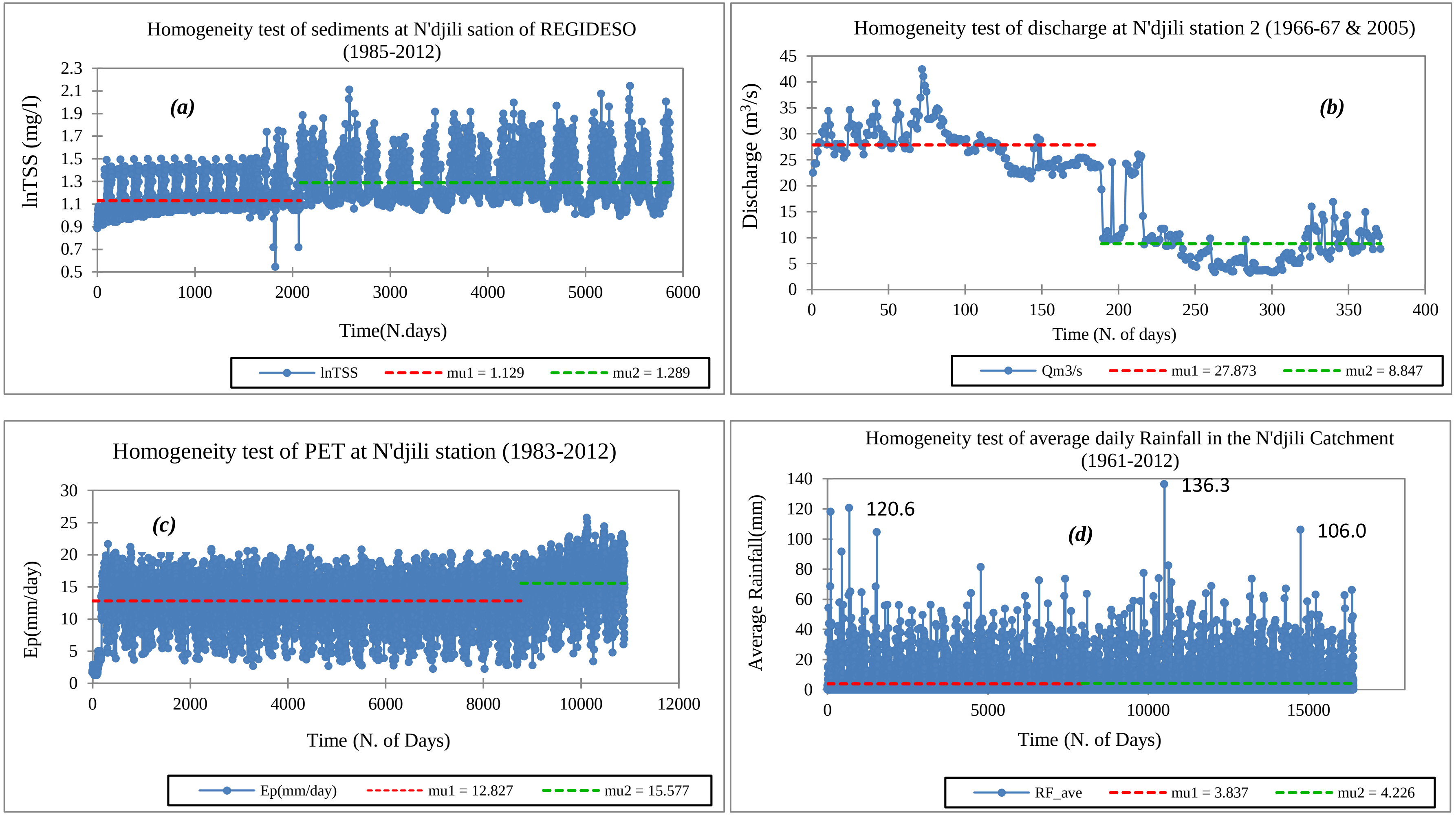


Figure 5.5a-d. Test of homogeneity for sediments, discharge, PET and rainfall

Table 5.3. Statistics of Homogeneity test for sediments, discharge, PET and rainfall

Pettit's test of Homogeneity				
Parameters	***K***	***t***	***p-Value (two-tailed)***	***alpha(α)***
Sediments(mg/L)	*4596793*	*2079*	*< 0.0001*	*0.05*
Discharge (m^3/s)	*33613*	*8767*	*< 0.0001*	*0.05*
Potential ET (mm/day)	*8406342*	*7929*	*< 0.0001*	*0.05*
Rainfall (mm)	*3297064*	*188*	*< 0.0001*	*0.05*

5.2.2. Time series analysis

Figure 5.6a-d illustrates the findings about the time series analysis performed concomitantly using polynomial transformation method for the rainfall with discharge, and rainfall with sediments in order to assess if the long-term pattern of the meteorological data is linked to the long-term pattern of both water quality and hydrological data. Among the two meteorological parameters used in the present study, only rainfall were specifically purposed to highlight the long-term trend because of its significant influence on both discharge and sediment loads. The statistics relate to the time series analyses are provided in Table 5.4.

The long-term trend highlighted in Figure 5.6a-d reveals that both observed and transformed data series for rainfall, sediments, and discharge are not linked. Furthermore, the long-term trend of rainfall is generally stationary than the others two parameters. This lets to assume that the shift in the long-term pattern of both sediments and discharge has to be likely found elsewhere and not as a direct consequence of the meteorological parameters. As supported by the goodness of fit statistics provided in Table 5.4, there is a long-term poor correlation ($R^2 <<< 0.50$) as well as none statistical significance (*p-Value* > 0.01) in the assessment the long-term trend of the three variables.

However, statistics from the Pearson test of correlation (Table 5.5) underline particularly a very significant difference (*p-Value*$= 0.003$) and a negative poor correlation ($R^2 = - 0.028$) in the long-term pattern of rainfall coupled with potential evapotranspiration. This could be probably due to the changes in the landscape of the N'djili Catchment which in turn affect the meteorological conditions.

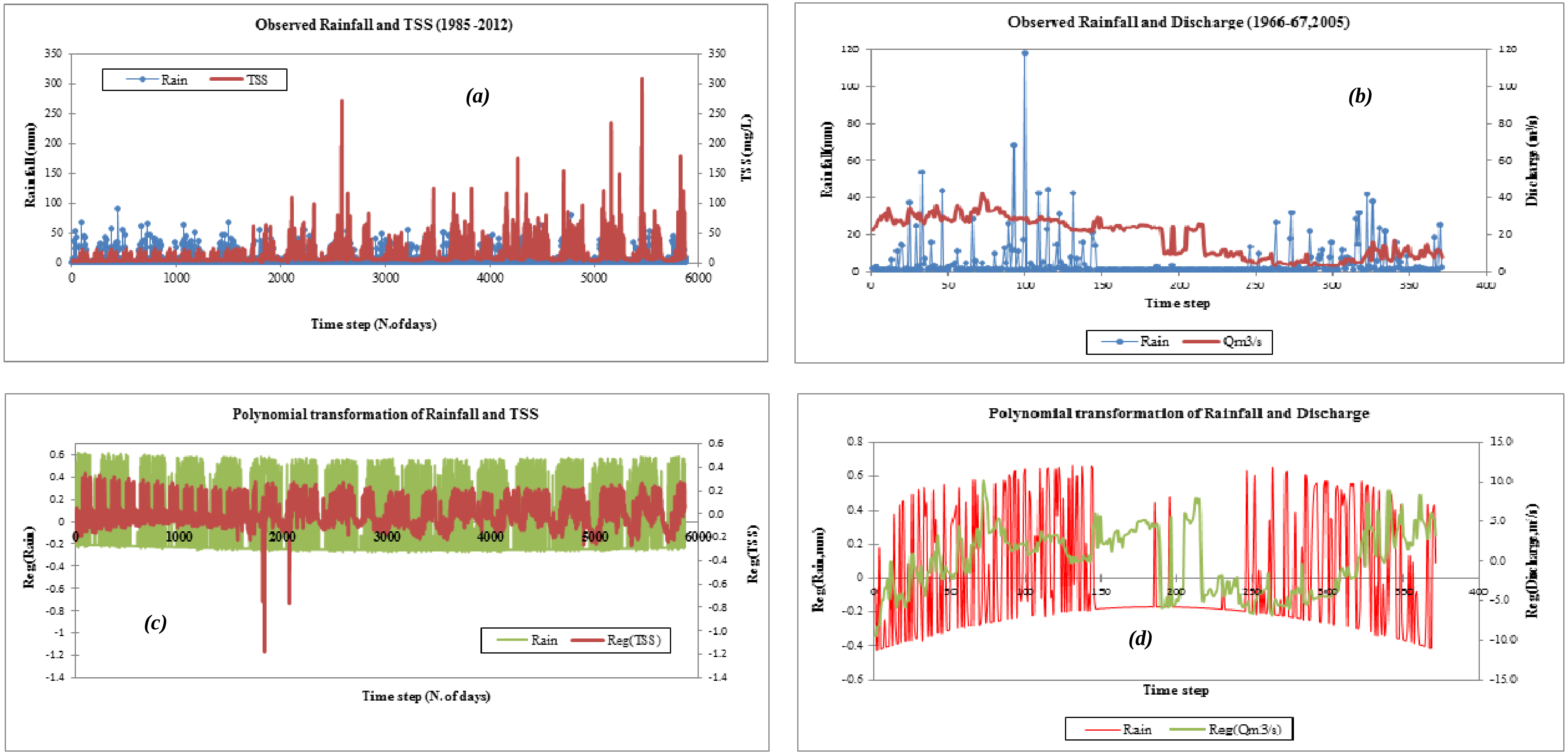


Figure 5.6a-d. Time series for rainfall against sediments and rainfall against discharge

Table 5.4. Statistics for Time series analysis

Goodness of fit statistics between Rainfall (mm) and Discharge (m^3/s)							
Parameter	***Value***	***Statistic***	***Value***	***Parameter***	***Value***	***Statistic***	***Value***
Intercept	0.169	***R^2***	0.050	***Intercept***	0.713	***R^2***	0.006
T^1	-2.726E-03	***Adjusted R^2***	0.045	***T^1***	-1.147E-02	***Adjusted R^2***	0.001
T^2	7.329E-06	***SSE***	39.491	***T^2***	3.083E-05	***SSE***	6050.084
Goodness of fit statistics between Rainfall(mm) and Sediments (mg/L)							
Parameter	***Value***	***Statistic***	***Value***	***Parameter***	***Value***	***Statistic***	***Value***
Intercept	-0.024	***R^2***	0.001	***Intercept***	-0.081	***R^2***	0.096
T^1	2.460E-05	***Adjusted R^2***	0.001	***T^1***	8.228E-05	***Adjusted R^2***	0.096
T^2	-4.189E-09	***SSE***	561.156	***T^2***	-1.401E-08	***SSE***	71.689

Furthermore, the investigation of the significance of the relationship between all the meteorological data (rainfall and potential evapotranspiration) against both water quality (sediments) and hydrological (discharge) parameters is elucidated by the test of correlation of Pearson in Table 5.5.

Table 5.5. Statistics of Pearson correlation between meteorological, water quality and hydrological parameters

Correlations			
Parameters	***Group 1***	***Discharge(m^3/s)***	***Rainfall(mm)***
Discharge(m^3/s)	Pearson Correlation	1	0.068
	Sig. (2-tailed)		0.193
	Sum of Squares and Cross-products	41122.793	2.80E+03
	Covariance	111.143	7.56
	N	371	371
Rainfall(mm)	Pearson Correlation	0.068	1
	Sig. (2-tailed)	0.193	
	Sum of Squares and Cross-products	2797.338	4.16E+04
	Covariance	7.56	112.331
	N	371	371
Parameters	***Group 2***	***TSS(mg/L)***	***Rainfall(mm)***
TSS(mg/L)	Pearson Correlation	1	0.01
	Sig. (2-tailed)		0.449
	Sum of Squares and Cross-products	1.35E+06	6788.815
	Covariance	229.491	1.156
	N	5872	5872
Rainfall(mm)	Pearson Correlation	0.01	1
	Sig. (2-tailed)	0.449	
	Sum of Squares and Cross-products	6788.815	350477.933
	Covariance	1.156	59.696
	N	5872	5872
Parameters	***Group 3***	***PET(mm/day)***	***Rainfall(mm)***

PET(mm/day)	Pearson Correlation	1	-.028**
	Sig. (2-tailed)		0.003
	Sum of Squares and Cross-products	136487.6	-9.29E+03
	Covariance	12.526	-0.852
	N	10897	10897
Rainfall(mm)	Pearson Correlation	-.028**	1
	Sig. (2-tailed)	0.003	
	Sum of Squares and Cross-products	-9284.788	7.82E+05
	Covariance	-0.852	71.717
	N	10897	10898

****. Correlation is significant at the 0.01 level (2-tailed).**

5.2.3. Double cumulative curves

Figure 5.7 highlights the double cumulative curves of the average daily sediments and average daily rainfall at N'djili station 2 from 1985 to 2012.

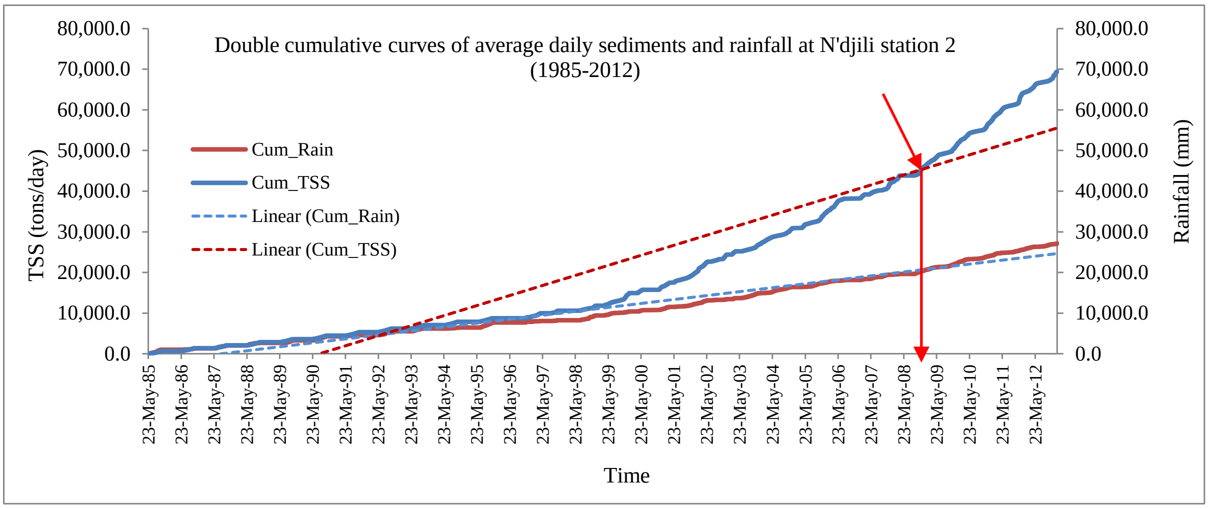


Figure 5.7. Double cumulative curves of sediments and rainfall at N'djili station 2 (1985-2012)

Similarly, Figure 5.8 shows the double cumulative curves of the average daily potential evapotranspiration and average daily rainfall at N'djili station from 1983 to 2012.

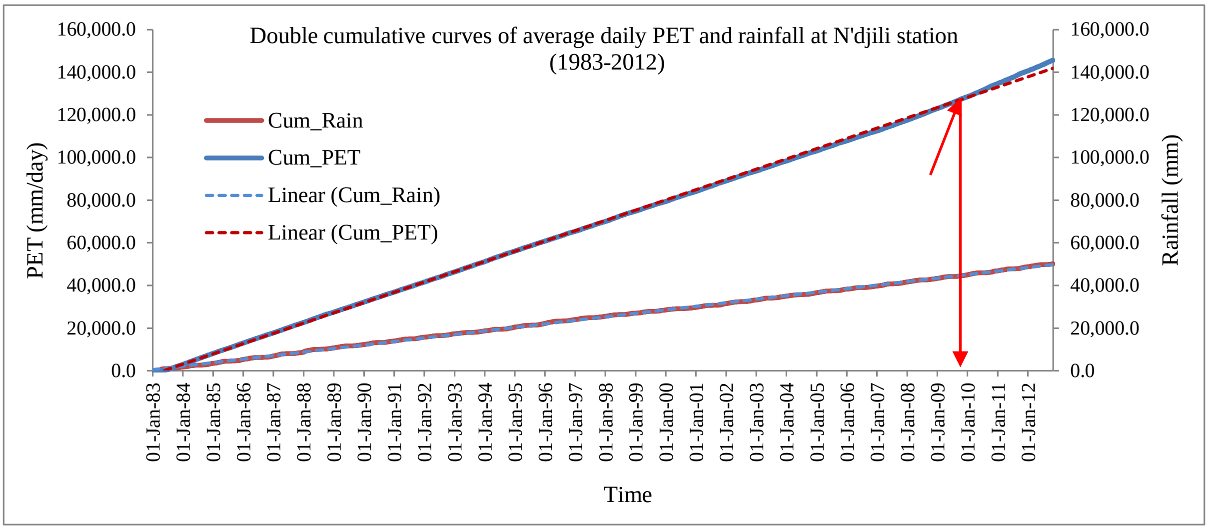


Figure 5.8. Double cumulative curves of PET and rainfall at N'djili station (1983-2012)

The double cumulative curves demonstrate how progressively the loads in sediments have increased over time to the extent of exceeding the normal line as opposed to rainfall pattern whose trend has remained stationary over time (Figure 5.7). Hence, with respect the observation period, the ratio of the total amount of cumulated sediments is close to three times (2.8) higher than the one for rainfall. Moreover, the upper break in slope of the cumulated curve of sediments over the normal line can be referred to the time period ranging from 2001 to date.

Similarly, the trend of both rainfall and potential evapotranspiration is all along stationary though potential evapotranspiration has got 2.9 of rates greater than the rainfall and the upper break in slope of the mass curve as referring to the normal line has intervened at the time period ranging from 2008 to nowadays (Figure 5.8).

5.3. Results for Objective 2

5.3.1. Land use/cover classification

The outputs from the land use/cover classification are presented in Figure 5.9. This classification was performed using ISODATA unsupervised classification, and Sieve and Clump as post-classification method.

5.3.2. Assessment of the significance change in land use/cover

The results related to the assessment of the level of significance of land use/cover in the N'djili Catchment from 1987 to 2012, are given in Tables 5.6. Table 5.6a assesses the quantity of change while Table 5.6b provides statistics of the analysis of variance in order to highlight the degree of the significance occurred in the landscape of the N'djili Catchment from 1987 to 2012. Hence, the cluster analysis illustrates the hierarchy that has taken place in the landscape of referenced catchment in that particular period (Figure 5.10).

5.3.3. Accuracy Assessment

Tables 5.7a-d provide the statistics resulted from the confusion matrix function performed for each Landsat images (1987, 1995, 2001, and 2012) in order to compare two classified images. So, the current study used the outputs from IsoData classification to match with the outputs from the post-classification for this purpose.

The accuracy level was determined using the overall accuracy and Kappa coefficient accuracy.

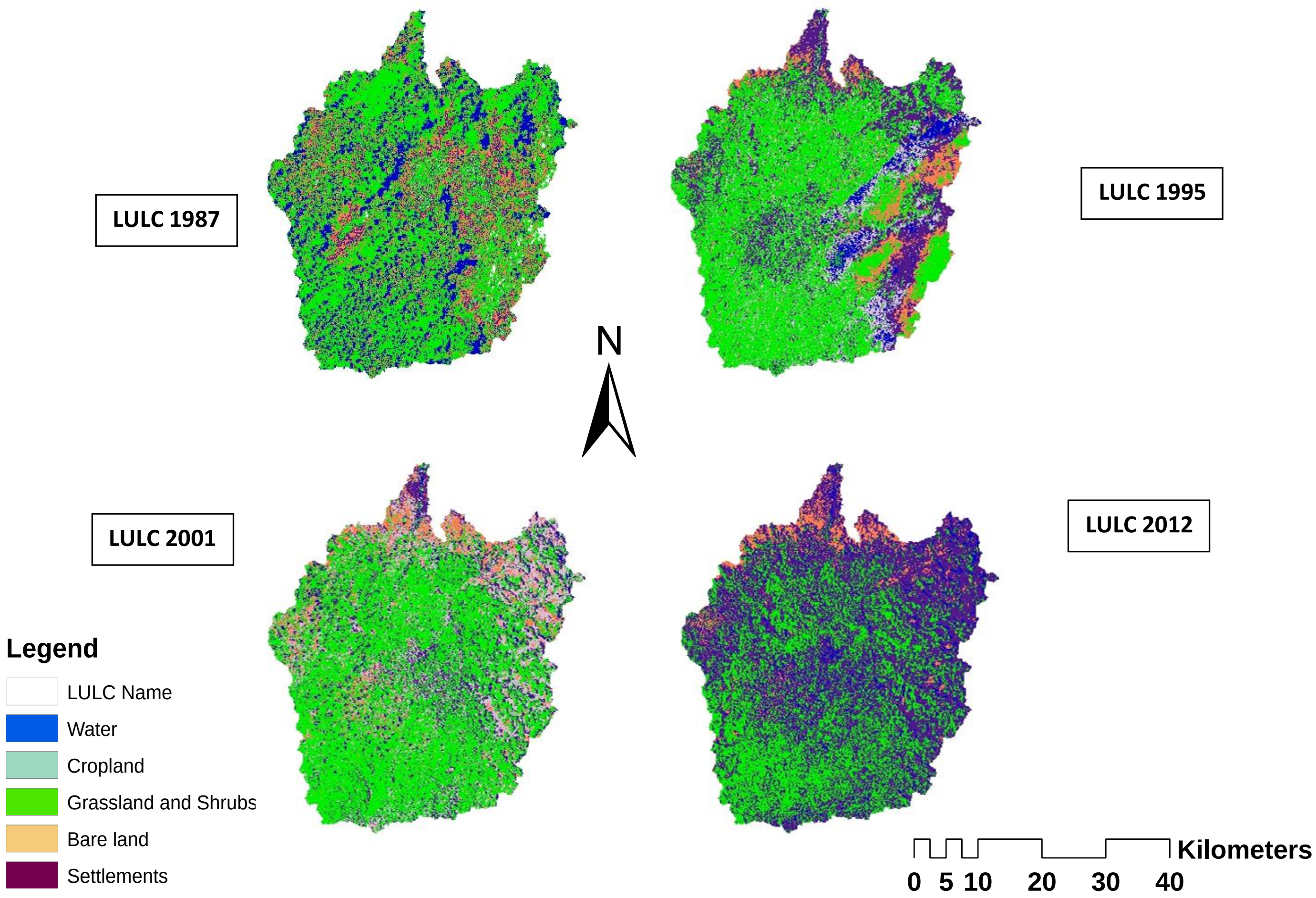


Figure 5.9. Land use/cover classification of the N'djili Catchment from 1987 to 2012

Table 5.6a. Assessment of the quantity of change in land use/cover from 1987 to 2012

Class name	1987		1995		2001		2012		Δ area (km^2)	Δ area (%)
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)		
Bare land	372.4	16.1	233.27	10.10	267.45	11.58	345.27	14.95	-27.10	-1.17
Cropland	220.8	9.6	310.62	13.45	416.53	18.08	208.55	9.03	-12.24	-0.53
Grassland and Shrubs	1273.2	55.1	1067.60	46.23	916.44	39.68	778.26	33.70	-494.96	-21.43
Settlements	303.5	13.1	605.65	26.22	629.80	27.22	902.21	39.07	+598.69	+25.93
Water	139.5	6.0	92.33	4.00	79.45	3.44	75.24	3.25	-64.25	-2.79

Table 5.6b. Statistics of the analysis of variance

ANOVA

		Sum of Squares	*df*	*Mean Square*	*F*	*Sig.*
Area (km2)	Between Groups	2036874.771	4	509218.693	21.338	.000
	Within Groups	357966.096	15	23864.406		
	Total	2394840.867	19			
Area (%)	Between Groups	3817.022	4	954.256	21.313	.000
	Within Groups	671.589	15	44.773		
	Total	4488.611	19			

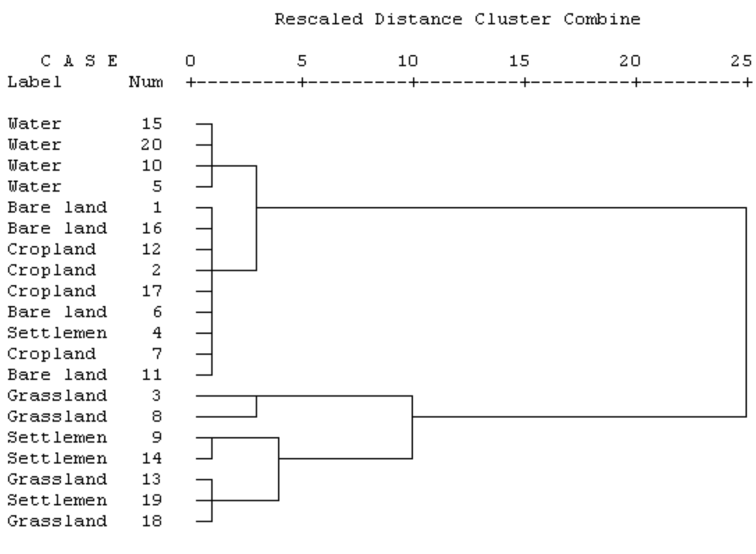


Figure 5.10. Hierarchy of land use/ cover classes of N'djili Catchment from 1987 to 2012

Table 5.7a. Accuracy assessment of land use/cover for 1987

Class name	Producer's Accuracy	Omission error	User's Accuracy	Commission error
	(%)	(%)	(%)	(%)
Bare land	97.43	2.57	68.42	31.58
Cropland	98.46	1.54	72.36	27.64
Grassland and Shrubs	95.93	4.07	71.08	28.92
Settlements	96.12	3.88	56.11	43.89
Water	99.70	0.30	79.61	20.39
Overall classification Accuracy		69.52		
Overall Kappa Accuracy		0.5615		

Table 5.7b. Accuracy assessment of land use/cover for 1995

Class name	Producer's Accuracy	Omission error	User's Accuracy	Commission error
	(%)	(%)	(%)	(%)
Bare land	96.76	3.24	76.58	23.42
Cropland	98.10	1.9	81.91	18.09
Grassland and Shrubs	97.16	2.84	89.52	10.48
Settlements	97.29	2.71	77.83	22.17
Water	98.69	1.31	87.91	12.09
Overall classification Accuracy		82.75		
Overall Kappa Accuracy		0.7915		

Table 5.7c. Accuracy assessment of land use/cover for 2001

Class name	Producer's Accuracy	Omission error	User's Accuracy	Commission error
	(%)	(%)	(%)	(%)
Bare land	96.65	3.35	75.36	24.64
Cropland	98.27	1.73	76.37	23.63
Grassland and Shrubs	97.85	2.15	90.51	9.49
Settlements	97.51	2.49	84.94	15.06
Water	98.35	1.65	82.56	17.44
Overall classification Accuracy		81.95		
Overall Kappa Accuracy		0.7797		

Table 5.7d. Accuracy assessment of land use/cover for 2012

Class name	Producer's Accuracy	Omission error	User's Accuracy	Commission error
	(%)	(%)	(%)	(%)
Bare land	96.06	3.94	73.97	26.03
Cropland	97.53	2.47	84.41	15.59
Grassland and Shrubs	98.68	1.32	87.17	12.83
Settlements	97.99	2.01	79.39	20.61
Water	98.47	1.53	84.53	15.47
Overall classification Accuracy		81.89		
Overall Kappa Accuracy		0.7789		

Through the interpretation of land use/cover classification, the N'djili Catchment was mostly occupied by grassland and shrubs areas followed by bare land areas, settlement areas, cropland areas and water bodies at the year of 1987 (Table 5.6a; Figure 5.9). Between 1987 and 1995, cropland and settlement areas exhibited progressive increases of which a notable accent must be made on the rapid expansion of the settlements areas (~ + 302.15 km^2), whereas the grassland and shrubs areas declined sensibly (~ -205.6 km^2) followed by bare land areas (~ 139.13 km^2) and water bodies (~ - 47.17 km^2). Between 1995 and 2001, there was a notable increase in cropland areas while grassland and shrubs areas kept decreased rapidly (~ -151.16 km^2), and followed by a slightly decrease in water bodies areas. The areas of open water decreased (by ~ - 12.88 km^2) from 1987 to 2001 due to the conversion of these areas into cropland and settlement areas. Between 2001and 2012, settlement and bare land increased considerably in that order by ~ + 272 km^2 and ~ + 77.82 km^2 whereas the other classes kept declined importantly.

Based on the change detection analysis from the LULC data (Figures 5.9 and 5.10, Table 5.6a), the settlement areas in the referenced Catchment increased from 303.5 km^2 in 1987 to 902.21 km^2 in 2012 or ~ + 598.69 km^2 with a trend to increase over time.

Figure 5.10 illustrates the hierarchy in land use/cover change with respect of the period of the classification highlighting the shift in category of the settlements from lower class to higher class which pattern was followed by bare land and cropland. Furthermore, the analysis of variance indicates a very significant change (*p-Value 0.000*) occurred in land use/cover of the N'djili Catchment. These changes can be likely attributed to human-induced. Consequently, these changes have got considerable impacts on the hydrology of the Catchment (Petchprayoon *et al*., 2010).

Lastly, statistics given in the series of Tables 5.7a-d indicate that the level of accuracy met under image classification in the present study can be considered as at least acceptable referring to the range of overall accuracy set by Helmer and Reufenacht (2005) while using IsoData unsupervised technique.

Error matrices produced to assess the land use/cover classification in the N'djili catchment show that the best overall classification accuracy were obtained from three land use/cover classification out of four; with an average accuracy of about 82.20%. Hence, the lowest overall accuracy was gotten for land use/cover classification performed in 1987; with a value of about 69.62% and the Kappa accuracy coefficient followed the level of accuracy achieved correspondingly in each classification ranging from 0.562 to 0.793 (Tables 5.7a-d).

5.4. Results for objective 3

These results consist of the simulations of the sediment loads using SWAT model based on the land/cover scenarios. Subsequent the sensitivity analysis, the model was calibrated using SUNGLASSES method followed by a manual adjustment, and then validated.

5.4.1. SWAT Model Calibration

Figure 5.11a-d shows the output simulations of the sediment loads from SWAT model in the downstream of the N'djili river at the water abstraction point of REGIDESO (N'djili station 2) for respectively 1987, 1995, 2001 and 2012.

Furthermore, the model performance evaluation was determined using dimensionless indices such as Nash-Sutcliffe Efficiency (NSE), Percent bias (PBIAS), Root square mean error to the standard deviation ratio (RSR), Pearson's correlation coefficient (r) and coefficient of determination (R^2). These indices are concomitantly and respectively presented with the plots in each year-scenario.

5.4.2. SWAT Model Validation

The output referred to the SWAT model validation is exposed in Figure 5.12 as well as the indices of the model performance evaluation. The current study used an independent dataset of the year 2006 for the same catchment and the land use map of the year 1995 was purposely chosen because of the amount of changes occurred during that time.

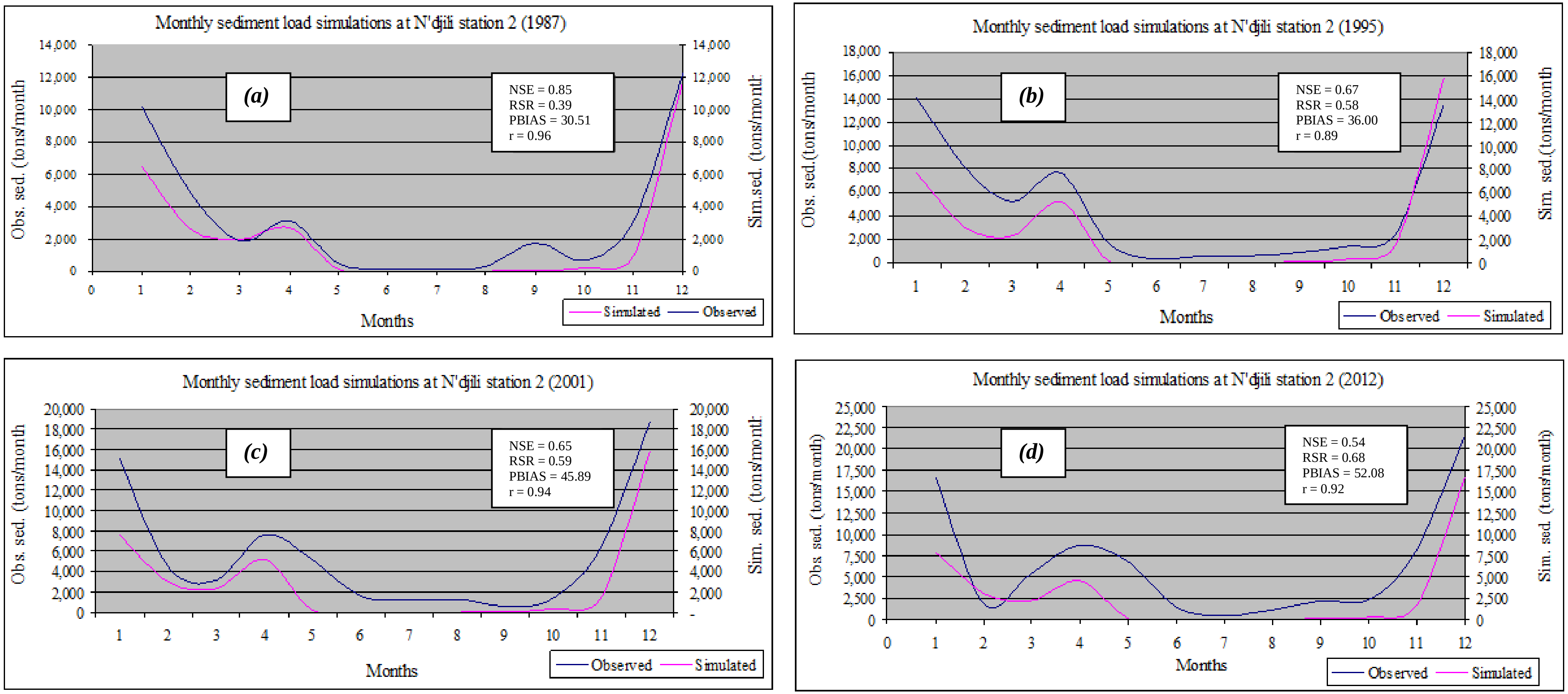


Figure 5.11a-d. SWAT model calibration of monthly sediment load simulations at N'djili station 2(1987-2012)

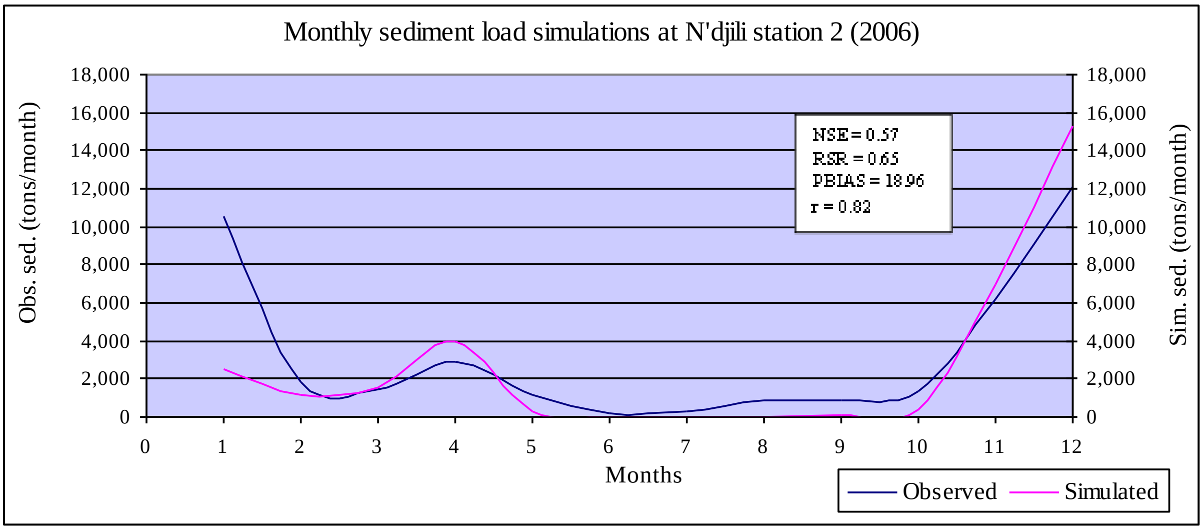


Figure 5.12. SWAT model validation of monthly sediment load simulations at N'djili station 2(2006)

The outcomes of monthly simulations of sediment loads from SWAT model based on four land use/cover scenarios elucidated in the series of Figure 5.11a-d , show that the maximum Nash-Sutcliffe Efficiency (NSE) index obtained for the all four simulations was about 0.85 observed at the year of 1987 whereas the minimum (NSE=0.54) was attained at the year of 2012. These could be probably due to the fact that certain pristine conditions governed the years before 1995, then declined as the change in land use/cover began progressively to impact the hydrological conditions which in turn affect the pattern in sediment loads of the N'djili River over time.

According to Moriasi *et al.*(2007), the maximum and minimum values that should NSE index reach for a monthly time step are respectively 0.86 and 0.49. On the basis of the work Saleh *et al.*(2000) as reported by Moriasi *et al.*(2007), the findings of the present study can be considered as adequate to very good performance rating based on this index.

Hence, the Percent bias (PBIAS) index reached for all the simulations ranges from 30.51 to 52.08 (Figure 5.11) which values fall within the category of satisfactory to good performance rating for PBIAS as classified by Van Liew *et al.*(2007).

Moreover, Root square mean error to the standard deviation ratio (RSR) index values attained for the all scenarios given in ascending order as 0.39,0.58,0.59,and 0.68; and comprise within the category of satisfactory, good ,and very good (Moriasi *et al.*, 2007).

On the other hand, the output from the SWAT model validation (Figure 5.12) indicates that the model performance rating for NSE, PBIAS, and RSR falls in the category of satisfactory for both NSE and RSR, and good for PBIAS on the basis of the guidelines followed at the above.

Indeed, focused on the graphical representation, Figures 5.11 and 5.12 illustrate that generally the prediction of the model was underestimated. However, the model was at least able to predict equally or exceed the observed values at some specific times either at the beginning of the year up to later April or at the last three months of the year. These periods usually coincided with the occurrence of higher rainfall and the effects experienced in a particular month during these periods can be extended to the next month in the same or the following year.

5.5. Results for objective 4

The findings of the prediction of the effect of sediment loads and turbidity on the water treatment cost of the N'djili Catchment was carried out using non-linear analysis and multi-linear regression model.

5.5.1. Non-linear regression analysis

Figure 5.13 illustrates the tendency of the amount of Aluminium Sulfate used to treat turbid water from the N'djili river at N'djili station of REGIDESO.

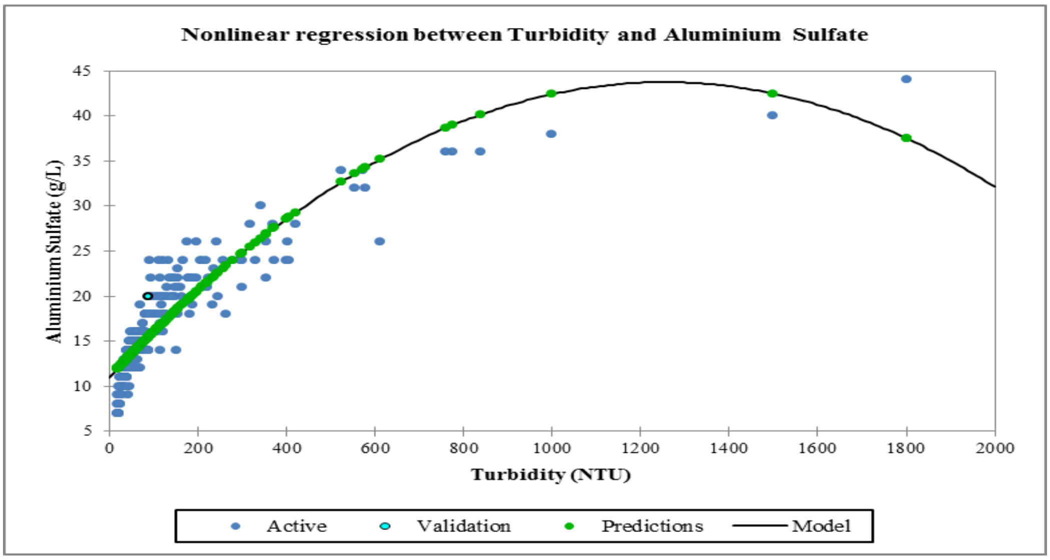


Figure 5.13. Non-linear regression between Turbidity and quantity of Aluminium Sulfate used to treat water from the N'djili River at the Station of REGIDESO

Furthermore, the equation and the statistics resulted from this model prediction are provided below in Table 5.8.

Table 5.8. Equation and Statistics of Non-linear regression between Turbidity and Quantity of Aluminium Sulfate used to treat water from the N'djili River at the Station of REGIDESO

Model Equation : **AS = 10.985 + 5.23E-02* (TURB) - 2.09E-05*(TURB)^2**

Goodness of fit statistics:		Model parameters:		
Observations	285.000	**Parameter**	**Value**	**Standard error**
DF	282.000			
R^2	0.820	**pr1**	10.985	0.231
SSE	1947.863	**pr2**	0.052	0.002
MSE	6.907	**pr3**	**0.000**	0.000
RMSE	2.628			

AS: Aluminium Sulfate

Figure 5.13 shows that the expected loads in turbidity will be found in the range of 20 to 400 NTU inferring to the amount of Aluminium Sulfate (AS) of about 7 to 30 g/L. However, this range can be multiplied up to 4.5 times than usual which in turn will require an additional quantity of AS up to nearly 45 g/L to treat the water from the N'djili river.

In fact, knowledge on the operating system of water treatment plant documented by UNEP (2011) reveals that the threshold value of turbidity loads in the water bodies should be below 1000 NTU or else the system will be forced to stop.

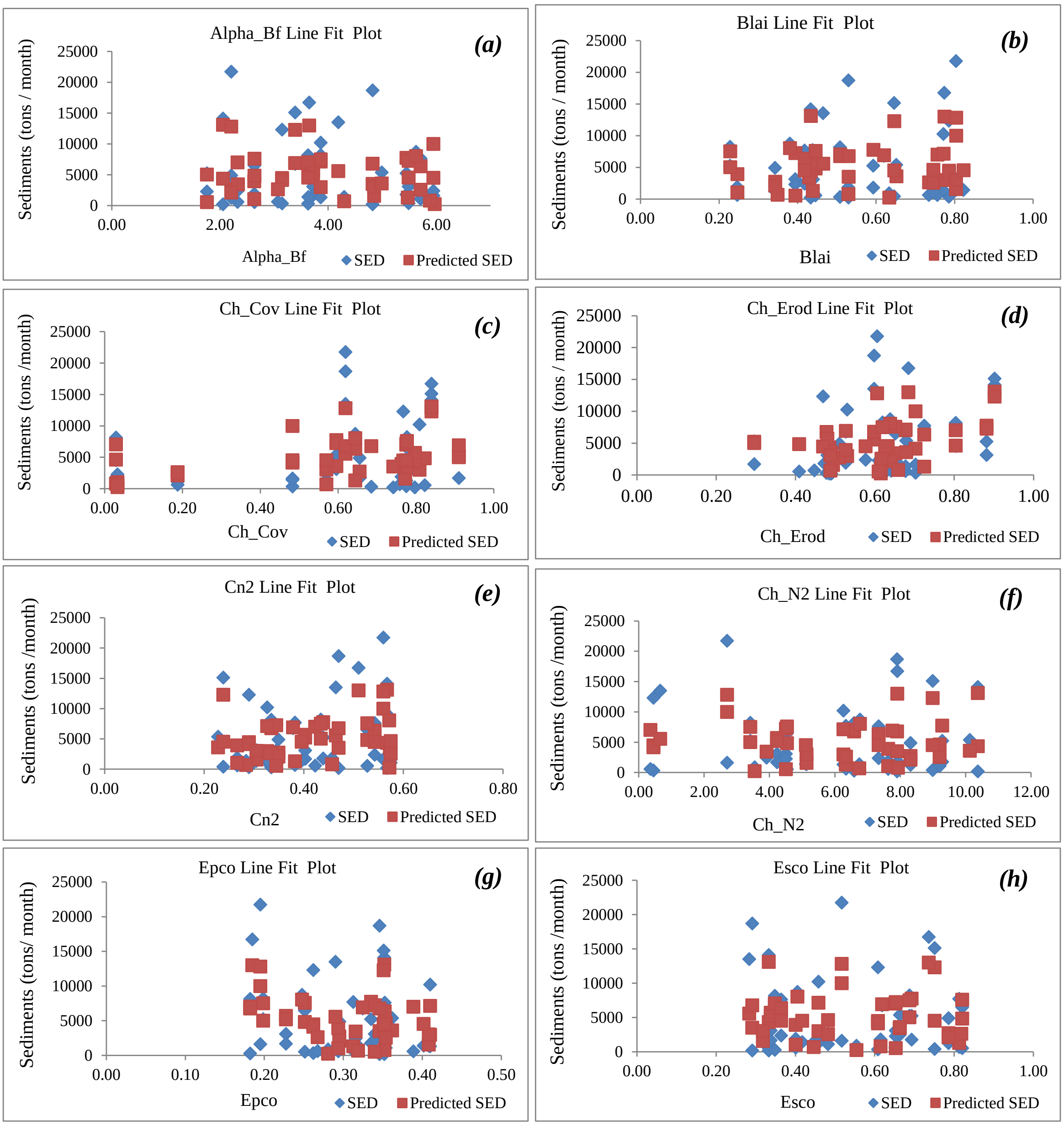
Moreover, the non-linear graphical representation (Figure 5.13) illustrates that the amount of AS applied for treating water from the N'djili river increases as the turbidity loads increase up to a certain extent of which an extra amount of AS can no longer be applied.

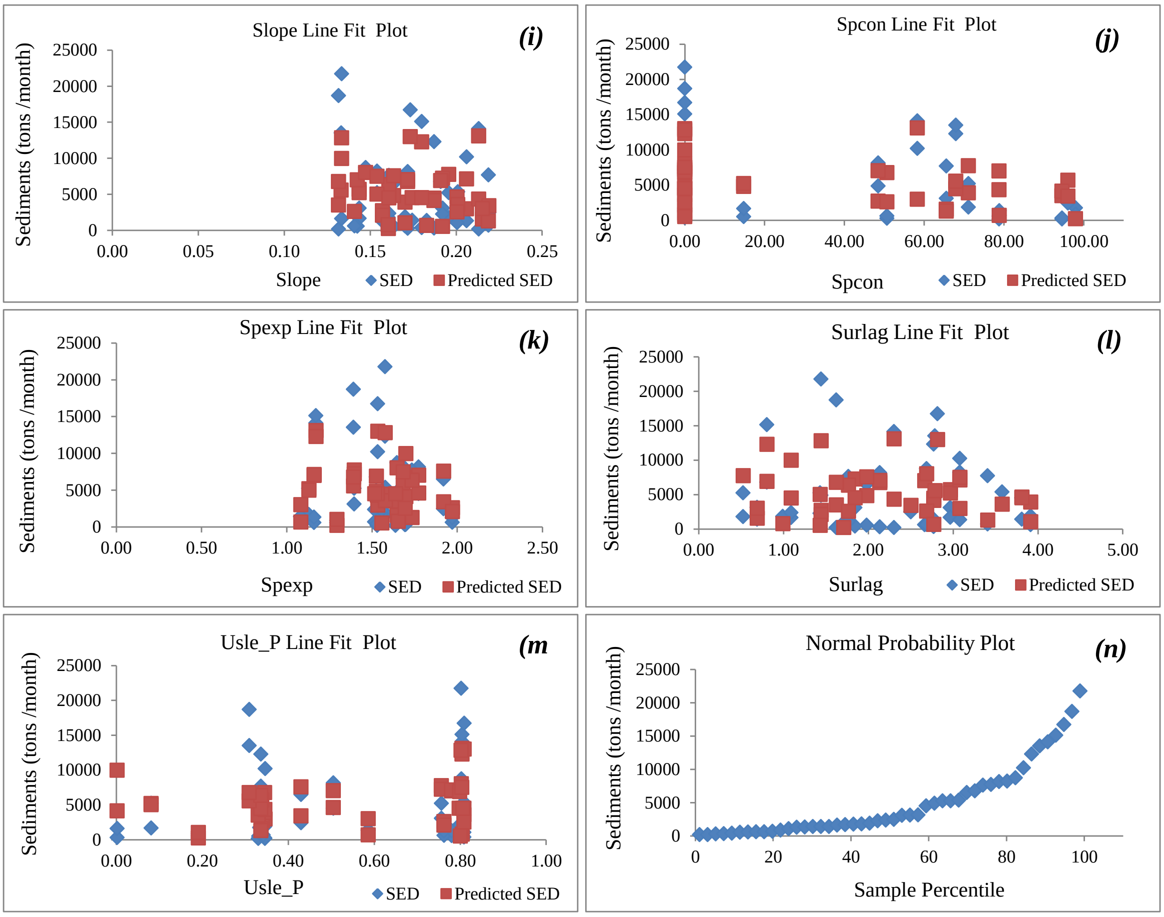
Table 5.8 gives the statistics related to the performed non-linear model and the equation of the relationship is given at the heading of this table. Furthermore, the coefficient of determination ($R^2 = 0.82$) and the root mean square error (*RMSE=2.63*) indicate that the model predicted adequately the trend in both turbidity and AS. As found by Kileshye-Onema *et al.* (2012) that the non-linear polynomial regression offers better model prediction than the linear one because of its flexibility to combine more than one parameter.

5.5.2. Multi-linear regression model

Figures 5.14a-n present the multi-linear model results. This model was performed using the thirteen most sensitive parameter sets from the outputs of SWAT sensitivity analysis in order to predict the observed sediment loads in the N'djili river and related statistics including the model equation are indicated below in Table 5.9.

Hence, details related to the referred parameter sets from SWAT sensitivity analysis used to build the multi-linear regression model, are provided in the appendix list.





Figures5.14a-n. Multi-linear model prediction of the observed sediment loads in the N'djili river using thirteen most sensitive parameter set from SWAT sensitivity analysis

Table 5.9. Multi-linear model statistics between the observed sediment loads and the thirteen most sensitive parameter sets from SWAT sensitivity analysis

Regression Statistics		**ANOVA**	***df***	***SS***	***MS***	***F***	***Sig. F***
Multiple R	0.64						
R Square	0.40	*Regression*	13	560983289	43152561	1.77	0.044
Adjusted R Square	0.18	*Residual*	34	828219296.9	24359391		
Standard Error	4935.52	*Total*	47	1389202586			
Observations	48						

Model Equation	***Sediments*** = 5481.2 - 609.6(***Alpha_Bf***) + 5257.6 (***Blai***) + 7214.8 (***Ch_Cov***) + 17406.6(***Ch_Erod***) + 84.4(***Ch_N2***) + 4534.4(***Cn2***) - 25155.3(***Epco***) - 4984.0(***Esco***) - 19773.9(***Slope***) - 23.9(***Spcon***) - 2415.1(***Spexp***) - 340.9(***Surlag***) + 1375.5(***Usle_P***)

The regression analysis set together with the analysis of variance (Table 5.9) reveal that the performed multi-linear model assumption is statistically significant (*p-value 0.04*) and acceptable based on the Pearson coefficient of correlation ($r = 0.64$), whereas the coefficient of determination ($R^2 = 0.40$) has shown a weak relationship between the combined thirteen most sensitive parameter sets and the observed sediments. This weak relationship can be attributed to the nature of each parameter set to induce affinity when set together though they are acting independently from each other.

However, Figure 5.14 (a-m) elucidates that the Spcon is the only parameter set which acts with higher magnitude than the others and it is respectively followed by (Ch-N2), Alpha-Bf, Surlag, and others. Physically based, these parameters refer to the sediment deposition within the river channel; surface roughness and sinuosity which determines the ability of the channel to move water and sediment as well as the contribution of the rainwater that percolates to the aquifer then seeping into the river channel. As a result, the channel efficiency and land management practices within the catchment affect its lag time which in fact has got a direct effect on surface runoff.

Figure 5.14n particularly indicates that there is normally a higher probability of all these parameter set to predict satisfactorily the observed value of sediments to a maximum of 25,000 tons/month.

As earlier mentioned, the shift in land use/cover in the N'djili Catchment has led to impact the pattern in sediment loads and considering the prediction attained through the performance of the multi-linear regression model, these attributes can help to address the loads in sediments of this river.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

From the objectives and results of the current study, the following conclusions and recommendations were made:

6.1. Conclusions

Objective 1: To detect long-term changes in water quality and hydrological parameters as compared to meteorological parameters resulting from LULCC

1. Based on the Pettitt's test of homogeneity, there is a clear significant change (*p-value* < 0.0001) which has occurred in the mean of the time series of data for water quality and hydrological parameters as opposed to meteorological parameters.
2. The time series analyses indicated that there is evidence of a poor long-term correlation ($R^2 <<< 0.50$) as well as none statistical significance (*p-value* > 0.01) from the Pearson test of correlation between meteorological, water quality and hydrological parameters.
3. The double cumulative curves analyses revealed that there is a stationary trend in general in the pattern of the meteorological variables with some demarcation observed for potential evapotranspiration as opposed to sediment pattern.

   The above considerations indicate that changes in water quality and hydrological parameters are not linked to meteorological changes.

Objective 2: To assess temporally and spatially the LULC in the N'djili Catchment

Based on the change detection from the land use/cover classification, the N'djili Catchment was mostly occupied by grassland and shrubs areas (~*55%*) in 1987. Between 1987 and 2012, the change in land use has led to decrease significantly (*p-value 0.000*) the grassland and shrubs areas and the ones for water bodies by ~ 21.4% and ~ 2.8% respectively. This change was mainly due to expansion of settlement areas by 25.93%. The cluster analysis indicates how progressively settlement areas have shifted over time from lower to higher coverage percent.

Objective 3: To assess the suitability of SWAT model in simulating sediments of the N'djili catchment based on the LULC changes

1. Referring to the SWAT model performance evaluation indices, the accuracy level achieved while performing the simulations of sediment loads having a basis of land use/cover changes in the N'djili Catchment, ranged from adequate to very good (*0.54-0.85*); satisfactory to good (*18.96-52.08*); and satisfactory to very good (*0.39-0.68*) performance rating for NSE,PBIAS and RSR respectively.
2. Throughout the simulations, the model prediction was underestimated. However, the model has shown its capability to predict equally or above the observed values with the occurrence of higher rainfall.

Objective 4: To predict the extent to which sediment loads and turbidity affect the treatment cost of the water supply at the abstraction point of the N'djili river

1. The non-linear regression model predicted adequately ($R^2=0.82$ *and RMSE=2.63*) the effect of turbidity loads to the water treatment cost expressed as amount of Aluminium Sulfate(AS) that has to be used. The predicted amount of AS will likely range from about 7 to 30 g/L which corresponds to about 20-400 NTU. Hence, the model prediction indicated a higher probability of this turbidity range to be multiplied nearly by 5 times than usual which situation will halt the water supply operating system unless a return into normal situation has come.
2. The multi-linear regression model using the thirteen most sensitive parameter sets from SWAT sensitivity analysis to predict sediments indicated that the model assumption is statistically significant (*p-value 0.04*) and acceptable only when relying on *r (0.64)*, whereas R^2 *(0.40)* has shown a weak relationship between the combined parameter sets and the observed sediments. As a result, the ranked and most sensitive parameter sets as derived from SWAT sensitivity analysis affect the channel efficiency and land management practices within the catchment which leads to sediment delivery

6.2. Recommendations

1. There is a real need to set a catchment management plan (CMP) which should be based on LULC attributes in order to address and protect the quality of the fresh water and water infrastructures.

2. Since most of the Catchment in the DR Congo are ungauged or poorly gauged, the use of distributed hydrological models such as SWAT and others can be useful for a preliminary assessment of water resources, and can provide some relevant background to decision makers. Further research shall seek on the comparison of the adequacy of those models.

3. In order to reduce sediment loads in the N'djili river there is a need to address parameters which sensibly affect directly or indirectly the loads in sediments. These parameters shall stand for erosion processes, and management practices.

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APPENDICES

Appendix 1: Table1. Parameter sets derived from SWAT Sensitivity Analysis

N°	Name	Rank	Description Parameter sets derived from SWAT Sensitivity Analysis
1	Alpha_Bf	3	Baseflow alpha factor
2	Blai	9	Maximum potential leaf area index
3	Ch_Cov	42	Channel cover factor
4	Ch_Erod	42	Channel erodibility factor
5	Cn2	13	SCS runoff curve number
6	Ch_N2	1	Manning's n value for main channel
7	Epco	14	Plant uptake compensation factor
8	Esco	12	Soil evaporation compensation factor
9	Slope	15	Average slope steepness
10	Spcon	2	Linear coefficient for within channel sediment routing
11	Spexp	4	Exponential coefficient for channel sediment routing
12	Surlag	11	Surface runoff lag time
13	Usle_P	6	USLE support practice factor

Appendix 1: Table2. Output Summary of the Multi-Linear Model

Regression Statistics		ANOVA					
R Square	0.403817		*df*	*SS*	*MS*	*F*	*Significance F*
Adjusted R Square	0.175864	Regression	13	5.61E+08	43152561	1.77	0.049
Standard Error	4935.523	Residual	34	8.28E+08	24359391		
Observations	48	Total	47	1.39E+09			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	5481.2	9110.1	0.602	0.551	-13032.7	23995.2	-13032.7	23995.2
Blai	5257.6	4538.9	1.158	0.255	-3966.4	14481.7	-3966.4	14481.7
Cn2	4534.4	7049.2	0.643	0.524	-9791.3	18860.0	-9791.3	18860.0
Epco	-25155.3	14697.8	-1.712	0.050	-55024.8	4714.2	-55024.8	4714.2
Esco	-4984.0	4596.7	-1.084	0.286	-14325.7	4357.6	-14325.7	4357.6
Ch_N2	84.4	344.1	0.245	0.808	-614.9	783.8	-614.9	783.8
Ch_Cov	7214.8	3050.7	2.365	0.024	1015.0	13414.5	1015.0	13414.5
Ch_Erod	17406.6	6699.3	2.598	0.014	3792.0	31021.1	3792.0	31021.1
Spcon	-23.9	22.7	-1.053	0.300	-69.9	22.2	-69.9	22.2
Spexp	-2415.1	3568.6	-0.677	0.503	-9667.3	4837.1	-9667.3	4837.1
Usle_P	1375.5	3709.9	0.371	0.713	-6163.9	8914.8	-6163.9	8914.8
Alpha_Bf	-609.6	583.0	-1.046	0.303	-1794.4	575.1	-1794.4	575.1
Surlag	-340.9	694.5	-0.491	0.627	-1752.4	1070.6	-1752.4	1070.6
Slope	-19773.9	34039.4	-0.581	0.565	-88950.4	49402.5	-88950.4	49402.5

Appendix 2: Table3. Sensitive Parameter Sets derived from SWAT Sensitivity Analysis

Control parameter were:

- ✓ number of intervals in Latin Hypercube = 10
- ✓ parameter change for OAT = 5.00E-002
- ✓ random seed number = 2003

Year	Month	Alpha_Bf	Blai	Ch_Cov	Ch_Erod	Cn2	Ch_N2	Epco	Esco	Slope	Spcon	Spexp	Surlag	Usle_P
1987	1	3.86E+00	7.72E-01	8.10E-01	5.30E-01	3.27E-01	6.26E+00	4.10E-01	4.59E-01	2.06E-01	5.83E+01	1.53E+00	3.08E+00	3.46E-01
1987	2	2.21E+00	3.43E-01	6.56E-01	5.11E-01	3.49E-01	8.32E+00	2.95E-01	7.86E-01	1.57E-01	4.85E+01	1.65E+00	1.44E+00	3.40E-01
1987	3	2.63E+00	2.47E-01	7.63E-01	5.26E-01	2.67E-01	7.63E+00	2.94E-01	4.01E-01	1.70E-01	7.11E+01	1.58E+00	3.92E+00	3.45E-01
1987	4	4.85E+00	8.04E-01	7.72E-01	4.95E-01	3.05E-01	5.13E+00	4.08E-01	3.18E-01	2.15E-01	6.56E+01	1.65E+00	6.92E-01	3.37E-01
1987	5	2.64E+00	4.46E-01	8.23E-01	4.09E-01	5.28E-01	4.54E+00	2.51E-01	8.21E-01	1.64E-01	1.48E+01	1.53E+00	1.98E+00	3.32E-01
1987	6	4.82E+00	5.30E-01	7.42E-01	4.91E-01	4.70E-01	7.91E+00	3.46E-01	2.91E-01	1.32E-01	9.46E+01	1.64E+00	1.62E+00	3.30E-01
1987	7	2.06E+00	4.34E-01	7.97E-01	4.85E-01	5.67E-01	1.04E+01	3.52E-01	3.33E-01	2.13E-01	7.88E+01	1.53E+00	2.31E+00	3.46E-01
1987	8	3.63E+00	5.09E-01	6.86E-01	4.78E-01	3.35E-01	6.59E+00	1.82E-01	3.48E-01	1.72E-01	5.07E+01	1.69E+00	2.14E+00	3.45E-01
1987	9	5.45E+00	5.93E-01	6.56E-01	4.73E-01	4.39E-01	9.28E+00	3.35E-01	6.93E-01	1.96E-01	9.79E+01	1.56E+00	5.26E-01	3.34E-01
1987	10	5.47E+00	4.39E-01	7.58E-01	4.48E-01	3.82E-01	6.34E+00	3.13E-01	8.13E-01	2.19E-01	7.88E+01	1.52E+00	3.41E+00	3.42E-01
1987	11	3.72E+00	4.40E-01	7.98E-01	4.80E-01	4.03E-01	4.23E+00	2.27E-01	3.38E-01	1.44E-01	9.60E+01	1.68E+00	2.97E+00	3.39E-01
1987	12	3.15E+00	7.86E-01	7.68E-01	4.70E-01	2.90E-01	4.59E-01	2.62E-01	6.08E-01	1.87E-01	6.80E+01	1.58E+00	2.77E+00	3.36E-01
1995	1	2.06E+00	4.34E-01	8.40E-01	9.02E-01	5.67E-01	1.04E+01	3.52E-01	3.33E-01	2.13E-01	5.83E+01	1.17E+00	2.31E+00	8.04E-01
1995	2	3.63E+00	5.09E-01	2.95E-02	8.04E-01	3.35E-01	6.59E+00	1.82E-01	3.48E-01	1.72E-01	4.85E+01	1.77E+00	2.14E+00	5.05E-01
1995	3	5.45E+00	5.93E-01	5.96E-01	8.82E-01	4.39E-01	9.28E+00	3.35E-01	6.93E-01	1.96E-01	7.11E+01	1.40E+00	5.26E-01	7.56E-01
1995	4	5.47E+00	4.39E-01	6.44E-01	7.25E-01	3.82E-01	6.34E+00	3.13E-01	8.13E-01	2.19E-01	6.56E+01	1.74E+00	3.41E+00	3.36E-01
1995	5	3.72E+00	4.40E-01	9.10E-01	2.96E-01	4.03E-01	4.23E+00	2.27E-01	3.38E-01	1.44E-01	1.48E+01	1.13E+00	2.97E+00	8.11E-02
1995	6	3.15E+00	7.86E-01	4.83E-01	7.03E-01	2.90E-01	4.59E-01	2.62E-01	6.08E-01	1.87E-01	9.46E+01	1.70E+00	2.77E+00	2.02E-03
1995	7	2.33E+00	7.57E-01	7.75E-01	6.77E-01	4.23E-01	3.60E-01	3.89E-01	6.52E-01	1.43E-01	7.88E+01	1.16E+00	2.67E+00	7.80E-01
1995	8	3.07E+00	7.35E-01	1.88E-01	6.42E-01	3.33E-01	6.34E+00	2.68E-01	8.19E-01	1.41E-01	5.07E+01	1.97E+00	2.69E+00	7.62E-01
1995	9	5.97E+00	6.34E-01	3.35E-02	6.15E-01	5.72E-01	3.55E+00	2.81E-01	5.54E-01	1.61E-01	9.79E+01	1.29E+00	1.71E+00	1.91E-01
1995	10	4.30E+00	3.49E-01	5.70E-01	4.88E-01	2.84E-01	6.75E+00	3.19E-01	4.46E-01	1.83E-01	7.88E+01	1.08E+00	2.77E+00	5.86E-01
1995	11	2.34E+00	4.29E-01	7.77E-01	6.52E-01	5.73E-01	3.92E+00	3.16E-01	6.63E-01	2.19E-01	9.60E+01	1.92E+00	2.50E+00	4.30E-01
1995	12	4.19E+00	4.66E-01	6.19E-01	5.98E-01	4.64E-01	6.62E-01	2.90E-01	2.84E-01	1.33E-01	6.80E+01	1.39E+00	2.79E+00	3.09E-01
2001	1	3.39E+00	6.47E-01	8.40E-01	9.02E-01	2.39E-01	9.00E+00	3.51E-01	7.51E-01	1.80E-01	5.83E-03	1.17E+00	8.07E-01	8.04E-01
2001	2	3.63E+00	7.46E-01	2.95E-02	8.04E-01	5.75E-01	9.21E+00	3.54E-01	4.83E-01	2.01E-01	4.85E-03	1.77E+00	3.81E+00	5.05E-01
2001	3	5.49E+00	3.95E-01	5.96E-01	8.82E-01	3.45E-01	4.51E+00	3.40E-01	6.53E-01	1.92E-01	7.11E-03	1.40E+00	1.84E+00	7.56E-01
2001	4	5.71E+00	4.19E-01	6.44E-01	7.25E-01	5.43E-01	7.34E+00	3.53E-01	3.64E-01	1.61E-01	6.56E-03	1.74E+00	1.77E+00	3.36E-01
2001	5	1.76E+00	2.29E-01	9.10E-01	2.96E-01	4.35E-01	3.42E+00	1.99E-01	6.88E-01	1.54E-01	1.48E-03	1.13E+00	1.43E+00	8.11E-02
2001	6	5.95E+00	8.04E-01	4.83E-01	7.03E-01	5.60E-01	2.70E+00	1.95E-01	5.17E-01	1.33E-01	9.46E-03	1.70E+00	1.09E+00	2.02E-03
2001	7	3.86E+00	7.72E-01	7.75E-01	6.77E-01	3.27E-01	6.26E+00	4.10E-01	4.59E-01	2.06E-01	7.88E-03	1.16E+00	3.08E+00	7.80E-01
2001	8	2.21E+00	3.43E-01	1.88E-01	6.42E-01	3.49E-01	8.32E+00	2.95E-01	7.86E-01	1.57E-01	5.07E-03	1.97E+00	1.44E+00	7.62E-01
2001	9	2.63E+00	2.47E-01	3.35E-02	6.15E-01	2.67E-01	7.63E+00	2.94E-01	4.01E-01	1.70E-01	9.79E-03	1.29E+00	3.92E+00	1.91E-01
2001	10	4.85E+00	8.04E-01	5.70E-01	4.88E-01	3.05E-01	5.13E+00	4.08E-01	3.18E-01	2.15E-01	7.88E-03	1.08E+00	6.92E-01	5.86E-01
2001	11	2.64E+00	4.46E-01	7.77E-01	6.52E-01	5.28E-01	4.54E+00	2.51E-01	8.21E-01	1.64E-01	9.60E-03	1.92E+00	1.98E+00	4.30E-01
2001	12	4.82E+00	5.30E-01	6.19E-01	5.98E-01	4.70E-01	7.91E+00	3.46E-01	2.91E-01	1.32E-01	6.80E-03	1.39E+00	1.62E+00	3.09E-01
2012	1	3.65E+00	7.75E-01	8.40E-01	6.85E-01	5.10E-01	7.91E+00	1.85E-01	7.36E-01	1.73E-01	5.83E-03	1.53E+00	2.82E+00	8.09E-01
2012	2	5.88E+00	5.30E-01	2.95E-02	6.59E-01	4.57E-01	7.93E+00	3.52E-01	6.15E-01	1.61E-01	4.85E-03	1.65E+00	9.93E-01	8.05E-01
2012	3	4.99E+00	6.52E-01	5.96E-01	6.79E-01	2.28E-01	1.01E+01	3.62E-01	6.64E-01	2.01E-01	7.11E-03	1.58E+00	3.58E+00	8.09E-01
2012	4	5.63E+00	3.81E-01	6.44E-01	6.38E-01	5.72E-01	6.77E+00	2.48E-01	4.05E-01	1.47E-01	6.56E-03	1.65E+00	2.69E+00	8.03E-01
2012	5	3.39E+00	6.21E-01	9.10E-01	5.27E-01	3.78E-01	7.76E+00	3.25E-01	6.19E-01	1.91E-01	1.48E-03	1.53E+00	8.07E-01	7.99E-01
2012	6	3.63E+00	8.23E-01	4.83E-01	6.33E-01	3.96E-01	5.11E+00	4.02E-01	4.17E-01	1.74E-01	9.46E-03	1.64E+00	3.81E+00	7.98E-01
2012	7	5.49E+00	6.47E-01	7.75E-01	6.26E-01	2.39E-01	9.00E+00	3.51E-01	7.51E-01	1.80E-01	7.88E-03	1.53E+00	1.84E+00	8.09E-01
2012	8	5.71E+00	7.46E-01	1.88E-01	6.17E-01	5.75E-01	9.21E+00	3.54E-01	4.83E-01	2.01E-01	5.07E-03	1.69E+00	1.77E+00	8.09E-01
2012	9	1.76E+00	3.95E-01	3.35E-02	6.10E-01	3.45E-01	4.51E+00	3.40E-01	6.53E-01	1.92E-01	9.79E-03	1.56E+00	1.43E+00	8.01E-01
2012	10	5.95E+00	4.19E-01	5.70E-01	5.77E-01	5.43E-01	7.34E+00	3.53E-01	3.64E-01	1.61E-01	7.88E-03	1.52E+00	1.09E+00	8.06E-01
2012	11	3.86E+00	2.29E-01	7.77E-01	6.19E-01	4.35E-01	3.42E+00	1.99E-01	6.88E-01	1.54E-01	9.60E-03	1.68E+00	3.08E+00	8.04E-01
2012	12	2.21E+00	8.04E-01	6.19E-01	6.06E-01	5.60E-01	2.70E+00	1.95E-01	5.17E-01	1.33E-01	6.80E-03	1.58E+00	1.44E+00	8.02E-01