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Management and Area-wide Evaluation of Water Conservation Zones in Agricultural Catchments for Biomass Production, Water Quality and Food Security

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Nuclear Techniques in Food and Agriculture

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MANAGEMENT AND AREA-WIDE EVALUATION OF WATER CONSERVATION ZONES IN AGRICULTURAL CATCHMENTS FOR BIOMASS PRODUCTION, WATER QUALITY AND FOOD SECURITY

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PREPARED BY THE
JOINT FAO/IAEA DIVISION OF NUCLEAR TECHNIQUES IN FOOD AND AGRICULTURE

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

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FOREWORD

Global land and water resources are under threat from both the agricultural and urban development to meet increased demand for food and from the resulting degradation of the environment. Poor crop yields due to water stress is one of the main reasons for the prevailing hunger and rural poverty in parts of the world. The Green Revolution of the 1960s and 1970s particularly in Latin America and Asia resulted in increased agricultural production and depended partly on water management. In the future, most food will still need to come from rain-fed agriculture. Water conservation zones in agricultural catchments, particularly in rain-fed areas, play an important role in the capture and storage of water and nutrients from farmlands and wider catchments, and help improve crop production in times of need in these areas.

Water conservation zones are considered to be an important part of water resource management strategies that have been developed to prevent reservoir siltation, reduce water quality degradation, mitigate flooding, enhance groundwater recharge and provide water for farming. In addition to making crop production possible in dry areas, water conservation zones minimize soil erosion, improve soil moisture status through capillary rise and enhance soil fertility and quality. These water conservation zones include natural and constructed wetlands (including riparian wetlands), farm ponds and riparian buffer zones. The management of water conservation zones has been a challenge due to the poor understanding of the relationship between upstream land use and the functions of these zones and their internal dynamics. Knowledge of sources and sinks of water and redefining water and nutrient budgets for water conservation zones are important for optimizing the capture, storage and use of water and nutrients in agricultural landscapes.

The overall objective of this coordinated research project (CRP) was to assess and enhance ecosystem services provided by wetlands, ponds and riparian buffer zones for improving water storage and nutrient use within agricultural catchments. The specific objectives were to determine the capacity of water conservation zones for water and nutrient storage, assess nutrient attenuation capacities, assess the link between water and nutrient dynamics and optimize water conservation zones for improving water storage and quality. The CRP was supported by in-house research and the provision of $^{15}N/^{14}N$ isotope ratio analysis of ^{15}N enriched plant samples at the FAO/IAEA Agriculture and Biotechnology Laboratories.

This CRP was implemented following the recommendations of a group of international experts. The research network includes participants from China, Estonia, France, the Islamic Republic of Iran, Lesotho, Nigeria, Romania, Uganda, Tunisia, the United Kingdom and the United States of America. The IAEA wishes to thank all CRP participants for their valuable contributions to the project. The IAEA officer responsible for this publication was K. Sakadevan of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture.

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SUMMARY

Global land and water resources are increasing under threat through increased demand for food, socio-economic development and contamination by anthropogenic activities. In the foreseeable future much of the food production need to come from rainfed agriculture. Therefore water conservation zones in agricultural landscapes play an important role in the capture and storage of water and associated nutrients and subsequently used for crop production. However, the management of water conservation zones has been a challenge due to the poor understanding of the relationship between upstream land use and the functions of these zones. Knowledge of sources and sinks of water into and out of the water conservation zones as influenced by upstream landuse is needed to develop management practices for optimizing the performance these water conservation zones.

This coordinated research project (CRP) entitled 'Strategic Placement and Area-Wide Evaluation of Water Conservation Zones in Agricultural Catchments for Biomass Production, Water Quality and Food Security' established a research network of twelve participants from ten countries (China, Estonia, France, Islamic Republic of Iran, Lesotho, Nigeria, Romania, Tunisia, Uganda and the United States of America). The overall objective of this CRP was to assess and enhance ecosystem services provided by water conservation zones (wetlands, ponds and riparian buffer zones) for improving the capture and storage of water and nutrient within agricultural catchments and their use for crop production. The specific objectives are to (i) determine the capacity of water conservation zones for water storage, (ii) assess nutrient attenuation capacities, and (iii) assess the link between water and nutrient dynamics. Water and nutrient balances based on input and output for farm ponds, wetlands and riparian buffer zones were quantified using hydro-chemical information. Isotopic signatures of oxygen-18 ($\delta^{18}O$) and hydrogen-2 (δ^2H) were used to trace the movement of water, and nitrogen-15 (^{15}N) to trace nitrogen (N).

Three types of water conservation zones were evaluated in participating countries based upon their use in agricultural catchments, namely: (i) water and nutrient storage for downstream irrigation use (farm ponds), (ii) *in situ* crop and biomass production (wetlands including riparian wetlands), and (iii) managing downstream water quality (riparian buffer zones). Piezometers were installed in and around most of the zones at various depths to record groundwater depth fluctuations and to collect water samples. Oxygen-18, hydrogen-2, and nitrogen-15 stable isotopic signatures were measured in water samples collected from surface waters, ground waters, rain water and runoff water. For each country, one catchment was selected for field studies based on the importance of agricultural production and water management practices. Preliminary land-use surveys were carried out for experimental catchments in all eight countries and the results are provided in Table 1.

TABLE 1. LAND USE OF EXPERIMENTAL CATCHMENTS

Country	Catchment	Major land-use	Area (ha)
China	Sanjiang Plains	Rice	92 000
Estonia	Porijogi	Livestock	12 600
Islamic Republic of Iran	Ab-Bandons	Rice	11 700
Lesotho	Ha-Matela	Maize, sorghum and livestock	300
Nigeria	Ekiti Valley	Rice, maize, yam	2 500
Romania	Galvacioc	Wheat and maize	3 200
Tunisia	Kamech	Wheat, barley, oat, etc.	260
Uganda	Manafwa	Rice	300

Based on the CRP objectives, the water conservation zones in Tunisia (farm pond) and The Islamic Republic of Iran (Ab-bandans, human-made water storage ponds) were grouped under water conservation zones that collect catchment run-off for improving food production through irrigation of crops downstream. China, Lesotho, Nigeria and Uganda (wetlands) were grouped under water conservation zones that are used for *in situ* food production. Finally, Estonia and Romania (riparian zones) were grouped under water conservation zones that regulate nutrient cycling, protect downstream water quality and generate biomass within the system.

A brief description of studies carried out in each of the water conservation zones is provided below:

- The sources of water to the farm pond in Kamech catchment was investigated using $\delta^{18}O$, $\delta^{2}H$ and hydrological processes in Tunisia.
- Isotopic and water mass balance studies were carried out in 30 Ab-bandans in northern Iran that capture water from the surrounding catchments to irrigate downstream rice fields.
- Field investigations using isotopic and conventional techniques were carried out in Northern China to assess water conservation zones for sustainable agricultural production.
- The *in situ* rice production and N use were investigated for rice wetlands in Eastern Uganda using ^{15}N isotopic techniques.
- In Nigeria, the environmental issues related to integrated management and characterisation of water conservation zone was studied.
- The hydrological and management constraints in two water conservation zones were examined in Lesotho.
- The N pathways in a riparian buffer zone were investigated in the Glavocioc river catchment in Romania.
- Two riparian buffer zones in Estonia were studied for optimizing N removal through denitrification.

Data on rainfall and other weather related information were collected for all countries to establish catchment water balance and identify sources of inflow to the water conservation zones. Oxygen-18, hydrogen-2, nitrogen-15 and other water chemistry measurements were carried out for all sources of water. In addition to water balance estimations, nutrient budgets for all water conservation zones were established.

Key findings from the CRP showed that in Tunisia, the $\delta^{18}O$ and $\delta^{2}H$ isotopes allowed to assess water cycle components of Kamech catchment. Results indicated that the upstream groundwater is disconnected from the farm dam even if they contribute to the stream base flow while runoff is the main flow that fills the dam. The water budget indicates that approximately 80 000 m^3 had infiltrated into the underlying alluvial aquifer during the year 2009-2010 while groundwater had supported the dam storage during high release periods and dry season by supplying about 10 000 m^3 to the dam. The dam with a surface area of less than 3% of the catchment area was able to capture more than 90% of the runoff water generated suggesting 3% surface area is sufficient to capture the entire runoff generated in the catchment. The water budget established of the farm pond showed that for most of the time the pond is recharging the unsaturated zone. Runoff in the catchment is mainly produced in autumn and winter during which annual rainfall occurs.

Water quality and isotopic signatures of water samples collected from 30 ab-bandans during winter, spring and summer showed that land use, fertilizer application and the location of these wetlands influence the amount of water captured by these wetlands. The seasonal variation of $\delta^{18}O$ and $\delta^{2}H$ in wetland water in southern Caspian low lands of The Islamic Republic of Iran depends on the input of rainfall in winter, snowmelt in spring, and summer pond evaporation. The relationship between $\delta^{18}O$ and $\delta^{2}H$, established for rainwater, snow and wetland water during spring season, suggested that wetland water is derived from rainfall/runoff and snow melt during spring. Changing irrigation scheduling from flood (rice yield of 3.5 tons ha^{-1}) to 8 day irrigation (rice yield of 3.3 tons ha^{-1}) achieved a total rice production of 5050 tonnes and increased rice water use efficiency from 2.85 to 1.34 m^3 water kg^{-1}. Results from the study in Iran showed that (1) cultivation area can be doubled, (2) rice production can be increased by more than 90%, and (3) rice water use efficiency can be increased by 50% through judicious use of water.

The evaporative isotopic signatures of $\delta^{18}O$ and $\delta^{2}H$ in surface waters of Sanjiang Plains in northeast China were a good indicator to study the mixing between groundwater and surface water. Groundwater in confined aquifer with age over 50 years that are depleted in heavy isotopes has been recharged by lateral flow from adjacent mountains. This groundwater in general is not affected by changes in wetlands and/or rice fields and therefore is less vulnerable to the pollution from fertilizer application. However, the yield of this water is limited. On the contrary, the unconfined aquifer is recharged by rainfall or riverbank infiltration at localities near rivers. It is more likely for the aquifer to be affected by nutrients released from intensive fertilizer applications, though its yield is rather substantial. The stable isotopic signatures with water chemistry data demonstrate that the use of wetlands for rice production is sustainable as it has not affected the quality of underlying groundwater. It is therefore suggested that surface water should be utilized together with groundwater in order to ensure sustainability of water supply for irrigation in the region. The results from this study have important implications for wetland reclamation and agricultural production on the Sanjiang Plain.

The average annual sediment yields from different hydrological response units in River Manafwa, Uganda were found to be high, ranging from 5.73 to 241 Mg km^{-2} yr^{-1} with an average of 45 Mg km^{-2} yr^{-1} while the average soil loss and runoff from the catchment is moderate and averaged 43 t $ha^{-1}yr^{-1}$ for sediments. Sediment deposition in the rice wetland was estimated at 5.07 cm m^{-2} yr^{-1}. Nitrogen use efficiency was found to be highly dependent on water management and fertilizer application. Fertilized plots had the highest N use efficiency (51.1%) compared to the control (13.7%). Nitrogen use efficiency decreased as less water is present in the rice wetland. Fertilizer application to rice wetlands increased grain yields by 40% with a benefit to cost ratio of 2.54 compared to 2.22 with unfertilized fields. For river Manafwa, there was a clear pattern of enrichment of $\delta^{18}O$ and $\delta^{2}H$ in downstream water indicating evaporation as the conditions become warmer in lowlands.

In Nigeria, the N rates applied significantly influenced the number of panicles, tillers, dry matter (t ha^{-1}) and grain yield (t ha^{-1}) of rice at Ado Akiti wetland soils. The best economic yield of 4.39 t ha^{-1} of rice was obtained on a Typic Endoaquept soil using fertilizer application based on soil test value. Nitrogen recovery of rice as shown by ^{15}N labelled fertilizer uptake was much higher using the soil test fertilizer application rate at site 3. Results obtained for N fertilizer use efficiency (NFUE) at sites 1 and 3 showed that when fertilizer is properly managed, rice grown on wetland soils usually makes use of higher proportion of N applied.

The land use and land management practices in the catchment of two wetlands namely Ha-Matela in the foothills and Thaba-putsoa in the mountains of Maseru in two different eco-regions of Lesotho showed that soil physico-chemical and morphological characteristics are affected by land management. There is great spatial heteroginity of soil physico-chemical properties within wetlands and this heteroginity can have important consequences on wetland biota and biogeochemistry. The study showed that land use and land management practices in the catchment influenced the soil physio-chemical characteristics. The results showed that *Ha-Matela* wetland should be protected from excessive utilization and appropriate policies implemented to protect the natural resources in order to spare them for future generation. Many of wetlands in Lesotho are found adjacent to rangeland or pastureland, as opposed to cultivated crops. Because of this animal grazing management can influence soil condition and the resulting impacts to wetlands. Depending on its intensity, grazing can increase species diversity and diversity along environmental gradients, as well as increase wetland plant community boundary definition. Grazing also decreases dead plant matter, and overgrazing can lead to decreased primary production. Overgrazing and severe trampling will reduce plant cover and increase the amount of bare soil. Therefore stocking rate management is critical to maintenance of wetlands existing in rangelands and if well-managed wetlands in these areas can exhibit high-quality conditions.

Studies carried out within the riparian zones of five vegetation types (agriculture, pasture, querceta forest, mixed forest, and wetland) in the small Glavocioc catchment (45 km^2) located in the Romanian Plain showed that vegetation present in riparian zones of rivers is the most important structure for nutrient uptake and to reduce nutrients into surface water bodies. The largest quantities of biomass were produce by mixed forest followed by querceta forest, a significant contribution of tree biomass in riparian zones. The nutrient uptake gradient related to soil moisture gradient, which means that, in areas with low water content (oxidized condition), plant uptake of nutrient dominates compared to areas with excessive water (reduced conditions) in which reduced forms (e.g denitrification products) dominate. The study showed that the Glavocioc riparian zone mosaic provides on one hand a high diversity, a source of natural resources (wood, biomass, food) and on the other hand great areas to reduce diffuse pollution from agriculture (riparian areas that function as buffer zones).

Investigations on N_2O and N_2 emissions and isotopic signatures of N2O and nitrate (NO_3^-) of groundwater in two (Porijõgi and Viiratsi) grey alder stands (riparian buffer zones) in southern Estonia showed that the main gaseous flux from both riparian alder stands was in the form of N_2, which was 278 (Viiratsi) to 995 times (Porijõgi) higher than the amount of N_2O emitted. Nitrous oxide accumulation in the groundwater was moderate. The greater of N_2 emission over N_2O in both areas and the strong relationship between NO_3^- and N_2O further suggested that denitrification is the main source of N_2O and N_2 fluxes in these grey alder riparian zones. This study also confirms that isotopic signatures of N_2O (^{15}N in the end and middle N in N_2O) may be used to distinguish N_2O fluxes from ecosystems with unsaturated and saturated groundwater situations. Further, the study showed that in riparian alder stands saturated with water, N_2 is the predominant denitrification product compared with N_2O which is a significant boost to address N_2O emissions from wetlands to the atmosphere.

Water conservation zones are a major source of water for groundwater recharge as shown by similar δ^2H (–102‰ to –68‰) and $\delta^{18}O$ (–14‰ to –9‰) signatures of both surface and ground waters. Isotopic signatures of water in run-off, rainwater, stream water and water conservation zones along with water balance calculations showed that more than 90 percent of the water captured by water conservation zones is by surface run-off during rainy periods. Nitrogen captured in water conservation zones is a major source of N for biomass production (215 kg N ha^{-1} yr^{-1}) within these zones and for irrigating adjacent farmlands and potentially reducing N input to downstream water. More than 60 percent of N removed by water conservation zones in agricultural catchments occurred through denitrification in Estonia as shown by N-15 techniques. Nitrogen-15 labelled nitrate and urea were useful for quantifying denitrification and biomass N use efficiency in wetlands, farm ponds and riparian buffer zones. These preliminary results showed that in wetlands and riparian buffer zones, denitrification is a major process leading to N removal from water (> 60 percent of N removal), and that most of this denitrification leads to the formation of N_2 gas rather than N_2O thus reducing greenhouse gas emissions to the atmosphere. Information collected from this research is useful for preparing guidelines and management practices that help farmers to optimize the capture and storage of water and nutrients in water conservation zones and their subsequent use for agricultural production and to improve downstream water quality and quantity.

USE OF ISOTOPIC AND RELATED TECHNIQUES FOR INCREASING WATER CONSERVATION AND YIELD PRODUCTION IN A PART OF ANZALI WETLAND IN THE ISLAMIC REPUBLIC OF IRAN

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Abstract

Water scarcity and uneven distribution of rainfall are the most important limiting factors for the development of agriculture in the Islamic Republic of Iran. In order to assess water quality, quantity and seasonal variation in isotopic signatures of oxygen-18 ($\delta^{18}O$) and hydrogen-2 ($\delta^{2}H$) a water and nutrient balance and nutrient uptake study was carried out in 30 different wetlands in the north of Iran (Ab-bandans). Water samples were collected in winter, spring and summer of 2010 and 2011 and analysed for chemical and isotopic compositions. Data showed that highest $\delta^{18}O$ and $\delta^{2}H$ were recorded in summer (-1.15‰ and -12.11‰ for $\delta^{18}O$ and $\delta^{2}H$) and the lowest $\delta^{18}O$ and $\delta^{2}H$ were recorded in winter (-7.50‰ and -47.32‰ for $\delta^{18}O$ and $\delta^{2}H$), respectively. The $\delta^{18}O$ and $\delta^{2}H$ signatures showed that the water at the Ab-bandan were enriched from spring (-3.57 and -27.72‰) to summer (-1.15 and -12.12‰), respectively. The relationship between $\delta^{18}O$ and $\delta^{2}H$ for pond water and local/global precipitation showed that rainfall and snowmelt can be a major source of water for these Ab-bandans. Water and nutrient balance based on input, output and storage showed that on average 7.6 million cubic meters of water along with 86 tonnes of nitrogen (N) and 17 tonnes of phosphorus (P) were captured and stored by these wetlands and are available for irrigating downstream rice crops. Flood irrigation of this water at a rate of 10 000 m^3 ha^{-1} over the growing season (April to September) was able to produce rice in an area of 730 ha with a yield of 3.5 tons ha^{-1}. However, changing the irrigation method from flood to an eight-day irrigation interval was able to cultivate 1 500 ha with similar yield and significantly increased water use efficiency and reduced energy use. The results of the study are useful to identify the sources of water in wetlands and to improve land and water management practices to optimize the capture and storage of water and nutrients for downstream irrigation.

1. INTRODUCTION

Scientific knowledge on water quality and quantity of all water resources is vital for the optimization and utilization of specific areas like permanent flood rice paddy fields [1]. Water scarcity is one of the main limiting factors for low agricultural productivity in The Islamic Republic of Iran. Even though irrigation agriculture generally provides 2 to 3 times more crop yield than rainfed agriculture, they are still on the low side by international standards [2]. Although arid and semi-arid climate with low rainfall (annual average of <250 mm) covers over two third of The Islamic Republic of Iran, a narrow part between the Caspian Sea and the Alborz mountains could provide humid climate with average annual rainfall between 1 200 to 1 800 mm (varies along the coastline). In this respect, constructed or human-made wetlands can be suitable options to capture, store and use water and nutrients in these areas to improve agricultural productivity and environmental quality.

In the southern Caspian lowlands, one of the most important types of wetlands is the Ab-bandans, a number of small, manufactured wetlands. These shallow water wetlands (also called as wetlands), varying in size from 3 ha to 1 000 ha, most were originally built as temporary water storage providing water for irrigation of rice fields during summer growing seasons [3]. Recent surveys by Department of the Environment, Islamic Republic of Iran have showed that there are still about 2160 wetlands in Gilan Province, Northern Iran covering an area of 8 353 ha. These wetlands are one of the major sources of water for agriculture in Caspian low lands, particularly for rice production.

Information on sources and fluxes of water in these wetlands is vital for optimizing the capture, storage and utilization of water and nutrients in water scarce arid and semi-arid areas [1]. The use of oxygen-18 and hydrogen-2 stable isotopes as naturally occurring tracers is a valuable tool to identify water sources and fluxes to and from rivers and lakes in catchments. Studies have shown that the evaporation of surface water increases the isotopic signatures of oxygen-18 ($\delta^{18}O$) and hydrogen-2 ($\delta^{2}H$) in the remaining water and deviate linearly from the local meteoritic water line (LMWL). However, such studies are often restricted to local scale water dynamics [4], [5] and used $\delta^{18}O$ and $\delta^{2}H$ to assess water sources of different lakes in western Canada. They showed that the $\delta^{18}O$ and $\delta^{2}H$ of surface waters were more positive than that of mean annual precipitation, indicating the basin-scale evaporation of surface waters. With isotopic mass-balance modelling, they also found that about 35% of inflow to the lake watershed was lost to evaporation [6], compared to sub-Arctic lakes in northern Sweden and showed that lake waters showed a range of isotopic signatures between different sites as effected by catchment elevation and timing of snow-melt. Until now no comprehensive assessment of water fluxes in wetlands was undertaken. In this respect, an assessment of water quality, quantity and water and nutrient balance in relation to upland activities and land use practices is important for developing strategies for effective management of water for agricultural use.

The objective of this paper was to assess the dynamics of water using isotopic signatures of oxygen-18, hydrogen-2, and nutrients of wetlands in Northern Iran and establish a water and nutrient balance for selected water and nutrient balance for those wetlands.

2. MATERIALS AND METHODS

2.1. Study and area

The study was carried out in Northern Iran (low lands of southern Caspian sea, Gilan province), bounded by geographical co-ordinates of X: 368376 to 43358 and Y: 4104370 to 4139522 (Figure 1). The water data used in the study were collected from 30 human-made wetlands. These wetlands have a range of surface area, volume and depth. The elevation ranges for the wetlands were classified by Digital Elevation Model (DEM) of watersheds. Catchment area, elevation, and long term average rainfall and evapotranspiration are provided in Table 1.

Surface area of wetlands and their usage were taken in to consideration when selecting these 30 wetlands. The hydrological regime for the area is a seasonal water cycle with maximum input to the wetlands in autumn and winter due to precipitation (rainfall and snow) and minimum input in summer. The major losses of water from the pond are evapotranspiration and discharge from the wetlands for irrigation. Land use, soil types, topography and climate for the catchment were characterized and details were provided elsewhere [3]. As shown in Table 1, the wetlands were grouped based on drainage area, and elevation.

Soil samples were collected from 0-30 cm of top soil (by Auger at three different points of each wetlands and finally mixing) from farmers field situated downstream of each wetland.

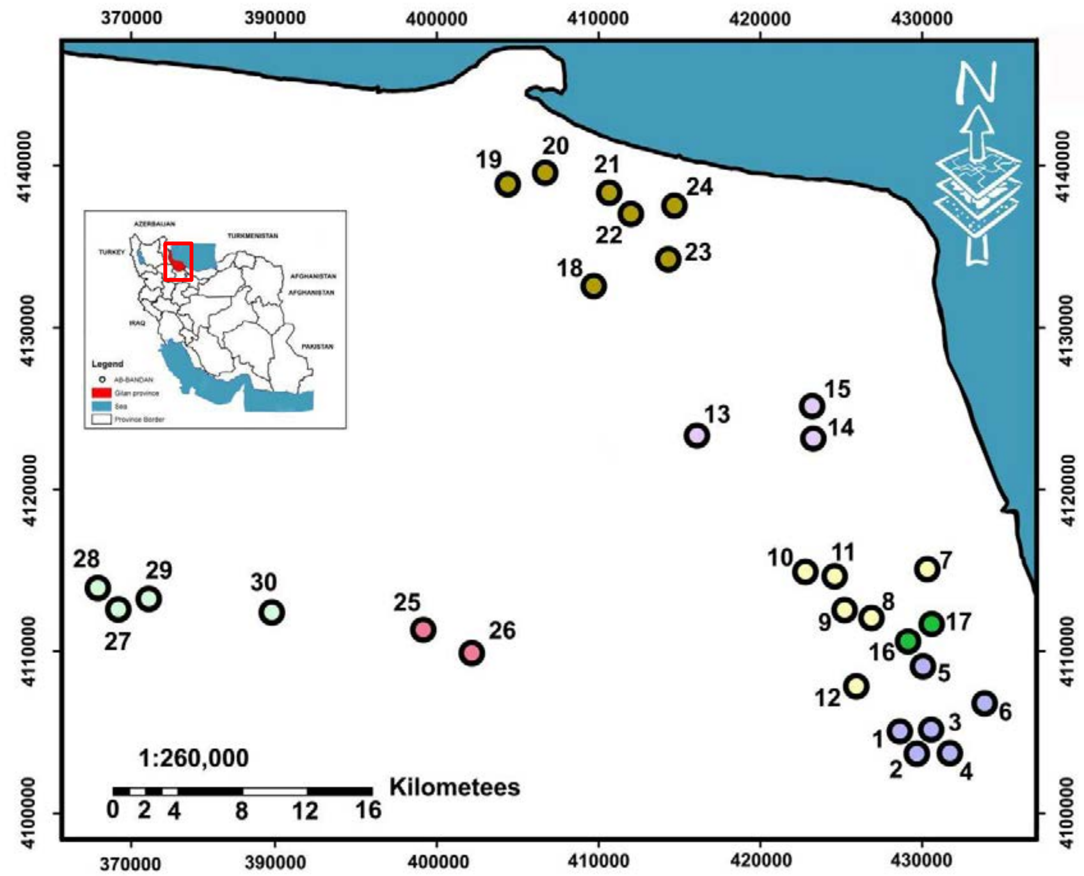

FIG. 1. Location of wetlands (Ab-bandans) in the Southern Caspian Low Lands, The Islamic Republic of Iran

TABLE 1. GEOGRAPHY AND CLIMATE CHARACTERISTICS OF POND CATCHMENTS

Pond No	Maximum elevation (msl)*	Minimum elevation (msl)	Annual rainfall (mm)	Average ET (mm)
1	261	11	1 218	763
2	261	11	1 218	763
3	261	11	1 218	763
4	261	11	1 218	763
5	5	0	1 218	763
6	6	0	1 218	763
7	-17	-22	1 431	792
8	243	-7	1 431	792
9	243	-9	1 431	792
10	430	-5	1 431	792
11	383	-13	1 431	792
12	100	25	1 431	792
13	-3	-16	1 431	792
14	-10	-19	1 431	792
15	-10	-19	1 431	792
16	6	-4	1 218	763
17	-1	-8	1 218	763
18	-6	-20	1 359	831
19	-16	-23	1 359	831
20	-17	-24	1 359	831
21	-15	-20	1 359	831
22	-8	-20	1 359	831
23	-7	-23	1 359	831
24	-20	-20	1 359	831
25	122	46.1	1 146	788
26	114	53.2	1 146	788
27	177	41	1 369	831
28	169	41	1 369	831
29	138	70.2	1 369	831
30	103	41.5	1 369	831

The general physiography of wetlands is provided in Table 2. The surface area of wetlands ranged from 1.1-48.12 ha with a median value of 4.83 ha. Wetlands with large surface areas are generally located at lower altitude (<20 msl). The catchment area for the wetlands ranged from 34–2547 ha with a median value of 239 ha. The average volume of water in each pond varies from 9-743 with a median value of 375 thousand cubic meters.

TABLE 2. PHYSICAL CHARACTERISTICS OF WETLANDS

No	Elevation (m)	evaporation (mm/year)	water depth (m)	pond area (ha)	volume of water (MCM)
1	286	763	1.5	6 750	0.10125
2	286	763	1.0	2 870	0.02870
3	286	763	1.0	4 750	0.04750
4	286	763	0.8	4 720	0.03540
5	30	763	0.5	1 820	0.00910
6	31	763	0.5	2 540	0.01270
7	8	792	0.5	4 080	0.02040
8	268	792	1.0	3 000	0.03000
9	268	792	1.0	12 370	0.12370
10	455	792	2.5	1 530	0.03825
11	408	792	0.9	7 760	0.06984
12	125	792	1.0	1 830	0.01830
13	22	792	0.8	13 560	0.10848
14	15	792	0.4	36 240	0.15583
15	15	792	0.5	12 280	0.06140
16	31	763	0.8	4 200	0.03360
17	24	763	0.8	4 000	0.03200
18	19	831	0.8	48 120	0.38496
19	9	831	0.7	5 300	0.03710
20	8	831	0.7	7 100	0.04970
21	10	831	0.9	44 120	0.39708
22	17	831	0.7	34.310	0.24017
23	18	831	0.8	25 170	0.20136
24	5	831	0.8	20 200	0.16160
25	147	788	1.0	5 770	0.05770
26	139	788	0.9	1 310	0.01179
27	202	831	6.0	12 380	0.74280
28	194	831	0.5	4 810	0.02405
29	163	831	2.8	1 100	0.03080
30	128	831	0.5	4 850	0.02425

2.2. Measurements

Climate, hydrology and physiographical data were collected from selected weather stations covering all 30 wetlands. Water samples were collected during three different seasons, at the beginning of the irrigation period (June 2010), at the end of the irrigation period (August 2010) and at the end of precipitation season (March 2011). Water samples were analyzed for chemical compositions (pH, CO_3^{2-}, Cl^-, SO_4^{2-} TDS, Na^-, Ca^{2+}, Mg^{2+}, NO_3^-, NH_4^+ and P), $\delta^{18}O$ and δ^2H during spring and summer 2010 and winter 2011. Mass accumulation of phytoplankton (living in the pond) was counted by volumetric measurement of water in the wetlands. The amount of water, nitrogen (N) and phosphorus (P) captured by wetlands, the change in $\delta^{18}O$ and $\delta^{2}H$ of water and other hydro chemical properties of water were measured during this period. Nitrogen and P budget for all wetlands were calculated based on the amount of water and the concentrations of N and P in the water. Land use, soil, topography and climate for the catchment were characterized along with water, nitrogen (N) and phosphorus budget for these "Ab-bandans".

2.3. Assessment of N fertilizer use efficiency

The N fertilizer use efficiency study was carried out using ^{15}N labelled urea. For this assessment, five farmers' fields were selected downstream of the following five wetlands. In these farmers field studies established in Pond No. 5 (Amlash County), Pond No. 12 (Langrood County), Pond No. 17 (Roodsar County), Pond No. 23 (Astane County), and Pond No. 27 (Rasht County). The nitrogen-15 enriched fertilizer was injected to the ^{15}N subplot by using a special valve connected to a gallon. The area of the isotopic subplot was about 2.25 m^2, which placed in the corner of plot (Figure 2). 4 250 %^{15}N atom excess was used for this study. Irrigation scheduling was carried out by conventional methods of farmers in the area.

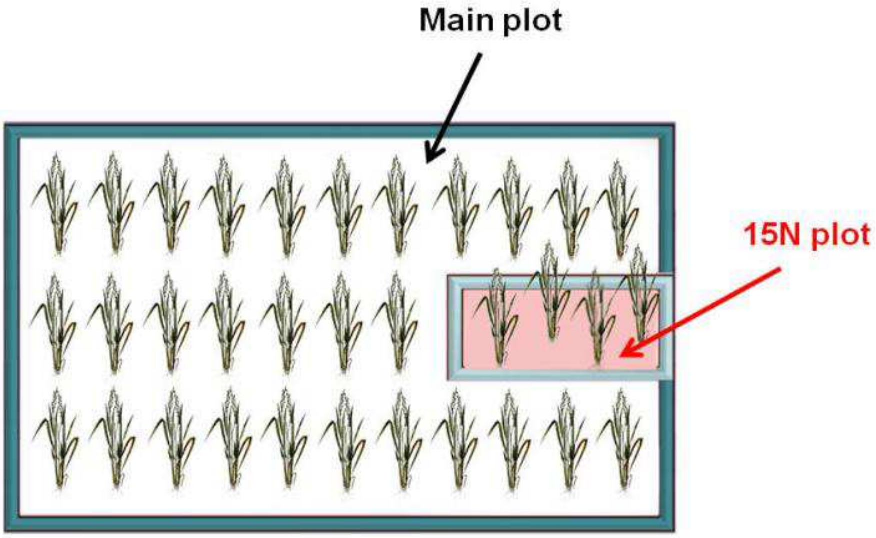

FIG. 2. 15N microplot applied with 4.250. % excess urea fertilizer

2.4. Isotopic fingerprints of water

The isotopic signatures of ^{18}O and ^{2}H are expressed as δ values **(**$\delta^{18}O$ and $\delta^{2}H$**)** representing deviations in per mil (‰) from standards for oxygen and deuterium such that

$$\boldsymbol{\delta_{sample} = (\frac{R_{sample}}{R_{standard}} - 1) \times 1\,000} :$$

where R is the $^{18}O/^{16}O$ or $^{2}H/^{1}H$, ratio in sample and standard

Statistical analyses for the chemical compositions were carried out using multivariate analysis [7].

3. RESULTS AND DISCUSSION

3.1. Rainfall

The monthly rainfall for the study area during the period 2009-2012 showed that rainfall fluctuates between years (Figure 3). The long-term annual average rainfall for the study area is approximately 1400 mm and this is very close to the annual rainfall in 2012. During the 2009 and 2010 the annual rainfall was below the long term average (1 030 and 900 mm for 2009 and 2010, respectively). Because of this water available for crop irrigation has been reduced. Most rainfall occurs during autumn and winter. However, on some occasions late summer also contributed to total rainfall.

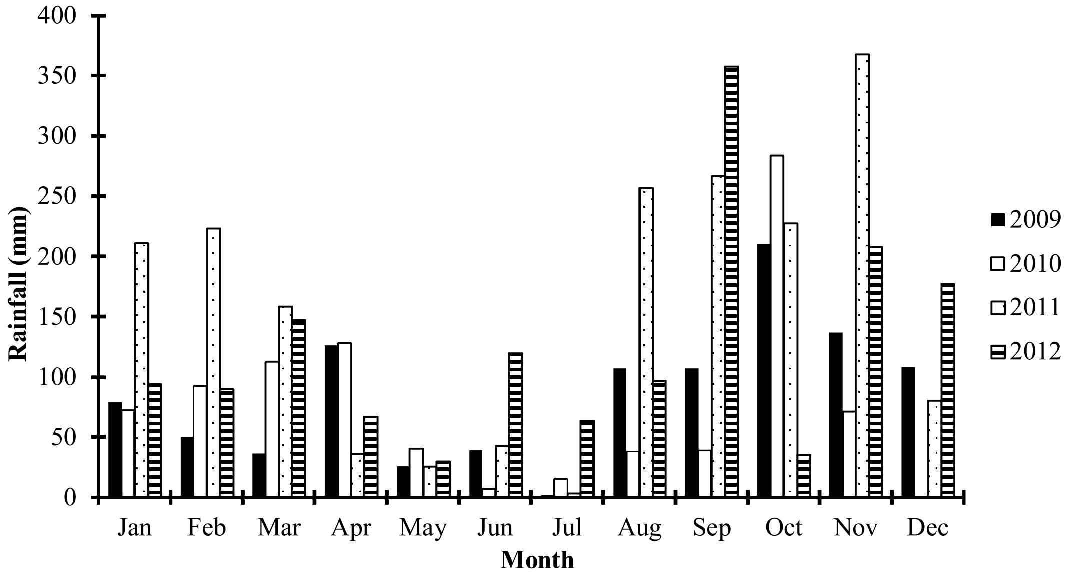

FIG. 3. Monthly rainfall for the study area during the period from 2009-2012

3.2. Chemical characteristic of water in the wetlands

The chemical and hydro biological characteristics of water in all 30 wetlands are provided in Table 3. Results of the analysis of variance revealed that pH, CO_3^-, Cl^-, SO_4^-, TDS, Na, Ca, Mg, NO_{3-}, NH_{4+} and P of wetlands vary significantly ($p< 0.01$ by Duncan's test) over spring, summer and winter

TABLE.3. MEAN CHEMICAL AND HYDRO BIOLOGICAL CHARACTERISTICS OF WATER IN DIFFERENT WETLANDS

Pond No.	TDS ppm	pH	Cl^{-1}	SO_4^{-2} mg/L	Na^{+}	K^{+}	Ca^{+2}	Mg^{+2}
1	202	7.49	0.37	1.70	0.65	0.07	2.08	0.93
2	345	7.20	0.47	6.68	0.72	0.06	3.97	2.47
3	174	7.30	0.43	2.31	0.58	0.06	1.40	1.18
4	222	7.32	0.38	37.4	0.63	0.09	1.97	1.30
5	159	7.54	0.38	1.91	0.54	0.06	1.38	0.65
6	227	7.51	1.02	2.55	0.61	0.02	1.97	1.38
7	872	7.42	2.75	1.70	2.34	0.09	1.48	0.95
8	280	7.20	1.78	24.3	1.47	0.13	2.62	0.75
9	672	7.29	1.72	1.82	1.47	0.15	1.87	0.77
10	193	7.44	0.73	1.95	0.84	0.09	1.58	1.08
11	255	7.65	0.98	2.45	0.98	0.06	1.78	1.25
12	271	7.87	1.77	1.97	0.83	0.04	1.80	1.03
13	642	7.82	5.85	25.3	3.43	0.10	3.68	1.75
14	720	7.78	6.17	29.5	3.53	0.13	3.83	2.47
15	401	7.84	2.47	2.98	3.01	0.18	2.65	2.05
16	659	7.86	6.85	23.4	1.16	0.08	3.92	2.62
17	417	7.83	2.77	3.02	1.12	0.09	2.83	2.83
18	727	7.89	6.40	4.00	3.62	0.18	2.87	2.98
19	629	7.96	4.88	19.2	3.11	0.16	2.55	2.88
20	1125	8.09	10.23	31.4	7.88	0.11	4.18	4.00
21	774	7.83	6.90	2.64	4.76	0.16	3.37	3.80
22	696	7.83	5.88	2.65	3.47	0.09	2.90	2.62
23	722	8.10	7.25	3.03	5.29	0.15	3.20	2.82
24	907	7.81	3.80	16.8	3.60	0.10	3.73	2.00
25	142	7.72	0.15	1.50	0.70	0.04	1.97	0.57
26	119	7.76	0.42	2.89	0.63	0.05	1.35	0.52
27	285	7.28	0.22	1.63	0.52	0.03	0.57	0.72
28	60	6.95	1.47	3.67	0.62	0.03	0.37	0.80
29	332	7.60	0.47	1.52	0.77	0.03	0.65	0.60
30	201	7.63	1.25	1.78	2.23	0.07	1.13	1.05

The highest water depths recorded in the winter (average of 1.89 m) and the lowest were in the summer (average 0.38 m). The volume of water decreased during the summer (0.27 to 0.018 million cubic meters from winter to summer). On average, the reduction in water column depth and water volume from winter to spring were 26.9% and 5.3% and from spring to summer were 23.7%, and 3.1%, respectively. The main reason for this phenomenon is the water demand for land preparation at the end of winter and irrigation during summer. All 30 wetlands are being recharged during winter through rainfall, runoff and snow melt which increases the volume of water. With minimum rainfall during summer, higher evapotranspiration losses and water discharge for irrigation, the amount of water available in these wetlands decreased.

Results of EC and TDS showed that there is a negative effect between EC, TDS and total volume of water of wetlands. In other words, with increase in volume of water, significant reductions have been observed in water salinity. It was concluded that consumption of water for rice production is not the only way of water loses from these wetlands. Therefore, it seems that one of the most important reasons for reduction of water during summer is evaporation of water from pond surface. In this condition, salt concentration will increase and electrical conductivity and total dissolved solids will increase too. According to the local legislation related to the water quality assessment program, it is prohibited to use water with TDS more than 2 000 mg l^{-1}. It is quite clear that in all selected wetlands, the amounts of salt are less than its critical point. Therefore, we do not have any problems arise with salinity in our fields. During winter, water is classified as good (0.25-0.75 dSm^{-1}) and during spring and summer water classify as medium (0.75-2.25 dsm^{-1}) ([8], [9] and [10]). Therefore, utilization of water for agriculture purposes does not have any hazard and restriction.

The results of pH are quite different from EC and TDS of the wetlands. The highest of pH was in the winter (7.96) and the lowest were recorded in the summer (7.17). In average, reduction rate of pH for each mounts from winter to spring were 7% and from spring to summer were 20%. According to the local legislations related to the quality assessment program, there is not any problem of water with pH between 6.5 and 8.4. One of the main reasons for reduction of pH during the summer is increments of acidic agents during the summer in the wetlands. By assessment of EC and TDS (during the summer) we are not able to predict special sorts of material related to the acidity and alkalinity agents. Particular attention shows that one of the most important acidic agents (SO_4) increased sharply during spring to winter from 230 to 2093 mgl^{-1} (2.4-21.8 $meql^{-1}$). This amount is four times higher than its critical point of irrigation (400-500 mgl^{-1}). Therefore, it concluded that this is the reason for increment of pH in the wetlands. It is worthy to mention that, most of the increments of sulphate occurred during the summer and there is no relationship between SO_4 and other cations, which is reported in this activity. In other words, SO_4 came in to the pond directly as pure sulphur or sulphuric acid added to the rivers or irrigation water and consequently flows in to the wetlands. Further investigations are required in this area.

The highest and lowest amounts of CO_3 were recorded in the spring (0.22 $meql^{-1}$), and winter (0.01 $meql^{-1}$) respectively. Statistical assessment reveals that concentration of carbonate will divide in to two different groups. The highest were in the spring (0.22 $meql^{-1}$) and the lowest were in winter and summer (0.027 $meql^{-1}$). One of the hypothetical theories to illustrate this event is high increments of biological activities during spring (compare with winter and summer). There are some biological organisms such as fishes and algae, which consume oxygen and release carbon dioxide to the water. Therefore, we can see some increment of carbon dioxide in to the wetlands. There were not any significant differences between concentration of bicarbonate (as a source of alkalinity) during different seasons and all of them placed in the same groups. This amounts is in the boarder of critical concentration points of HCO_3 (1.5-2.0 $meql^{-1}$) to restrict application of it.

Results of the analysis of variance showed that water depth, wetland area, and pH, CO_3^{2-}, Cl^-, SO_4^{2-} TDS, Na^-, Ca^{2+}, Mg^{2+}, NO_3^-, NH_4^+ and P of wetland vary significantly ($p< 0.01$ Duncan's test) during spring, summer and winter (Figure 4). The concentrations of anions and cations increased from spring to summer and then decreased over the period from summer to winter.

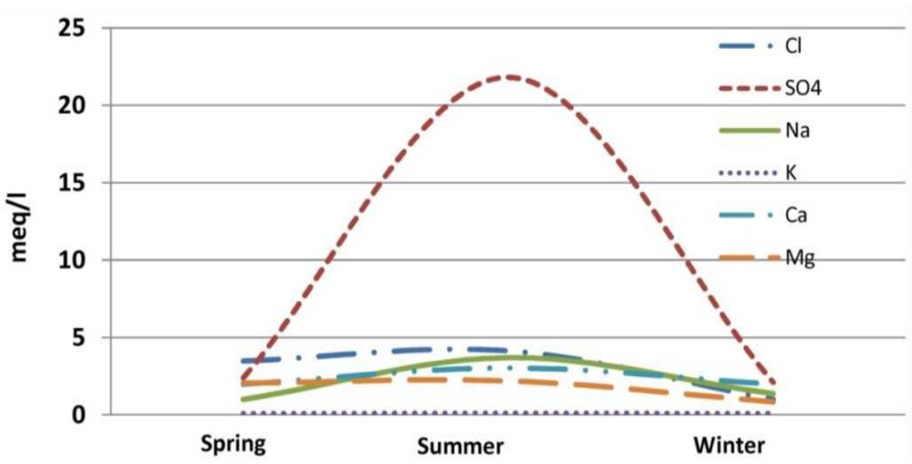

FIG. 4. Seasonal effect of pond characteristics and chemical properties of water (average of 30 wetlands)

3.3. Nitrogen

The highest amount of nitrate (NO_3) was observed during the winter (15.4 mg l^{-1}) and the lowest (2.2 mg l^{-1}) amount was recorded in spring (Figure 5). This may be due to greater NO_3 input by runoff from the catchment to the pond and reduced losses of NO_3 from the pond during winter with low temperature causing reduced plant growth and N uptake, low microbial activity leading to reduced denitrification activity.

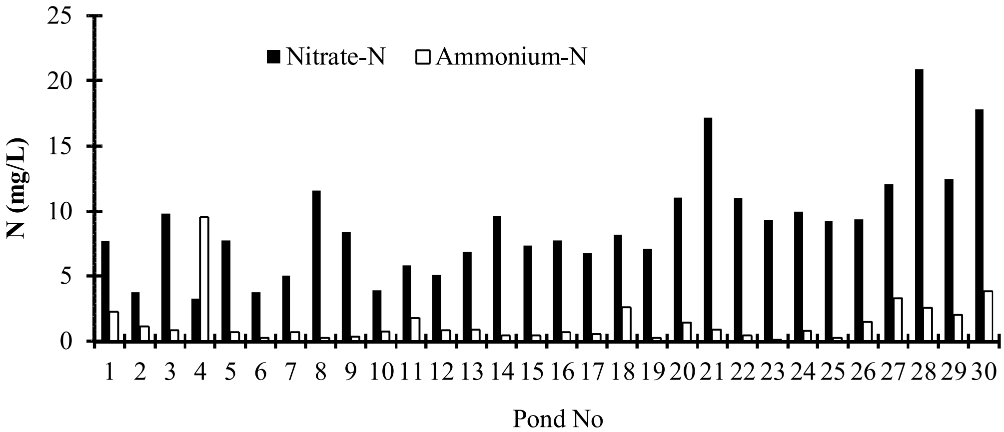

FIG. 5. Nitrate and ammonium concentrations in different wetlands

For ammonium (NH_4), the highest (2.2 mg l^{-1}) concentrations found during the spring and the lowest (1.0 mg l^{-1}) in winter. The reason for low NH_4 concentrations during spring is not clear. However, plant uptake, conversion to NO_3 and subsequent denitrification during the hot weather in summer might have contributed to the low concentrations of NH_4 in the pond water.

The highest concentration of phosphorus (3.2 mg l^{-1}) was observed in the summer and the lowest (1.3 mg l^{-1}) were observed in the spring (Figure 6). In this respect water samples during winter and spring were not significantly different. On average, the change in concentration was only 5%

from winter to spring (not statistically significant). However, the average P concentration increased by 63% from spring to summer.

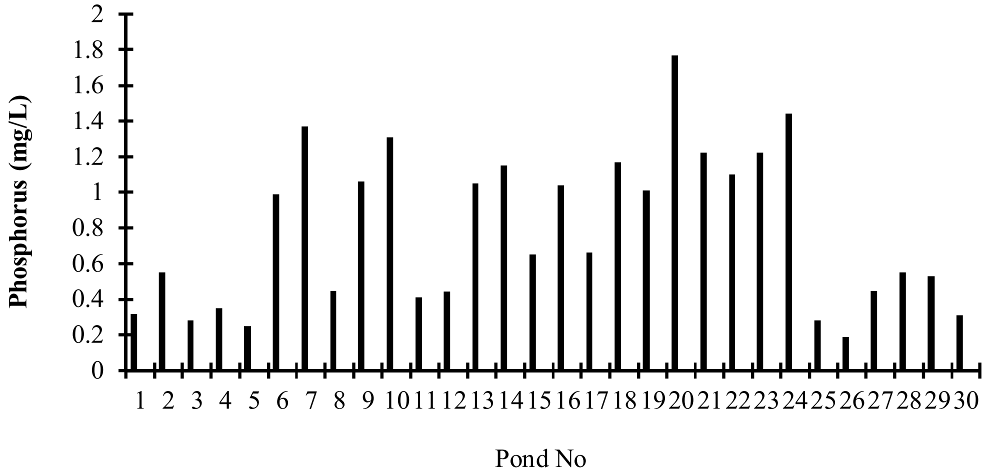

FIG. 6. Average phosphorus concentrations in different wetlands

Water, N and P balance in the wetlands over winter, spring and summer showed that on average 7.6 million cubic meters of water with 86 tonnes of N and 17 tonnes of P were available annually in all thirty wetlands for irrigating rice fields.

3.4. Soil characteristics of rice fields downstream of the wetlands

Chemical characteristics of soil from the field sites are showed in Table 4 (related to different counties). Maximum, minimum and average of pH in soil-saturated paste were recorded 8.24, 6.39 and 7.42 respectively. The lowest soil pH was detected in Amlash County (wetlands 1 to 6) and these wetlands have the lowest amounts of percentage carbonate calcium equivalent (CCE). On the other hands, most of the wetlands in Astane County have the highest amounts of percentage CCE. The maximum, minimum and average electrical conductivity for soils were seen 3.12, 0.16 and 0.74 dS m^{-1} respectively. On average land areas related to wetlands No 10, 11 and 12 have more chemical components (like nitrogen, potassium, CCE, pH, EC and O.C). In general no particular problems were noted for soil properties associated with rice production in eastern Gilan province.

Results of the irrigation studies showed that an average of 17% of urea fertilizer applied was recovered by rice, under permanent flood systems and there were not any significant differences between nitrogen fertilizer use efficiency in different wetlands in different county (Table 5).

3.5. Rice production related to the irrigation management

Preliminary results existing data showed that on average 7.6 million cubic meters of water with 86 tons of nitrogen (N) and 17 tons of phosphorus (P) captured and were available annually in 30 "Ab-bandans" for irrigation. This water can be used to irrigate an area of up to 1500 ha producing 5000 tons of rice). Irrigation management practice had a major influence on water used and rice yield (Figure 7). Flood irrigation at a rate of 10 000 m^3 ha^{-1} was able to produce a total of 2 561 tons of rice (an average yield of 3.5 tons ha^{-1}). However, by changing the method from flood to 8 days irrigation interval at a rate of 4 500 m^3 ha^{-1}, about 1 500 ha of land can be irrigated with a total production of 5 050 tons of rice. This showed that cultivation area and rice production could be increased by more than 50% and 94%, respectively by changing irrigation practice.

TABLE 4. CHEMICAL CHARACTERISTIC OF SOILS FROM FARMERS' FIELD

Pond No	County	pH	EC dS/m	OC %	CCE %	Total N %	Total P mg/kg	Total K mg/kg	Sand	Silt	Clay	Texture
1	Amlash	6.39	0.292	2.03	0.5	0.17	67.8	188.6	21	31.5	47.5	clay
2	Langrood	6.89	0.779	3.2	3.5	0.28	33.3	148.3	59	21	20	sandy loam
3	Roodsar	7.73	0.605	4.21	9	0.36	29.2	168.6	48	36	16	loam
4	Astane	7.68	0.667	1.56	12	0.13	31.4	238.8	40	19	41	clay
5	Rasht	7.22	1.19	4.37	0.5	0.38	55.4	178.6	43	31.5	47.5	loam

TABLE 5. - NITROGEN FERTILIZER USE EFFICIENCY UNDER PERMANENT FLOOD IRRIGATION SYSTEM IN DIFFERENT WETLANDS UNDER RICE CROPPING

Pond No	County	dry matter ton/ha	Plant N %	N uptake Kg/ha	% ^{15}N excess in plant	%Ndff	FNY Kg/ha	Fertilizer use efficiency (%)
1	Amlash	3.988ab	1.21	48.41b	1.82a	42.87	20.76a	17.30a
2	Langrood	3.164a	1.57	49.75b	1.49b	35.03	17.43a	14.52a
3	Roodsar	3.771ab	1.48	45.78c	1.67ab	39.43	18.05a	15.04a
4	Astane	4.256a	1.34	56.82a	1.76a	41.39	23.52a	19.60a
5	Rasht	3.725ab	1.42	53.00a	1.74a	40.90	21.67a	18.60a
LSD=0.05		710.5	0.18	10.8	0.84	17.45	7.54	6.76

Values with same letters in each column indicate no significant difference between mean values at 5% confidence level in Duncan test

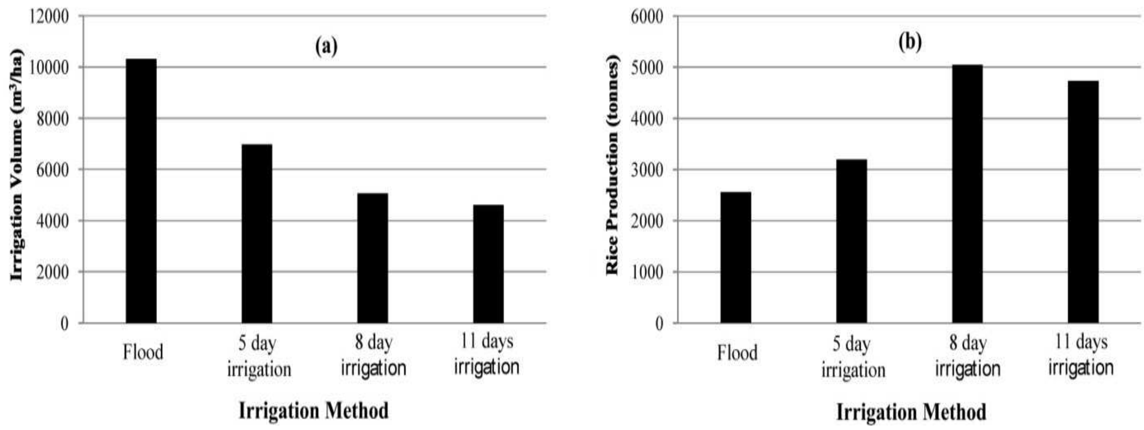

FIG. 7. Influence of irrigation methods on amount of water used (a), total rice production (b).

3.6. Isotopic signatures of $\delta^{18}O$ and $\delta^{2}H$ and their seasonal variations

The maximum, minimum and the mean isotopic signatures of pond water measured during winter, spring and summer are shown in Table 6. These values are within the broad range of signatures observed for lakes [11].

TABLE 6. ISOTOPIC SIGNATURES OF OXYGEN-18 AND HYDROGEN-2 IN ALL THIRTY WETLANDS DURING WINTER, SPRING AND SUMMER

Pond No.	$\delta^{18}O$‰ (vs SMOW)				δD‰ (vs SMOW)				d excess
	Max	Min	Mean	SD	Max	Min	Mean	SD	
1	0.45	-7.47	-3.21	4.0	-1.44	-45.96	-23.53	22.3	2.13
2	2.54	-7.26	-1.95	4.9	0.18	-46.57	-17.54	23.6	-1.93
3	-0.90	-7.11	-3.54	3.1	-8.97	-45.70	-25.66	18.4	2.69
4	-0.41	-7.78	-3.34	3.7	-4.57	-48.12	-23.71	21.8	3.02
5	-0.17	-7.11	-2.91	3.5	-3.53	-46.22	-22.58	21.4	0.73
6	-0.20	-7.71	-4.61	3.8	-3.97	-46.43	-29.70	21.4	7.17
7	-1.61	-7.62	-4.81	3.0	-17.25	-48.24	-33.78	15.5	4.68
8	5.26	-8.51	-1.44	6.9	18.57	-60.09	-19.27	39.3	-7.73
9	3.41	-6.52	-1.75	5.0	11.67	-42.96	-17.35	27.3	-3.39
10	-2.85	-7.75	-5.30	2.4	-17.26	-48.40	-33.26	15.6	9.14
11	-0.32	-5.57	-2.81	2.6	-12.26	-37.82	-24.23	12.8	-1.71
12	-1.24	-6.89	-4.82	2.9	-16.33	-43.55	-31.99	13.7	6.58
13	-0.01	-8.05	-2.98	4.1	-8.81	-49.65	-24.91	20.6	-1.06
14	1.02	-7.85	-2.31	4.5	-6.05	-48.50	-22.18	21.4	-3.68
15	-1.04	-8.54	-5.05	3.8	-16.09	-54.10	-36.10	19.0	4.26
16	1.26	-7.58	-3.44	4.4	1.71	-49.07	-25.69	25.4	1.81
17	1.35	-6.42	-3.40	3.9	2.37	-41.68	-24.08	22.2	3.15
18	-1.46	-7.42	-5.06	3.0	-17.51	-46.33	-35.22	14.5	5.26
19	-2.41	-8.08	-5.44	2.8	-20.47	-49.13	-36.32	14.4	7.21
20	-4.16	-6.93	-5.72	1.4	-29.44	-42.46	-37.62	6.6	8.12
21	-3.53	-7.36	-5.83	1.9	-26.72	-44.85	-38.19	9.2	8.42
22	-3.45	-8.15	-5.44	2.4	-26.38	-50.69	-37.04	12.2	6.51
23	-1.77	-7.25	-4.83	2.7	-18.68	-44.73	-33.70	13.1	4.91
24	-3.82	-6.03	-5.11	1.1	-27.24	-37.63	-34.05	5.3	6.79
25	-4.66	-8.14	-6.43	1.7	-33.76	-49.42	-40.33	7.9	11.12
26	-5.27	-8.12	-6.73	1.4	-32.41	-50.83	-42.16	9.2	11.71
27	-1.35	-6.42	-3.98	2.5	-14.87	-38.58	-27.35	11.9	4.45
28	-1.04	-7.67	-3.90	3.3	-5.58	-47.37	-25.39	20.9	5.82
29	1.83	-8.85	-3.46	5.3	2.02	-54.08	-25.34	28.1	2.37
30	1.69	-9.54	-2.86	5.6	5.82	-60.92	-23.34	33.5	-0.48

Data showed that wetlands have a range of $\delta^{18}O$ (2.54‰ to -9.54‰) and $\delta^{2}H$ (5.82‰ to -69.9‰) values and these isotopic signatures are influenced by local hydrology and different seasonal parameters (including rainfall, temperature and land use in the catchment). For any given wetlands, the amounts of $\delta^{18}O$ and $\delta^{2}H$ will depend on the hydrological balance between inputs (direct precipitation, groundwater, surface and stream inflows) and outputs (evaporation, groundwater loss, surface and stream outflows) ([12]; [13]; [6]). Therefore any kind of water reservoirs need to be identified that have the potential to accurately record explicit aspects of environmental variations and climate change ([14]; [15]).

Isotopic signatures of pond waters during winter, spring and summer showed that most wetlands in winter have light isotopic signature compare with other seasons (Figure 8).

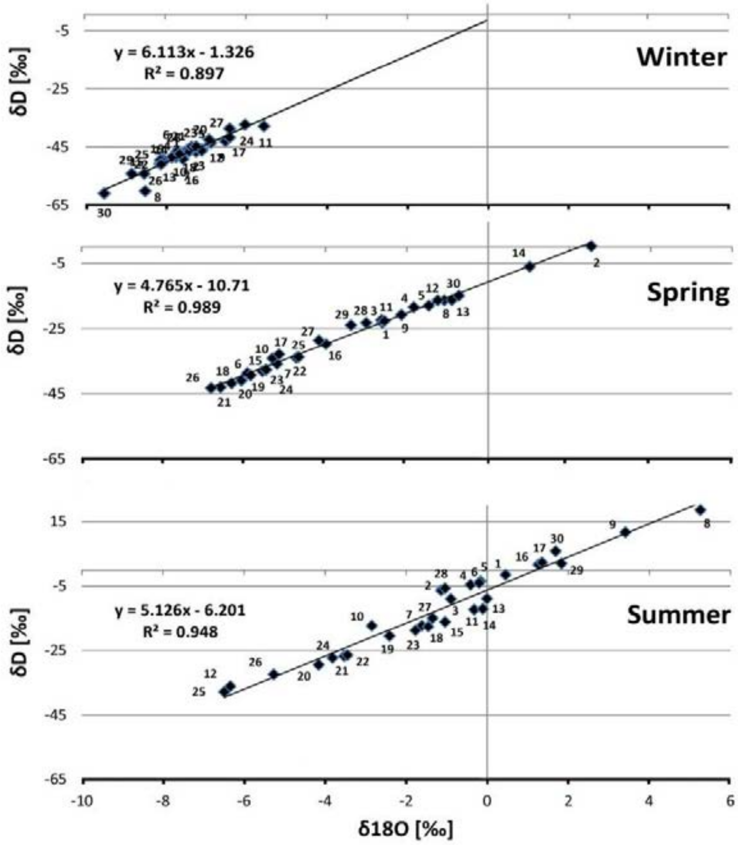

FIG. 8. Relationship between $\delta^{18}O$ and $\delta^{2}H$ signatures in for winter, spring and summer seasons

The relationship between δ^{18}O and δ^{2}H in rainfall is well understood on a global scale [16] known as the Global Meteoric Water Line (GMWL), and is given by the equation

$\delta D = 8\delta^{18}O + 10‰$ (1)

For the local meteoric water line (LMWL), [17] the correlation for the relationship between δ^{18}O and δ^{2}H in precipitation water for Ljubljana (Slovenia) and is provided by the equation

$\delta D = 8\delta^{18}O + 9.2‰$ (2)

The slopes of the relationship between δ^{18}O and δ^{2}H in water during winter (6 113), spring (4765) and summer (5 126) are lower than that of both global and local meteoric water lines (equations 1 and 2). Also the mean d-excess for water during winter (-1 326), spring (-10.71) and summer (-6 201) are lower than that of both global and local meteoric water lines. Deuterium excess (the term d of the equation $\delta D = 8\delta^{18}O + d$), corresponding to what is referred to as the Meteoric Water Line. The value of d becomes higher as evaporation rates are high due to high temperature and low relative humidity in the atmosphere during the formation of water vapour. In the Mediterranean region, the d excess value of precipitation is relatively high. However, the significantly lower d-excess values (<10‰) of water sample from wetlands may be indicative of water in the wetlands was sourced from rainfall/runoff that are subjected to evaporation in a warm and dry atmosphere in the region.

Dual isotope plots of δ^{15}N and δ^{13}C which were constructed for plant (growing within walking distance of the wetlands) shows a lack of strong correlation between δ^{15}N and δ^{13}C, indicating that these two signatures showed different response patterns across all wetlands (Figure 9).

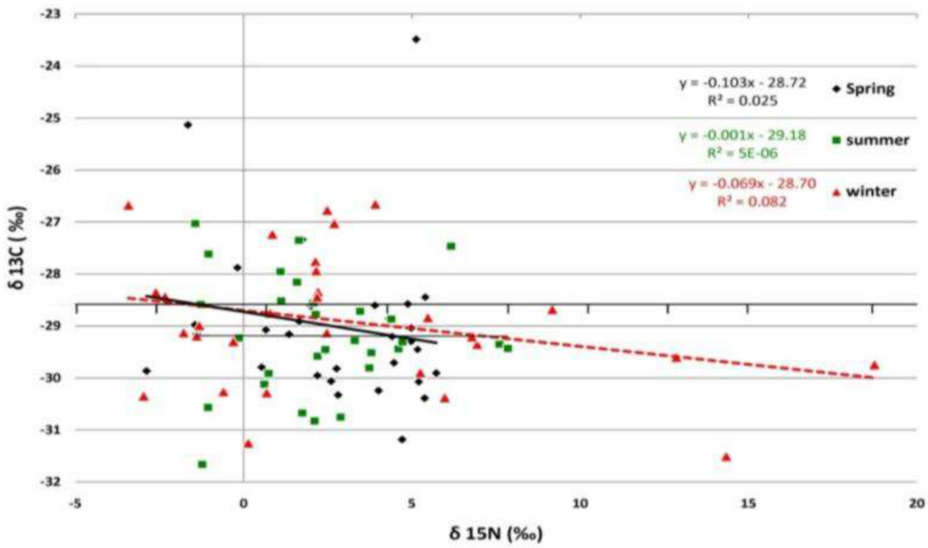

FIG. 9. Relationship between δ^{13}C and δ^{15}N of plant material

Figure 10 shows plots of δ^{18}O versus δ^{2}H values in winter, spring and summer. Data showed that most of the wetlands in winter have light isotopic signature compare with other seasons. Comparison of isotopic data related to local wetland with isotope signature of local precipitation (or precipitation on a global scale) can be a useful tool for assessing water resources in a wide range of water reservoirs.

The relationship between δ^{18}O and δ^{2}H in rainfall is well understood on a global scale and is known as the Global Meteoric Water Line (GMWL), and has been defined as $\delta^{2}H = 8\ \delta^{18}O + 10‰$ [16]. Figure 10 shows plot of δ^{18}O versus δ^{2}H local meteoric water line (LMWL) from selected wetlands in the north of The Islamic Republic of Iran in relation to GMWL and Mediterranean meteoric water line (MMWL). The LMWL is determined from a linear regression of all the wetlands water data [6] Data showed that the isotopic composition for almost all wetlands lie below the GMWL, indicating that water in these lakes has been affected by evaporation. We can conclude that most

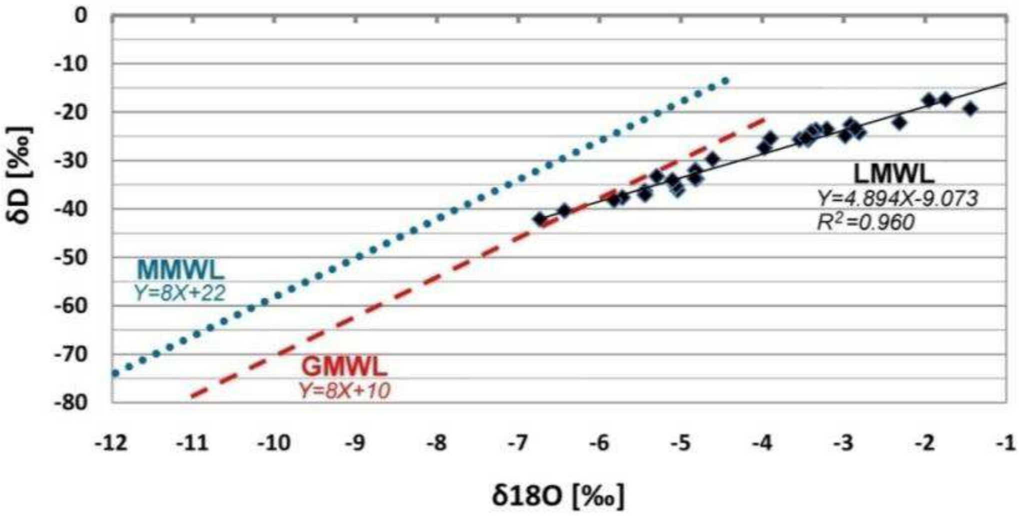

FIG. 10. Plot of $\delta^{18}O$ versus $\delta^{2}H$ values from 30 wetlands in the north of Iran shown in relation to the Global Meteoric Water Line (GMWL), Mediterranean Meteoric Water Line (MMWL) and Local Meteoric Water Line (LMWL) [17], [18], [5]

wetlands in the north of The Islamic Republic of Iran (except wetlands No. 2, 12, 14 and 25) do not receive sufficient inputs of recharge water to diminish the effects of summer evaporation (with average of $\delta^{18}O$ and $\delta^{2}H$ value of -4.08 ‰ and -29.05 ‰ respectively).

Evaluation of isotopic signatures at different elevation can provide unique information about the water resources available for the wetlands. At higher altitudes where the average temperature is lower, precipitation will be isotopically depleted as a result from the cooling of air masses as they gain altitude (altitude effect). Normally, the depletion of $\delta^{18}O$ from the altitude effect range from -0.15‰ to -0.5‰ per 100 m rise in altitude [6]. Additionally, higher catchment elevation results in later snowmelt in spring/summer because of lower temperatures, extending the period during which isotopically depleted snowmelt can influence the isotopic composition of the pond water. These together will result in depleted $\delta^{18}O$ lake values [6]. Unfortunately, the relationship between mean catchment elevation, $\delta^{18}O$ and d-excess values in our experiment is not clear for summer and winter period. This is because of the short range of elevation (under investigated). The highest altitude was belonged to the pond No. 29 as 83 m a.s.l. and this range is not enough to show altitude effect on isotopic signatures.

4. CONCLUSION

Normally, seasonal variation of $\delta^{18}O$ and $\delta^{2}H$ in wetlands is determined by the input of winter snowmelt (with light isotopes) to the wetlands in the early spring, the influence of relatively enriched summer rainfall and the effect of evaporation later in the summer ([19]; [6]). Based on the results from $\delta^{2}H$ and $\delta^{18}O$ analyses of surface water collected from different wetlands in the north of Iran, we can conclude that they are mainly endure high amounts of subsequent evaporation and recharged by meteoric water. In other words, most wetlands in the north of The Islamic Republic of Iran do not receive sufficient inputs of recharge water to diminish the effects of summer evaporation (with average of $\delta^{18}O$ and $\delta^{2}H$ value of -4.08 ‰ and -29.05 ‰ respectively). There are an exception for wetlands No. 2, 12, 14 and 25. Unexpectedly, there is a significant decrease in water isotopes from spring to summer. The main reason for this phenomenon is inputs of recharge water with a light isotope signature source (like ground water)

[6]. We found that farmers try to pump ground water in to these wetlands to retain water storage to its normal level. The amounts of light water inputs to the wetlands 12 and 25 are more than 2 and 14. Therefore, isotope signature of wetlands 12 and 25 in summer reached to its lightest value (equal to the winter). Data also shows that the isotopic compositions for wetlands in Siyahkal county (wetlands No. 25 and 26) lie close the GMWL, suggesting that these wetlands are not significantly affected by isotopic enrichment due to evaporation. This does not mean that there is no evaporation fractionation occurring at the surface of these lakes; rather, that the evaporation has not caused any significant change of the $\delta^{18}O$ lake. Probably most of the wetlands have short residence times (because of low catchment/pond ratio) and high amounts of recharge by snow melting). Both these features act to minimize the effect of evaporation.

We made sense that input from snowmelt could have a significant part in determining $\delta^{18}O$ in water reservoir. In other words, the effect of the melted water on the $\delta^{18}O$ pond depends on catchment elevation, the amount of snow in the catchment and the pond to catchment ratio. These items need to be identified and clarified before final interpretation. Therefore, understanding of the $\delta^{18}O$ records requires a detailed knowledge of the processes that control and modify any water reservoir signal, and this must be determined for each individual pond system. A possible explanation of changing $\delta^{18}O$ wetlands over time is a change in the seasonal distribution of rainfall. We want to highlight the importance of understanding the specific seasonality of hydrology related to each wetland. Therefore, further sampling and analysis of isotopic data from rainfall; groundwater and snow (in different seasons and elevation) are needed to improve our knowledge of the new and past relationship between climate changes, $\delta^{18}O$ precipitation and $\delta^{18}O$ in the wetland.

The "Ab-bandans" in Northern Iran are an important source of water and nutrient for rice crop by capturing and storing rainfall and snowmelt during winter and spring. This water can be used to irrigate up to 1 500 ha of cropland providing more than 5 000 t of rice. The $\delta^{18}O$ and $\delta^{2}H$ signatures showed that the water in the Ab-bandons was enriched from spring (-3.57 and -27.72‰) to summer (-1.15 and -12.12‰), respectively. The seasonal variation of $\delta^{18}O$ and $\delta^{2}H$ in pond water depended on the input of winter snowmelt (with light isotopes) during the early spring period and the enriched summer rainfall and evaporation in late summer. The linear relationship between $\delta^{18}O$ and $\delta^{2}H$, their slopes and d-excess showed that the pond water is mainly derived from rainfall/runoff and snow melt. The results also showed that most wetlands in the north of The Islamic Republic of Iran do not receive sufficient inputs (groundwater input or rainfall) of water during summer.

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REFERENCES

[1] LEONTIADIS, I.L., et al., Isotope hydrology study of areas in Eastern Macedonia and Thrace, Northern Greece, J Hydrol. 182 (1996) 1-17.

[2] SMEDEMA, L.K., Irrigated agriculture in The Islamic Republic of Iran: A review of the principal sustainability, reform and efficiency issues (2003) 28.

[3] TEIF, S.S., Qualitative and quantitative assessment of water reservoir (Ab-bandan) in north of Iran (Gilan province), firm report (2004) 850.

[4] VANDENSCHRICKA, G., et al., Using stable isotope analysis (δD–δ18O) to characterise the regional hydrology of the Sierra de Gador, south east Spain, Journal of Hydrology 265 (2002) 43–55.

[5] WASSENAAR, L.I., et al., Isotope hydrology of precipitation, surface and ground waters in the Okanagan Valley, British Columbia, Canada, Journal of Hydrology 411 (2011) 37–48.

[6] JONSSON, C., et al., Stable oxygen and hydrogen isotopes in sub-Arctic lake waters from northern Sweden, Journal of Hydrology 376 (2009) 143–151.

[7] JOHNSON, R.A., WICHERN, D.W., Applied Multivariate Statistical Analysis. 5rd ed. Prentice Hall, New Delhi (2002) 642.

[8] CHRISTIAUSEN, ET AL., Irrigation water quality. J. Irrigation and Drainage Div., ASCE. 103 (1977) 155-169.

[9] FIPPS, G., Irrigation water quality standards and salinity management strategies. Texas Cooperative Extension, The Texas A&M University System. Bulletin No. 1667 (1995) 4-03; Extension publications can be found on the Web at: http://tcebookstore.org.

[10] KIRDA, C., Assessment of irrigation water quality. Options Méditerranéennes, Sér. A /n031, (1997) Séminaires Méditerranéen.

[11] JASECHKO, S., et al., Terrestrial water fluxes dominated by transpiration. Nature. 496 (2013) 347–350.

[12] GIBSON, J.J., et al., Pan-derived isotopic composition of atmospheric water vapour and its variability in northern Canada, J Hydrol. 217 (1999) 55–74.

[13] LENG, M.J., et al., Isotopes in lake sediments. In: Leng, M.J. (Ed.), Isotopes in Palaeoenvironmental Research. Springer, Dordretch, The Netherlands, (2005) 147–176.

[14] LENG, M.J., ANDERSON, J.N., Isotopic variation in modern lake waters from western Greenland. The Holocene 13 (2003) 605–611.

[15] LENG, M., MARSHALL, J.D., Paleoclimate interpretation of stable isotope data from lake sediment archives. Quaternary Science Reviews 23 (2004) 811–831.

[16] CRAIG, H., Isotopic variations in meteoric waters. Science 133 (1961) 1702–1703.

[17] VRECˇA, P., et al., Isotopic characteristics of precipitation in Slovenia and Croatia: Comparison of continental and maritime stations, J Hydrol. 330 (2006) 457– 469.

[18] OGRINC, N., et al., Spatial and seasonal variations in d18O and dD values in the River Sava in Slovenia, Journal of Hydrology 359 (2008) 303– 312.

[19] EDWARDS, T.W.D., et al., Use of water isotope tracers in high-latitude hydrology and paleohydrology. In: Pienitz, R., Douglas, M.S.V., Smol, J.P. (Eds.), Long-term Environmental Change in Arctic and Antarctic Lakes. Springer, Dordretch, The Netherlands (2004) 187–207.

IMPACT OF SMALL HILL FARM PONDS ON WATER FLOW AND NITROGEN TRANSFER IN MEDITERRANEAN AGRICULTURAL CATCHMENT (KAMECH, CAP BON, TUNISIA)

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Abstract

Wetland ecology and the downstream water quality and quantity depend on water dynamics. In arid/semi-arid environments average annual rainfall is seasonal, highly variable and significantly less than evaporation. Groundwater discharge can be a major component of the water balance in these environments. Determination of the wetland water budget is therefore essential part of wetland characterization. Some elements, such as surface inflow, precipitation, evaporation, surface outflow, and variation of lake level, can be measured easily at the site. However, it is difficult to determine the groundwater inflow and outflow. In this paper, the stable isotope mass balance together with the conventional water budget are applied to the water storage of a small hill dam (capacity of 142 460 m^3), the Lake Kamech, located in the peninsula of Cap Bon, north eastern Tunisia, in order to assess the interaction between ground and surface waters. The $\delta^{18}O$ and δ^2H isotopes allowed for assessing water cycle components over the catchment. Results indicated that upstream ground waters are disconnected from the lake even if they contribute to the stream base flow while runoff is the main flow that filled the lake. The water budget indicates that approximately 80 000 m^3 had infiltrated into the underlying alluvial aquifer during the 2009-2010 water year while groundwater had supported the lake storage during high releases periods and during dry season by supplying about 10 000 m^3 to the lake.

1. INTRODUCTION

In North Africa, and in all regions around the Mediterranean Sea, state policies have promoted the creation of numerous small water bodies (ponds and wetlands) also called as water conservation zones within agricultural catchments during the last few decades. In terms of impacts, they are used for capture and storage of water and nutrients and improve downstream water quality. These water conservation zones in agricultural catchments have been mainly studied in term of surface water budget, giving less importance to exchanges between surface water and shallow groundwater. Nevertheless, paradoxical effects of these exchanges may be observed on nitrate contamination. On the one hand, small farm ponds could represent potential inputs of pollutants to the aquifer and on the other hand; denitrification in ponds could be a sink for N and reduce contamination of groundwater. In semi-arid catchments, most hydrological impact studies have been conducted with respect to land use/land-cover modifications such as forestation, forest clearing, intensification of agricultural practices and climate change [1]. Investigations on water and soil conservation (WSC) effects on catchment hydrology have mainly concerned with changes induced by large dams [2,3,4]. Studies on impacts of small farm ponds on water exchange and pollution dynamics are extremely rare as identifying effects of environmental changes on hydrological processes is difficult. The diversity and variability of factors controlling the runoff/rainfall relationship as well as surface- ground water interactions may have opposite effects and may mask each other [5]. Furthermore, small water ponds, or ponds with a few meters of water column depth, developed upstream of larger dams can be qualified as human-made wetlands. In this context, the question of the effects of these wetlands on nutrient cycle, in particular on nitrogen cycle can be raised.

Tunisia provides an interesting example of such hydrological systems that include the development of farm ponds. In the 1990's, the Tunisian administration in charge of land use and agricultural soil conservation (DG/ACTA) launched a program for water and soil conservation works (WSCW). Among the various actions that were undertaken, almost 700 small dams with an average volumetric capacity of 100 000 m^3 were built along the Tunisian dorsal in a semi-arid context. These small hill dams are intended to prevent silting up to downstream larger reservoirs, to enhance aquifers recharge, to prevent flooding of downstream areas and to provide surface water storage for local agriculture and crop irrigation [6].

The overall objective of this project was to assess water dynamics of small farm ponds in the Mediterranean upstream catchments. The specific objectives were to (1) assess effects of farm ponds on water exchange between surface and shallow ground waters and (2) nitrogen dynamics, particularly denitrification under these conditions as hydrological processes influence nitrogen dynamics.

1.1. Water exchanges between surface and shallow aquifer

In a catchment, the water exchanges between surface and shallow groundwater are classified by the following three main types depending on spatial scale (1) Diffuse exchange due to rainfall infiltration and percolation, or to the capillary rise, through the vadose zone and taking place over the whole catchment area; (2) concentrated exchange due to stream runoff infiltration along the hydrographic network, and (3) localized exchanges due to water infiltration, or exfiltration, occurring, for example, at a water or soil conservation works site.

Diffuse exchanges have been largely studied in humid regions and in a less extend in arid and semi-arid regions. The concentrated exchanges have been extensively studied in humid regions. All studies dealing with hydrological and hydrochemical processes in riparian zones for the two last decades have provided a comprehensive understanding that allows now to quantify and to model concentrated water exchanges under climatic conditions such as arid, semi-arid and humid regions. Less work has been carried out on exchanges of water in arid and semi-arid regions. One of the characteristics in these regions is that stream water and shallow groundwater are disconnected most of the times. It follows that vadose zone under the wadi bed plays a crucial role on the stream water infiltration. Recent work based on the survey of a small rural Mediterranean catchment shows that concentrated exchanges can represent up to 50% of the total exchanges [7]. These interactions depend on both the groundwater dynamics and the pond water level variations. Consequently, investigations should be undertaken at the catchment scale by coupling the study of groundwater dynamics, and hence the diffuse and concentrated groundwater recharges, and of the surface runoff fluxes that contribute to pond water level variations.

Denitrification corresponds to the reduction of nitrate into gaseous nitrogen compounds such as nitric oxide (NO), nitrous oxide (N_2O), and nitrogen (N_2). Denitrification has environmental benefits when the end product is gaseous dinitrogen (N_2). In this case, denitrification acts as a natural remediation process decreasing the water pollution by nitrate. Denitrification is expected to occur in anaerobic conditions where oxygen is lacking [8]. Denitrification processes have been extensively studied in riparian zones in humid climate regions (e.g. [9], [10]), particularly in the. riparian zones (these zones constituted of soils saturated most of the times by shallow groundwater where appropriate conditions are met for denitrification occur). Within farm ponds and wetland ecosystems, denitrification is expected to occur especially in the sediments where anaerobic conditions prevail. Denitrification in the sediments could reduce nitrate diffusion from the overlying water (pond water), the nitrate formed by nitrification within the sediment, or the groundwater nitrate in case of significant groundwater- surface water exchange. Denitrification rates can be influenced by a number of environmental factors such as temperature, organic carbon and nitrate contents, sediment grain size and water content in soil. Along with sediment, denitrification within saturated soils around the pond/wetland as well as at the bottom of the water floor could also contribute to nitrate reduction. Few references concerning arid and semi-arid regions are available about denitrification rates and factors of control in pond ecosystems, and even about nitrate water contamination in upstream agricultural catchments.

2. METHODS

2.1. The Kamech catchment

The project was carried out at the Kamech research catchment, which is part of a long-term Environmental Research Observatory OMERE (Observatoire Méditerranéen de l'Espace Rural et de l'Eau) and is recognized as a research catchment by the French Ministry of research (http://www.umr-lisah.fr/omere/). This site is one of the research programs of HYDROMED [11]. Information on hydrology, climate, land use and land management have been collected for the catchment since 1994.

The Kamech catchment, extending between 10°52'E and 10°53'E longitude and between 36°52'N and 36°53'N latitude, is located on the north-western mountains of the peninsula of Cap-Bon, in the east of Tunisia in the Gouvernorat of Nabeul (Figure 1). It is an elementary cell (2.5 km^2) of the mountain landscape of this region and represents a basin head of one of the main surface water resources of the area, the Lebna wadi (218 km^2) that runs in to a downstream dam of 24.7 million cubic meters.

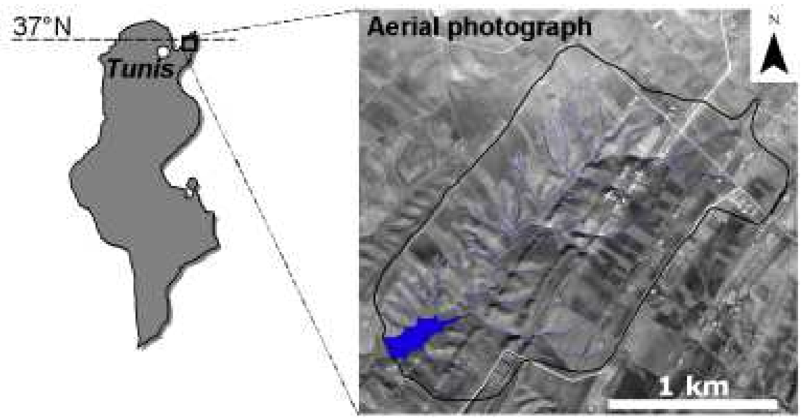

FIG. 1. Geographical location of the Kamech catchment (www.umr-lisah.fr/omere/).

Agricultural system in this catchment is characterized by the association of farming and breeding on low-size parcels with a mean surface lower than 1 ha. More than 70% of the catchment is cultivated. The bio-climate is in the limit of Mediterranean sub-wet and semi-arid superior (P/ETP from 0.2 to 0.5).

2.2. Climate

According to the closest station, Kélibia, the climate is of upper semi-arid type. At this station, the mean annual temperature is about 18°C varying between 27°C and 10°C. Mean annual rainfall amount is of 450 mm with a standard deviation of 150 mm for 90 years period (1901-1990, Table 1)). The ombrothermic diagram indicates a dry period that lasts six months and spreads out from April to September. However, annual precipitations show a great interannual variability [12]. Rainfall events showed two types [13] with (1) long rain events occurring successively during periods lasting for three to four days. These events generally last more than one hour, intensities are lower than 10 mm/h with one or two peaks. These winter rains come from westerly to north-westerly directions and are of Atlantic origin with probable vapour enrichments on the Mediterranean western basin, and (2) stormy events often of short durations occurring mostly during autumn and spring. Precipitation amounts recorded during the seven year period (1995-2002) in the catchment area were higher than those observed at the reference station of Kélibia. However, annual and monthly heterogeneity remained marked in the basin of Kamech (Table1). An average of 120 rainy days was observed for the Kamech catchment among which only ten days could generate runoff over the basin.

TABLE 1.RAINFALL CHARACTERISTICS ON THE KAMECH CATCHMENT

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Total
94-95	14.5	114.5	61.5	57	109.5	3.5	86.5	28.5	2.5	9	1	7.2	495.2
95-96	33	130	72	104.5	115.3	305.2	102.5	59	60.5	40	2	12.5	1036.5
96-97	30.5	126	21	54.5	67	29.5	8.5	57.5	4.5	2.5	0	4	405.5
97-98	125.7	138.4	109.6	101	74.5	13	87.5	51	32.5	0.5	1	16	750.7
98-99	63	118.5	99.2	104	185.7	63.8	28	21.5	11	2.5	2	1.5	700.7
99-00	79	10.5	337.5	68	34	52.5	27.5	54.2	20.5	83.4	1.5	1.5	769.1
00-01	60.5	147	40	133	43	85	37	54	24.5	1	0.5	0.5	626
01-02	28	3	64	163.5	21	25.5	5.5	28.5	32.5	4	9	18.1	402.3
Mean	54.3	98.5	100.6	98.2	81.3	72.3	47.9	44.3	23.6	17.9	2.1	7.7	648.2
Std D.	36.1	57.6	99.9	37.9	54	97.9	38.4	15.3	18.9	29.6	2.9	7	214.4

The evaporation rate is very important (between 1 000 and 1 500 mm) as measured by the Colorado bac implemented in the basin. Monthly values showed that evaporation is characterized by a marked seasonal variation, ranging around 2 mm/day during November to February and increasing to 5 mm/day in April and to more than 8 mm/day between July and August. The advection term is strong because of the Cap-Bon peninsular position, approximately 40 days of winds were observed at Kélibia, with a maxima average of 15 m/s (1984 to 1998 period). The total radiation is also significant due to latitude and Mediterranean type climate.

2.3. Geology

The undulating landscape of the Kamech catchment results from a recent Quaternary morphogenesis digging villafranchiens flattenings in perpendicular valleys and small valleys. Oldest geological formations outcropping in the catchment are Saouaf formations of Middle Miocene period (Serravalien-Tortonien lower) while most recent ones are of Quaternary period.

Geological formations of the catchment area mainly constituted of marls and mudstones associated with thin ferruginized sandstone benches with monoclinal SE dips of 20 to 50° (Figure 2).

2.4. Geology

The undulating landscape of the Kamech catchment results from a recent Quaternary morphogenesis digging villafranchiens flattenings in perpendicular valleys and small valleys. Oldest geological formations outcropping in the catchment are Saouaf formations of Middle Miocene period (Serravalien-Tortonien lower) while most recent ones are of Quaternary period. Geological formations of the catchment area mainly constituted of marls and mudstones associated with thin ferruginized sandstone benches with monoclinal SE dips of 20 to 50° (Figure 2).

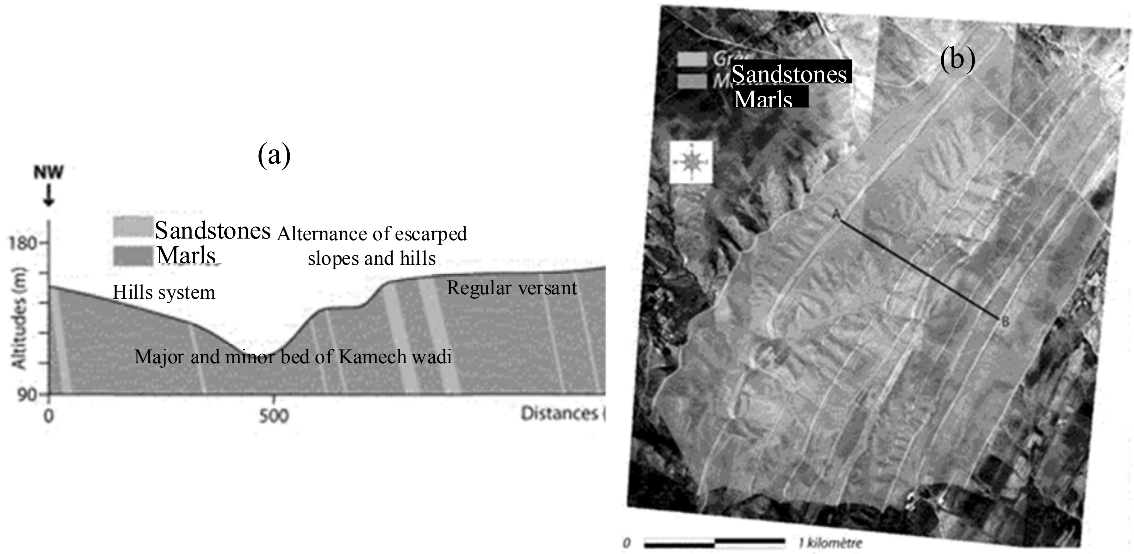

FIG. 2. Geological features of Kamech catchment. (a) major and minor bed of Kamech Wadi and (b) surface feature of the Wadi ([13], modified).

2.5. Soils characteristics

Soils in the Cap-Bon peninsula resulted from morphogeologic and climatic effects (Mediterranean climate) on pedogenesis processes [14]. Anthropogenic activities have a significant effect on erosion and deposits processes [15]. According to substratum type and its predominant constituents (sandstone, marls or limestone), to pluviometric mode, to slopes and to erosion processes, different soils are recognized in the Cap-Bon region, from Entisols to Inceptisols and Alfisols (according to USDA classification).

Soils in the catchment are developed from a succession of marl layers and associated to a very thin sandstone layer [16]. According to this substratum type and its predominant constituents (sandstone, marls or limestone), to pluviometric mode, to slopes and to erosion processes, four major soil types are recognized in the Cap-Bon region according to the FAO classification [17]. Three of the four soil classes, namely Luvisols, Cambisols and Vertisols, are mostly covered by annual crops, whereas the fourth class, Regosol is more commonly associated with pasture and shrubs. Rock outcrops coincide with ridges. Soil textures are very variable ranging from clay to sandy loam according to USDA textural triangle with clay contents varying from 10 to 50 percent. Bulk densities range from 1.38 $g.cm^{-3}$ on Haplicregosols with 44% slope to 1.63 g/cm^3 on Haplicluvisols. Most soils, except those with high clay content like the vertisols, exhibit, over a large proportion of the year, surface crusts caused by the impact of the heavy rainfalls that occur in autumn and spring. The depth of the soils is highly variable and ranges from a few centimeters for Regosols on the steepest slopes to 200 cm for other soil classes. Two processes were identified as rulers for water runoff and storage in soil: (1) Clay soil cracking and (2) variability of soil features [18].

2.6. Catchment land use

The Kamech catchment reflects the typical agricultural situation of the Cap Bon region in Tunisia. It is characterized by agricultural activities. The number of land owners is large which leads to both large land fragmentation (273 parcels) and high spatio-temporal variation in land uses. The average field size is 0.62 ha and varies between 0.08 ha and 13 ha. Land use in this catchment can be classified into eight basic categories including six cropping systems (171 ha of cereals, legumes, market gardening, vineyards, orchards and fallow), and two pasture systems (90 ha of annual pastures-herbaceous and perennial pastures-shrubs) [13].

The annual crops (wheat, barley, oat, faba bean, chickpeas, and vetch grass) account for more than 80% of the arable area in the Kamech catchment. Typically, in the Cap Bon region, the annual crops rotate on a given field from cereals to legumes. Large diversity of agricultural operations is associated to land use (Figure 3).

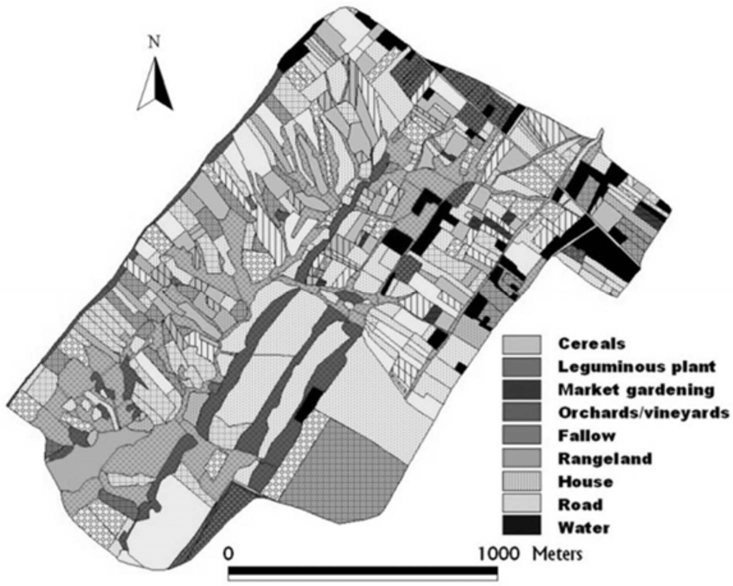

FIG. 3. Land uses 2010-2011

Soils and land uses are characterized by a great spatial variability in relation to vegetation cover and water retention capacities of soils. This spatial variability is due to natural condition (soil, topography) but also to human activities (great number of farmers and agricultural practices). As a result, the Kamech catchment exhibits large spatial and temporal variations of infiltration-runoff properties and water fluxes through soils [12].

2.6. Dam water uses for irrigation

Approximately 20,000 and 50,000 m^3 of pond water per year is supplied for irrigation depending upon the amount of rainfall. The irrigation is mainly supplied to industrial culture of tomato and pepper practiced by approximately 20 farmers on small parcels of land with an average area of 0.63 ha. Extension of irrigated area varies from year to year ranging between 5 and 20 ha and is continuously increasing due to the importance of the pond to the local agricultural system and due to the state encouragement to develop irrigated farming. Manure is the main fertiliser used by farmers. Observed trends indicated that an evolution of users attitude with respect to a non-ensured resource during the transitional period between pluvial and irrigated farming systems. Irrigation practices started with the use of two irrigation systems, (a) drop-to-drop system used to produce intensive farming with fertilization and high-productivities species and (b) lined-aspersion system for local varieties of tomato and pepper cultures. State subsidies encourage farmers to introduce water saving techniques in agricultural practices.

2.7. Water storage in the soil reservoir

The main phenomena responsible for water fluxes and retention in soils at Kamech catchment is the shrinkage cracks of clayey soils. Indeed, most of the Kamech catchment soils consist of shrinking clays. At the end of the dry season, these soils are abundantly fissured and enhance the water storage at the beginning of rainy season (September or October). The duration of clay swelling period is variable according to precipitation amounts at the beginning of the season [19]. The maximum water retention storage of this crack system has been estimated to 70 mm on fields of 30 to 40% slope [11], this network is completely closed for a cumulative rain of 200 mm. Different water stocks of the soil reservoir have been determined over the catchment according to soil types and land uses [12]. Large temporal variability was observed during the hydrological year in relation with precipitation regime. For more than 80% of the catchment, saturation storage was reached after a cumulative rainfall of 400 mm. However, some parcels shown a storage volume of 500 mm indicating the probable existence of residual water or a groundwater contribution. At this stage, this potential water soil reservoir volume was estimated around 987 000 m^3 representing the volume of 7 dam lake capacity. The storage is the lowest at the end of the cropping season [12].

2.8. Water quantity and quality measurements

Field work mainly consisted in collecting and analysing surface water (runoff, pond), ground water and rain water during different periods of the hydrological cycle: low-water runoff, high-water runoff and flood events (Figure 4). Major chemical analyses were carried out in the Laboratory of Radio-Analysis and Environment of National School of Engineering of Sfax (Tunisia) by using liquid-ion chromatography. A Water chromatograph equipped with columns IC-PakTM CM/D for cations, using EDTA and nitric acid as eluent was used for cation analyses. Anions were analysed using a Metrohm chromatograph equipped with columns CI SUPER-SEP using phthalic acid and acetonitric acid as eluent. The overall detection limit for each major element was about 0.04 mg/l. For each analysis, the ionic balance was better than 5%.

Oxygen-18 and hydrogen-2 (^{18}O, ^{2}H) stable isotopic signatures of water were measured by Cavity Ring Down Spectrophotometry (laser spectroscopy) and reported in the usual δ notation relative to Vienna Standard Mean Oceanic Water. Typical precisions are ±0.1% and ± 1.0% for the ^{18}O and ^{2}H), respectively.

Water analysed for both mineral nitrogen forms (ammonium and nitrate) and chloride was sampled in 1 litre polyethylene bottles. Conductance, temperature and pH were measured in situ by a field conductivity meter (consort K 912) and pH meter (consort C 933). Bottles are taken to the laboratory in the same day and immediately filtered at 0.45µm. Samples were then stored at 4°C. Analyses were carried out during the next 48 hours. Analyses had been carried out on a spectrophotometer DR/4 000 (MODEL 48 000 and 48 100) with a direct reading and calibrated for several parameters with corresponding standards, used with visible spectra and tungsten-halogen lamp (320 à 1100 nm) [20]. Ammonium in water was measured according to blue Indophenol method [21]. Nitrate was measured by spectrophotometry of molecular absorption [21]. Nitrite was analysed by spectrophotometry of molecular absorption (Int. Norm 1984). Chloride was measured by Mohr method [21]. Analyses were carried out in the Laboratory of Sciences and Technics of Environment (LSTE) of the INAT in collaboration with LRAE and IRD teams. Precision has been determined according to the protocol of incertitude estimation of physico-chemical analyses (AFNOR XP T 90-220, 2003) based on the GUM (Guide to the expression of Uncertainty in Measurement) for which each samples is analysed three times. Incertitude ranges are 8-68%, 8-67%, 70-77% and 0.3-7.5% respectively for nitrate, nitrite, ammonium and chloride. These large ranges should be taken in to account during the discussion of results. Temporal and spatial variations are considered significant when greater than these incertitude values.

The investigation aims to identify, characterize and quantify exchanges between surface and shallow ground waters by analysing and interpreting hydrological, chemical and isotopic observations and also to study the nitrogen cycle at the catchment scale, and more specifically to quantify any localize denitrification fluxes within the catchment.

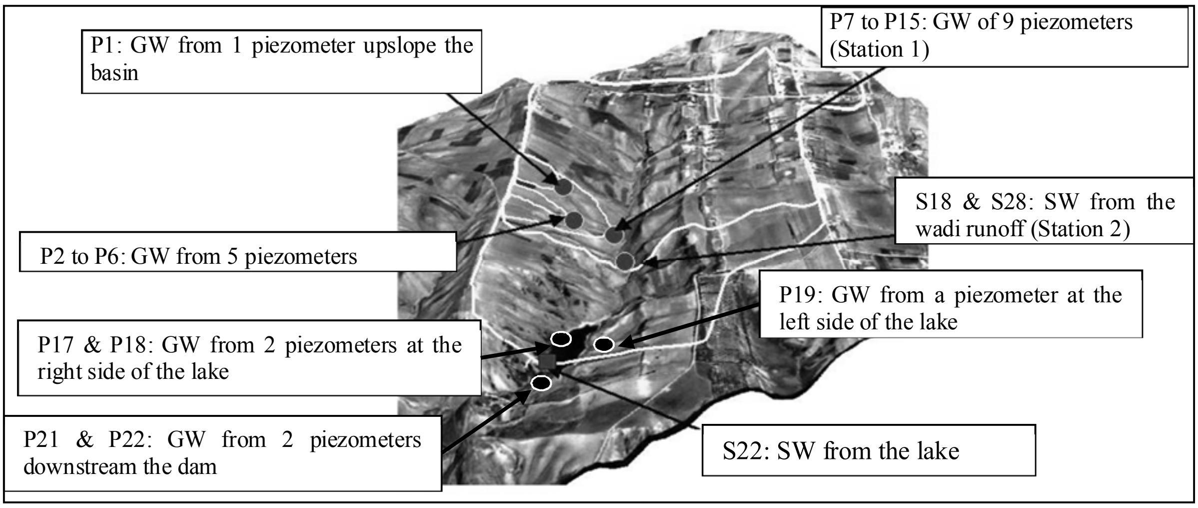

FIG. 4. Monitoring network as stated in September 2009. Sampling points have been reduced according to the first year project to three sites (wadi-S28, lake-S22 and precipitation)

2.9. Isotopic fingerprints of water

The isotopic signatures of ^{18}O and ^{2}H are expressed as δ values, representing deviations in per mil (‰) from standards for oxygen and deuterium such that

$$\boldsymbol{\delta_{sample}} = (\frac{\boldsymbol{R_{sample}}}{\boldsymbol{R_{standard}}} - \mathbf{1}) \times \mathbf{1000}$$

where R is the $^{18}O/^{16}O$ or $^{2}H/^{1}H$, ratio in sample and standard, respectively

3. RESULTS AND DISCUSSION

Inflow and outflow contributions to the hydrologic budget of ponds can be determined using a stable isotope mass balance method. This provides a way for integrating the spatial and temporal complexities of the flow around such a pond. However, each component of the water balance equation should be known in terms of quantity but also in term of isotopic signatures.

3.1. Precipitation signatures

The relationship between isotopic signatures oxygen-18 and hydrogen-2 ($\delta^{18}O$ and $\delta^{2}H$) in water is primarily a reflection of differences in their equilibrium fractionation factors. The slope of the Global Meteoric Water Line (GMWL) expresses this ratio, which is eight times for oxygen as that of hydrogen [20].

Stable isotopic signature of precipitation on the Kamech Lake (Sept.2009 – June 2013, 124 events) varies between 0.95 and -13.73‰ VSMOW for $\delta^{18}O$ and between 0.87 and -89.3‰ VSMOW for $\delta^{18}H$, respectively. The local meteoric water line is obtained by the monthly weighted isotopes contents (Figure 5). The slope of 8 had been imposed what revealed a d-excess of 13.52 (R^2=0.907) likely induced by the combined influence of both the depleted eastern Mediterranean (d-excess= +22) and the Atlantic (d-excess= +10) origin on the air masses. Event data reported on the $\delta^{2}H$ *vs* $\delta^{18}O$ diagram show a slight evaporation effect due to the presence of arid vapour in the precipitation. As a reference, the Global meteroric water line (GMWL, d-excess=10) is also shown in Figure 6.

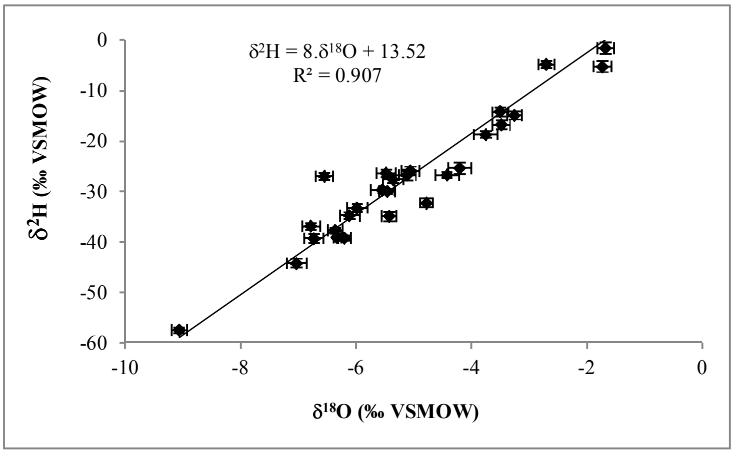

FIG. 5. Local meteoric water line for the Kamech Lake precipitation (monthly weighted stable isotopes contents of precipitation)

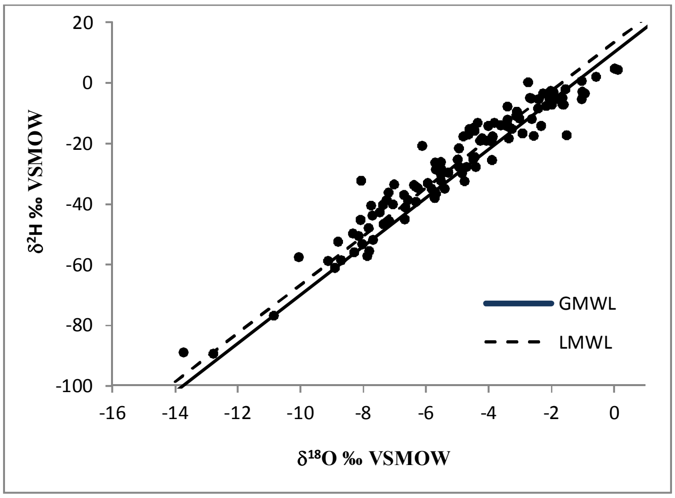

FIG. 6. δ^2H vs $\delta^{18}O$ (‰ VSMOW) for Kamech precipitation (event data)

High values of d-excess observed for some rainfall events could be related either to arid vapour sources of air masses or to rainout effect ([22], [23]). Seasonal variations show more depleted values during cold season indicating that the ^{18}O content signal is thermo-dependent with an enrichment during hot season (-0.71‰ VSMOW) and a depletion at cold season (-7‰ VSMOW).

3.2. Runoff water (wadi)

Mediterranean catchments present particular hydrological behavior as a consequence of the marked seasonal characteristics of climate. Within the year, the succession of wet and dry conditions favor the occurrence of a variety of hydrological processes, operating simultaneously or successively. The proportion of precipitation that contributes to stream flow is what remains after considering several losses, including the evaporation of intercepted precipitation by the vegetation canopy and ground cover (e.g., litter), evaporation from the soil, and transpiration. Transpiration (i.e., passive water loss through plant stomata driven by climatic forces) is generally assumed to be minimal during storm events since vapour pressure deficits are low and leaf surfaces are wet. The net precipitation remaining after these losses are removed may be delivered to the stream through a variety of flow pathways. Such water flow pathways control many ecological processes, biochemical transformations, exchange reactions, and mineral weathering rates. Flow paths determine largely the geochemical evolution along the flow gradient and the contact time in the subsurface (or residence time) has much control on the surface water quality [24].

Runoff, when occurring, had been sampled each week (Sept. 2009 - June 2013; 60 samples). Stable isotopic signature for oxygen ($\delta^{18}O$) vary between -7.02 and +3.20‰ VSMOW and hydrogen ($\delta^{18}H$) between -37.05 and +0.19‰ VSMOW. Most isotopic signatures of stream flow are plotted along the LMWL indicating that overland flow and direct runoff is the main contribution to stream flow (Figure 7). Enriched points are mainly sampled during the dry season (april-may) at the end of the runoff period indicating that the evaporation is affecting water through its flow path. On the other hand, depleted points are observed during the wet season (November-December), values remain on the same range of winter precipitation but could also be related to the influence of groundwater on stream flow processes (Figure 6).

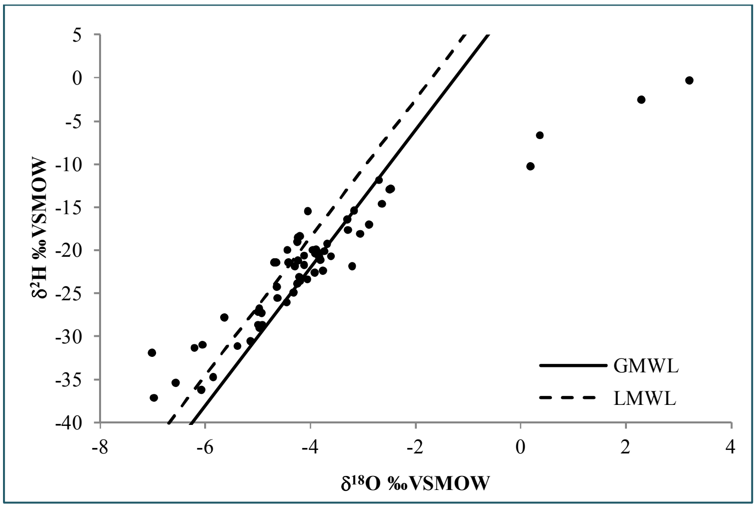

FIG. 7. $\delta^{18}O$ vs $\delta^{2}H$ (‰ VSMOW) for the wadi runoff of the Kamech catchment

3.3. The Kamech pond waters

Variation of the isotopic signatures of water in the Kamech pond observed weekly throughout the monitoring period (Sept.09 – Jan.12; 117 samples). Stable isotopic signatures vary between -3.83 and +4.79 ‰ VSMOW for $\delta^{18}O$ and between -18.74 and 21.08 ‰ VSMOW for $\delta^{18}H$. Data plot clearly indicate the "evaporation effect" with a 4-slope line (Figure 8).

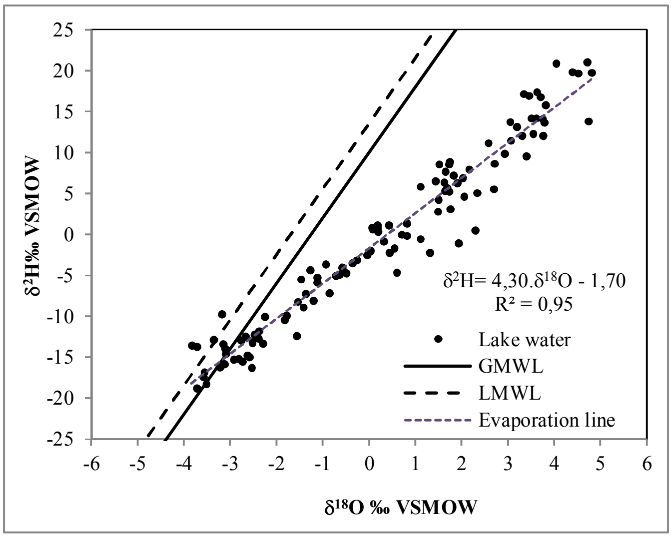

FIG. 8. $\delta^{18}O$ vs $\delta^{2}H$ (‰ VSMOW) for the Kamech Lake waters

Data also show clear seasonal trend closely related to the volume variation (Figure 9). During the high-water season, isotopic signature is fluctuating in relation with precipitation, stream flow over flow and probably released volumes. However, during the low-water season, the signal is continuously enriched due to evaporation effect that became the most important term of the water balance.

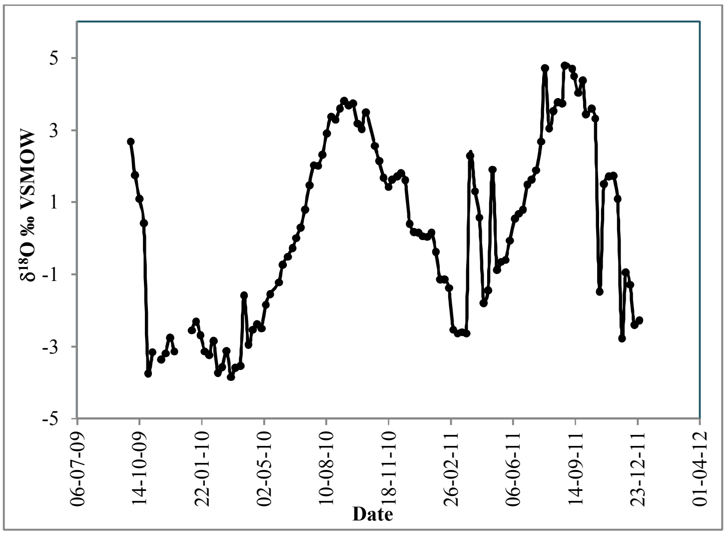

FIG. 9. Seasonal variation of mean $\delta^{18}O$ of the Kamech pond

Water sampled from the lake during the first year (2009) revealed quite low salinity values varying between 582 and 924mg/l, dominant ions are chlorides, sulphates and calcite leading to mixed faces. A slight spatio-temporal variation is observed. Total dissolved solids, calcite and chloride contents increased during the wet season because of minerals and salts dissolved by rainfall and/or runoff water (Table 2).

TABLE 2. HYDROCHEMISTRY OF WATER IN KAMECH POND

Hydrochemistry										
Month	Cl^-	NO_3^-	SO_4^{2-}	CO_3^{2-}	HCO_3^-	Na^+ mg/L	K^+	Mg^{2+}	Ca^{2+}	TDS
Oct-09	110	0	107	0	165	76	7.2	21	71	582
Nov-09	136	0	112	24	98	98	4.7	23	47	600
Jan-10	209	3.2	195	0	159	105	7.2	35	91	802
Feb-10	210	4.1	197	0	183	116	4.8	40	98	920
Mar-10	204	11.2	44	0	256	92	4.7	36	86	730
May-10	209	3.9	207	0	98	147	0	41	43	868
Jun-10	270	25.5	247	0	49	200	0	43	43	859
Jul-10	255	0	205	0	73	156	4.9	40	68	924

Data indicated that the salinity varies between 582 and 924 mg/l, with chloride, sulphates and calcium as predominant ions (Table 2). During October, November, January and March, water of the Kamech pond showed a decrease in sulphate concentration and TDS values that could be explained by a mixing with fresh rainfall water with 70 mg/l salinity.

3.4. Groundwater

Ground waters had been sampled every month during the first year of the project in order to identify their isotopic signatures of water and also to detect eventual seasonal variation. Ground waters were distinguished according their location: upslope (Piez1 to Piez16), around the pond (Piez17 to Piez19) and downstream of the pond (Piez21 to Piez22) (Figure 4).

Upstream and around the pond, stable isotopic signatures vary between 0 and -6 ‰ VSMOW for ^{18}O and between 0 and -35 ‰ VSMOW for ^{2}H. Range of stables isotopic signatures indicated that a stable signal which was weakly influenced by hydrological processes (recharge – evaporation) (Figure 10a). However, no seasonal variation has been clearly observed for all ground waters (Figure 10b). The very large spatial heterogeneity observed in geochemical data could be explained by particular hydrogeological context since water is lodged in little perched aquifers of different geological formations and variable depths.

Eighteen samples have been collected from two piezometers located downstream the dam (piezometer 21 and 22). Stable isotopic signatures vary between -2.24 and 2.69 ‰ vs SMOW for ^{18}O and between -10.95 and -16.92‰ vs VSMOW for ^{2}H. For this area, data plot below the local meteoric water line indicating an evaporation effect that could be explained either by the limited depth of the water table or by a direct recharge from the lake through overflow of released water (Figure 10c). The isotopic signature of groundwater downstream the dam is close to that of lake but less enriched indicating that the recharge is likely a mixing between over flow, releases and infiltration. Stable isotopic signatures of piezometers located around the lake used for the isotope budget are considered constant at a monthly scale. No seasonal variation was observed for these ground waters. The enrichment is quasi constant over the year and seems to reflect the mean signal of the lake water. Major elements indicate a mixed faces with no seasonal variation.

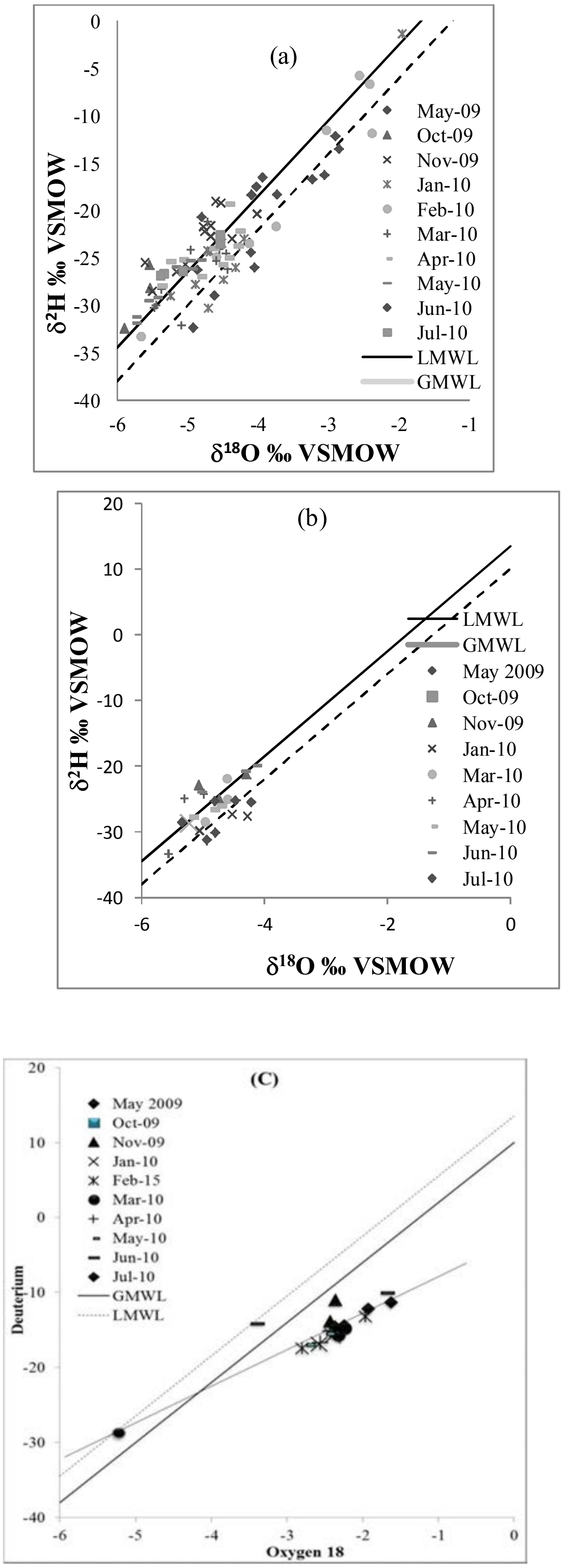

FIG. 10: $\delta^{18}O$ vs $\delta^{2}H$ of water for (a) groundwater upstream of the pond, (b) around the pond and (c) downstream of the pond

3.5. Water budget of the Kamech Lake

Lakes are dynamic and complex systems that interact with surrounding environments and are related to different water compartments of water cycle through inflow and outflow of surface and ground waters, precipitations and evaporation. All components of the water budget of a wetland (Figure 11) are subjected to both short and long term variations which are related to seasonal variation in input and output of water and impacts of climate variability or by modification of either natural or human related actions at the catchment.

The water budget reflects the relationship between input and output of water to Lake Kamech. This water budget considers both groundwater and surface water. Inflow to the lake includes surface inflow, direct precipitation, and groundwater inflow beneath the lake. Outflow from the lake includes direct evaporation, irrigation usage, groundwater outflow, water released from the pond and over flow. For a specific time period, the water budget should take in to account all different components that occur at the lake level. The water balance is provided by the following equation:

$$\Delta V = \left(V_r + V_p + V_{gw}\right) - \left(V_{ev} + V_d + V_{dv} + V_i + V_u\right)$$

where

ΔV : storage variation in the lake ; V_r : volume of runoff flow; V_{gw} : volume of groundwater inflow V_p : volume of precipitation; V_{ev} : volume of evaporation; V_i : volume of infiltration outflow; V_d : volume of overflow of the dam; V_u : volume of uses (irrigation); V_{dv} : volume of dam releases

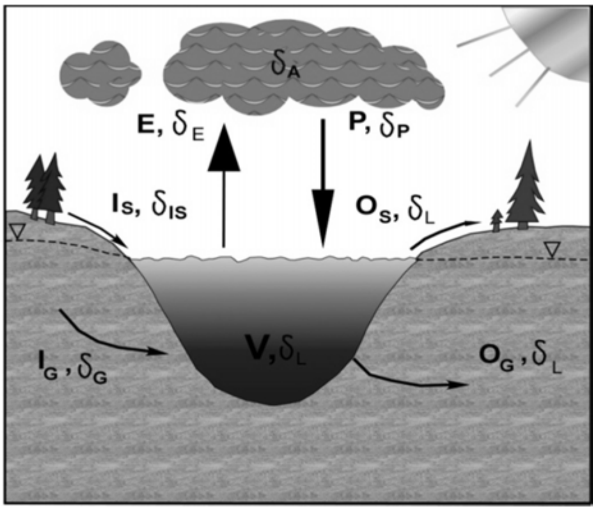

FIG. 11. Inflow and outflow of a wetland and corresponding isotopic signature (δ_A, δ_E, δ_P, δ_{IS}, δ_L, and δ_G are isotopic signatures of Atmospheric moisture, Evaporation water, Precipitation water, pond Inflow water, Lake water and Groundwater respectively and E, P, I_s, O_s, I_G, O_G and V are evaporation, precipitation, inflow, outflow, groundwater discharge, groundwater recharge and pond water, respectively) .

Some of these elements, such as surface inflow, precipitation, evaporation, surface outflow, and variation of lake level, can be measured easily at the site. However, it is difficult to determine the groundwater inflow and outflow. Although these quantities could be calculated as a residual term of the water budget equation, they yield information only on absolute contributions of groundwater flow or net exchanges between groundwater and the pond, defined as $V_{L-G} = V_{gw} - V_i$

The water budget established for a monthly time interval during the 2009-2010 hydrological year reveals that exchanges between the lake and the underlying aquifer are mostly negative (Figure 12) which means that for most of the time the pond is recharging water to the groundwater.

FIG. 12. Monthly Water budget of the Kamech Lake (m^3)

October and June are the only months during which water exchange volume are dominated by groundwater exfiltration (water flows to the pond from groundwater). During October, high volume of water released (42 036 m^3) had induced abrupt drop of the storage level in the pond and therefore the water level became below the water level of the underlying groundwater. This difference induced an inversion of fluxes between the two water masses. The weekly water budget highlighted that the inversion of flux immediately follow the release period. On the other hand, during the dry season, inflow decreased and the storage level also decreased. When this level becomes below the groundwater level, the flux inversion occurs and the groundwater discharges toward the lake.

The isotopic mass balance had been applied at daily; weekly and monthly scales. First results confirm that the infiltration is the dominant process controlling the pond-groundwater exchanges. Daily calculations indicate that water released from the pond, highly disturb the pond-groundwater system equilibrium and led to the inversion of water fluxes from the aquifer to the pond. Except short periods, maximum of net exchanges volume are estimated for March when the storage level is at its maximum. The water budget indicated that approximately 69,000 m^3 had infiltrated into the underlying alluvial groundwater during the 2009-2010 water year. However, this alluvial groundwater table had supported the pond level during high diversions periods and during dry season by supplying about 10 000 m^3 to the lake.

3.6. Nitrogen distribution over the catchment

At the catchment scale, nitrogen (N) cycle is controlled by biochemical transformation and physical transport by water from the catchment to its discharge point. Nitrogen balance studies for sub-humid and humid climates are well-defined ([25], [26]). In these areas, N concentrations in farm ponds depend mainly on surface runoff and showed seasonal fluctuations. Many authors had observed that N is mainly transferred in subsurface water and that denitrification takes place in the saturated riparian zone. This project had focused on the external cycle of N to identify transport processes over the Kamech catchement. This catchment is characterized by low natural vegetation cover since more than >60% of landscape is cultivated.

Simplified schematic of N distribution in the catchment is shown in Figure 13. This schema presents rain-fed cultivated plots and a succession of humid zones the latest being supplied by the Kamech pond surrounding saturated area. Biomass production of the considered wet zones are not of main interest for food production but are delivering crucial ecological services, thus, given first results on N characterisation of different compartments of the catchment, they seem to play a very important role in the mitigation of nutrient fluxes from the crop production that is located upland. This scheme, if identified, could help design mitigation solution for N fluxes from rain-fed fields and villages by natural and artificial wet zones what could be of high interest for farmers and local authorities.

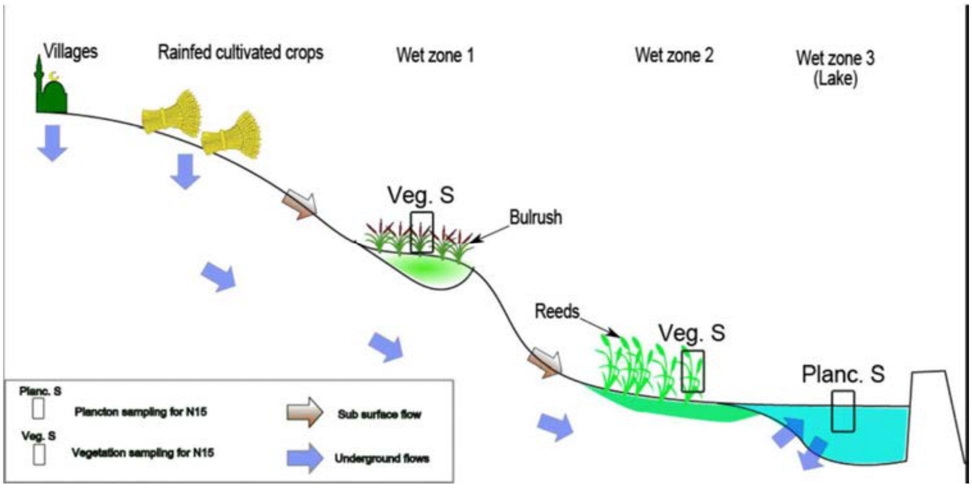

FIG. 13. Mitigation of nitrogen fluxes by natural and artificial wet zones

Nitrate and ammonium data indicated that spatio-temporal variations of mean nitrite concentration are in trace level with low standard deviation indicating that nitrite contents can be considered as constant for the basin (Figure 14). Spatial variation of mean ammonium concentration and their standard deviation are very low. Ammonium variations are considered of natural levels. Spatio-temporal variations of nitrate concentrations are significant with a large range from 0.19 to 43.45 mg/l. High standard deviations indicate a large dispersion of values around mean values. Lowest nitrate concentrations are recorded upstream the watershed (piez1 (0.19 ± 0.40 mg/l), piez2 (1.17 ± 2.12 mg/l), and piez3 (0.96 ± 0.74 mg/l)). Highest values are observed in piez12 with a mean value of 18.30 ± 9.6 mg/l. Wadi values are quite low however, greater than upstream and range around 4 mg/l (Piez14: 3.56 ± 3.59 mg/l; piez20: 3.91 ± 1.83 mg/l). Low nitrate content at surface water could be explained by denitrification phenomenon and transformation of nitrates in vapour phase nitrogen. Around the lake, nitrate contents are piez18: 5.58±5.40; piez19: 1.25±0.97 mg/l; piez21: 2.73±0.175 g/l and piez22 : 2.06±1.33 mg/l. The nitrate content of lake water is about 2.71 ± 1.59 mg/l.

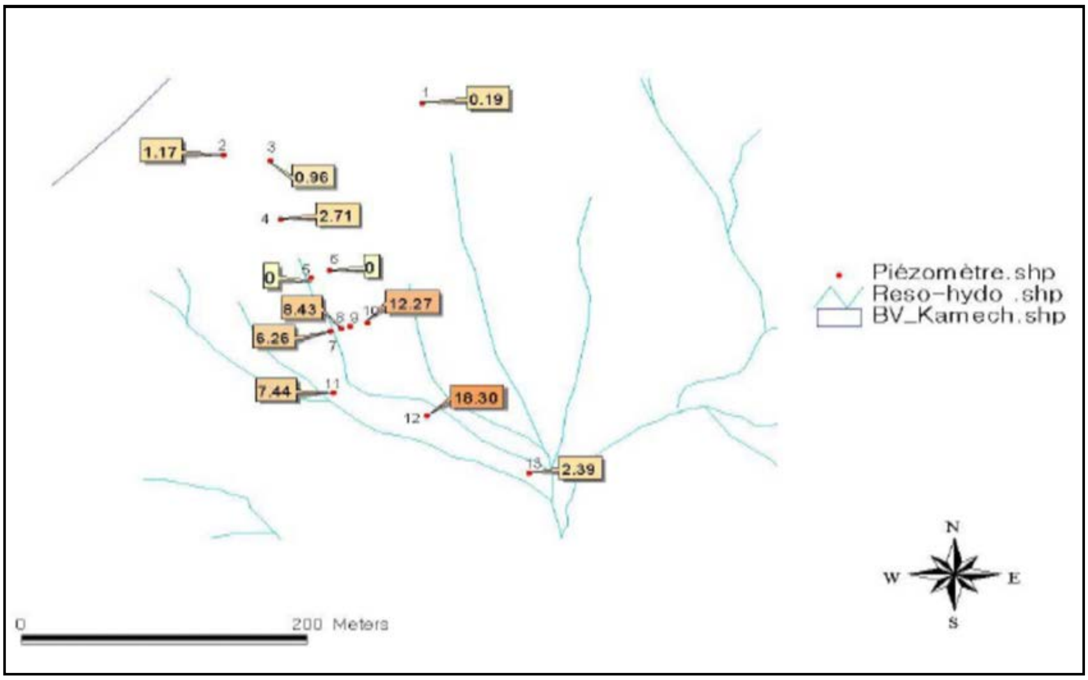

FIG. 14. Nitrate distribution in groundwater of Kamech watershed.

4. CONCLUSION

The study focussed on the water budget of the Lake Kamech in order to determine the different water fluxes that take place in the catchment and the exchanges fluxes between the pond and its below ground system. This objective was carried out in order to define the contribution of the storage pond in water storage and conservation in the region. The isotopic balance applied at daily, weekly and monthly scales confirms that water resources at the catchment scale, is constituted by the surface pond and by an underlying alluvial groundwater mainly recharged by the lake infiltration. Daily calculations indicated that water releases, carried out to protect the pond, highly disturb the lake-groundwater system equilibrium and led to the inversion of water fluxes from the aquifer to the lake. Except these short periods, maximum of net exchanges are estimated for March when the storage level is at its maximum. The water budget indicateed that approximately 79 000 m^3 had infiltrated into the underlying groundwater during the 2009-2010 water year. The groundwater had supported the pond storage during high diversions periods and during dry season by supplying about 10 000 m^3 to the lake. The study showed that with less than 3% of the catchment area the pond received more than 90% of its water from the catchment runoff during the rain period and less than 10% from the groundwater sources mainly during the dry period when the pond water level decreased below the groundwater level as a result of diversion.

The water quality of storage ponds and other conservation zones is of a great interest in Tunisia since nutrient contamination and pollutants transfer in irrigated catchment are raising issues after the implementation of the strategy of intensive irrigated crops in large landscape related to great reservoir (great dams) and/or easy-access groundwater system. The Kamech catchment is of limited interest in terms of crop productions since agriculture practices are mainly rain-fed with some random (unpredictable) small irrigated parcels. However, detailed investigations have been carried out for N characterisation of different compartments of this catchment what suggested a schema of denitrification in the catchment. This schema has been based on classical techniques (major elements, nitrate, nitrite,). Nitrate is the main N form which was observed in all the hydrologic compartments of the Kamech catchment. The low N concentrations in lake can have two reasons: (1) when considering the low N concentration in wadi flow, the first reason would be that N transport in Kamech catchment from soils to the wadi and then to the lake does not occur because the source of N in soils is limited due to a complete absorption of available soil mineral N by plants. (2) the second reason would be that N is transported to the lake by surface runoff and that denitrification or aquatic plant absorption in lake would decrease N concentrations.

REFRENCES

[1] LEDUC, G. FAVREAU and P. SCHROETER, Long-term rise in a Sahelian water-table: The Continental Terminal in South-West Niger, Journal of Hydrology 243 (2001) 43–54.

[2] SEITZINGER, SP, Denitrification in freshwater and coastal marine ecosystems: ecological and geochemical significance. Limnol. Oceanogr. 33 (1988) 702–724

[3] GÜNTNER, A., M.S. KROL, J.C. DE ARAUJO and A. BRONSTERT, Simple water balance modelling of surface reservoir systems in a large data-scarce semiarid region, Hydrological Sciences Journal 49 (5) (2004) 901–918

[4] THOMS, M.C. and F. SHELDON, Water resource development and hydrological change in a large dryland river: the Barwon-Darling River, Australia, Journal of Hydrology 228 (2000) 10–21

[5] ZAHAR, Y., GHORBEL, A., J., ALBERGEL, Impacts of large dams on downstream flow conditions of rivers: Aggradation and reduction of the Medjerda channel capacity downstream of the Sidi Salem dam (Tunisia), Journal of Hydrology 351 issue 3-4 318-330

[6] LACOMBE, G., CAPPELAERE B., LEDUC C., 2008, Hydrological impact of water and soil conservation works in the Merguellil catchment of central Tunisia ,Journal of Hydrology 359, issue 3-4 210-224

[7] ALBERGEL, J., NASRI, S., BOUFAROUA, M., PEPIN, Y., 2001. Bilan de l'érosion sur les petits bassins versants des lacs collinaires de la dorsale tunisienne. In: Servat, E., Albergel, J. (Eds.), Hydrologie des régions méditerranéennes. UNESCO. IRD, Montpellier 63–70.

[8] DAGÈS, C., VOLTZ, M., LACAS, J. G., HUTTEL O., NEGRO, S., LOUCHART, X., An experimental study of water table recharge by seepage losses from a ditch with intermittent flow, Hydrological Processes 22, no18 (2008) 3555-3563.

[9] HILL, A.R., Nitrate Removal in Stream Riparian Zones. Journal of Environmental Quality 25 (1996) 743-755.

[10] HAYCOCK, N.E. and G. PINAY, Groundwater nitrate dynamics in grass and poplar vegetated riparian buffer strips during the winter, Journal of Environmental Quality 22 (1993) 273–278.

[11] CLÉMENT J.C., PINAY G., MARMONIER, P., Seasonal dynamics of denitrification along topohydrosequences in three different riparian wetlands. Journal of Environmental Quality 31 (2002) 1025-1037.

[12] ALBERGEL, J. ET NASRI, S. Hydromed: rapport final du programme de recherche sur les lacs collinaires dans les zones semi-arides du pourtour méditerranéen. Contrat Européen INCO DC ERBIC 18 CT 960091 – STD4 IRD / INRGREF Tunis (2001) 120 + annexes.

[13] MEKKI I., Analyse et modélisation de la variabilité des flux hydriques à l'échelle d'un bassin versant cultivé alimentant un lac collinaire du domaine semi-aride méditerranéen (Oued Kamech, Cap Bon, Tunisie), Doctorat, Université de Montpellier II, Sciences et Techniques du Languedoc (2003)

[14] FOX D., CARREGA, P., MORSCHEL, J., EMSELLEM, K., La dégradation des sols, website of the Nice Sophia Anthopolis University, http://unt.unice.fr/uoh/degsol/ (2008)

[15] MTIMET, A., Atlas des sols tunisiens. Ministère de l'agriculture de Tunisie (1999) 165.

[16] C.E.P.E., Carte phytoecologique de la Tunisie septentrionale. Annales de l'Institut National de la Recherche Agronomique de Tunisie 39 (5) (1967) 1-213.

[17] COLLINET, J., ZANTE, P., Etude de l'érosion sur les versants, destransferts de l'eau et de solutés dans les sols, impacts des aménagements anti-érosifs. In: Albergel, J., Nasri, S. (Eds.) «Rapport final duprogramme de recherche sur les lacs collinaires dans les zones semi arides du pourtour méditerranéen (HYDROMED)», Contrat Européen INCO DC ERBIC 18 CT 960091 – STD4 IRD/INRGREF Tunis (2001) 73–85.

[18] FAO, World reference base for soil resources. ISRIC-ISSS-FAO, Rome (1998).

[19] CASENAVE, A., ET VALENTIN, C., A. Runoff, capability classification system based on surface features criteria in semi-arid areas of West Africa. Journal of Hydrology (1992) 130 231.

[20] IBIZA, D., Analyse et modélisation des écoulements sur des bassins dans le nord tunisien. ORSTOM, Tunis et Ministère de l'agriculture de Tunisie (1983) 314.

[21] CLARK, I., and FRITZ P., Environnemental Isotopes in Hydrology, Lewis Publishers, Boca Raton (1997).

[22] HACH CAMPANY, Spectrophotometre DR/4000 Modeles 48000 et 48100 Rapport technique, Colorado, USA (2001) 116.

[23] RODIER, J., BAZIN, C., BROUTIN, J.P., CHAMBON, P., CHAMPSAUR, H. ET RODI, L. L'analyse de l'eau, eaux naturelles, eaux résiduaires, eau de mer. 8e édition. DUNOD, Liège, Belgique (1997) 1383.

[24] HOEFS, J., Stable Isotope Geochemistry, 4th ed., Springer-Verlag, Berlin (1997).

[25] COPLEN, T.B., A.L. HERCZEG, and C. BARNES, Isotope engineering: using stable isotopes of the water molecule to solve practical problems, in Environmental Tracers in Subsurface Hydrology, ed. by P.G. Cook and A.L. Herczeg, Kluwer Academic Publishers, Boston (2000).

[26] MCGUIRE, K. and J. MCDONNELL, Stable isotope tracers in watershed hydrology in stable isotopes in ecology and environmental science, ed. by Michener R. and Lajtha K., Blackwell Publishing, 2nd edition (2007).

CHEMICAL AND ISOTOPIC CONSTRAINTS ON GROUNDWATER SURFACE WATER INTERACTION IN A WETLAND TERRAIN WITH IMPLICATIONS ON SUSTAINABLE AGRICULTURE: A CASE STUDY OF THE SANJIANG PLAIN, NORTH EAST CHINA

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Abstract

The Sanjiang Plain in Northeast China is one of the main grain production areas in the country and is supporting a rich biological diversity. However, the wetlands and forest lands have shrunk to one fifth of their original size in the last five decades because of increasing population and land reclamation for agriculture. Identification of the extent of coupling between groundwater and surface water connections is essential to improving agricultural water management in the area. Using a multi-tracer approach involving water chemistry and stable and radio isotopes (^{2}H, ^{18}O, ^{3}H, ^{13}C, ^{14}C), integrated with data on groundwater regime, demonstrated that it is possible to delineate the mechanism of hydraulic and chemical interactions of groundwater with various surface water sources including rivers, ponds and paddy rice fields of a wetland terrain. Regional variations in hydrogeology are main factors controlling groundwater recharge and regime. Results showed that the evaporative isotopic signature in surface water can be used as a good indicator to study mixing between groundwater and surface water. Groundwater in the confined quaternary aquifer with ages over 50 years that are depleted in heavy isotopes is recharged by lateral flow from nearby mountains. This groundwater is in general not affected by changes in the wetlands and/or rice fields and therefore is less vulnerable to the pollution from fertilizer application, however, with limited yield. On the contrary, the unconfined quaternary aquifer is recharged by rainfall or riverbank infiltration at localities near the rivers. It is more likely for the aquifer to be affected by nutrients released from intensive fertilizer applications, though its yield is rather abundant. It is suggested that surface water should be utilized together with groundwater in order to ensure sustainable water supply for irrigation in the region.

1. INTRODUCTION

Sustainable agricultural development requires improved water management at the watershed or river basin scale in order to achieve efficient water use and greater agricultural productivity. Therefore, it is necessary to understand the water-nutrient-crop interactions for improving water management in agriculture. Northeast China, especially in Songhuajiang and Sanjiang catchments with many wetlands, is probably one of the most suitable regions for agriculture in North China Plain [1]. With an area of about 1.2 million ha, the region is a major source of food supply for the population. It is famous for large-scale land reclamation and 35 percent of the wetlands have been reclaimed for rice paddy cultivation since the 1950s. In order to meet the water requirement for paddy cultivation, groundwater was extracted at about 2.2 million mega litres per year, and the fertilizer application amounts to 225–525 kg N ha^{-1} [2]. The “black soil” prevalent in the area is very rich in nutrients, and the annual precipitation is high in most part of the region which is appropriate for agriculture. Other conditions such as temperature, infrastructure and government policy are also favourable for agriculture in the region. In order to ensure food security for the region, the local governments have launched plans to increase crop production in the region by an estimated five million tons per year through improved land and water management measures. To achieve this ambitious goal means that more water will be diverted from surface and groundwater sources for irrigation needs and the reclamation of more waste lands will have to be carried out in the west of Jilin Province and the low land of Heilongjiang Province. However, there has been a steady decline in groundwater level and deterioration of water quality in the region as a result of continued increase in water and fertilizer use for agriculture. The excess water from irrigated rice wetlands will recharge groundwater leading to a groundwater table rise and salinization risks. It will also impose an additional risk on the quality of surface water. Therefore, it is of paramount importance to assess these impacts in order to sustain the agricultural production and water quantity and quality in this area.

In short, issues of water and nutrient budgets of agricultural wetlands, as well as hydrological and biogeochemical processes within and around wetland systems in North China Plains in general and Shanjiang Plains in particular require thorough investigation and understanding in order to increase the efficiency of water and nutrient use and reduce the risk of agricultural activities on surface and ground water resources. There is a major water conservation and quality issue in the reclaimed rice lands in the Northeast China region. The question is whether or not irrigation using groundwater can be sustainable in view of the water table decline and surface water quality deterioration.

The overall objective of this project is therefore to study the hydrological and biogeochemical processes in rice wetlands systems and to identify impacts of rice wetlands on water resources.

2. MATERIALS AND METHODS

The Sanjiang Plain (43°49′-48°27′N, 129°11′-135°05′E) is located in the northeastern part of Heilongjiang Province, Northeast China (Fig.1). It encompasses a total area of 6.2 million ha. The Plain is bordered by the Xiaoxinganling Mountain to the west, and the Heilongjiang River and the Wusuli River to the north and east, respectively (Fig.1). The elevation of the lower plains ranges from 50 to 60 msl, while that of the highest mountain in the south is 1429 msl. The mean annual temperature increases from 1° C in the southern mountainous region to 3° C in the northern plain [3]. The mean annual precipitation in the plain is around 600 mm, most of which falls between June and September, accounting for about 70% of the total annual rainfall.

Although the Songhua River is a perennial river, there are many ephemeral rivers within the plain, e.g., the Nongjiang River, the Bielahonghe River, running through the Sanjiang Plain (Figure.1). The thick Quaternary sediments deposited in this area are mainly alluvial, fluvial, or lacustrine sediments. In the western part of the Sanjiang Plain, the diluvial aquifer is made of highly permeable cobble and gravel deposits, forming a uniform unconfined aquifer (District I) with the water table shallower than 10 m. To the east, the aquifer is covered by a 16-20 m thick clay and becomes confined or semi-confined (District II) (Figure. 2). In the lower reaches of the plain, the aquifer is made of highly permeable cobble and gravel deposits, forming a uniform unconfined aquifer (District III).

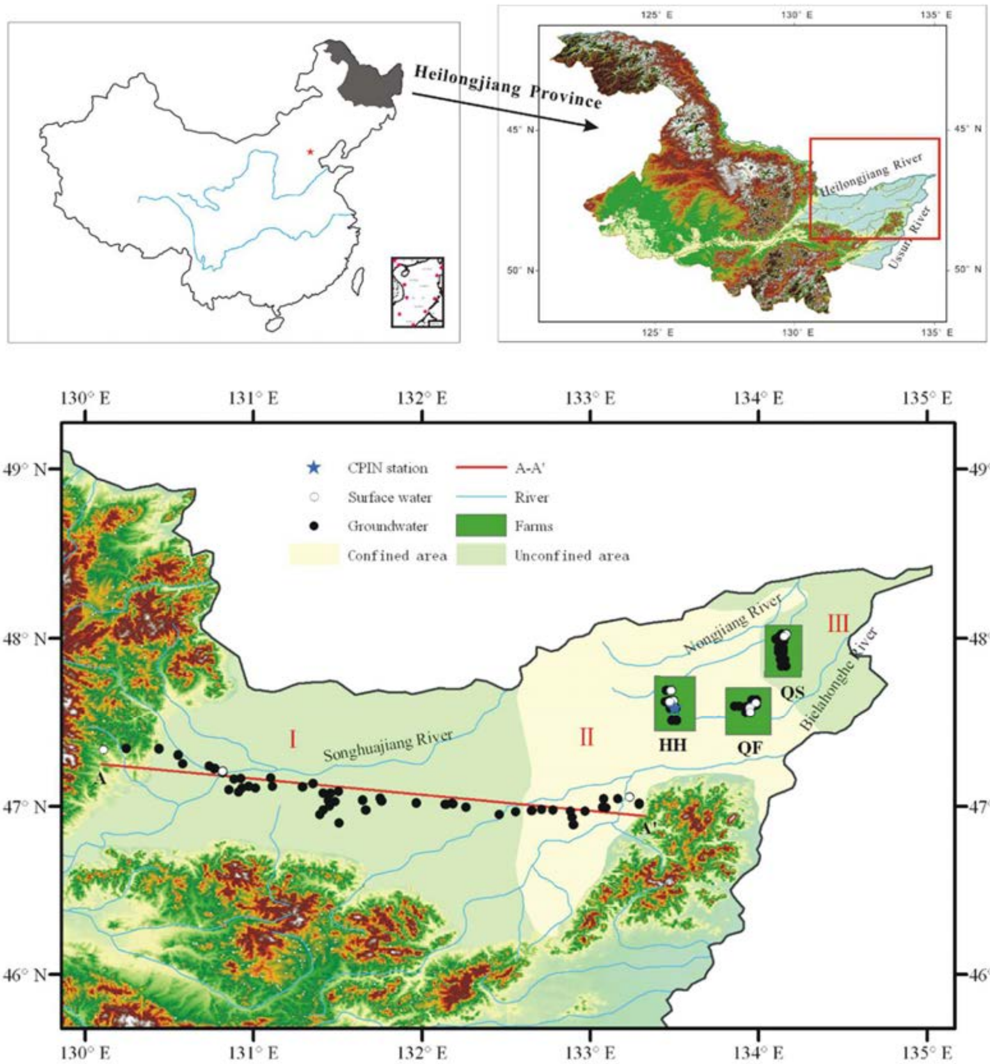

FIG. 1. *Geographical distribution of mountains, rivers and sampling sites in the Sanjiang Plain. Filled circles are groundwater sampling sites, blank circles are surface water samples. Districts I and III are the unconfined aquifer and District II is the confined aquifer.*

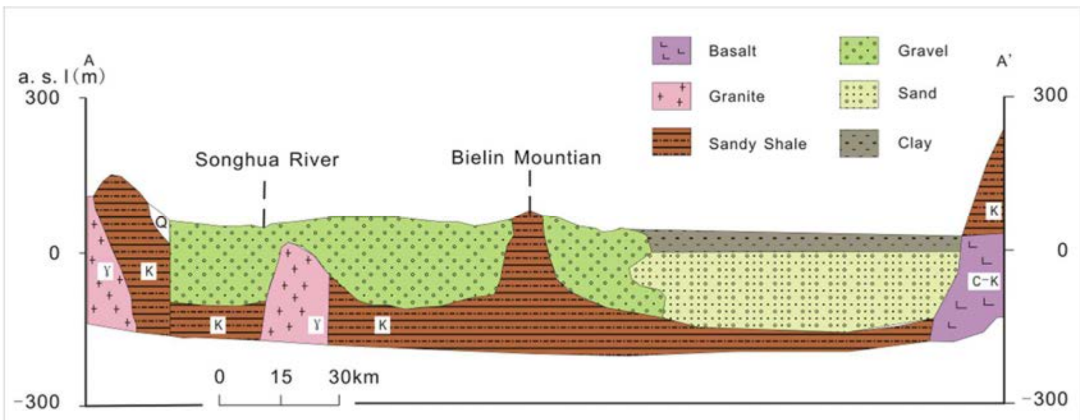

Fig. 2. Schematic hydrogeological cross section along the transect A-A' in Fig.1.

The Sanjiang Plain contains a historically famous marsh, Bei Da Huang [4]. In the 1940s, more than 5 million (M) ha of marshes and wet meadows existed [5]. However, in order to meet the food demand spurred by the increasing population, reclamation plans called for agricultural land to be constructed from wetlands in the Sanjiang Plain (Figure 3). Thereafter, the cultivated land area increased from about 0.79 M ha in 1949 to 5.24 M ha in 2000. Accordingly, the wetland area has decreased from 5.35 M ha in 1949 to 0.84 M ha in 2000 ([3], [6]).

Paddy cultivation dominates the agricultural sector in the region, leading to large amounts of groundwater exploitation (6.65 $ML \cdot ha^{-1} \cdot yr^{-1}$(corresponding to 665 mm)) and fertilizer application (146 kg $ha^{-1} \cdot yr^{-1}$). Urea ($CO(NH_2)_2$), di ammonium phosphate ($(NH_4)_2HPO_4$) and ammonium bicarbonate (NH_4HCO_3) are the most widely used nitrogen fertilizers. There are mainly three types of farmlands in Sanjiang Plain: Paddy fields, irrigated land and dry land [7]. Figure.3 is the wetland-farmland landscape in Sanjiang Plain. Generally, there are mainly three types of crop in Sanjiang Plain, which are rice, corn and soybean [7], which are all cultivated and harvested once every year. In District I, the main crop is corn, while in District II the main crops are rice and soybean and in District III is soybean [8]. The total cultivated area for rice was 0.85Mha, for corn 1.85 Mha and for soybean 1.33Mha in Sanjiang Plain in 2011 [2]. About 0.59 million tons fertilizer was used in 2011 in Sanjiang Plain, of which nitrogen fertilizer accounted for 0.23M tons, phosphate fertilizer 0.095 milion tons, potash fertilizer 0.086 million tons and compound fertilizer 0.18 million tons. Rice and corn cultivation begins in May each year and harvest begins in October, while soybean cultivation begins in May each year and harvest begins in September, during which mechanized operations are fully implemented.

FIG. 3. Wetland-farmland landscape in Sanjiang Plain

2.1. Water sampling

Ground and surface water samples, from paddy fields, drainage channels and rivers were taken for isotopic (^2H, ^{18}O, ^3H, ^{13}C and ^{14}C) and chemical analyses from three typical farms of Honghe (HH), Qianfeng (QF) and Qianshao (QS) Farms, respectively at the northeast part of the Sanjiang Plain in July 2009. Following preliminary interpretation of these data, a further sampling campaign for isotopes was conducted in August 2011 along the transect throughout the plain extending 250 km in an east-west direction. Two typical hydrogeology conditions can be found along the transect, the unconfined aquifer in the west and confined aquifer in the east (Figure 1). Precipitation samples from the Sanjiang station were collected monthly between January 2005 to November 2006 (data from China precipitation isotope network) and August 2010 to September. 2011 (conducted by this study). Locations of all samples are shown in Figure 1.

2.2. Analysis

All water samples for chemical analysis were filtered (0.45µm membrane filters). An aliquot was acidified with 1% HNO_3 for cation analysis. Water chemistry was measured at the Beijing Research Institute of Uranium Geology. The cation measurement was based on National Analysis Standard DZ/T0064.28-93 while anions based on DZ/T0064.51-93. Alkalinity was measured using an automatic titrator (785 DMP™). Analytical precision was 3% of concentration based on reproducibility of samples and standards, and the detection limit for bicarbonate is 0.05 mg/L. The charge balance error for all samples was within ±4%. Stable isotopes were analyzed by Cavity Ring Down Spectrophotometry using PICARRO.L1102-i Laser Absorption Water Isotope Spectrometer in the Water Isotope Lab of Institute of Geology and Geophysics, Chinese Academy of Sciences. Results are reported as δ^2H and $\delta^{18}O$ and provided by the following:

$$\delta = \left(\frac{R_{sample}}{R_{standard}} - 1\right) \times 1000 \quad (1)$$

with the standard of Vienna Standard Mean Ocean Water (VSMOW). The analytical precision is 0.5‰ and 0.1‰ for δ^2H and $\delta^{18}O$, respectively.

To examine the ages of groundwater, water samples for tritium (^3H) and radiocarbon (^{14}C) measurements were collected. Tritium was determined on electrolytically enriched water samples by low-level proportional counting and the results are reported as tritium unit (TU) with a typical error of 1 TU. The measurement was performed at the Open Laboratory of Environmental Geology and the Central Laboratory of Hydrogeology, the Ministry of Land Resources, China. The ^{14}C of dissolved inorganic carbon (DIC) was determined radiometrically by liquid scintillation counting after conversion to benzene in Beta Analytic Inc, USA. The ^{14}C activity was reported as percent modern carbon (pmC).

3. RESULTS

3.1. Water quality

The Piper diagram for samples in the study area is presented in Figure 4. It shows that all samples are on the far left-hand side of the central diamond, characterized by high concentrations of alkaline-earth metal ions. The Sulin classification, introduced in 1946 by V. A. Sulin， was used to recognize four main types of water in the study area. The results show that $NaHCO_3$ type is the dominant hydrochemical face in the groundwater of the confined aquifer (District II). However, groundwater in the unconfined aquifer (Districts I and III) can be classified into several types, including $NaHCO_3$, Na_2SO_4, $MgCl_2$, and $CaCl_2$.

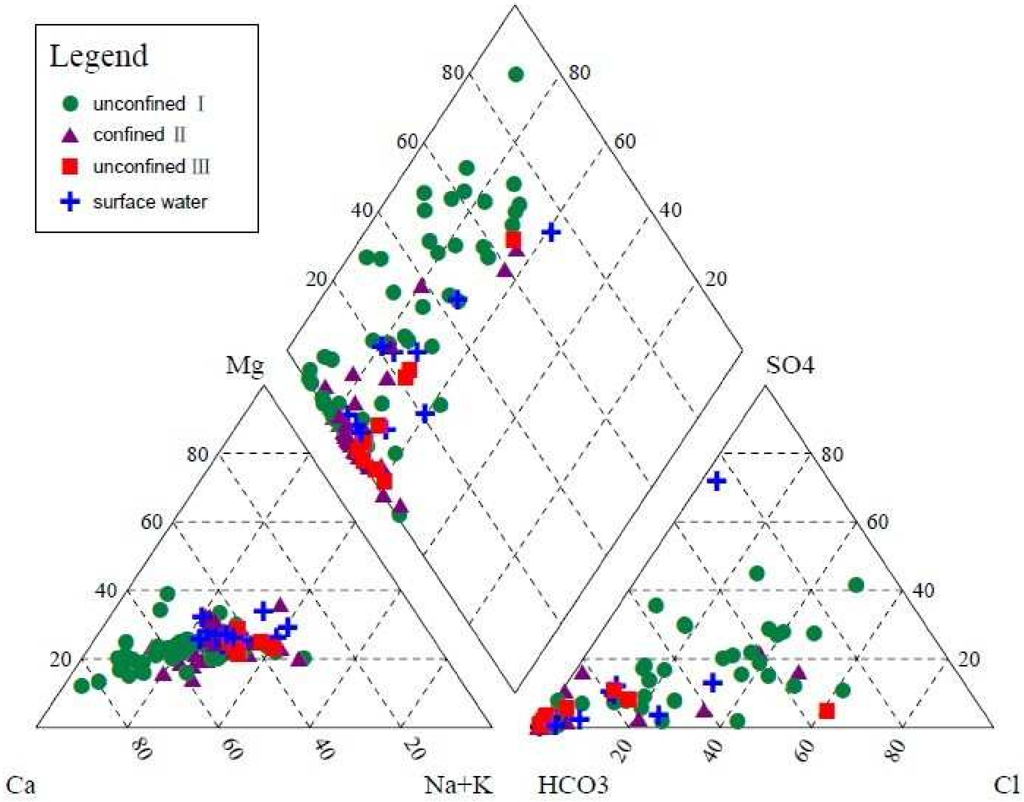

FIG. 4. The Piper chart of groundwater in the Sanjiang Plain

Groundwater nitrate is used as a primary indicator of agricultural impact and it was found that the impacts of fertilizer overuse on groundwater quality (nitrate concentrations) were also controlled by the local hydrogeological conditions. Figure 5 illustrates that the concentrations of groundwater NO_3 vary greatly under different hydrogeological conditions. For example, in the unconfined aquifer (Districts I), the concentrations of NO_3 range from <0.05 to 458 mg/L; while in the confined aquifer (District II), NO_3 concentrations were less than 10 mg/L. Obviously, groundwater in the unconfined aquifer is affected more remarkably by agricultural activities at the surface than that in the confined aquifer. It is interesting that groundwater NO_3 concentrations in District III are also low (<10 mg/L), which is quite different from that of District I. One of the reasons is that fewer fertilizers were used in District III than in District I.

The TDS values of surface water (including river, channel, ponds, and paddy fields) are the lowest with a mean value of 85.8 mg/L. The TDS values of groundwater range from 86 to 1 432 mg/L. The highest TDS for groundwater was found at FJ19 with NO_3 concentration of 458 mg/L. A co-variation of the total dissolved solids (TDS) with NO_3 concentrations in district I can be seen in Figure 6, indicating human activities were the main reason for high NO_3 in groundwater. The confined aquifer, which is covered by a 16-20 m thick clay layer, has ensured the surface water cannot easily infiltrate into groundwater and so kept the groundwater underneath free from contamination.

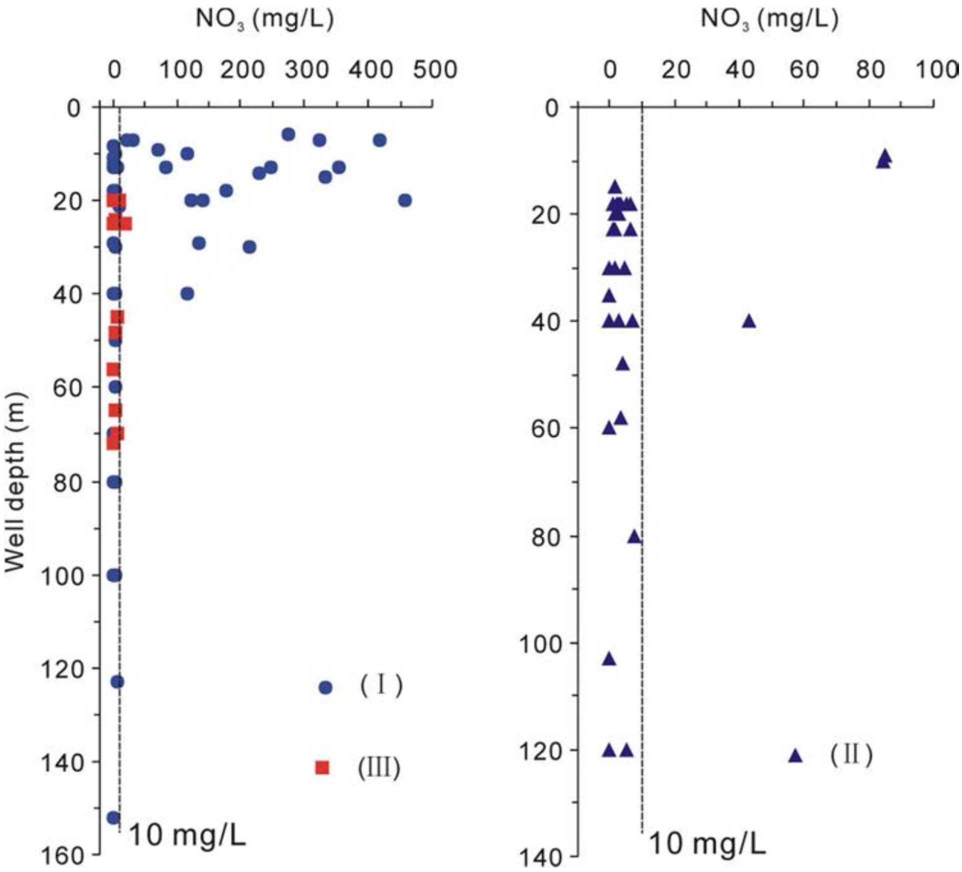

FIG. 5. Change in NO_3 concentrations with groundwater depth in all three districts

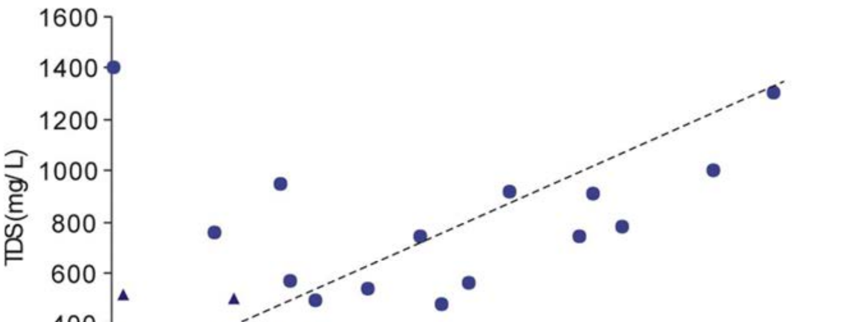

FIG. 6. Plots of NO_3 versus TDS for groundwater samples from three districts in the Sanjiang Plain

The Na/Cl ratio conforms better to the concentrations of NO_3 (Figure 7). The low Na/Cl ratios (<1) are correspondent to elevated NO_3. In this situation, the chloride of the groundwater can also combine with magnesium and calcium in addition to sodium.

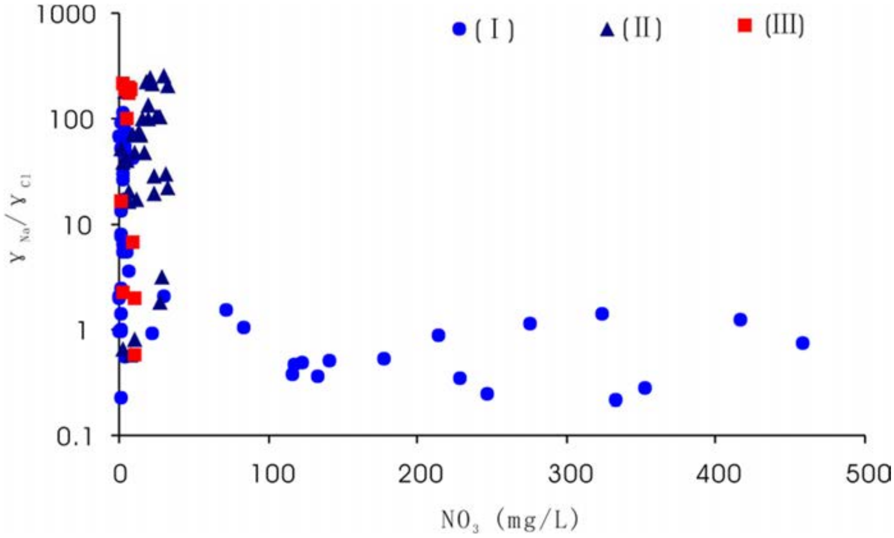

FIG. 7. Na/Cl ratio versus NO_3 concentrations of groundwater

The groundwater Ca^{2+} behaves similarly to groundwater NO_3. An elevated calcium concentration (>50mg/L) can be found in the shallow groundwater of the unconfined aquifer (Districts I and III), while in the confined aquifer (District II), most of them are lower (<50 mg/L) (Figure 8). Calcium (Ca^{2+}) the effective calcium contents of the soil in Sanjiang Plain are high and ranged between 2 500 - 4 500mg/L [9]. The unconfined aquifer is influenced by vertical infiltration, and the interaction with the calcium-rich soil leads to the high calcium concentrations in the shallow groundwater. However, in the confined aquifer, lateral groundwater flow probably dominates the groundwater recharge. Lack of carbonate are certified by the low ^{13}C values of groundwater, so no high calcium concentrations of groundwater are found in the District II.

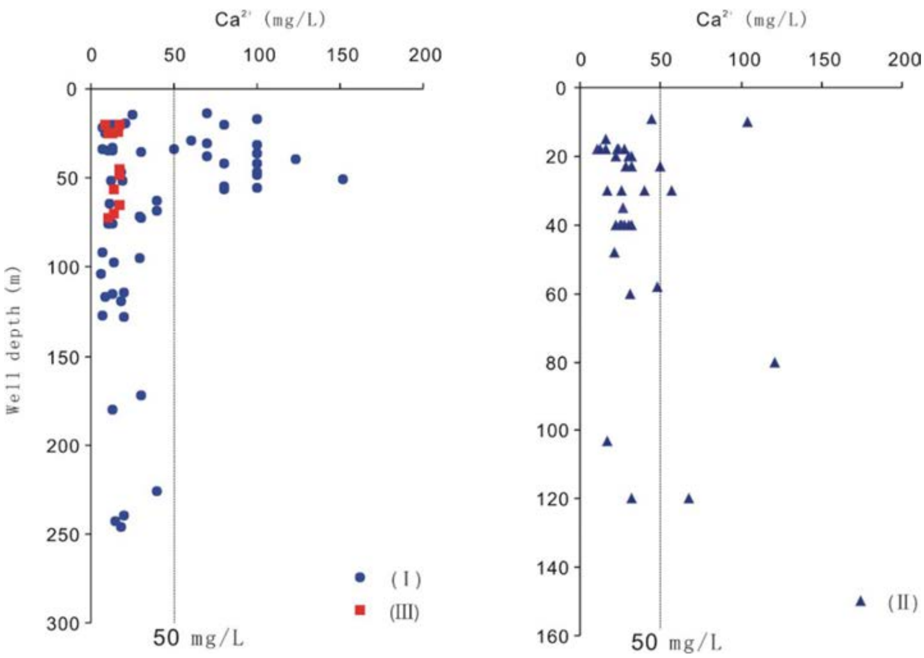

FIG. 8. Plots of Ca^{2+} versus groundwater well depth for samples from three districts in the Sanjiang Plain

3.2. Stable isotopes of waters

3.2.1. *Isotopes in the precipitation*

The $\delta^{18}O$ signatures of precipitation of CPIN Sanjiang station vary from -28.2‰ to -4.7‰ and δ^2H from -207.3‰ to -38.26‰. Precipitation during the winter season is more depleted than that of the summer season in isotopic signatures of O-18 and H-2. Since November of every year, the air temperature drops to below zero and the isotopic compositions of precipitation in the form of snow are always lower than -15‰ and -100‰ for $\delta^{18}O$ and δ^2H, respectively. This is in accordance with Qiqihar Station from the global network for isotopes in precipitation (GNIP). The average annual weighted mean of $\delta^{18}O$ and δ^2H in the Sanjiang Station for the two complete years (from Jan. 2005 to Dec. 2005 and from Aug. 2010 to Jul. 2011) are –12.3‰ and -90.7‰, respectively.

A significant linear correlation (R^2=0.99) exists between the two parameters $\delta^{18}O$ and δ^2H (Figure 9). Both slope (7.51) and intercept (-0.92) of the linear regression line show typical isotopic pattern of precipitation in a cold region ([10], [11]).

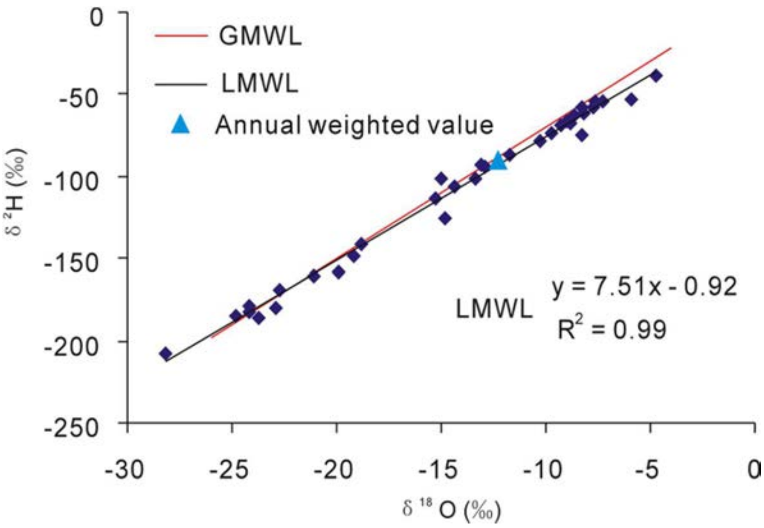

FIG. 9. Stable isotope plots of precipitation. Regression equation of LMWL is $\delta^2H=7.51\delta^{18}O$-0.92 ($R^2$=0.99)

3.2.2. *Isotopes in surface water*

Fifteen samples of surface water were collected in the study area in order to identify the isotopic signature of rivers and irrigation water from paddy fields. The river water samples S1 and S4 are plotted on the Local Meteoric Water Line (LMWL). However, samples S2 and S4 are located along a line with slope of 5.7, indicating that there was an evaporative enrichment effect (Figure 10). The channel water samples (C1 and C2) were enriched in heavy isotopes, and also showed the effect of evaporation. The isotopic composition of irrigation water from paddy rice fields entering drainage channels was also comparable to that of rainfall, showing a wide range from 9.0‰ to -12.6‰ for $\delta^{18}O$, with a mean value of -10.4‰. Most of the irrigation water in paddy fields was located above of the LMWL, which may be ascribed to the effect of condensation.

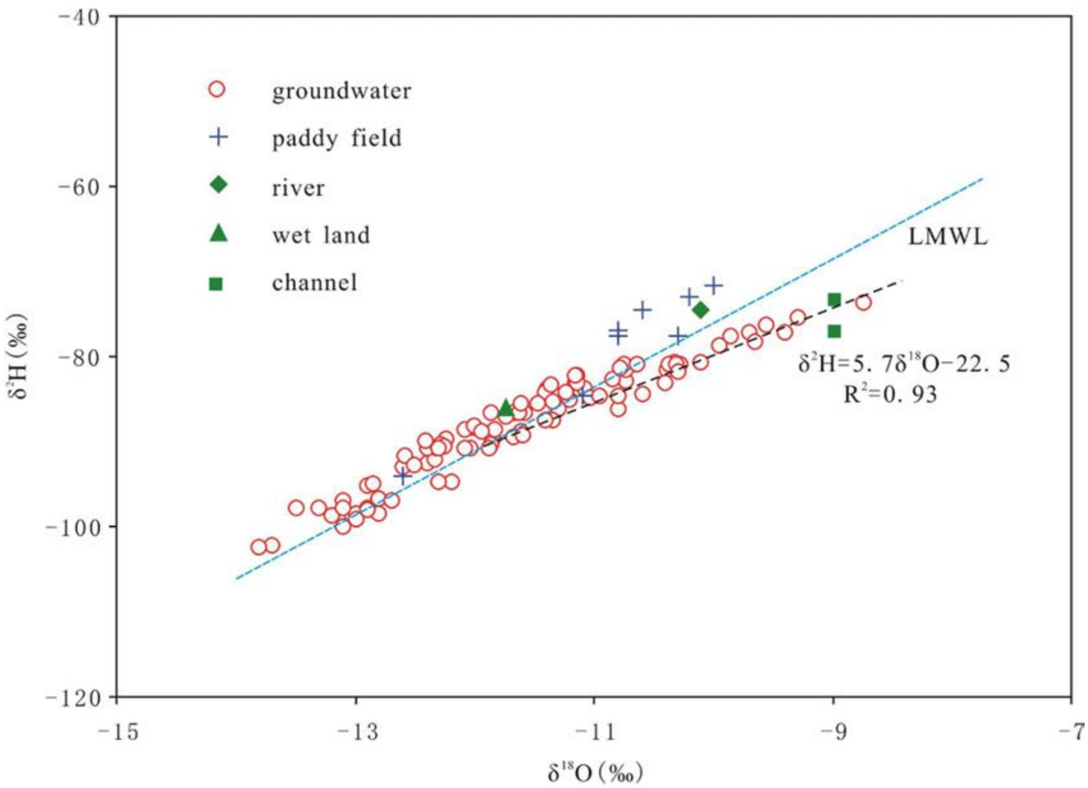

FIG. 10. The relationship between $\delta^{18}O$ and δ^2H of surface water and groundwater in the Sanjiang Plain

3.3.3. Isotopes in groundwater

Stable isotopic signatures of groundwater samples collected from the unconfined area (districts I and III) and the confined area (district II) displayed significant variations (Figure 11). In the confined area, all samples were located on the LMWL, except for DX14 and DX16. Stable isotopic signatures ranged from -8.7‰ to -12.6‰ with a mean value of -11.6‰ for $\delta^{18}O$, and from -73.5‰ to -92.0 ‰ with a mean value of -86.9% for δ^2H. Almost all groundwater in the confined area were located on the LMWL with depleted $\delta^{18}O$ and δ^2H isotopic signatures compared with the weighted average of the local precipitation, which indicated that the confined aquifer was mainly recharged by lateral groundwater flow from the mountainous areas surrounding the plain. Whilst in the unconfined area, stable isotopic compositions showed a small enrichment with a mean value of -11.1‰ and -84.4 ‰ for $\delta^{18}O$ and δ^2H, respectively. Some ground waters in the unconfined area were located on the LMWL, others were on the right side of the LMWL with enriched $\delta^{18}O$ and δ^2H isotope composition compared with the weighted average of the local precipitation, which indicated the impact of evaporation.

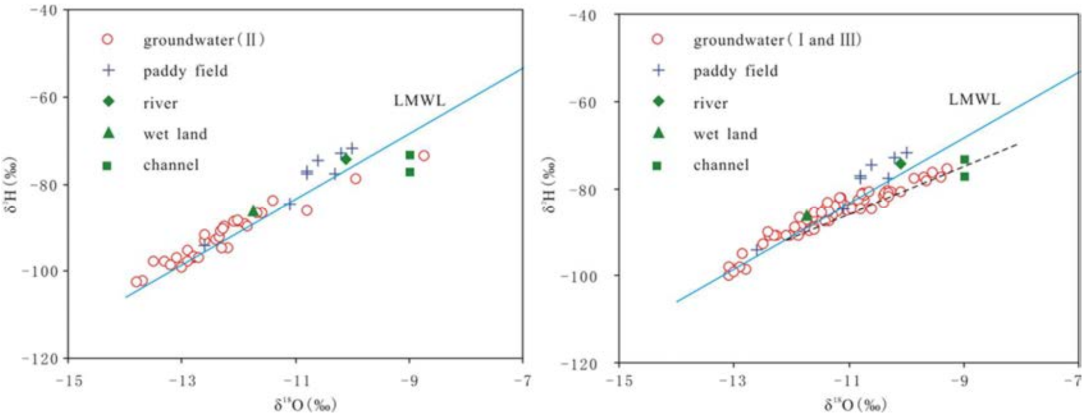

FIG. 11. The relationship between $\delta^{18}O$ and δ^2H of groundwater in the unconfined (HH), and the confined aquifer (QF and QS) in the Sanjiang Plain

Groundwater in the three farms (HH, QF, and QS Farm) has specific isotopic characteristics. Oxygen isotopic signatures of groundwater samples in HH and QF Farms ranged from -13.5 to -12.2‰ and -13.8 to -12.3‰, with averages of -12.9‰ and -13.0‰, respectively. The $\delta^{18}O$ and δ^2H from five groundwater samples collected in QS farm were higher than that of others, which was closer to surface waters. These groundwater isotopic signatures from three farms (HH, QF, QS) were used to identify the groundwater-surface interaction and the δ^2H-$\delta^{18}O$ plots of groundwater are shown in Figure 12. The aquifer of HH and QF farms is confined (District II) and that of QS is partly unconfined (District III). The groundwater in HH and QF farms was more depleted in heavy isotopes than the surface water, indicating that lateral groundwater flow probably dominates the groundwater recharge, and that interaction between groundwater and surface water does not occur. This is in accordance with groundwater levels in HH and QF farms which show similar changes with overall water table decline but with intra-annual fluctuations observed with the groundwater exploitation.

However, a distinctive isotopic feature was found in the QS farm. Groundwater was enriched in ^{18}O as compared to HH and QF farms. This enrichment suggested that the aquifer in QS farm was probably influenced by vertical infiltration, and there exists a relatively strong connection between groundwater and the surface water. QS Farm is located close to the Bielahonghe River (S3 with $\delta^{18}O$ of -9.6‰ and δ^2H of -77.9‰), and groundwater levels decline in a moderate way with a negligible intra-annual fluctuation (Figure. 12).

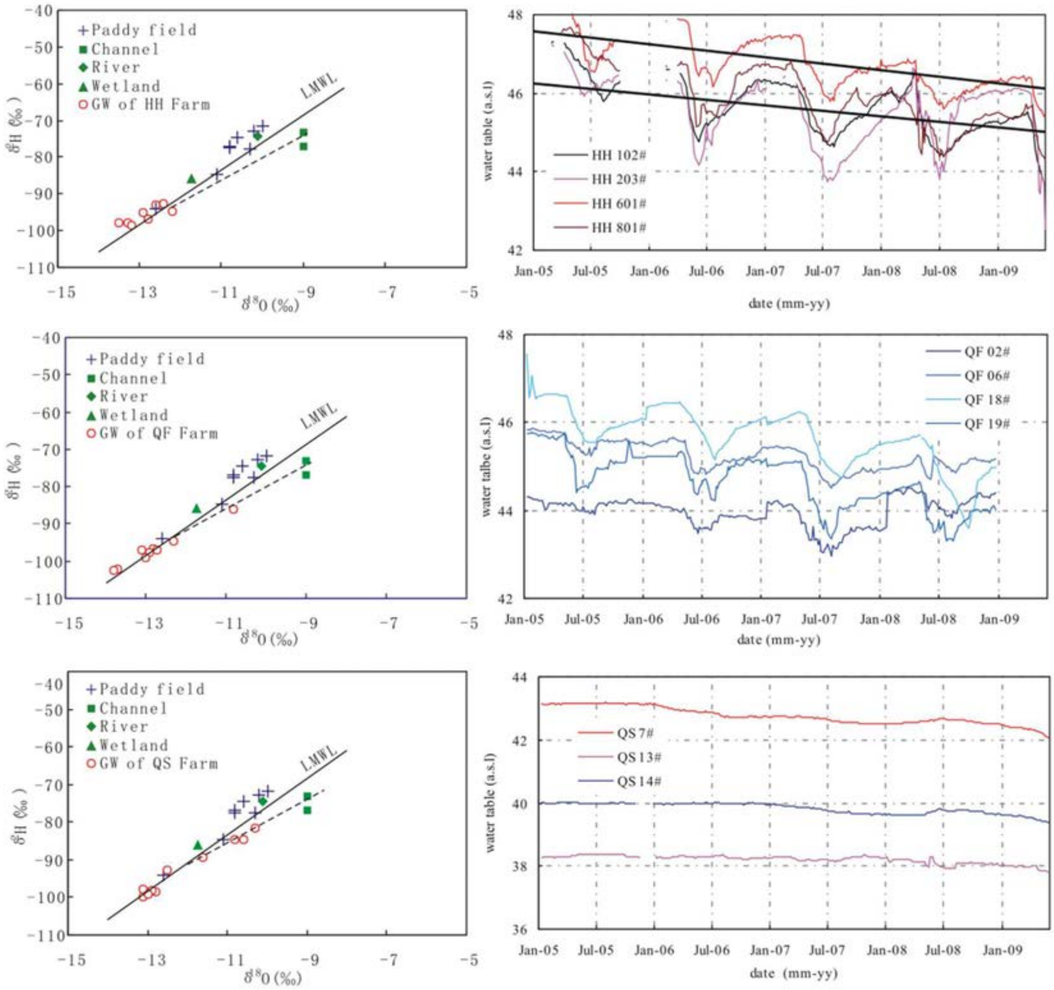

FIG. 12. Isotopes of precipitation and groundwater in Honghe (HH), Qianfeng (QF) and Qianshao (QS) farms and groundwater regime of the three farms

3.3. Groundwater residence time

3.3.1. Tritium contents

Tritium (^3H) content of groundwater was measured only for the three farms, representing confined and unconfined areas. The tritium contents of groundwater from the HH and QF Farms in the confined area (district II) ranged from <1.0 TU to 2.2 TU with groundwater depth ranging from 18 to 120 m. However, tritium contents of groundwater from the QS Farm in unconfined area (district III) ranged from <1.0 to 71.3 TU with groundwater depth ranging from 20 to 72 m.

Tritium, forming part of the water molecule and carrying the information on the water molecules themselves, is one of the most important transient and ideal tracers used in hydrological research [12]. Tritium contents of Qiqihar station (near the study area with attitude of 47°23'0") displayed a similar range to the Ottawa station (in Canada with latitude of 45°19'12") during the overlapping period (Figure 13). Both of the tritium records were taken from IAEA network (http://isohis.iaea.org). Due to the latitudinal banding characteristic, the precipitation tritium record of Ottawa can be used as the input function of tritium in precipitation in the Sanjiang Plain.

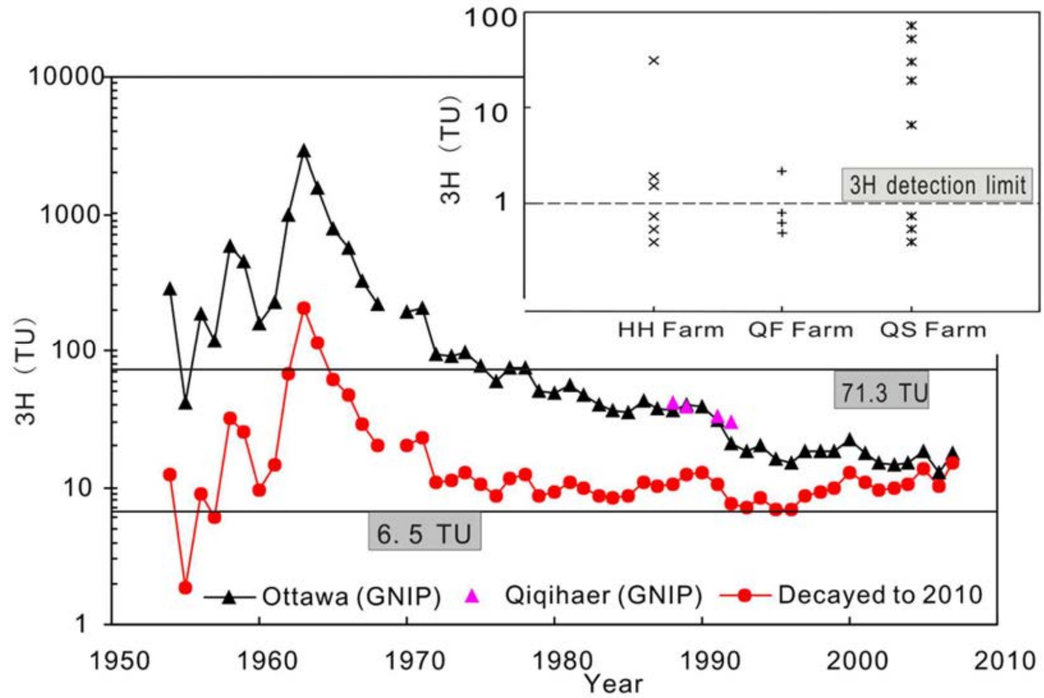

FIG. 13. The precipitation ^3H input from 1954 to 2007 and the decayed value for 2010

Current atmospheric level of tritium is around 10TU (Tritium Unit). Groundwater recharged before the bomb peak should have tritium decayed to below 6.5TU (Figure 13). Those samples higher than this value are considered recharged after the "bomb test", or 1960. Tritium in groundwater from HH and QF farms shows low levels, with narrow ranges of <1.0-1.9 TU and <1.0-2.2 TU, respectively, indicating that groundwater in HH and QF farm is older than 50 years. Groundwater in QS farm shows a wider range of variations in tritium (<1.0-71.3 TU), but levels of tritium are related to the sampling locations. Samples with high levels of tritium (6.5-71.3 TU) are shallow groundwater collected near the river, and those collected away from the river deeper groundwater samples showing low levels of tritium (<1.0 TU). For example, the ^3H concentration of 29.9 TU in sample QS2, clearly indicating that there was a young (post-bomb-peak) component derived most probably from infiltration of modern precipitation.

This location dependent tritium concentrations suggest that groundwater near the river has relatively short residence times. The distribution of tritium in three farms suggested that aquifers contain pre-modern water, but they are recharged by modern water near the river where better hydraulic connections are developed.

3.4. Radiocarbon age of groundwater

Groundwater ^{14}C was measured for samples selected from the three districts. Samples FJ02, FJ14, HC03, HG 01, HG10 and QS represented the unconfined aquifer, and DX02, DX12, HH01, HH02, QF01 the confined aquifer. The highest value was found in the shallowest well (sample QS01 with well depth of 20 m) and lowest value was found in the deepest well (sample FJ14 with well depth of 152 m).

Radiocarbon analyses for 11 groundwater samples were shown as percent modern carbon (pmC) where the range is from 30.7 to 98.4 pmC. The ^{13}C values are in the range of -13.5‰ and -20.1%, indicating that they were less affected by carbonate dissolution and the silicate weathering is the dominant process [13].

However, accurate ^{14}C age estimation depends on the knowledge of initial ^{14}C content, geochemical system and data availability. Plotting the ^{3}H value plotted versus the ^{14}C activity, however, can give a good indication of initial activity [14]. Below the ^{3}H detection limit, the initial ^{14}C content can be considered as the initial value. This method could reduce uncertainties of initial ^{14}C estimates during recharge processes affected by temperature, pH, CO_2 partial pressure, soil context, and the effects of plant photosynthetic cycles on ^{13}C content. From such an analysis (Figure 14), an upper limit of the initial ^{14}C activity of about 80 pmC is obtained. Using this value, the ages of groundwater were determined by the ^{14}C dating method. Generally, the ^{14}C ages of groundwater ranged from modern to 7910 years. The age of groundwater in the confined aquifer was older than that of groundwater in the unconfined aquifer in the same depth range, due to modern recharge by precipitation to the later one.

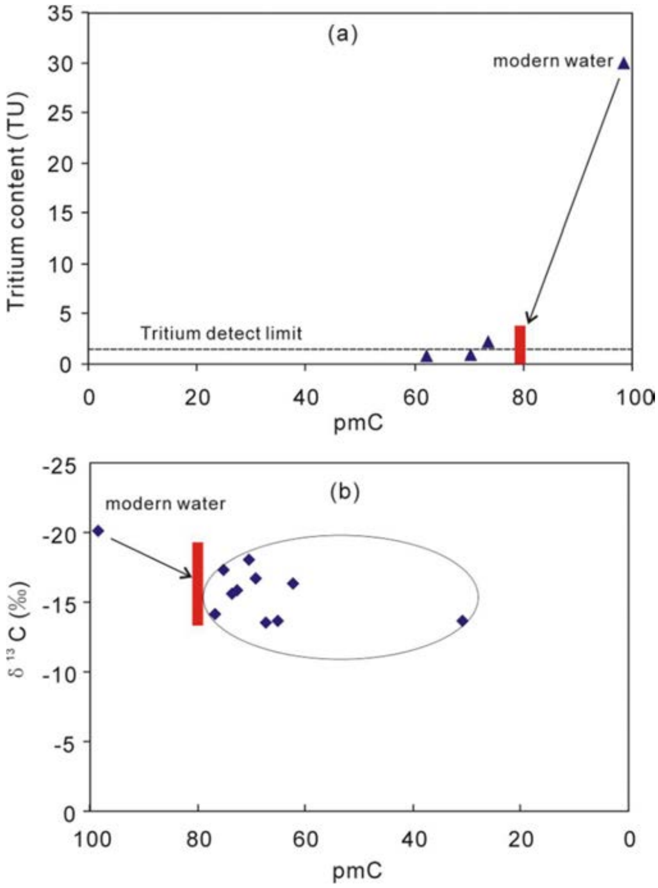

FIG. 14. Groundwater inorganic evolution and its implication for initial ^{14}C content. (a) Once below the ^{3}H detection limit, the initial ^{14}C content can be considered as the initial value; (b) The ^{13}C content is relative stable except for the sample with very high ^{14}C content.

3.5. Implications on agricultural sustainability

In the rice growing season, groundwater is pumped from the aquifers to the surface for paddy irrigation, which flows afterwards into a small drainage channel from the paddy field and finally discharged into the river. Compared with the elevated NO_3 concentrations in some shallow groundwater samples, the significantly low levels of NO_3 in river water indicates that the water quality enhancement services have been performed by the natural wetlands [15,16], which is defined as "wetlands function" [17]. It is evident that wetlands in Sanjiang Plain are rather efficient in nutrient retention, and the nitrogen loading is still below the capacity of wetlands. High efficiency nutrient retention of the catchments would attribute to the high coverage of natural wetlands in Sanjiang Plain. Natural wetlands cover about 13% of the catchment area. A large body of literature indicates that a significant increase of water quality at the catchment scale will be found when wetlands accounts for about 2-7% of the total catchments [18, 19].

From a sustainability perspective, the most optimal location or spatial arrangement of agricultural land in wetlands catchments seems to be the most effective tool to prevent the deterioration of water quality [14]. Reclamation of wetlands for agriculture near the river should therefore be strongly discouraged: firstly, riparian zone should be restored due to its wetland function, which can reduce the nutrient load of through-flowing water by removing NO_3 from surface water and subsurface runoff; subsequently, because of the coarse sediment beneath the riverbed, surface water is easily infiltrated to the aquifer and riparian zone is vulnerable to pollution.

Integrated use of groundwater and surface water is ideal for the farms that are located in areas within district II, where local recharge to groundwater is rather limited so water table decline is expected to grow fast. Ground regime needs to be monitored regularly in order to ensure a better management scheme for groundwater use.

4. CONCLUSIONS

Stable isotopes, tritium, radiocarbon and water chemistry data have enabled clarification on the interaction between groundwater and surface water in the wetland ecosystem under agricultural transformations, using Sanjiang Plain, NE China as an example.

Results show that the interaction pattern varies tremendously over the region as hydrogeological conditions change, which control the interaction between groundwater and surface and consequently groundwater depth and quality. High tritium, nitrate and evaporative isotopic signature in the unconfined aquifer suggest that surface water can easily infiltrate into shallow groundwater in districts I and III. On the contrary, in the confined aquifer of district II, since groundwater resources in the confined area are derived from lateral flow, renewal of groundwater is in the time scale of thousands of years. Local vertical recharge to groundwater is limited and fast decline of water table is anticipated with the irrigation practices.

Our results have significant implications on wetland conservation and agriculture sustainability in a wetland terrain. More strict measures are needed to protect groundwater quality in localities of districts I and III, where high nitrate concentrations are found. For district II, integrated use of surface water together with groundwater is optimal solution to the fast decline of water table and to ensuring water supply for agricultural irrigation and prevention of groundwater from being contaminated.

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REFERENCES

[1] LIU, Y., et al., Land use/cover changes, the environment and water resources in northeast China. Environ. Manage. 36 (2005) 691–701.
[2] Statistical Yearbook of Heilongjiang Province, (2011).
[3] LIU, X.T., MA, X.H., Effect of large-scale reclamation on natural environment and regional environmental protection in the Sanjiang Plain. Scienta Geographic Sinica. 20 (2000) 14-19.
[4] HUANG, Y.A.O., Marshland conversion to cropland in northeast China from 1950 to 2000 reduced the greenhouse effect. Global Change Biology 16 (2010) 680-695.
[5] LIU, X.T., MA, X.H., Natural environmental changes and ecological protection in the Sanjiang Plain. Science, Beijing (in Chinese) 2002.
[6] LI, Y., et al., The Landscape Pattern and Ecologic Effect of the Marsh Changes in the Sanjiang Plain. Scientia Geographica Sinica 6 (2002).
[7] XIE，W.H., Investigation on the ground of Sanjiang Plain in Heilongjiang Province. Heilongjiang Agricultural Sciences 2 (2009) 141-143.
[8] QIAN，Z.Y., Strategic studies of water-soil resources configuration, ecology and environment protection and sustainable development in Northeast China. Beijing：Science Press, (2007) 26-26.
[9] LI, Y.Y., Study on the Status and Distribution of Soil Nutrients in Songnen and Sanjiang Plains in Heilongjiang Province. Heilongjiang Agricultural Sciences. (2010) 25-28.
[10] CRAIG, H., Isotopic Variations in Meteoric Waters. Science, 133 (1961) (346) pp
[11] ROZANSKI, K., L. Araguas-Araguas, and R. Gonfiantini, Isotopic patterns in modern global precipitation. Climate Change in Continental Isotope Records 78 (1993) 1-36.
[12] EDMUNDS, W.M., Geochemistry's vital contribution to solving water resource problems. Appl. Geoch. 24 (2009) 1058-1073.
[13] VERHAGEN, B.T., ET AL., Radiocarbon and tritium evidence for direct rain recharge to ground waters in the northern Kalahari. Nature 249 (1974) 643-644.
[14] VERHOEVEN, J.T.A., ET AL., Regional and global concerns over wetlands and water quality. Trends in ecology and evolution 21 (2006) 96-103.
[15] ZEDLER, J.B., Wetlands at your service: reducing impacts of agriculture at the watershed scale. Frontiers in Ecology and the Environment 1 (2003) 65-72.
[16] MANDER, U., et al., Purification processes, ecological functions, planning and design of riparian buffer zones in agricultural watersheds. Ecological Engineering 24 (2005) 421-432.
[17] MALTBY, E., Functional assessment of wetlands: towards evaluation of ecosystem services. Woodhead Publishing Ltd. (2009).

[18] MITSCH, W.J., et al., Reducing nitrogen loading to the Gulf of Mexico from the Mississippi River Basin: Strategies to counter a persistent ecological problem. BioScience 51 (2001) 373-388.

[19] ARHEIMER, B., et al., Integrated catchment modeling for nutrient reduction: scenarios showing impacts, potential, and cost of measures. AMBIO: A Journal of the Human Environment 34 (2005) 513-520.

ASSESSMENT OF IMPACTS OF LAND-USE ON WETLAND HEALTH IN LESOTHO: MORPHOLOGICAL PROPERTIES AND SOIL NUTRIENT CHANGES IN TWO CONTRASTING WETLANDS

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Abstract

Wetlands occupy an estimated 96,381 ha in Lesotho and support more than 300,000 households through agriculture and inland fishery activities. Managing wetlands for maximising benefits is an important task for natural resource managers and policy makes in Lesotho. This study was carried on two wetlands located in two agro-ecological zones of Lesotho (*Ha-Matela* in the Foothills and *Thaba-putsoa* in the Mountains of Maseru). The objective of the study was to evaluate the effect of morphological characteristics on soil nutrient changes and selected physico-chemical properties in these wetlands. Soil data from wetlands collected and were analyzed using standard procedures. Subsequently, data collected were subjected to statistical analysis. Results showed that both wetlands still maintain their morphological properties, typical of wetland soils. The mean soil properties varied widely across sites and year and they varied from moderate to high. Significant differences were observed only between total sand, soil organic carbon, available phosphorus and bulk density. The study showed that land use and land management practices in the catchment influenced the soil physio-chemical characteristics. From the study, it is therefore recommended that the *Ha-Matela* wetland should be protected from excessive utilization and appropriate policies implemented to protect the natural resources in order to spare them for future generation.

1. INTRODUCTION

In Lesotho wetlands are located in rangelands and provide services to local communities in terms of grazing, water provision and medicinal plants [1]. Two wetland types unique to Lesotho are the mires and tarns and are reported as being threatened with degradation due to overgrazing and mismanagement [2]. One of the most important effects of wetlands in the landscape is to take-up water and to prolong river flows [3]. Their ability to store and slowly release water after storms not only prevents flooding, but also helps to keep streams flowing when they might otherwise be dry thus also maintain aquatic resources through much of the year. Because of their relatively high soil moisture and nutrient levels, wetlands often provide premium locations for cropping compared with surrounding landscapes, and are thus favoured places for cultivation, particularly in the drawdown period and dry season [4,5].

Wetlands produce great quantities of food that attract many animal species. The complex, dynamic feeding relationships among the organisms inhabiting wetland environments are referred to as food webs. The combination of shallow water, high levels of inorganic nutrients, and high rates of primary productivity (the synthesis of new plant biomass through photosynthesis) in many wetlands is ideal for the development of organisms that form the basis of the food web [6].

Wetlands are also critical to mitigating climate change and they have an important and underestimated role in both carbon storage and the regulation of greenhouse gas emissions [7]. Wetlands, such as mangroves and floodplains, can play a critical role in the physical buffering of climate change impacts.

Hydrology plays a critical role in wetland development and ecosystem structure and functions [8]. The hydrology of wetlands is largely controlled by precipitation and evapotranspiration. Even slight changes in hydrology may result in significant alteration of wetland processes, species composition and ecological functions [9]. Climate change and its potential hydrological effects are increasingly contributing to uncertainties on future demand and availability of water [10].
Investigations on the effects of climate change on wetlands have become the global priority area of research and development. It is believed that climate change will have its greatest effect on wetlands by altering hydrologic regimes. Any alterations of these regimes will influence biogeochemical and hydrological functions in wetland ecosystems, thereby affecting the socioeconomic benefits of wetlands that are valued by humans.
Wetlands are primarily valued for water supplies for agriculture, domestic purposes, and industrial needs and for commercial fishery. However, Solomon et al., [11] showed that there is growing scientific evidence that human-induced climate change affect the functioning of wetlands and their socio-economic benefits. Climate change-induced effects in Lesotho are expected to have a far-reaching regional impact on regional fresh water resources as the country forms major source of fresh water and drainage areas extending into the Atlantic basin through South Africa, Namibia and Botswana [12].
As one of the earth's most important freshwater resources wetlands are also the most threatened due to inadequate water holding capacities, excessive withdrawal, pollution by sewage and sludge, eutrophication, leached fertiliser and insecticides [13].
However if the rate of input of sediment, organic matter, nutrients and other natural or manmade contaminants exceeds the functional capacity of a given wetland to absorb and transform, then one would expect contaminants to be passed along to adjacent streams or lakes. An important point regarding wetlands and water quality is the proximity to aquatic systems (streams and lakes) and this is a critical factor that must be addressed when prioritizing management activities. Wetlands adjacent to streams and lakes will provide the most immediate water quality benefits. The major impacts to wetlands adjacent to cultivated uplands are increased pond levels immediately after rainfall events, increased sedimentation and increased nutrients. Water quality impacts begin with the loss of capacity for wetland soils to stabilize sediment deposits adequately. Associated effects are related to organic matter, nutrients, pesticides and other chemicals that are intricately associated with chemically active clay-sized particles. Rather than being transformed in the wetland, they pass through to streams and lakes, where they contribute to eutrophication or conditions toxic to aquatic organisms [14].
A better understanding of relationship between human activities and water chemistry is needed to identify and manage sources of anthropogenic stress in wetlands. Water quality in an aquatic ecosystem is determined by many physical and biological factors. The addition of nutrients and changes in water, salinity levels and land use due to agriculture, human settlements, and small industries may induce reversible or irreversible ecological changes in wetlands [15]. In Lesotho, wetlands are increasingly utilised for house utilities and livestock watering. grazing causes vegetation removal, homogenisation of the plant communities and introduction of invasive species together constituting real threats to the biodiversity of wetlands. Unrestricted livestock grazing in riparian habitats also increased sedimentation, a common nonpoint source pollution [16, 17]. The excessive sediment loading serves as a pollutant and negatively affects stream biota: It fills stream pools, alters hydrologic channels, and covers rocky stream bottoms [18]. Another detrimental consequence of grazing on wetlands is trampling. Taboada et al., [19] found that in riverine wetlands soil infiltration rates were much lower in cattle grazed areas than

ungrazed. Soil structural stability also decreased due to trampling as the soil was pulverised and soil aggregates were destroyed.

Wetland losses in Lesotho are quite evident in all the four agro-ecological zones (AEZ) particularly in the mountain AEZ. A large number of wetlands in Lesotho exist in the mountain AEZ which forms the largest part of the country and is heavily used for livestock grazing. The wetlands in this AEZ are subjected to intense livestock pressure and many of them are already showing high levels of degradation such as erosion resulting from overgrazing i.e. animals, human pressure and poor land management practices have combined to expose many of the country's wetlands to severe forms of degradation. The occurrences of extreme events such as droughts and floods have been on the rise world-wide and these are speculated to be the result of global climate change. Lesotho is already experiencing high temperatures; low and uneven distribution of rainfall with frequent occurrence of droughts. These conditions pose a serious threat to wetlands which are already severely impacted.

The overall objective of the study was to assess the current status of two wetlands in two AEZs of Lesotho in terms of their soil physico-chemical characteristics and to evaluate possible impacts of climate change on these wetlands. The specific objectives of the study are to (1) assess and describe the soil physicochemical and morphological properties of two wetlands, (2) assess the likely impact of climate trend (Rainfall and Temperature), and (3) to suggest plausible management strategies and efforts that can be used to enhance ecosystem services provided by wetlands in the Kingdom of Lesotho.

2. MATERIALS AND METHODS

2.1. Study sites

The study was carried out on three wetlands located separately in three AEZs of Lesotho namely the Mountains (Thaba-Putsoa), the Foot-Hills (Ha-Thetsane) and the Lowlands (T'sakholo) (Table 1).

TABLE 1. TYPES OF WETLANDS AND THEIR GEOGRAPHY

Agro-ecological zones (AEZ)	Site	Typology of wetlands	Elevation	Co-ordinates (UTM)†	Level of impact	Sediment loads
The Mountains	Thaba-putsoa	Lacustrine	2638m	3256612.20; 608767.30	Pristine	Low
The Foot-Hills	Ha-Thetsane	Riverine	1750m	3265594.8; 557984.9	High	High
	Ha-Matela	Riverine	1820m	3261705; 581192.44	Medium	Medium
Southern Lowlands	T'sakholo	Lacustrine	1570m	3493961.8; 531469.7	High	High

The Thaba-Putsoa is located 70 kilometres to the southeast of the capital Maseru and is situated in the Mountain agro-ecological zone at an elevation of 2638 msl (Fig. 1). Topography is steep rolling and it is characterised by very low temperatures in winter ranging between – 8 °C to 7 °C with frequent occurrences of snow. Mean annual temperatures range between – 8 °C to 30 °C

(Table 2). Rainfall occurs predominantly between October and April ranging between 1000 mm and 1300 mm annually. Lithosols are the major soil group found in this area [20].

The soils in this area are fragile and have thin horizon of rich black loam except in valley bottoms. Vegetation of the study area can be classified under Afroalpine Grassland Zone.

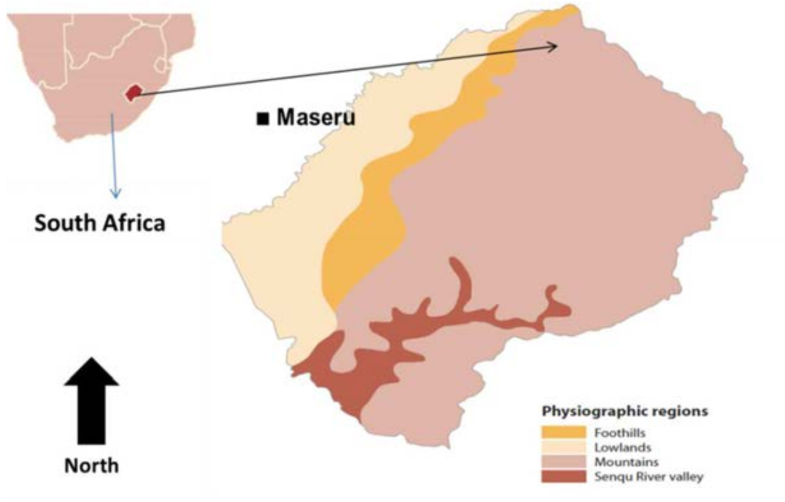

FIG.1. Agro-ecological zones of wetlands in Lesotho

Ha Thetsane estate is located in western part of Maseru at an of altitude 1 510 msl. The digital elevation model is shown in Figure 2.

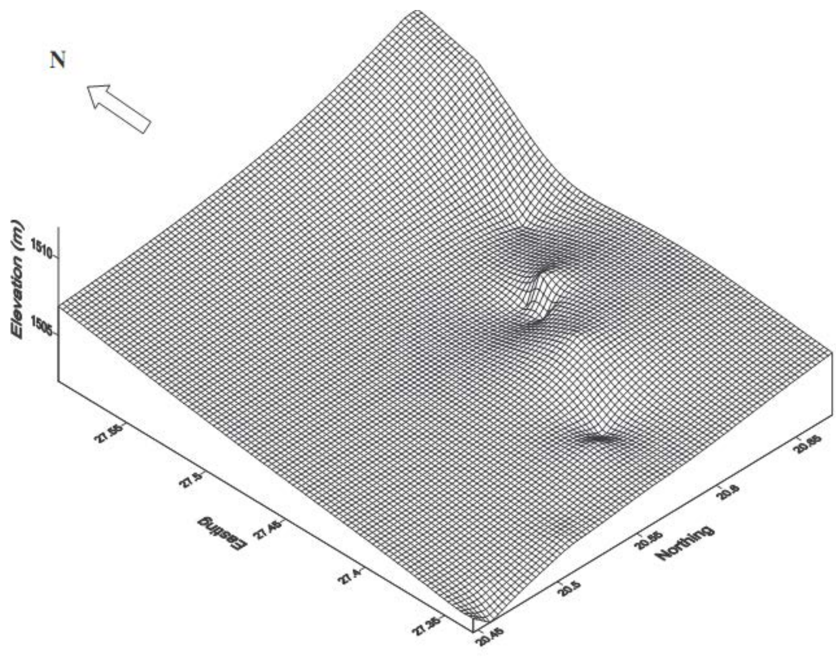

FIG 2. Digital elevation model of the Ha Thestane

It is situated in the lowlands of Lesotho below the scarp formed by the Clarens.
The climate is mild, with hot summer days relieved by cool nights. Precipitation falls mostly from October through April. Average temperatures range from 14° to 28°C in January and from -1° to 16°C in July. The lowlands expose the earliest rocks, the Burgersdorf Formation, Early Triassic Period of the Mesozoic Era on their riverbeds. These are the polycolored mudstones, siltstones, and sandstones. The cliff forming Clarens Formation is the youngest of the sedimentary deposits and is prominent as the tan colored cliffs and plateaus of the lowlands. Maseru soil series originate from the Burgersdorf, Molteno and Elliot formations characterized by nearly level to gentle sloping terrain.
The Ha Matela wetland is a Riverine wetland situated in the foothills AEZ at an elevation of 1820 msl. The geology of this land is Lesotho formation and it falls within the Afromontane Grassland zone characterised by grasses. The land use types found in this area are pasture and cropping and as such, this area is medially impacted upon by people and animals.
The T'sakholo area is located in Mafeteng district approximately 76 kilometres to the south of the capital Maseru. Rainfall occurs predominantly between October and April ranging between 600 to 900 mm annually. The soils in this area are highly erodible duplex soils with extensive gully formation and desertification and characterised by sandy-clay texture. The vegetation cover in this area mainly consists of typical grass species. The mean annual rainfall and temperature for T'sakholo are provided Table 2.

TABLE 2. MEAN ANNUAL RAINFALL AND TEMPERATURE FOR THABA-PUTSOA AND T'SAKHOLO

Year	**Thaba-Putsoa**			**T'sakholo**		
	Rainfall (mm)	Minimum Temp (°C)	Maximum Temp (°C)	Rainfall (mm)	Minimum Temp (°C)	Maximum Temp (°C)
1997	59.8	6.0	18.93	51.0	8.5	22.53
1998	60.3	6.5	19.68	68.0	8.7	23.22
1999	41.2	6.7	19.52	44.2	8.8	24.09
2000	56.4	6.3	18.37	73.9	8.3	21.31
2001	69.8	6.2	18.69	96.7	8.5	22.35
2002	42.7	6.0	18.80	74.5	8.3	22.95
2003	43.8	6.3	19.58	42.3	8.7	24.00
2004	53.2	5.7	16.95	39.2	8.9	23.04
2005	48.1	6.4	19.56	49.6	9.1	23.13
2006	72.8	6.4	18.49	83.0	8.4	21.75
2007	46.7	6.2	19.27	45.4	8.3	23.30

2.2. Field studies

At each location two transects ranging between 250-700 meters long were chosen and profile pits (> 0.50m) dug and described. Drainage, vegetation, land use and degree of erosion data from these sites were recorded for general site description: Soil properties including colour, horizon boundary, structure, consistency, texture, mottles and roots density were also described: Soil samples were taken from the horizons in each profile pit and the maximum depth of soil examination was made at different depths and pits were dug at intervals of 50 cm. The soils were classified using the criteria set by USDA Soil Taxonomy. From each study area soil samples were collected from the last horizon up to the first horizon, packed, labelled and transported to the laboratory for routine soil analysis. The soil samples were air-dried for 48 hours and crushed to pass through a 2 mm sieve, and analyzed for the following parameters.

2.3. Laboratory analysis

Particle size was determined by standard hydrometer method. Soil pH was determined in water and KCI (1:2.5 soil water ratio). Soil organic carbon (SOC) was determined by standard analytical method. Assuming that soil organic matter (SOM) contains 58% carbon SOM was calculated by multiplying SOC by a factor 1.724. Available phosphorus (P) was determined using standard method. Soil Organic carbon pool (SOC-pool) was calculated using a relationship given by Wairiu and Lal [21].

$$SOC_{pool} = d \times BD \times C_{content} \quad (1)$$

Where C-pool (kg C m^{-2}), d: soil layer thickness (m), BD: bulk density (kg m^{-3}), C-content (g g^{-1}).

The cation exchange capacity (CEC) was determined using Ammonium acetate at pH 7. The base cations (Ca^{2+}, Na^{+}, Mg^{2+} and K^{+}) were extracted using 1N NH_4OAc and the filtered extracts were determined with Atomic Absorption Spectrophotometry.

2.4. Statistical analysis

Statistical analyses were performed using the General linear model procedure (Prog GLM) [22]. Mean comparison was carried out using Duncan's Multiple Range Test (DMRT) at 5% significance level. The Stepwise Multiple Regression Analysis (SMRA) (Prog Reg procedure) [22] was used to determine which soil physico-chemical properties accounted for most variation and thus would require outmost management for sustenance of the wetlands.

3. RESULTS AND DISCUSSION

3.1. Morphological characteristics of study area

The morphological properties of study sites in terms of land use, colour, horizon boundary, texture, structure, consistency, concretions, roots and drainage varies extremely with each other. In Thaba-Putsoa soils exhibited mainly black and very dark greyish colours while in T'sakholo most horizons had light-brown to brown and reddish brown colours. Many of the horizons in Thaba-Putsoa have hues with low chroma (≤ 3) colours which reflect poor drainage or seasonal mottling. Features such as grey or low chroma observed in Thaba-Putsoa indicate soil wetness brought about by oxidation-reduction cycles due to ground water fluctuations. Wetland soils in a reduced state typically have a dark, gray, mottled appearance with two or less chroma colours. In T'sakholo soil colour ranged between light-brown to brown and reddish brown with hues 2.5Y, 7.5YR and 10YR with chroma values ranging between 2-8. These colours indicate a relatively high amount of iron-oxide which may be due to the parent material. Boundaries ranged mostly between wavy and clear on both sites with mainly sandy-loam texture in Thaba-Putsoa and a fairly variable texture (sandy, sandy-clay, Silt-loam and clay) in T'sakholo. Structure was found to be mainly crumb and single-grain in both sites with more concretions in T'sakholo than in Thaba-Putsoa. Both sites have many roots in the top horizons but decreases down the profile. Drainage is poor in T'sakholo and moderately drained in Thaba-Putsoa [20].

3.2. Physico-chemical characteristics of soil from study areas

The main physico-chemical properties of the soils of the study sites are presented in Tables 3 and 4. The soil particle size distribution for Thaba-Putsoa soil showed that the sand content is high and ranged from 51.3 to 78% (Table 3). These soils are commonly found throughout grasslands and are stony, gravelly and are usually on steep hillsides and embankments with very low fertility and sparse low vegetation that is used for grazing.

TABLE 3. PHYSICO-CHEMICAL PROPERTIES OF THABA-PUTSOA RANGELAND SOILS

Profile pits	Horizon	Sand	Clay	Silt	SOC	CEC¶	EC	pH_w	Av-P
		--------------%-------------				meq/100 g soil	ds/m		mg/kg
				Transect 1					
1	1	57	12	31	11.1	0.53	0.09	4.97	2.16
2	1	59	14	27	25.2	0.53	0.09	4.88	2.734
	2	69	10	21	20.97	0.90	0.07	5.25	4.15
	3	63	14	23	10.88	0.51	0.08	5.14	1.32
3	1	59	6	35	20.28	0.56	0.09	4.83	2.02
	2	61	12	27	19.07	0.49	0.08	4.83	1.64
4	1	59	12	29	24.75	0.62	0.1	5.34	1.97
	2	75	10	16	27.19	0.64	0.09	5.4	0.4
	3	67	10	23	23.29	0.83	0.08	4.97	3.28
5	1	68	12	20	22.19	0.70	0.09	4.8	2.03
	2	67	8	25	17.85	0.70	0.07	4.99	1.43
	3	65	6	29	21.56	0.70	0.07	4.94	1.05
	4	61	12	27	27.51	0.83	0.07	5.18	1.7
6	1	69	8	23	26.68	0.44	0.11	4.99	2.19
	2	65	10	25	15.18	0.51	0.1	5.12	1.54
7	1	57	14	29	11.11	0.49	0.18	4.39	3.66
	2	51	12	37	13.77	0.44	0.13	4.58	2.85
				Transect 2					
1	1	62	12	26	16.34	0.40	0.1	4.49	2.52
	2	70	10	20	4.43	0.38	0.12	4.99	1.7
	3	75	8	17	15.14	0.61	0.09	5.03	1.92
2	1	64	4	32	6.53	0.68	0.12	4.93	2.36
	2	74	10	16	14.53	0.54	0.1	5.06	2.46
3	1	66	4	30	13.36	0.62	0.13	5.09	1.1
	2	78	10	12	15.26	0.56	0.11	5.11	0.51
4	1	64	12	24	0.6	0.41	0.11	4.69	1.76
	2	74	2	24	18.6	0.75	0.2	5.1	2.14
5	1	66	4	30	15.47	0.64	0.1	5.27	1.21
	2	74	16	10	14.56	0.73	0.09	5.7	1.97

The sand content in T'sakholo soil ranged from 34. 72 – 64.72% (Table 4). The T'sakholo wetland exists in the lowland AEZ and this zone is characterised by highly erodible duplex soils with a sandy texture. The locations of both wetlands are believed to have influenced the high sand content observed on these study sites. This finding may also explain the reason for moderately higher values of BD which vary with depth on both sites.

TABLE 4. PHYSICO-CHEMICAL PROPERTIES OF T'SAKHOLO SOIL (TRANSECT 1)

Profile Pits	Horizon	Depth	pH_w	Sand	Silt	Clay	SOC	EC	CEC	Av-P
		cm		-------------%------------				ds/m	meq/100 g soil	mg/kg
1	1	30	7.05	51	30	19	1.74	0.07	0.53	2.08
	2	15	7.86	41	36	23	2.48	0.07	0.47	6.52
	3	15	7.92	41	38	21	1.59	0.13	0.48	0.01
	4	15	6.25	49	26	25	3.38	0.21	0.61	0.01
	5	15	6.52	49	30	21	1.97	0.21	0.52	1.49
2	1	30	7.56	41	36	23	0.31	0.07	0.63	0.01
	2	30	7.54	51	26	23	1.59	0.68	0.67	0.6
	3	15	7.65	41	38	21	0.7	0.15	0.69	0.79
3	1	15	7.45	41	38	21	1.46	0.06	0.48	3.86
	2	15	7.35	41	36	23	1.59	0.05	0.40	1.19
	3	15	7.96	51	28	21	2.1	0.05	0.34	0.5
4	1	15	7.65	51	26	23	3.51	0.09	0.77	0.01
	2	15	7.45	41	38	21	2.74	0.12	0.51	5.33
	3	15	7.54	37	23	41	1.72	0.25	0.45	2.87
5	1	15	7.56	55	22	23	2.74	0.06	0.60	2.08
	2	30	7.52	41	36	23	1.59	0.07	0.25	6.33
	3	30	7.42	41	36	23	2.23	0.14	0.36	1.09
6	1	15	7.34	41	36	23	4.02	0.19	0.42	9.68
	2	15	7.33	51	28	21	1.51	0.22	0.31	5.63
	3	15	7.46	51	30	19	1.46	0.17	0.35	5.73
7	1	15	7.55	41	36	23	1.23	0.29	0.46	9.19
	2	15	7.46	59	22	19	2.23	0.22	0.62	0
	3	15	7.74	51	28	21	1.97	0.19	0.46	0
	4	15	7.32	41	36	23	1.85	0.29	0.72	0.1
8	1	25	7.05	55	30	15	0.31	0.29	0.67	3.65

The silt clay ratio ranged from 1.14 to 3.88 in most pedons on both sites, indicating that the soils are slightly weathered [23]. Results have also indicated that the (SOM)/silt+clay ratio is very low in T'sakholo compared to Thaba-Putsoa. The soil pH recorded for Thaba-Putsoa for all pedons was acidic in water (4.39 – 5.4) while soil pH recorded for T'sakholo indicated an almost neutral level in water (6.8 – 7.89). The SOC varied irregularly with depth in all pedons on both sites, though at T'sakholo it was very low (0.31 – 7.9%) and high in Thaba-Putsoa (0.6 – 27.19%). According to VandenBygaart et al., [24], the variability in soil organic carbon (SOC) usually changes with depth through the profile and much of this variability is a consequence of the characteristics of the soil horizons in the soil profile (e.g., their permeability and thickness, the degree to which SOC concentration differs between horizons). Assuming that soil organic matter contains 58% carbon, SOM was found to be much higher at Thaba-Putsoa, ranging between 1.03% and 46.88% in all pedons. This is attributed to low temperature and high moisture content which are characteristic of this study area, hence lowering the rate of plant residue decomposition. However, at T'sakholo, SOM is relatively low (0.54 – 13.78%) and this condition may be due to little plant residue accumulation as the site is extensively being used for grazing.

The SOC-pool varied considerably between the two study sites but was generally high in Thaba-Putsoa ranging between 29 – 170.31 Kg C/m^2 while in T'sakholo it was low ranging between 0.41 – 58.58Kg C/m^2 (Figure 3). The cation exchange capacity (CEC) varied across all pedons and did not show any significant pattern on both sites. The electrical conductivity (EC) was within the range of 0.07 and 0.18 dS/m (Thaba-Putsoa) and 0.07 – 0.9 dS/m (T'sakholo) indicating low salt concentration. Available phosphorus (P) was significantly low on both sites ranging between 1.1 to 4.15 mg/kg (Thaba-Putsoa) and 0.01 mg/kg to 9.68 mg/kg (T'sakholo). Water quality improvements are achieved by removal of plant nutrients such as phosphorus (P) and so the low P content observed in the soils of these two wetlands is indicative of low nutrients input, especially from agricultural fields.

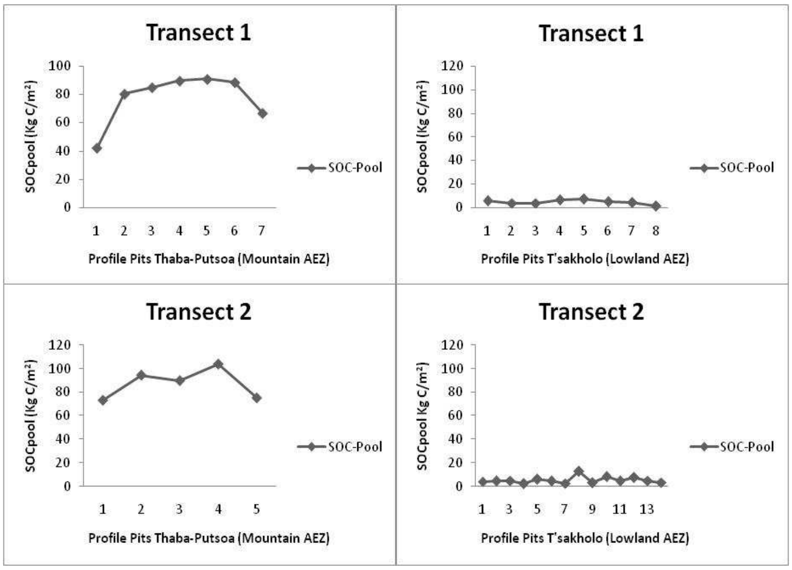

FIG. 3. SOC pool across pits on both sites

The Duncan Multiple Range Test (DMRT) at 5% significant level was run to evaluate variation of the physico-chemical properties across all pits on both Thaba-Putsoa and T'sakholo. There seem to be less variation with regard to all the physico-chemical in Thaba-Putsoa especially in second transect. Even though texture is highly dominated by sand particles in both transects its content together with that of silt and clay are significantly less different in the first transect. Generally there is no great variation in the second transect of this site except that electrical conductivity (EC), pH (water & KCI) and delta pH (ΔpH) are significantly different across all pits. Significant differences are observed in the first transect. The contents of sand, silt and clay particles are significantly different in all pits. Soil organic matter (SOM), EC, pH (water and KCI) and delta pH differ significantly across all pits. The carbon pool (C-pool) is not significantly different. The cation exchange capacity (CEC), base cations (Ca^{2+}, Na^+, Mg^{2+} and K^+) and available phosphorus (P) are not significantly different in all pits on both transects of this site.

In T'sakholo site high variability exists as indicated by the DMRT at 5% significant level. Soil pH in water is significantly different across all pits while delta pH (ΔpH) is not significantly different. The silt particles including silt:clay ratio are not significantly different in all pits of the first transect but the other particles (sand and clay particles) including silt:clay ratio are significantly different in all pits. The contents of SOC, SOM, EC, available phosphorus (P) and

C-pool are also significantly different in all pits. The CEC in the first transect is significantly different in all pits while in second transect it is not significantly different. The base cations (Na^+, Ca^{2+} and K^+) in the first transect are significantly different in all pits except Mg^{2+} which is not significantly different. In the second transect however Mg^{2+} is generally not significantly different. Available P is significantly different in the second transect while it is not significantly different in the first transect across all pits.

Generally there is great spatial variability of the soil physico-chemical properties within both study sites. Wetlands are complex ecosystems exhibiting considerable spatial variability and anthropogenic activities affect self-organization in wetlands, in turn affecting spatial patterns of soil properties such as pH, nutrient concentrations, and SOM content. Considerable differences in soil parameters were also recognized within the wetland portion, even though the change in elevation was minimal. Soils are characteristically heterogeneous and it is therefore common to find soils within a small area showing wide variations in properties such as pH, texture, structure and CEC [25]. These variations may not be surprising when one considers the fact that soils are formed as a result of interaction between the soil forming factors combining in different ways. In addition there are many anthropogenic factors that can be responsible for variation in soil properties and these include factors such as grazing, bush burning and cultivation. In Lesotho grazing and burning especially in wetlands is common.

The stepwise multiple regression analysis was carried out to find out which of the soil physico-chemical properties need to be managed effectively for sustenance of the two wetlands. Results show that of all properties the most important for sustainability of these wetlands is SOC (Tables 5 and 6). The partial R^2 for SOC at T'sakholo wetland is 94% (Table 10) showing that SOC is very important and contributes 94%. This indicates that there is a need to increase the OC content in this wetland in order to manage it effectively. Also in Thaba-Putsoa the partial R^2 for SOC is 44% (Table 5) followed by BD (10%). These results indicate that in order to sustainably manage the Thaba-Putsoa wetland SOC and BD must be improved and most importantly it must be improved at T'sakholo. This measure can successfully be achieved by allowing accumulation on plant residue and managing properly the grazing of animals on these sites. A Basotho traditional management approach called Maboella can be very effective as it allows pastures to be properly rested.

TABLE 5. SUMMARY OF STEPWISE MULTIPLE REGRESSION ANALYSIS FOR PHYSICO-CHEMICAL PROPERTIES THABA-PUTSOA

Step	Variable entered	Variable removed	Number in Vars in	Partial R^2	Model R^2	C(p)*	F value	Pr> F
1	OC		1	0.442	0.442	893.01	50.77	< 0.0001
3	BD		3	0.101	0.864	175.07	46.03	< 0.0001
5	EC		5	0.019	0.908	103.49	12.37	0.0008
7	Silt		7	0.007	0.925	79.31	5.60	0.0213
8	Sand		8	0.023	0.947	42.03	24.87	< 0.0001
9		EC	7	0.001	0.946	42.46	1.54	0.2195
11	Clay		7	0.015	0.958	21.94	20.70	< 0.0001
13	C-pool		7	0.006	0.961	16.78	8.77	0.0044
14	Av-P		8	0.004	0.965	12.77	5.64	0.0209

TABLE 6. SUMMARY OF STEPWISE MULTIPLE REGRESSION ANALYSIS FOR PHYSICO-CHEMICAL PROPERTIES OF T'SAKHOLO SITE

Step	Variable entered	Variable removed	Number in Vars in	Partial R^2	Model R^2	C(p)	F value	Pr> F
1	OC		1	0.94	0.941	208.49	2352.26	< 0.0001
2	Sand		2	0.03	0.971	30.72	151.00	< 0.0001
3	K		3	0.0012	0.972	25.74	6.12	0.0145
4	CEC		4	0.0010	0.973	21.90	5.21	0.0239
5	Silt		5	0.0008	0.974	19.22	4.29	0.0400
6	Clay		6	0.0020	0.976	8.94	12.11	0.0007
7		Sand	5	0.0002	0.976	7.96	1.00	0.3185

3.3. Morphological characteristics of wetland soils

3.1.1. Ha-Matela and Ha-Thetsane wetlands

Soil morphological properties of two wetlands of Ha-Matela that include pores, concretions, structure, texture, colour, horizon depth and boundaries showed that Transect one has thick horizons and the dominant structure in this transect is granular structure. Texture varies across pits and there is a common distribution of pores in all pits and horizons. In Transect 2, horizon depth ranges from shallow (10 cm) to thick (55 cm) with clear boundaries and loamy texture. The dominant structure is granular and there is a common distribution of pores throughout the pits and horizons. Transect 3 horizons' depth ranges from 5 to 51 cm with top soils being shallower (5-25 cm) and sub soils being thicker (50-51 cm). Horizon boundaries are clear. Texture is loamy and structure varies both within and across pits. The proportion of pores varies across pits. Along the stream, the top soils are of medium thickness while the sub-soils are very thick and this is thought to be due to continued soil erosion when the stream overflows. Most horizon boundaries are smooth and texture is mostly loamy. The dominant soil structure is crumb with few to common pores.

The mean separation across pits and transects showed that relatively higher bulk densities (1.32–1.35 g/cm^3), low base cations especially of Na, Ca and K which ranged between 0.001-0.012 cmol/kg for soils in this wetland. The SOC-pool ranged between 74.46–133.70 g/cm^2. Similarly, the results of the micronutrient contents across pits and transects showed that soils contain varying concentrations of micronutrients within and across transects. Copper content ranges between 1.29 and 4.31mg/L, iron content ranges between 10.46 and 34.79 mg/L, zinc content ranges between 0.10 and 0.72 mg/L and manganese content ranges between 11.28 and 33.13 mg/L.

In Ha-Thetsane wetland results showed higher concentrations of Na, K, P and N suggesting that this wetland is highly polluted when compared with those from the Mountains and Foot-Hills agro-ecological zones (Table 7). When compared to the WHO standard, results showed that P and K contents are gradually approaching the toxic levels, hence, industries releasing pollutants into the wetlands should be alerted.

TABLE 7. SELECTED SOIL PROPERTIES EXAMINED IN THE POLLUTED WETLANDS, LESOTHO

	Upstream			Down Stream			WHO
	1	2	3	1	2	3	
pH-w	7.42	7.63	7.37	7.55	7.80	7.61	6.5-9.2
pH-K	7.31	7.16	7.15	7.23	7.47	7.44	na
Sand (%)	57.50	32.84	54.84	55.72	48.39	44.39	na
Clay (%)	20.67	30.67	22.44	20.00	24.67	20.89	na
Silt (%)	21.83	22.72	32.28	24.84	26.94	34.72	na
EC (ms/cm)	0.92	0.41	0.89	0.92	1.11	1.49	1.5
P (mg/kg)	3.47	2.72	2.44	5.80	4.02	4.63	5
TN (%)	0.02	0.02	0.02	0.06	0.04	0.08	50
Org C (%)	1.05	1.12	1.12	0.74	0.76	1.06	na
CEC (Cmol/kg)	0.81	0.77	0.72	0.72	0.75	0.75	na

WHO= World Health Organization standard; na= not available

3.1.2. Comparison of wetland characteristics and dynamics

The Ha-Matela wetland has been subjected to cropping and continuous grazing for over a decade. Soil morphological properties showed thick top soils (10-30 cm) for the wetland and are dominated by granular structure with a common distribution of pores. Texture varies within and across pits and horizons in all transects but transect one and two are dominated by loamy soils whereas transect three is dominated by a clayey texture. Along the stream, the top soils are of medium thickness (15-40 cm), while the sub-soils are very thick (30-94 cm). Most horizon boundaries are smooth and texture is mostly loamy. The dominant soil structure is crumb with few to common pores.

In Thaba-putsoa wetland, morphological characteritics are different from Ha-Matela the wetland soils in Thaba-putsoa exhibited mainly black and very dark greyish colours. As discussed previously features such as grey or low chroma observed in Thaba-putsoa indicate soil wetness brought about by oxidation-reduction cycles due to ground water fluctuations.

Information for *Ha-Matela* (HM) in 2009 on texture (sand, silt and clay) ranged between 8.00% (silt) to 64.7% (clay) with means of 30.4±1.49% (sand), 27.5±1.34% (silt) and 42.4±1.78% (clay). The coefficient of variation (CV) of textural component varies between 26-30.7%. In addition, the silt:clay ratio has a mean of 0.74±0.07 and ranged between 0.15-1.93. Soils with silt/clay ratios below 0.15 are of old parent materials while soils with silt/clay ratio above 0.15 are of young parent materials, therefore HM soils are of young parent material. Also soils with silt/clay ratios less than 0.25 are at an advanced stage of weathering while those with ratios greater than 0.25 indicate a low degree of weathering hence HM soils are of low degree of weathering. Moreover soil organic carbon (SOC) ranged between 0.01 to 0.04% with a mean of 0.02±0.01%. Generally the SOC as well as soil organic matter (SOM) are very low at *Ha-Matela* because of continuous utilization (i.e. high anthropogenic activities which -increased livestock, watering and grazing). The Bulk density (BD) is slightly high and varies between 1.22 -1.42 g/cm^3 with the mean of 1.29±0.01 g/cm^3 and CV of 3.88%. In addition, the available Phosphorus (AP) ranged between 0.07-0.74 mg/kg which is very low, suggesting that the soil is acidic with the pH of 3.55-6.06. Also C-pool is very low in *Ha-Matela* ranging between 0.129-0.724 kg C/m^2 with the mean of 0.387±0.01 kg C/m^2 and CV of 48.9%.The higher the CV, the more variable the property. The base cations (Na, Mg, Ca and K) have means of 0.77±0.03 cmol/kg, 1.18±0.06cmol/kg, 0.45±0.03 cmol/kg and 0.38±0.01 cmol/kg, respectively. The CEC is also low (i.e.0.77±0.01 cmol/kg). The soil organic matter: silt+clay ratio an indicator of the rooting volume of plants [25,26] ranged between 0.1 to 0.35 with a mean of 0.06±0.01. The importance of the soil organic matter (SOM) in soils cannot be overemphasized, especially in the tropics [26]. In the Pampa region of Argentina, for example, SOM was reported as being is strongly related to clay + silt content of soil and for any given soil texture [26]. In addition, Quiroga, et al., [26] showed that the SOM/clay + silt (SSCR ratio) and SOM/clay were identified as important land qualities that may be promising tools for assessing soil quality, at least by relating these to nutrients derived mainly from organic matter mineralization. The SSCR ratio is reported to be high in soils with good conditions for plant growth, whereas in deteriorated soils values will be low [26]. They [26,27] have also reported that the yields of crops are closely related to soil texture.

Results for *Ha-Matela* (HM) in 2010 showed that the sand, silt and clay, content has means of 22.31±, 36.3± and 41.6±% respectively and the CV varied between 6.14 – 13.2%. Again, the silt/clay ratio of the soil ranges between 0.72-1.14 with a mean of 0.88±0.05.This showed that the soil is of young parent material and with low degree of weathering. In addition, the SOC during 2010 also ranged between 6.21-9.62% with a mean of 7.33±0.32%. This might be connected with heavier livestock grazing in the area during the summer. The bulk density (BD), total N C-pool, and available P had means of 1.27±0.01 g/cm3, 0.33±0.01%, 13.9±0.60 kg C/m^2 and 0.12±0.01 mg/kg. The base cations (Ca and K) were relatively higher and ranged between 0.77 cmol/kg and 0.78 cmol/kg as well as between 0.24 cmol/kg to 0.72 cmol/kg. The CEC was very low and has means of 0.83±0.01. The SSCR in 2010 ranged between 10.68 and 18.69 with a mean of 14.88±0.83 (Table 5). This also suggests that these soils offers good conditions for wetland plants to thrive [26,27].

The summary statistics of Ha-Matela wetlands showed that the soil texture (sand, silt and clay) contents had means of 36.9±2.02%, 34.1±3.22% and 29±2.32% respectively. The CV for textural component ranged between 21.4-39.0%. The silt /clay ratio was ranged from 0.40-4.70. This was slightly high indicating low weathering. The SOM silt to clay ratio (SSCR) ranged between 0.03-0.08 with a mean of 0.06±0.003. The soil pH (water and KCl) is low (4.46-5.91) as well as the mean ranging between 0.17-0.18 meq/100 g. At low pH, the soil is reported to be dominated by acid cations which are Fe, Al and hydrogen, which lead to P and K being retained in the soil colloids. The SOC was found to range between 1.22-2.81% which may have resulted in the recorded low BD of 1.29-1.43 g/cm^3 with the mean of 1.34 g/cm^3 and the CV of 3.24%. Moreover, the C-pool was also very high varied between 30.1-182.8 kg/cm^2 with the mean of 100.8 kg/cm^2. This may have been as a result of heavier defecation of the livestock in the area during the summer of previous year. The base cations (Na, Mg, Ca and K) were very low with means of 0.03±0.02 cmol/kg, 0.15±0.02 cmol/kg, 0.008±0.001 cmol/kg, 0.03±0.02 cmol/kg. The C-pool is however higher at this site and ranged between 30-182.8 kg C/m^2 with a mean of 100.8±12.5 kg C/m^2. The silt: clay ratio is high and ranged between 0.40-4.76 with a mean of 1.46±0.29 and the SSCR is however low with a mean of 0.06±0.003.

the summary statistics for Thaba-putsoa showed that the clay content is very low ranging between 10.3-23.0%with a mean of 15.5±0.73%and the CV for the textural component ranged between 10.6-28.7%. The weatherability in terms of silt/clay ratio ranged between 0.70-2.84 which means that the soils were slightly weathered to and of young parent materials. The soil bulk density (BD) is a measure of wetness, volumetric water content and porosity and ranged between1.43-1.56 g/cm^{3}with a mean of 1.50±0.01 g/cm^3. The SOC varied between 3.00-16.0% with the mean of 6.34 and CV of 58.8%. The Available P (AvP) of the soil TP was found to be very low ranging from 0.01-0.05 mg/kg with the mean of 0.03 and the CV of 40%. The low SSCR indicate high SOM, therefore there is high level of N fertilization leading to high TN in the soil. In addition, the C-pool varied from 1.08-36.5 kg/cm^2 which is very high, with the mean of 13.9±1.725 kg/cm^2 and the CV of 61.9% moderate variability of soil properties.

The physico-chemical characteristics for *Thaba-putsoa* (TP) showed that the textural contents (sand, silt and clay) had means of 66.7±1.61%, 23.1±1.57% and 10.0±0.57%. The CVs of these variables varied between 9.0-21.2%. The result showed that the soil had acidic pH-water and KCl which ranged between 4.61 and 4.20. The SOC varied between 10.4-25.7% with a mean of 17.1±1.45% and the CV of 31.90%. The high SOC indicated low BD ranging from 0.11-1.60 g/cm^3, with the mean of 1.16 g/cm^3 and the CV of 42.5%. The SOC fluctuated irregularly in the soil horizons which is the indication of continuous deposition of SOM [25]. Like other years, the mean of SSCR ranged between 0.89±0.89 and the CV of about 33.40%. The C-pool is high and ranged between 0.19 and 1161.50kg C/m^2 with a mean of 739.4013.9±1.72 kg C/m^2 and CV of 33.40% which was high. High C-pool is indicative of little or no anthropogenic impacts.

The results of the mean separation for the two sites, (*Ha-Matela* and *Thaba-putsoa*) and sampling years (2010 and 2011) are presented in Table 9. Significant differences were observed only between total sand, silt:clay ratio, SOC, AvP and BD (*Ha-Matela*) and BD, pH-KCl, and AvP (*Thaba-putsoa*). Notably, in *Ha-Matela* wetland, the following soil properties (i.e. sand, silt: clay ratio, BD, AvP, C-pool and SSCR) had absolute increases of between +0.08 (6.34%) (BD) to +86.9 (625.2%), while others decline. In Thaba-ptusoa however, soil properties (i.e clay, BD, pH-water, pH-KCl, C-pool and SOM had absolute increase of between +0.07 (1.64%) (pH-KCl) to +725.5 (C-pool) and other soil properties declined. Decrease in the soil pH (water and KCl) may be attributed to water-logging during which the soil pH is reported to be acidic. Increase in the AvP may be attributed to high P that may be in the droppings of grazing-livestock coupled with fertilizers applied to the cereals planted at this site. High C-pool may be attributed to animal droppings, though samplings precluded areas that are heavily infested with animal droppings. In wetlands at *Thaba-putsoa*, though soils are acidic, the slight increase in the soil pH might be connected with increased native vegetation that abounds in this site. The higher C-pool may also be connected with the fact that these wetlands have little or no anthropogenic activities, and the native wetland vegetation were able to sequester carbon into the soils.

The results of the study have revealed that the two wetlands under this study have a high sand content and this is believed to be influenced by soil types found on both locations of wetlands. The results have also shown that the BD on both sites is moderately high and this observation is believed to be linked to the high sand content shown by the soils of the studied wetlands. Many factors contribute to high BD and one of them is grazing which is a dominant land practice in both wetlands especially T'sakholo (Lowland AEZ). Bulk density under grazed pastures was higher compared to nongrazed pastures and had a significant effect on organic carbon and total N contents in the surface soils.. It is also reported that grazing animals can alter the hydrology and the drainage pathways at a site by compacting the topsoil, which is indicated by increased bulk density and decreased macroporosity (MP).

The silt:clay ratio in both wetlands ranged between 0.63 – 5.79 (Thaba-Putsoa) and between 0.56 – 2.23 (T'sakholo) suggesting that weathering class according to [22] is between 3 – 1 (i.e. slightly weathered soils to non or weakly weathered soils). In terms of the SSCR, results showed that very low ratios 0.00 – 0.05 (T'sakholo) compared to 0.03 – 0.26 (Thaba-Putsoa) which is an indication that wetland soils located at the former site will have good conditions for plant growth.

According to [26], soils with high SSCR ratios were found to provide good conditions for plant growth. The pH was different between both sites. Both the soil organic carbon (SOC) and SOC-pool varied irregularly with depth in all pedons on both sites though at T'sakholo they were very low and high in Thaba-Putsoa. This variation may be attributed to climate, vegetation type and grazing intensity as these factors vary greatly between the two study sites. It is reported that there is a strong correlation between climate and soil carbon pools where organic OC decreases with increasing temperatures [28,29], because decomposition rates (microbial respiration) double with every 10ºC increase in temperature [30]. Thus decomposition rates in wetlands are a function of climate (temperature and moisture enhanced microbial activity) and the quality (chemical composition) of the organic matter entering the system. Thaba-Putsoa is characterised by low temperatures for most of the year because it exists on the mountain AEZ, this may explain why there is high C-pool in this area compared to T'sakholo where mean annual temperatures are always high because it exists in the lowland AEZ. Furthermore several interacting variables can contribute to SOC heterogeneity at the landscape scale due to factors such as erosion and redistribution of soil [31,32], soil bioturbation by plants, animals, and microfauna [33] including landuse and land-use cover changes. Results further showed that SOM was much higher at Thaba-Putsoa ranging mostly between 1.03% and 46.88% in all pedons. However at T'sakholo SOM is relatively low (0.54 – 13.78%) and this condition may be due to little plant residue accumulation as the site is extensively being used to grazing.

The results also showed that low contents of exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and low CEC as well, this may be attributed to the parent material or weathering status of the soil. The EC for both sites indicated low salinity levels. Wetland salinity by itself probably is not a critical water quality issue, however, because of the connection among wetlands, streams, lakes and aquifers, it may be a first indicator of possible changes to these water resources [14]. According to the Cowardin system for wetland water salinity classes EC values less than 0.8 ds/m indicate fresh water thus the studied wetlands can be classed as fresh water systems. The fact that these wetlands exist on two different AEZ and they are not adjacent to cultivated lands nor at a disposal of hazardous materials explains the reason why their EC values are so low. This cenario may also explain the low available P observed in both wetlands. Since both wetland soils have a sandier texture they are rendered ineffective in retaining (sorbing) large amounts of P. This is because it is reported that wetlands with more finely textured soils are able to sorb more P than those with coarser substrates [34]. Phosphorus is often the limiting nutrient (extremely low) in freshwater systems and its supply is important in regulating primary productivity [35]. However too much P in a water body can result in an overproduction of algae, leading to the severe water quality problem.

4. CONCLUSION

The study examined physicochemical properties of two wetlands situated on two different AEZ of Lesotho. Climate change impact was examined for these two wetlands using climatic data (rainfall and temperature) from LMS. The following conclusions have been reached from this study:

a) There is a distinction of the textural composition in wetlands soils between those in the mountain AEZ and lowland AEZ.
b) Wetland soils in the mountain AEZ have more acidic soil reaction than those in the lowlands AEZ and very low nutrient status coupled with low CEC.

c) Wetlands in mountain AEZ have high SOC and SOM and compared to wetlands in the lowland AEZ.
d) There is great spatial heteroginity of soil physico-chemical properties within wetlands and this heteroginity can have important consequences on wetland biota and biochemistry

Climate change is likey to impart severely on already diminishing wetlands of Lesotho with potentially disastrous consequences on water projects in Lesotho. Many of wetlands in Lesotho are found adjacent to rangeland or pastureland, as opposed to cultivated crops. In these areas, grazing animal management influences soil condition and resultant impacts to wetlands. Depending on its intensity, grazing can increase species diversity and diversity along environmental gradients, as well as increase wetland plant community boundary definition. Grazing also decreases dead plant matter, and overgrazing can lead to decreased primary production. Overgrazing and severe trampling will reduce plant cover and increase the amount of bare soil. Therefore stocking rate management is critical to maintenance of wetlands existing in rangelands and if well-managed wetlands in these areas can exhibit high-quality conditions. [35]

Wetlands are very crucial because of their ability to sink CO_2 and this implies that their management should be paramount as their degradation can be a positive feedback to global climate change. A range of human actions, including policies, strategies, and interventions should be employed to address specific issues that will lead to healthy wetlands conditions. This may involve governance, institutional, legal, technical, economic, or behavioral changes and may operate at local or micro, regional, national, or international level (or a combination of these) and at various time scales.

REFERENCES

[1] BISARO. A., Managing ecosystem services at multiple levels: Institutional change in the wetlands of the Lesotho Highlands. Potsdam Institute for Climate Impact Research, Germany (2008).

[2] FRENKEN, K., AND I. MHARAPARA (eds), Wetland Development and Management in SADC Countries: FAO (2001).

[3] BEGG, G., The Values and Benefits of Wetlands. National Centre for Tropical Wetland Research (2001).

[4] KOTZE, D. C., WETLANDS AND WATER QUALITY ENHANCEMENT. Mondi Wetlands Project (2000).

[5] TURPIE, J., BARNES, J., ARNTZEN, J., NHERERA, B., LANGE, G.M., and BUZWANI, B.. Economic value of the Okavango Delta, Botswana, and implications for management. Okavango (a) Delta Management Plan (2006).

[6] Technical Aspects of Wetlands: Wetland Hydrology, Water Quality, and Associated Functions, Virginia Carter. United States Geological Survey Water Supply Paper 2425. Available on-line at http://water.usgs.gov/nwsum/WSP2425/hydrology.html.

[7] THE CONVENTION ON BIOLOGICAL DIVERSITY, Year in review 2007, 52.

[8] SUN., G, MCNULTY, S.G., AMATYA, D. M., SKAGGS, R.W., SWIFT, L.W., JR, SHEPARD, J. P., and H., RIEKERK, A comparison of watershed hydrology of coastal forested wetlands and the mountainous uplands in the Southern US. Journal of Hydrology (2002) 92-104: Elsevier.

[9] ACREMAN, M.C., and MILLER, F.. Hydrological impact assessment of wetlands. International Symposium on Groundwater Sustainability (ISGWAS) (2006) 225-255.
[10] MILLENNIUM ECOSYSTEM ASSESSMENT,. ECOSYSTEMS AND HUMAN WELL-BEING: WETLANDS AND WATER Synthesis. World Resources Institute, Washington, DC (2005)
[11] SOLOMON, S., QIN, D., MANNING, M., MARQUIS, M., AVERYT, K., M., TIGNOR, M.B., MILLER, H.L.J. and Z. CHEN 2007. Climate change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the intergovenmental panel on climate change.
[12] MARAKE, M.V., LOWRY, M. P., and S., RAMASAMY, Strengthening Capacity for Climate Change Adaptation in Agriculture:Experience and Lessons from Lesotho; Food and Agriculture Organization of the United Nations, Rome (2011).
[13] RAMANA, P., S.K., and, G. SANKRI. 2008. Evaluation of Water Quality of MagadiWetland in Gadag District, Karnataka. Sengupta, M and R. Dalwani (Eds). Proceedings of Taal: The 12 th World Lake Conference: (2007) 355-359.
[14] SEELIG, B. and S. DEKEYSER, Water Quality and Wetland Function in the Northern (a) Prairie Pothole Region. NDSU Extension Service, North Dakota State University (2006)
[15] PIYANKARAGE, S.C, MALLAWATANTRI, A.P., MATSUNO, Y. and K.A.S. PATHIRATNE. Human impacts and the status of water quality in the Bundala RAMSAR wetland lagoon system in Southern Sri Lanka. Kluwer Academic Publishers.
[16] NERBONNE, B.A. and B. VONDRACEK, Effects of local land use on physical habitat, benthic macroinvertebrates, and fish in the Whitewater River, Minnesota, USA. Environ. Manage. 28 (2001) 87-99.
[17] SOVELL, L.A., VONDRACEK, B., FORST, J.A., and K.G. MUMFORD, Impacts of rotational grazing and riparian buffers on physicochemical and biological characteristics of southeastern Minnesota, USA, streams. Environ. Manage. 26 (2000) 629-641.
[18] LYONS, J., WEIGEL, B.M., PAINE, L.K., and D.J. UNDERSANDER, Influence of intensive rotational grazing on bank erosion, fish habitat quality, and fish communities in southwestern Wisconsin trout streams. J. Soil Water Conservation. 55 (2000) 271-276.
[19] TABOADA, M.A., R.S., LAVADO, SVARTZ, H., and A.M.L. SEGAT, Structural stability changes in a grazed grassland natraquoll of the Flooding Pampa (Argentina. Wetlands 19 (1) (1999) 50-55.
[20] MATS'ELA, K., OLALEYE, A.O., RATHEBE, K., RASEKOLELE, M., NTLELE, M., PHEKO T. AND ODUNUGA, B.O. Morphological Properties, Soil Nutrient Changes in Selected Properties in Two Contrasting Wetlands in Lesotho. Communications in Soil Science and Plant Analysis (2015). DOI:10.1080/00103624.2015.1081692.
[21] WAIRIU, M., and R. LAL. Soil Organic Carbon in Relation to Cultivation and Topsoil Removal on Sloping Lands of Kolombangara, Solomon Islands. Soil & Tillage Research 70 (2003) 19-27.
[22] STATISTICAL ANALYSIS SYSTEM.. SAS/STAT, Version 8e, Statistical Analysis Institute, Inc., Cary, New Caldonia.
[23] NAPOLI, R.A., EDOARD , C.C and G.D., EGIDIO, Using Pedostratigraphy Level and GIS to generate 3 Dimensional Maps of the Quartenary Soil Cover and Reclamation of Geomorphological Developemnts of the Montaq Sensor(Central Italy) (2006) 167-175.
[24] VANDENBYGAART, A.J., GREGORICH, E.G., ANGERS, D.A., and B.G. MCCONKEY, Assessment of the lateral and vertical variability of soil organic carbon. Canada Journal of Soil Science, (2007) 433 - 444.

[25] OLANIYAN, J.O., and OGUNKUNLE, A.O., An assessment of the accuracy of soil map of Kwara state, Nigeria. Nigerian Jounal of Soil Science, 17 (2007)
[26] QUIROGA, A., FUNARO D., NOELLEMEYE, E., and N. PEINEMANN, Barley yield response to soil organic matter and texture in the Pampas of Argentina. Soil & Tillage Research 90 (2006) 63–68. Elsevier B.V.
[27] OLALEYE, A.O and SEKALELI T.Spatio-Temporal Variability of Rainfall and its Impact on Selected Wetlands of Lesotho, XXV International Union of Geodesy and Geophysics (IUGG), Melbourne Australia. June 28-7th July, (2010)
[28] KIRSCHBAUM, M.U.F.. The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic storage. Soil Biology and Biochemistry 27 (1995) 753-760.
[29] ALBRECHT, S. L., AND P. E. RASMUSSEN. 1995. Soil quality and soil organic matter. 101-104. In Columbia Basin Agricultural Research Annual Report. Spec. Rpt. 946. Oregon State University in cooperation with USDA-Agricultural Research Service, Pendleton, OR.
[30] HARTEL, P.G., The soil habitat, 26-53, In Principles and Applications of Soil Microbiology. 2nd edition. D. M. Sylvia, J. J. Fuhrmann, P. G. Hartel, and D. A. Zuberer, Eds. Pearson Prentice Hall. Upper Saddle River, New Jersey (2005).
[31] GREGORICH, E.G., K.J., GREER, D.W., ANDERSON, and B.C., LIANG,. Carbon distribution and losses: erosion and deposition effects. Soil Tillage Res. 47 (1998) 299–310.
[32] LOBB, D.A., and R.G. KACHANOSKI,.Modeling tillage erosion in the topographically complex landscapes of southwestern Ontario, Canada. Soil Tillage Res. 51 (1999) 261–277.
[33] GABET, E. J., REICHMANN, O. J. AND SEABLOOM, E. W. 2003. The effects of bioturbation on soil processes and sediment transport. Annu. Rev. Earth Planet. Sci. 31: 249–273.
[34] DARKE, A. K. and M. R. WALBRIDGE. 2000. Al and Fe biogeochemistry in a floodplain forest: implications for P retention. Biogeochemsitry 51: 1-32.
[35] PANT, H. K. and K.R. REDDY. Phosphorus sorption characteristics of estuarine sediments under different redox conditions. Journal of Environmental Quality 30 (2001) 1474-1480.

THE EFFECT OF LAND USE PRACTICES ON POLLUTION DYNAMICS IN THE HIGHLANDS OF UGANDA

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Abstract

Smallholder agriculture in sub-Saharan Africa is characterized by poor farming practices, soil erosion, sediment deposition in low land areas and the subsequent water pollution. This study was designed to link agricultural management practices to nutrient and water use efficiencies of lowland wetland rice production systems, soil and water quality. Four major issues studied in this project include (a) quantifying the magnitude of upstream erosion (b) determining sediment loading rates in the streams (c) estimating sediment deposition in wetlands, with a view of understanding retention capacities and (d) assessing fertilizer use efficiency under rice cropping. The study was carried out in Manafwa catchment (314 km^2) within Mount Elgon which is a trans-boundary ecosystem located in Eastern Uganda and Western Kenya. A combination of field data collection, the application of stable isotopic techniques and modelling with soil water assessment tool (SWAT) in a geographic information system (GIS) platform and a cost-benefit analysis were used for assessing rice wetlands for socio-economic and environmental benefits. The soils in the upland were predominantly Lixic ferralsols (33.3%) followed by Nitisols (19.7%). Mean annual rainfall in the region is over 1500 mm varying with altitude. Water levels in river Manafwa increased with rainfall and sometimes exceed 10.45 m with overflow and causing widespread floods in low lying areas. Pollution as measured by the turbidity of water in river Manafwa was highest during the rainy seasons. The observed average discharge of river into the wetland is 7.68 $m^3\ s^{-1}$ with an average sediment concentration of 160 g l^{-1}. Runoff source areas were not necessarily the sediment source areas (about 0.1% of the catchment contributes 30% of the runoff) and most of the runoff contributing areas (moderate to high yield) are located in the western part of the catchment. Sediment source areas are located in the south-eastern part of the catchment and about 20% of the catchment generates 70% of the sediments in River Manafwa. The average annual sediment yields from different hydrological response units were found to be high ranging from 5.73 to 241 Mg $km^{-2}\ yr^{-1}$ with an average of 45 Mg $km^{-2}\ yr^{-1}$ while the average soil loss and runoff from the catchment is moderate and averaged 43 t $ha^{-1}yr^{-1}$ for sediments. Sediment deposition in the rice wetland was estimated at 5.07 cm $m^{-2}\ yr^{-1}$. Nitrogen use efficiency was found to be highly dependent on water management and fertilizer application. Fertilized plots had the highest N use efficiency (51.1%) compared to the control (13.7%). Nitrogen use efficiency decreased as less water is present in the rice wetland. Fertilizer application to rice wetlands increased grain yields by 40% with a benefit to cost ratio of 2.54 compare to unfertilized fields with benefit to cost ratio of 2.22. For river Manafwa, there was a clear pattern of enrichment of oxygen-18 and hydrogen-2 in downstream water attributable to selective evaporation of lighter isotopes as the conditions become warmer in lowlands.

1. INTRODUCTION

Identifying and understanding the dynamics of pollution sources, pathways and sinks are important pre-requisites for the sustainable management of fragile ecosystems [1]. The need for knowledge and information increased as a result of the impact of climate change on land and water eco-systems. The requirement for appropriate mitigation and adaptation measures to buffer the populations and the landscape resources against the adverse impacts (flooding, soil erosion and agricultural productivity) of climate change is high. In Uganda, most fragile ecosystems including wetlands and mountain in the Eastern part of the country, are undergoing various forms of conversions and environmental degradation, threatening the sustainability of livelihoods of population [2] The knowledge on the nexus between the mountain and wetland ecosystems is important for identifying appropriate intervention for the sustainable use of land and water resources in these regions.

There was limited understanding of the relationship between anthropogenic activities and the functions of rice wetland systems in Manafwa catchment. Often the activities and hydrological processes that take place in the upper reaches of the catchment affect the downstream water storage, nutrient availability and dynamics. Systemic knowledge of the sources and sinks of water (e.g. magnitude, frequency, duration, timing, rate of the water flow regimes, nutrient and their cycling into and out of the system as influenced by upland activities is essential for making decisions for selection of sustainable management practices of these systems for conservation and reuse of water and nutrients. The objective of the project was to quantify water fluxes through these wetland areas; and to determine the capacity of these wetlands for water storage, assess nutrient/pollutant attenuation capacity and to understand the link between water and nutrient dynamics in wetlands and rice production.

The specific objectives of the study were to assess (a) erosion magnitude in the upstream (b) sediment loading rates in the streams (c) deposition in the wetland, with a view of understanding retention capacities within the catchment, and (d) fertilizer use efficiency under wetland rice. This study focused on an interlinked mountain-wetland ecosystem. To achieve the general objectives of the project, the project was partitioned into four phases each phase covering a one year period which had specific objectives/activities though some of the activities were overlapping as they have not been completed within the timeframe. The study was carried out over a period of five years from December 2008 to August 2013.

2. METHODS AND MATERIALS

2.1. Location

The project was carried out at Sinje sub-catchment, Manafwa Catchment, Mount Elgon, Eastern Uganda. Geographically, the study area lies between $1^0$07’07”N, $34^0$13’07”E and $1^0$07’24”N, $34^0$31’22”E. Mt. Elgon is a trans-boundary ecosystems located in both Eastern Uganda and Western Kenya (Figure 1).

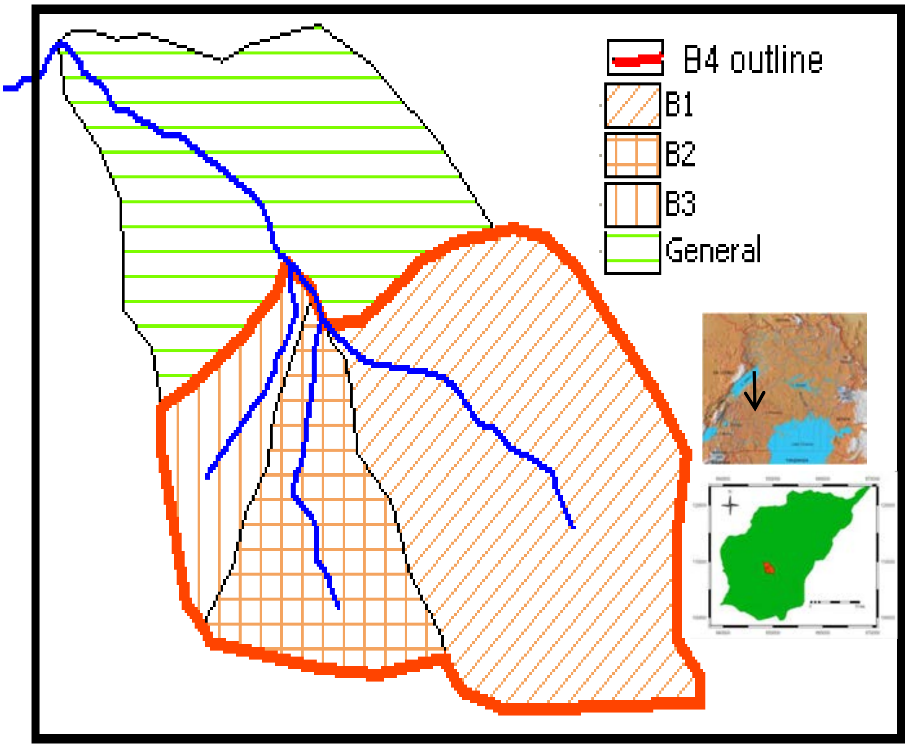

FIG.1. Location of the Sinje micro-catchment. Mt. Elgon and Manafwa Catchment are shown as inlets

The elevation of the catchment ranges from 1 240 to 1 560 m.s.l with a mean elevation of 1 401 m. The climate of Mount Elgon is classified as humid subtropical and is dominated by seasonally alternating moist south-westerly and dry north-easterly air streams. The rainfall distribution shows a weak bimodal rainfall pattern. Rainfall occurs between April to December, with June and July the lowest. Mean annual rainfall amounts over 1500 mm and is a function of altitude (Figure.2). The average minimum and maximum temperatures are 15 and 28^{0}C respectively for the catchment.

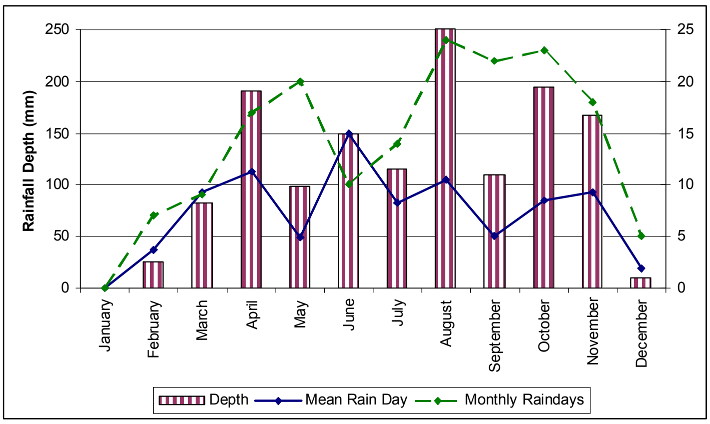

FIG. 2 Mean monthly rainfall total and rain days in 2007

2.2. Soil types and geology

According to the FAO classification the major soils of Manafwa catchment (Figure. 3) include *Nitisols (19.7%), Lixic ferralsols (33.3%), acric ferralsols (6.8%), petric plinthosols (29.3%),* and *gleysols(12.8%). Lixic ferralsols* in Manafwa is formed by the Bubutu and Bududa series and Tororo complex which are deeply weathered red or yellow soils derived from basement complex granites and/or Elgon volcanics. *Acric ferralsols* are represented by the Bubulu series and Mbale complex. These soils are red sand clay loam and occasionally laterized. The parent materials are Basement Complex mica schists/granites and amphibolites. *Nitisols* are represented by the Masaba, Bugusege and Benet series, and the Sipi catena. *Plintosols* are represented by Lwampanga series and Mazimasa complex and Buruli catena. The parent materials are lake deposits derived from/ and basement complex granites, gneisses, etc. The soils are reddish brown in colour, sandy loams and loams textured on laterite. *Gleysols* are basically peat or peaty sands and clays located in the valley.

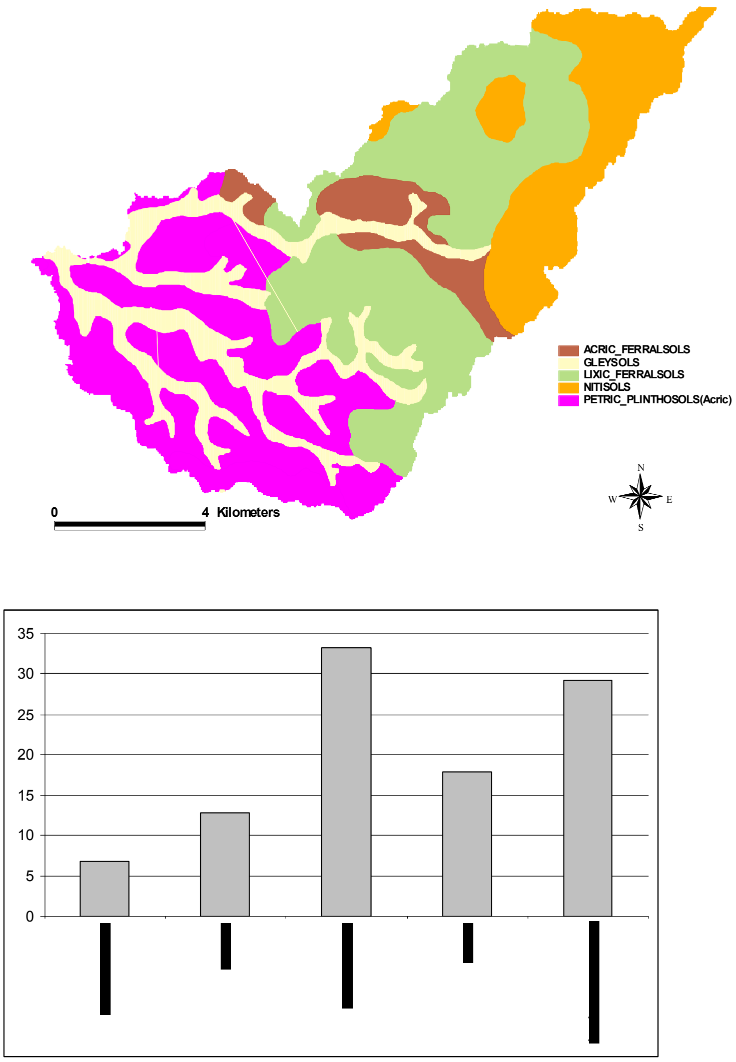

FIG. 3. Distribution of soil types and the area in Mount Elgon

2.3. Cropping systems and land use in the study area

The cropping system in the area reflects the montane farming system which is typical of Mt. Elgon with both annual and perennial crops. Many crops are grown owing to the climatic conditions and relatively fertile soils. The crops include coffee, banana, maize beans, potato, cassava, groundnut among others. Over 90% of the farmers practice intercropping due to land scarcity. There can be up to six intercrops on a single cropping field and annually there can be up to three crop cycles particularly for beans. The cropping and hydrological aspects from a baseline survey conducted in January 2009 are given in Table 1.

TABLE 1. DESCRIPTION OF SELECTED SITES AND LAND USES IN THE MANAFWA CATCHMENT

Location	Description
Wanende	• Rice and sugar cane are the major crops grown nearer the bank while maize and bananas appear the further one moves away from the banks. • Small stream wish water flowing at very low speed and cannot be used as source for domestic use unlike other locations • Base of stream is predominantly clay soil
Nambale	• Land use along the banks is mainly pasture land but with some scattered woodlots • The adjacent slopes have grazing land with some scattered shrubs at the middle slope and bananas at the bottom slopes
Mbale-Manafa district boundary	• A point where Manafwa district separates with Mbale • Land use is predominantly yams on one side and Eucalyptus woodlots on the other • Water level is similar to Wanende but stream base containing plinthic material instead
Manafa Bridge	• Intercrops of banana-coffee, bananas-cassava, sugarcane and vegetables such as cabbage, tomatoes are the mail crops grown • River shows evidence of flooding beyond permanent banks
Pasa junction	• Large tributary of R. Manafwa • Evidence of extensive sand extraction
Liso	• Also large tributary of R. Manafwa • Banks of streams mainly used for grazing with settlements in the further parts
Bugumanai Bridge	• Settlements very close to the riverbank of the stream • The banks are sharp and deep ($\underset{\sim}{}$2 m)

2.4. Water Inflows and Outflows

The water inflows and outflows are marked by the source(s) and mouth(s) respectively of river Sinje and its tributaries. To be able to quantify the contribution of a particular area within the watershed to sediment and nutrient loads, it is necessary to determine these parameters at the inflow and outflow points of the draining streams. For this reason, water samples were continuously be taken at the outlets of each tributary and at the mouth of river Sinje.

2.5. Field Measurements

2.5.1. Soil and water measurements

The monitoring of runoff and soil loss was undertaken at 12 geo-referenced sites within Sinje Sub-catchment. Geographical locations as well as the altitude of each site are given in Table 2. Four sites were used for monitoring total suspended solids (TSS) and discharge. These sites were also used for detailed monitoring and analysis of total nitrogen (TN) and total phosphorus (TP).

TABLE 2. LOCATIONS FOR RUNOFF AND SOIL LOSS MEASUREMENT

Site	GPS Reading	Altitude (M)	Slope Gradient (%)
1	0°59'05.06"N, 34°19'55.73"E	1280	32
2	0°59'04.15"N, 34°19'55.38"E	1289	32
3	0°58'55.16"N, 34°20'09.15"E	1318	24
4	0°59'09.88"N, 34°19'53.83"E	1268	22
5	$0^0$59'26.36"N, $34^0$19'57.30"E	1259	14
6	$0^0$59'26.84"N, $34^0$19'56.99"E	1259	12
7	0°58'56.82"N, 29°05'30.15"E	1287	31
8	0°59'05.29"N, 34°19'54.54"E	1290	31
9	$0^0$59'21.37"N, $34^0$20'06.00"E	1269	27
10	$0^0$59'21.37"N, $34^0$20'06.00"E	1279	26
11	0°58'54.02"N, 34°20'09.80"E	1318	13
12	0°58'53.76"N, 34°20'09.86"E	1309	14

2.5.2. Hydraulic conductivity of the wetland soils

The hydraulic conductivity of the soil of the wetland was estimated using the auger hole method, at three sites. An auger of 5 cm diameter was used to scoop soil in the wetland up to 2 m depth with minimum disturbance, and water was allowed to equilibrate with ground water table. The rate of water flow in the cavity was measured every minute up to equilibrium.

2.5.3. Erosion and sediment modeling

A GIS-based SWAT model has been used to simulate erosion and sediment patterns in Manafwa catchment [3]. The layers used in this simulation included: soil, land use/land cover, digital elevation model (DEM) and climate data. Soil data was obtained from the National Soils Laboratory at Kawanda; land use/land cover was clipped from the USGS data set; the DEM was generated from digitized contours of the area while climatic data was obtained from the Department of Meteorology. The model was calibrated using data observed from experimental plots as well as discharge data (1960-2009) obtained from the Directorate of Water Resources Management in Uganda.

2.5.4. Efficiency of N-fertilizer use in paddy rice experiment.

A factorial experiment was conducted in Doho rice scheme in the lower reaches of Manafwa catchment (Figure. 4). Two factors that include water management and nitrogen (N) fertilizer application were considered. The water management was at three levels namely: good, moderate and poor and two levels of N fertilizer application namely 120 kg/ha of urea (labelled with ^{15}N at 2% atom excess) and control with no fertilizer application (Table 3). Each treatment was replicated three times. Six micro plots each measuring 2 m^2, were for this purpose laid out randomly in 20 x 20 m^2 plots.

Parameters monitored in each plot include daily water levels, plant phonological characteristics, biomass and grain yields. At physiological maturity, sampling carried out for roots, shoot and un-milled rice grain. Soil samples were collected at two depths (0-15 and 15-30 cm) prior to planting and at harvest for N use efficiency determination (Table 3). The soil and plant samples were processed and sent to IAEA in Vienna, Austria for analysis of plant N, ^{15}N excess, plant C and ^{13}C. The fertilizer N use efficiency was calculated using the following equation [4];

$$\%Ndff = \frac{\%^{15}N\ atom\ excess\ of\ plant}{\%^{15}N\ atom\ excess\ in\ Fertilizer} \times 100 \qquad (1)$$

FIG. 4. Rice experiment in Doho wetlands

TABLE 3. SAMPLING FRAMEWORK FOR THE ISOTOPIC N-FERTILIZER USE EFFICIENCY EXPERIMENT IN PADDY RICE

Descriptor	**Treatment**
Rate of ^{15}N fertilizer application	120 kg N/ha (52g of ^{15}N urea for a 2m^2 plot), replicated thrice at three locations
Approx. 2% ^{15}N enrichment of urea fertilizer	To use the fertilizer directly as urea
Time of application of ^{15}N labelled fertilizer	At planting and tasseling (26 g of ^{15}N urea for a 2m^2 plot)
Time of harvest	At physiological maturity

2.5.5. Water physico-chemical characterization (18O)

The physico-chemical water characterization will cover 7 sites namely; River Manafwa upstream, River Manafwa Bridge, River Manafwa downstream entrance into Doho rice scheme, underground water, wetland water, Lake Kyoga water. Water samples were picked and taken for laboratory analysis at IAEA, Vienna, Austria.

2.5.6. Economic benefit of rice growing in Doho

The economic benefit analysis was done by considering production costs of rice that included the cost of planting materials, fertilizers, pesticides, transport, local fees and labor for planting, weeding, harvesting and processing) against the sell price of the produce. This information was obtained from three key informants. Yield data was obtained from the rice experiment that was conducted.

3. RESULTS

3.1. Chemical characteristics of soil and water

An analysis of soil chemical and physical properties at twelve monitoring sites showed that the mean values of Ca, K, Na, N, and SOM contents were higher in the 0-15 cm soil depth (Table 4 and Table 5). On the contrary, pH, Available P (Av. P) and Mg increased from 0-15 cm (top soil) to 15-30 cm (sub soil) soil depth (Table 4 and Table 5). Overall, pH ranged from 5.6 to 6.2 in the topsoil and 5.8 to 6.6 in the sub soil, all above the critical value; SOM varied from 2.2 to 3.7% in the top soil and 1.7 to 2.9% in the sub soil; N ranged from 0.14 to 0.21% and 0.1 to 0.18% in the upper and bottom soils respectively and these values were below the critical value. Consistently, Av. P had a higher site variation with the two soil depths. It varied 17 and 33 times from 1.1 to 18.3ppm and from 0.61 to 20ppm in the top soil and sub soil respectively. Similarly, K varied but five times from 0.34 to 1.81 C mol kg^{-1} in the top soil and six times from 0.23 to 1.47 C mol.kg^{-1} in the sub soil while Na in the topsoil varied 12 times ranging from 0.03 to 0.36 C mol kg^{-1} and seven times from 0.04 to 0.28 C mol kg^{-1}in the bottom soil. Like all the nutrients so far mentioned, Ca also varied though three times from 3.3 to 9.5 C mol kg^{-1} in the topsoil and four times from 3.74 to 13.2 C mol kg^{-1} in the sub soil and Mg in the top soil ranged from 0.69 to 3.65 C mol kg^{-1} varying five times, while in the sub soil, it varied three times from 1.26 to 3.74 C mol kg^{-1}.

For the physical properties, sand and silt had greater values in the topsoil. Conversely, the mean clay content was greater in the sub soil. The sand content ranged from 25 to 34% in the top soil and 18 to 32% in the sub soil; silt varied approximately three times from 10 to 26 in the top soil and approximately two times from 15 to 26 in the sub soil; clay varied from 42 to 64% in the top soil, while in the sub soil, it ranged from 43 to 58%.

TABLE 4. SOIL PHYSICAL AND CHEMICAL CHARACTERISTICS FOR 0-15 CM LAYER (0-15CM)

Statistic	pH	Av.P	Ca	K	Mg	Na	N	SOM	Sand	Silt	Clay
		ppm	-------------$cmolkg^{-1}$-------------				--------------------%--------------------				
N	12	12	12	12	12	12	12	12	12	12	12
Mean	6	6.8	5.8	0.87	2	0.18	0.17	2.9	29	20	51
Median	5.9	5.8	5.6	0.76	2.18	0.15	0.17	2.83	29	20	50
Minimum	5.6	1.1	3.3	0.34	0.69	0.03	0.14	2.21	25	10	42
Maximum	6.2	18.3	9.5	1.81	3.65	0.36	0.21	3.67	34	26	64
Range	0.6	17.2	6.2	1.47	2.96	0.33	0.07	1.46	9	16	22
STDEV	0.18	5.63	2	0.42	0.95	0.1	0.02	0.37	2.8	4.32	5.48
SE	0.05	1.62	0.58	0.12	0.28	0.03	0.01	0.11	0.81	1.25	1.58
C.V (%)	3	82.5	34.6	48.6	46.8	57.7	12.5	12.6	9.64	21.5	10.8
Skewness	-0.2	0.7	0.57	0.82	0.08	0.28	0.18	0.28	0.23	-0.81	0.98
Kurtosis	-0.6	-0.61	-0.6	0.05	-1.08	0.36	-0.7	0.36	-1.01	0.54	1.09

TABLE 5. VARIATION OF SOIL PROPERTIES IN THE SUB SOIL (15-30CM)

Statistic	pH	Av.P	Ca	K	Mg	Na	N	SOM	Sand	Silt	Clay
		ppm	------------c mol kg^{-1}------------				-------------------%-------------------				
N	12	12	12	12	12	12	12	12	12	12	12
Mean	6.1	7.2	5.8	0.52	2.12	0.13	0.15	2.28	26.2	21	52
Median	6.1	5.8	4.8	0.44	2.0	0.14	0.15	2.28	26	22	54
Minimum	5.8	0.61	3.7	0.23	1.26	0.04	0.10	1.70	18	15	43
Maximum	6.6	19.9	13.2	1.47	3.74	0.28	0.18	2.90	32	26	58
Range	0.80	19.3	9.5	1.24	2.48	0.24	0.08	1.2	14	11	15
STDEV	0.24	6.14	2.7	0.34	0.67	0.07	0.02	0.36	4.5	3.1	5.2
SE	0.07	1.80	0.77	0.10	0.19	0.02	0.01	0.11	1.3	0.90	1.5
C.V (%)	4.0	85.7	45.6	64.7	31.6	51.0	14.2	16	17.1	15	10
Skewness	0.62	0.82	1.9	2.2	1.2	0.71	0.88	0.004	-0.26	-0.29	-0.45
Kurtosis	-0.3	-0.43	3.0	3.7	0.97	0.71	0.64	-0.99	-0.98	-0.36	-1.28

SE: Standard Error, STDEV: Standard Deviation

3.2. Characteristics of water

Results of chemical and physical characteristics of water for the period from 2008 to 2010 are provided in Table 6. The highest turbidity was recorded in March of 2010 followed by August of 2008 and May of 2009. The lowest was observed in December 2008 followed by March 2009 and lastly, January 2010. Highest and lowest pH values were observed in the month of September and August 2009 respectively. Alkalinity was found to be highest in the month of September and lowest in October of 2008. Highest and lowest color value was observed in the month of August and March of 2009 respectively.

TABLE 6. MONTHLY MEAN VARIATION OF PHYSICO-CHEMICAL PARAMETERS OF RIVER MANAFWA IN 2008-2010

Month	Turbidity (mg/l)			Color (pt)	Alkalinity (mg/l)	pH	Total rainfall (mm)	
	2008	2009	2010	2009	2008	2009	2009	2010
January		24	280	478			85	60
February		41	408	139			33	286
March		21	704	88			97	274
April		246	673	1068			277	103
May		417	525	1427			299	199
June		119		481			43	23
August	583	347		866	64	6.5	65	
September		356			464	7.1	80	
October	413	411			64	6.8	136	
November	323	350			75	6.9	195	
December	19	226			100	6.8	302	

The average water level in the river was highest (10.45 m) in May, 2010 with total rainfall of 199 mm (Table 7). However, during late February and March, 2010, the river flooded and destroyed most of the crops and other properties along the bank. Average water level and rainfall during these months was 9.95 m, R/F 285.5 mm and 10.284 m, R/F 273.5 mm respectively. Rainfall was recorded highest in February (285.5 mm). Average water level increased with rainfall except in the Month of May, 2010 where rainfall was low with high water level (Table 7).

TABLE 7. WATER LEVEL VARIATIONS IN RIVER MANAFWA AT MBALE – TORORO BRIDGE

Days	Jan	Feb	Mar	April	May	June
	Daily water level meters					
1	10.52	9.65	11.62	10.31	10.43	10.18
2	10.29	9.65	11.72	10.25	10.42	10.13
3	10.35	9.65	11.18	10.52	10.26	10.12
4	10.08	9.74	10.87	10.28	10.21	10.10
5	10.06	9.74	10.85	10.23	10.27	10.12
6	10.14	9.75	10.72	10.15	10.36	10.11
7	10.28	9.77	10.44	10.07	10.37	10.08
8	9.99	9.77	10.39	10.01	10.37	10.19
9	10.58	9.75	10.32	9.98	10.37	10.11
10	11.18	9.67	10.22	9.93	11.20	10.04
11	10.19	9.6	10.14	9.89	11.03	9.94
12	10.45	9.60	10.05	9.99	11.75	9.96
13	10.12	9.60	10.02	9.96	10.77	9.96
14	10.02	9.6	9.99	9.96	10.55	10.25
15	9.89	9.6	9.95	9.99	10.49	10.53
16	9.79	9.6	9.94	10.20	10.78	10.21
17	9.79	9.69	9.91	10.08	10.51	10.25
18	9.77	9.67	9.91	10.07	10.43	10.23
19	9.76	9.61	9.90	10.34	10.27	10.14
20	9.76	9.61	9.96	10.25	10.25	10.03
21	9.81	9.94	9.95	10.22	10.18	9.99
22	9.89	9.98	9.94	10.20	10.22	9.96
23	9.81	11.17	9.94	10.13	10.23	9.94
24	9.77	10.32	10.02	10.22	10.52	9.91
25	9.74	10.06	10.01	11.13	10.29	9.98
26	9.69	12.15	10.02	10.47	10.18	9.93
27	9.65	11.53	10.2	10.27	10.22	9.89
28	9.64	10.18	10.2	10.18	10.23	9.89
29	9.64		10.04	10.12	10.22	9.89
30	9.63		10.03	10.15	10.13	9.93
31	9.63		10.43		10.30	
Average	9.99	9.95	10.28	10.18	10.45	10.07
Total	60	285.5	273.5	103	199	23

The results indicated that high turbidity in the rainy seasons is due to surface runoff carrying dissolved organic matter and other soil particles. In 2009, the high rainfall was recorded in the months of April to May and October to December and during these periods the turbidity was high. In 2010, high rains were recorded in the months of February to May. However, turbidity was highest in the year of 2010 due to highest rainfall received compared to 2009 during the months of February to May and average water level was highest during those months in the year 2010. During the period of short or no rains, turbidity decreased.

The pH value of the river was observed to be slightly acidic to slightly alkaline in nature with small variation in the year of 2009 during the period of data collection. The highest pH was (7.14) in September. The highest and lowest alkalinity values were all above 40mg/l hence this water is considered to have hard water characteristics, which helps to maintain the pH value in a slightly alkaline conditions. Water color showed a positive correlation with rainfall (R^2= 0.67). Water color increased with increase in rainfall and the highest color value (1 427.9 pt) was recorded in May which had the highest rainfall (299.2 mm) during the period of water color data collection in the year 2009. There was a strong correlation among turbidity, color and rainfall (R^2 = 0.85). High rainfall in the Month of May of the year 2009 led to high turbidity and color.

3.3. Hydraulic conductivity of the wetland soils

Results from hydraulic conductivity measurements showed that water table was at 120 cm below the soil surface in March and hydraulic conductivity was of 2.5 cm/h (0.016 m/yr); insinuating that the sub-soil was mainly clayey.

3.4. Characteristics and classification of the wetland

Table 8 and Table 9 showed wetland characteristics which vary with depth; at the time of soil profile description, the soil was moist and five horizons were described ranging from 0 - 180 cm in depth. The dominant soil color of the different horizons is dark grey with black color at the surface. The wetland has mottles which are fine in size and range from distinct in prominence at the surface layers to prominent in the deeper layers. The major soil type in the wetland is clayey and the soil structure in the wetland is graded as moderate at the surface to strong at the deeper horizons in terms of its development hence the soils are well developed. In terms of size, the structure ranges from coarse to very coarse as the depth increases and the structure is mainly sub-angular blocky.

TABLE 8. CHARACTERISTICS AND CLASSIFICATION OF THE WETLAND

Slope %	0
Topography	Flat
Micro relief	0
Water table	170 cm
Root outcrop	0
Water erosion	0
Gravel	0
Soil drainage class	V
Grazing	0
Cultivated	Yes
Crops at site	Fallow
Crops within the hectare	Rice

TABLE 9. DEPTH CHARACTERISTICS OF WETLAND SOILS

Soil Depth (cm)		0- 15	15-30	30-55	55-108	108-180 +
Moisture status		moist	moist	moist	moist	Wet
Colour		5YR 2.5/1	7.5YR 3/2	10YR 3/1	10YR4/1	10YR4/1
Colour code		BL	DB	VDG	DG	DG
Mottles	Absence	Moderate	Moderate	moderate	few	few
	Size	fine	fine	fine	fine	coarse
	Prominance	distinct	Few	few	few	prominent
	Colour code	DYB	DYB	DG	DRB	Black
Texture		SCL	ZC	SCL	C	C
Consistence	Moist	FR	FI	VFR	FI	0
	Wet	S (SP)	SS (NP)	NS (NP)	S (SP)	NS (P)
Structure	Development	M	S	W	S	S
	Size	Coarse	VC	VF	Coarse	VC
	Type	SAB	SAB	SAB	SAB	AB
Clayskins	Absence	0	0	0	Few	Common
	Prominanace	0	0	0	few	prominent
Distinct pressure faces		0	0	0	0	0
Distinct shiny ped faces		0	0	0	0	M
Cracks		0	0	0	3 mm	0
Pores	Absence	MMM	MFM	MMM	F0M	F0F
	Size	FMC	FMC	FMC	F0C	F0C
Mineral nodule	Absence	0	0	0	FEW	0
	Size	0	0	0	Fine	0
	c-conc,s-seg	0	0	0	S	0
	Type	0	0	0	FM	0
Distinct Fe-induration		0	0	0	0	0
Roots	Absence	MM0	M00	FF0	F00	F00
	Size	FM0	F00	FM0	F00	F00
Horizon boundary		distinct and wavy	Smooth and gradual	Distinct and wavy	CS	

Note; YR-Yellow red, DYB-Dark yellow black, SCL-Sandy clay loam, ZC-Silt clay, C-Clay, FR-Friable, VFR-Very friable, FI- Fine , VC-very coarse, VF-very fine, SAB-Sub angular blocky, AB-Angular blocky, MMM, Moderate, MFM- Moderate few moderate, F0M- Few none moderate, FOF- Few none few, FOC-Few none common, FMC- Few moderate common, FM-Few moderate, V- Very poorly drained, BL-Black, DB-Dark brown, VDG- very dark greyish, DG-Dark greyish, DRB-Dark red brown

3.5. Spatially modelled patterns of erosion and sediment loading in Manafwa catchment Runoff and sediment hotspot areas

The observed discharge (1960-2005) when entering the wetland ranges between 3 m^3/s (base flow) and 25 m^3/s (peak flow); with an annual average was of 7.7 m^3/s. The simulated discharge ranged from 3 m^3/s to 28 m^3/s, with an average of 10 m^3/s (Figure 5); the simulated average concentration of sediment was 160 g/l equivalent to 260 ton/day. Runoff and soil loss hotspots from Manafwa catchment showed that runoff source areas are not necessary sediment source areas (Figure 6 and Figure 7). Ten square kilometers (about 0.1% of the catchment) is contributing 30% of the runoff in the catchment. Most of the runoff contributing areas (moderate to high yield) are located in the western part of the catchment. Sediment source areas are located in the south-eastern part of the catchment. Twenty percent of the catchment generates 70% of the sediments in the catchment.

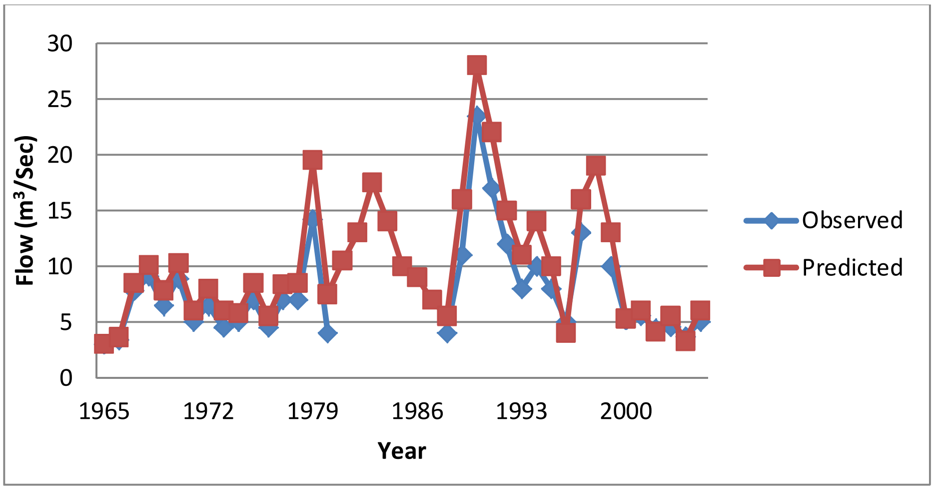

FIG. 5. Predicted and observed discharge, Manafwa river (1965-2005)

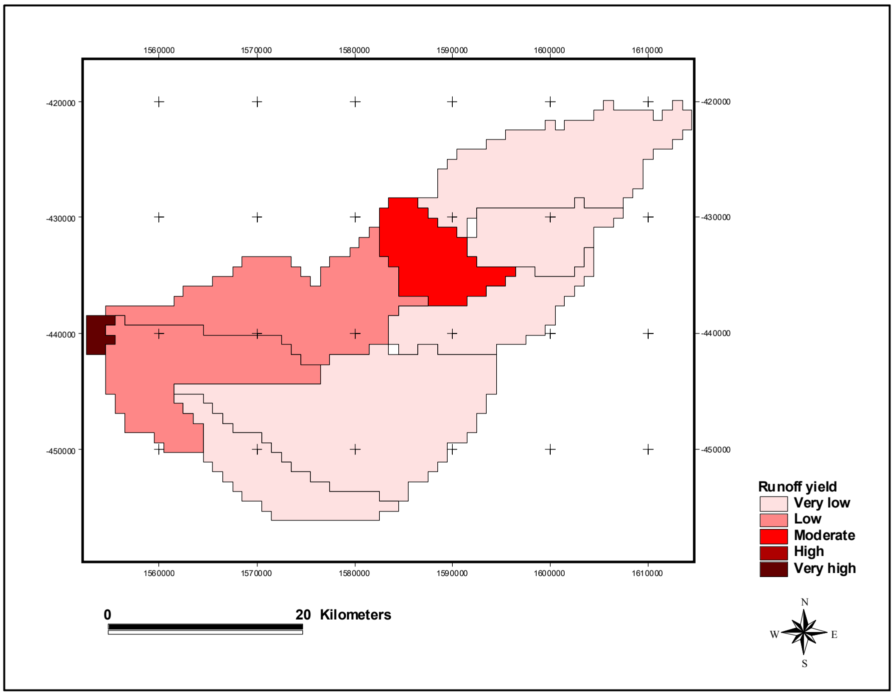

FIG. 6. Runoff hotspot areas in Manafwa catchment

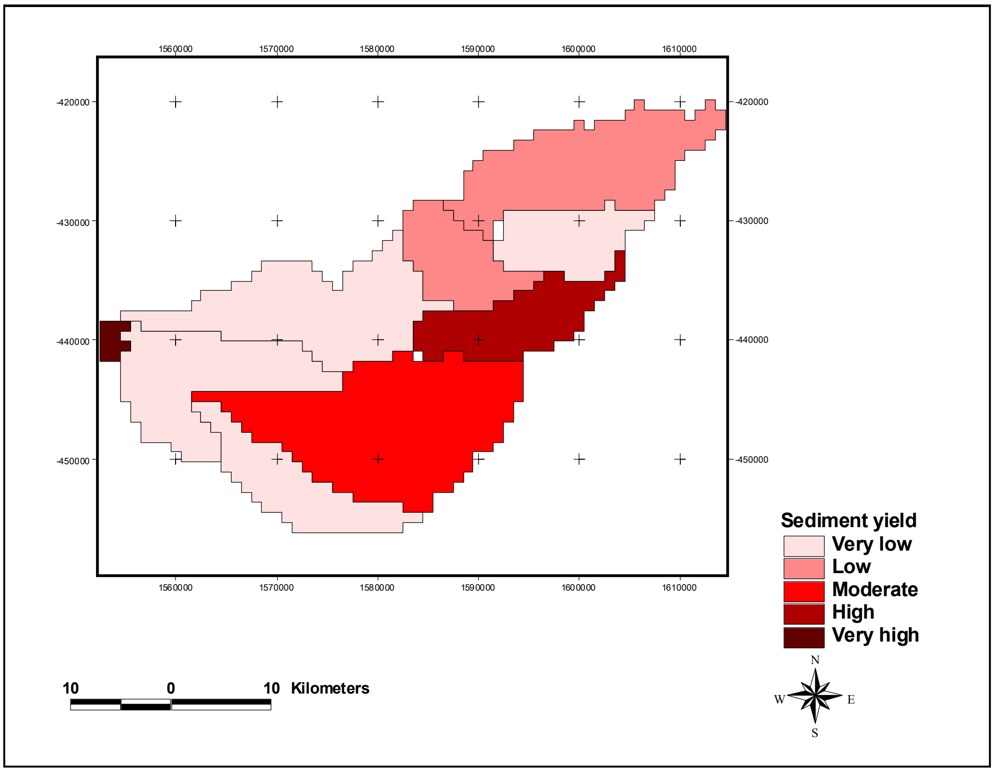

FIG 7. Sediment hotspot areas in Manafwa catchment

The average annual sediment yields from different hydrological response units are ranging from 5.7 to 241 Mg km^{-2} yr^{-1} (average of 45 Mg km^{-2} yr^{-1}) which is relatively high compared to other catchments in Uganda [5], though comparable to published values for other undisturbed tropical catchments (e.g. [6];[7]). If the 241 Mg km^{-2} yr^{-1} generated by the 10 km^{2} is excluded the average annual sediment yield fall to 18 Mg km^{-2} yr^{-1} which is slightly closer to other sediment yields in Ugandan catchments. The ten km^{2} is covered by mostly sandy soil at the outlet of the catchment. The average soil loss and runoff losses from the catchment is moderate and averaged 43 t/ha/yr for sediments and 135 m^{3} ha^{-1} yr^{-1}. This insinuates that sediments found in suspension in river Manafwa are not from interill and rill erosion only, but might also be coming from gullies, river bank erosion and landslide areas. Manafwa catchment count the highest number of landslide scares among Uganda's catchments. From 98 recent landslides mapped it was estimated that about 11 million m^{3} of slope material have been displaced in Manjiya county ([8];[9];[10]).

Manjiya County, within the Mbale district and situated on the southwestern footslopes of Mount Elgon, is the most sensitive area for landslides in Uganda [11]. Mass movements associated with intense rain-storms are reported to have occurred periodically in Manjiya since the early 20th century but the increase in fatalities and losses as a consequence of the enormous population growth draws attention to the phenomenon [9].

3.6. Sedimentation of wetlands

Information obtained through field observation in the study area showed that half of the volume of water abstracted from the river through the wetland on a daily basis. Assuming that the sediment concentration of the abstracted water is similar to that of the main river, the wetlands received about 130 ton/day of sediment (13.7 kg/m^2/yr). This represents a sediment accumulation of 5.07 cm/m^2/yr. There is need; however, to estimate for a relatively long time the quantity of water deviated by rice farmers at Doho.

3.7. Potential impact to the wetland

Suspended sediments in water alter water quality, primary productivity, and invertebrates in aquatic ecosystems [12]. Suspended sediment reduces light penetration and reduces the rate of photosynthesis [13] and covers substrates critical to the production of periphytic algae and macrophytes. Critical sediment depth goes up to 0.25 cm for significant reduction of species richness, emergence, and germination of wetland macrophytes ([14];[15]). Wetland water depth reduction might also result in the development of monotypic stands of vegetation that provide little biological diversity and exacerbate problems with farmers for soil and water management.
Sediment effects on primary production translate into impacts on organisms at higher trophic levels through the aquatic food chain. Declines in algal production, loss of standing vegetative structure [16], and covering of organic matter [17] make wetlands less productive of invertebrates through the indirect loss of forage and habitat. Direct effects include covering of invertebrates and their eggs, and clogging of filtering apparatuses. High levels of silt and clay also are toxic to zooplankton and/or reduce feeding rate and assimilation, thus reducing energy available for reproduction [18]. Aquatic invertebrates play critical roles in wetlands to facilitate nutrient cycling [19] and are required foods for wildlife ([20];[21]).

3.8. Nitrogen uptake and efficiency

Nitrogen use efficiency was dependent on water management and fertilizer application ($P<0.001$), and the interaction between water management and fertilizer application was also statistically significant ($P=0.019$). Fertilized application had the highest N use efficiency (51.1%) compared to the control (13.7%) (Figure 8). N use efficiency decreased as water management decreased (Figure 9).

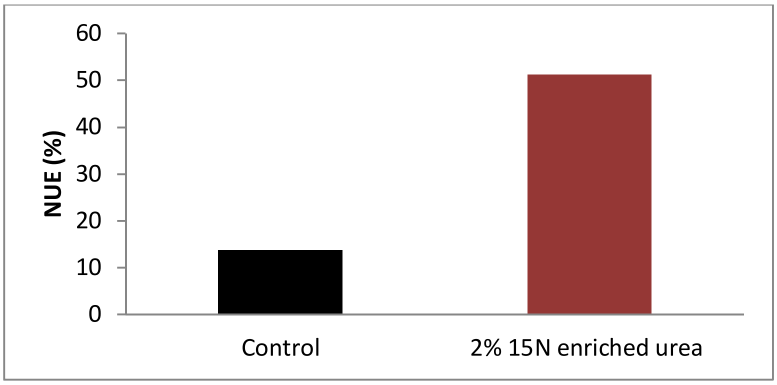

FIG. 8. Nitrogen application and nitrogen use efficiency

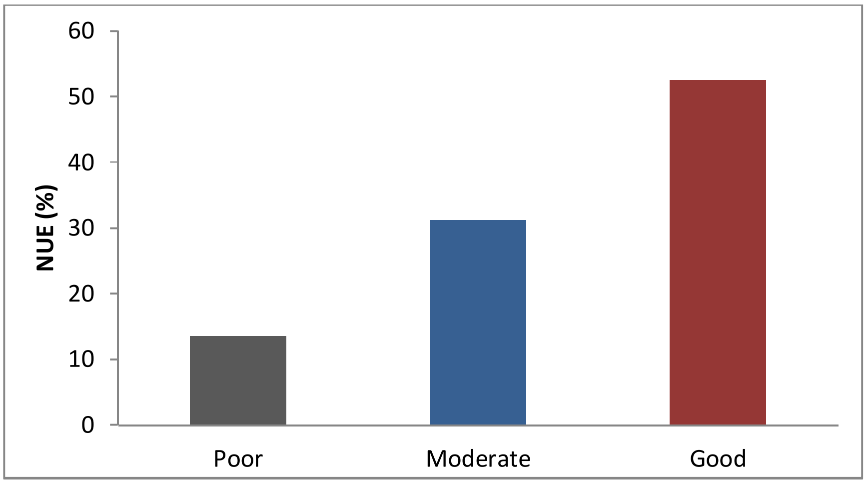

FIG. 9. Effect of water management on nitrogen use efficiency, in Doho Rice Scheme

Table 8 shows the concentration of nitrogen in the different vegetative part of the rice crop under control (no N application) and 2% ^{15}N enriched with urea application. The concentration of N in all the different part of rice (grain, root and shoot) was higher under plots which had received 2% 15N enriched with urea treatment ($P<0.01$); except in the upper zone for root and shoot. As for the NUE, water management had a significant effect on the nitrogen concentration for the different parts of the rice crop ($P\leq0.05$). Water management had a positive effect on nitrogen concentration in rice.

TABLE 9. CONCENTRATION OF NITROGEN GRAIN, ROOT AND SHOOT OF RICE, IN DOHO RICE SCHEME

Water management	Treatment	Grain	Root	Shoot	Plant
		%			
	Control	0.013	0.015	0.020	0.048
Poor	*2% 15N enriched urea 15N*	0.47	0.013	0.014	0.497
	Control	0.007	0.009	0.014	0.029
Moderate	*2% 15N enriched urea 15N*	0.523	0.211	0.479	1.213
	Control	0.007	0.239	0.500	0.747
Good	*2% 15N enriched urea 15N*	0.511	0.271	0.572	1.354
LSD (≤0.05)	Treatment	*0.124*	*0.051*	*0.204*	*0.252*
	Location	*0.101*	*0.042*	*0.167*	*0.206*
	Location*Treatment	*0.175*	*0.072*	*0.289*	*0.357*

3.9. Nitrogen content in soils

As expected, plots that received ^{15}N labelled fertilizer were enriched with urea (Figure 10) suggesting that applied fertilizer remained in the soil after harvest

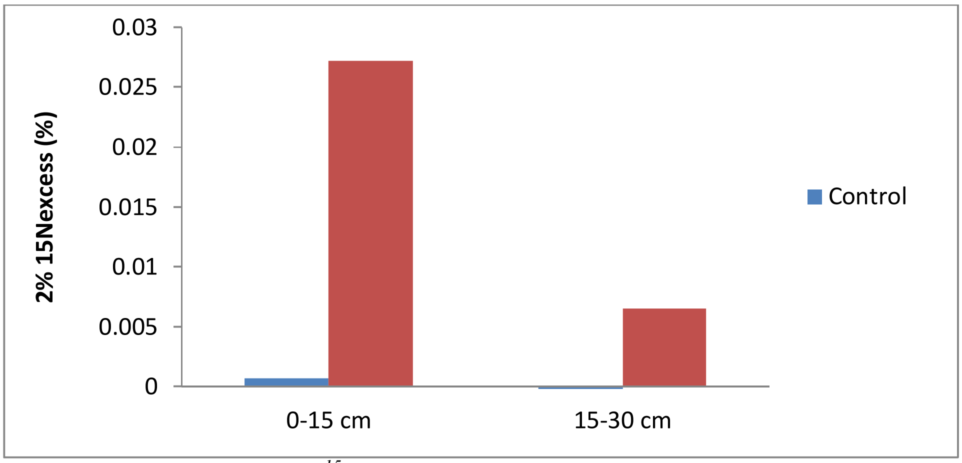

FIG 10. Applied N content (^{15}N) in control and fertilized plots

N content: Nitrogen content varied with water management and soil depth (Table 10) ($P \leq 0.05$). Plots that had moderate water management had lowest N content. As expected top soils had higher N content than the sub-soils for poor and moderate water management categories.

TABLE 10. NITROGEN CONTENT FOR THE DIFFERENT WATER MANAGEMENT CATEGORIES AND AT 0-15 CM AND 15-30 CM SOIL DEPTH

Water management	**Soil N content (%)**	
	0-15 cm	**15-30 cm**
Poor	0.3911	0.3651
Moderate	0.2982	0.2536
Good	0.4142	0.4098

Nitrogen application and soil water management were the key drivers of rice yield, N uptake, transport and transformations of N in the soil. These results corroborates with earlier findings ([22;23;24]). Nitrogen losses may increase due to the alternation of aerobic and anaerobic soil conditions ([25].

3.10. Grain and biomass yields from different applications

Table 11 shows the grain (un-milled and milled) and biomass yield in rice field trials conducted in Doho rice wetlands that receive water from Manafwa river. The grain yield both milled and un-milled. Both biomass and grain yield increased in fertilized plots compared to unfertilized plots.

TABLE 11. BIOMASS AND GRAIN YIELD IN DOHO RICE WETLANDS

Treatment	**Un-milled grain yield (ton/ha)**	**Milled grain yield (ton/ha)**	**Biomass (ton/ha)**
Fertilizer	7.67	3.6	24.59
No fertilizer	6.15	2.9	19.77

^{15}N isotopic signatures of rice grain and shoot showed that water management practices affected the amount of fertilizer N taken up by the rice crop, ranging from 34.6 kg N ha^{-1} under poor water availability to 57.7 kg N ha^{-1} under permanent water availability (Figure 5).
At the end of rice growing season, less than two percent of fertilizer N was present in the top 30 cm soil depth suggesting possible N losses through leaching, denitrification and volatilization. The rice wetland removed more than 70 percent of the applied fertilizer. The wetland rice production provided a minimum net economic return of US$1 300 per ha per cropping season.

3.11. Rice cultivation economic return in Doho

The economic return (ha) due to rice cultivation is given in Table 12 for fertilized and un fertilized rice plots. Weeding, water maintenance, harvesting and processing take 60% and 65% of total cost of rice production in fertilized and un fertilized rice plots; respectively. This is followed by the land preparation and transplanting cost. Fertilized plots (benefit to cost ratio=2.54) attracted more profit than the un-fertilized plots (benefit to cost ratio=2.22). The difference of profit per ha of land was estimated to 497 USD per season; representing a loss of 337,960 USD per annum to Manafwa catchment for not applying fertilizer for rice producton.

TABLE 12. GROSS MARGIN PER HECTARE OF RICE CULTIVATION IN MANAFWA CATCHMENT

*Input	Costs (Ugshs)	
	Fertilized	**Un fertilized**
Seed	96000	96000
Chemical fertilizers and agrochemicals	422400	192000
Land preparation and transplanting	547200	547200
Weeding, water maintenance, harvesting & processing	1704000	1704000
Land tax and interest	60000	60000
Crop yield (Kg/ha)	3592	2880
Total variable costs	2829600	2599200
Gross revenue from grain production	7184000	5760000
Net profit	4354400	3160800
Benefit to cost ratio	**2.54**	**2.22**

**one US$ is equivalent to 2400 Ugandan Schilling (Ugsh).*

3.12. Stream water pollution assessment using 18O isotopic analysis

Figure 11 showed the ^{18}O analysis for the water samples taken along R. Manafwa. There was a gradual increase in the isotopic signatures of both $\delta^{18}O$ and δD along river Manafwa from the mountain to low lands. There was a spontaneous rise in both $\delta^{18}O$ and δD as the river flows towards the lake. At this stage $\delta^{18}O$ moved from negative to positive values.

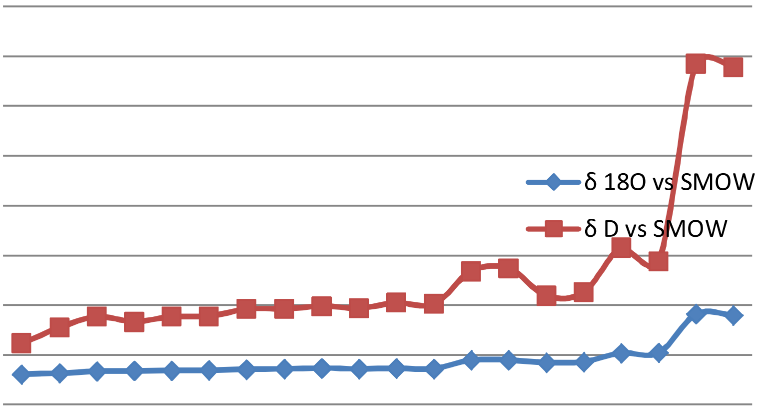

FIG. 11. ^{18}O and ^{2}H signatures of water along R. Manafwa

River Manafwa flows from the mountains downwards, the conditions become warmer and the water gets more evaporated resulting in enrichment in heavy stable isotopes (O-18 and D). The lighter isotopes tend to evaporate as the conditions get warmer leaving the heavy isotopes in the water. As the water gets evaporated and becomes more enriched in heavy isotopes, its isotopic signature becomes more and more positive as evidenced by both O-18 and D increasing and becoming more positive. The big increase occurs as the river flows to the Lake due to the fact that river water flows fast and is not very much evaporated compared to lake that is more stagnant and hence more exposed to evaporation (lake water is much more enriched in heavy isotopes than river water and that is the reason why it is much more positive than river water).

Isotopic signatures of $\delta^{18}O$ and δD are plotted against each other for water from the River Manafwa and the relationship ($\delta D=4.4593\ \delta^{18}O+10.612$, $R^2=0.9899$) is shown in Figure 12. The slope of the relationship is lower than both the African meteoric water line-AMWL, ($\delta D=7.4\delta^{18}O+10.1$, $R^2=1$) and Global meteoric water line-GMWL ($\delta D=8\delta^{18}O+10$, $R^2=1$). The waters of River Manafwa, the sample data are plotted in space together with the Global meteoric water line-GMWL and African meteoric water line-AMWL due to extreme continentally of rainfall in interior Africa.

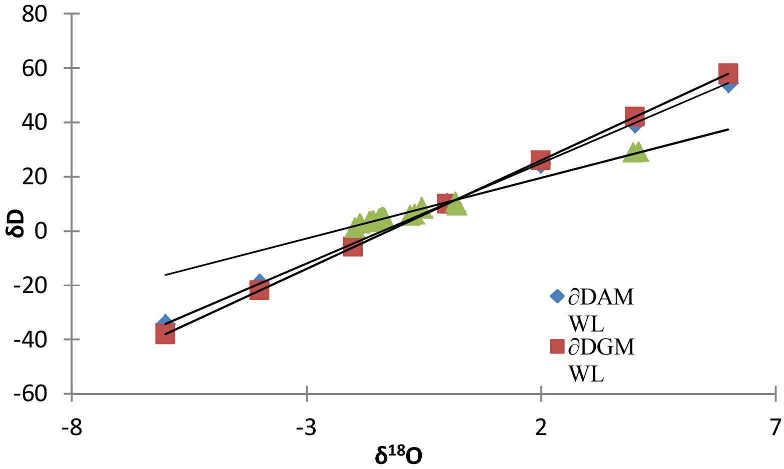

FIG 12. Relationship between $\delta^{18}O$ and δD in water of Manafwa River with global meteoric water line (GMWL) and the African meteoric water line (AMWL)

Figure 12 showed that the isotopic signatures of river water in a majority of location lie above the GMWL and the AMWL. The results showed that the river water receive sufficient input of water from the mountain to compensate evaporation.

4. CONCLUSIONS

The cropping system in the Manafwa catchment reflects the montane farming system which is typical of Mt. Elgon with both annual and perennial crops. Many crops like coffee, banana, maize beans, potatoes, cassava, and groundnuts among others are grown owing to the conducive climatic conditions and relatively fertile soils; and over 90% of the farmers practice intercropping understandably due to land scarcity. The major land use in the Manafwa micro catchment is small scale farming (84.8%) followed by degraded tropical forest (4.05%) and woodland (3.5%).

The observed mean content values of Ca, K, Na, N, and SOM were higher in the topsoil and on the contrary, pH, Av. P and Mg increased with soil depth. The range soil depth values of pH, SOM and N were smaller than the range values of other chemical soil properties. Overall, pH ranged from 5.6 to 6.2 in the topsoil and 5.8 to 6.6 in the bottom soil; SOM varied from 2.2 to 3.7% in the topsoil and 1.7 to 2.9% in the lower soil depth; N ranged from 0.14 to 0.21% and 0.1 to 0.18% in the upper and bottom soils respectively in the catchment. Sand and silt had greater values in the topsoil (0-15 cm). Conversely, the mean clay content was greater in the lower soil depth (15-30cm). The sand content ranged from 25 to 34% in the topsoil and 18 to 32% in the bottom soil; silt varied approximately three times from 10 to 26 in the upper soil and two times from 15 to 26 in the bottom soil; clay varied from 42 to 64% in the topsoil, while in the bottom soil, it ranged from 43 to 58%. The water table was at 120 cm below the soil surface in March and hydraulic conductivity was of 2.5 cm/h (0.016 m/yr); insinuating that the sub-soil was mainly clayey

Physical and chemical parameters of water were varied over time. The highest turbidity was recorded in March of 2010 followed by August of 2008 and lastly, May of 2009. The lowest was observed in December 2008 followed by March 2009 and lastly, January 2010. Highest and lowest pH values were observed in the month of September and August 2009 respectively. Alkalinity was found to be highest in the month of September and lowest in October of 2008. Highest and lowest color value was observed in the month of August and March of 2009 respectively. And the highest average monthly water level was 10.45 m in May, 2010 with total rainfall of 199 mm.

The observed discharge (1960-2005) when entering the wetland ranged between 3.03 m^3/s (base flow) and 25 m^3/s (peak flow); with an annual average was of 7.68 m^3/s while the simulated discharge ranged from 3.04 m^3/s to 28 m^3/s, with an average of 10.04 m^3/s; the simulated average concentration of sediment was 160 g/l equivalent to 260 ton/day. Runoff source areas are not necessary sediment source areas. Ten km^2 (about 0.1% of the catchment) is contributing 30 % of the runoff in the catchment. Most of the runoff contributing areas (moderate to high yield) are located in the western part of the catchment. Sediment source areas are located in the south-eastern part of the catchment. Twenty percent of the catchment generates 70 % of the sediments in R. Manafwa. The average annual sediment yields from the different hydrological response unit are ranging from 5.73 to 241 Mg km^{-2} yr^{-1}, averaged 45 Mg km^{-2} yr^{-1}

Environmental effects due to the wetland cultivation included; Increased incidences of pests and diseases like rodents, birds , rice yellow mottle virus, high incidence of blast,soil fertility decline due to persistent cultivation of the crop, Excessively low temperature which only favors one variety of rice (Shakti variety) to perform very well than others, Prevailing weeds especially http://en.wikipedia.org/wiki/Eudicot *Striga hermonthic,* Mono cropping without rotation affects nutrient replenishment, Planting three times a year leads to over exploitation of the nutrients, Application of mineral fertilizers affects water quality in the wetland and subsequently the diversity and abundance of the resident flora and fauna, Flooding of water in the rice scheme reduces stream flow to L. Kyoga, and Propagation of rice pests and diseases due to continuous planting of same crop season after season.

Fertilized plots had the highest N use efficiency (51.1%) compared to the control (13.7%) and N use efficiency decreased as water management deteriorates. The concentration of N in all the different part of rice (grain, root and shoot) was higher under plots which had received 2% 15N enriched with urea treatment ($P<0.01$); except in the upper zone for root and shoot. Water management had a significant effect on the nitrogen concentration for the different parts of the rice crop ($P\leq 0.05$) and water management had a positive effect on nitrogen concentration in rice.

Carbon content only varied with water management and moderately managed plots had the lowest carbon content ($P<0.001$). 2% 15N enriched with urea excess was highest on plots were the fertilizer had been applied. Nitrogen content varied with water management and soil depth ($P\leq 0.05$). Top soils had higher N content than the sub-soils for poor and moderate water management categories. Nitrogen application and soil water management were the key drivers of N uptake, transport and transformations of N in the soil.

For the economic return (ha) due to rice cultivation, weeding, water maintenance, harvesting and processing take 60% and 65% of the total cost for a fertilized and not fertilized rice garden; respectively, followed by the land preparation and transplanting cost. Fertilized garden (benefit to cost ratio=2.54) attracted more profit than the un-fertilized garden (benefit to cost ratio=2.22). The difference of profit per ha of land was estimated to 497 USD per season; representing a loss of 337,960 USD per annum to Manafwa catchment for not using fertilizers.

The ^{18}O analysis for the water samples taken along R. Manafwa showed a gradual increase in both $\delta^{18}O$ vs SMOW and δD vs SMOW as R. Manafwa flows from the mountains up to the low lands. There was a spontaneous rise in both $\delta^{18}O$ vs SMOW and δD vs SMOW as the river flows towards the lake. At this stage $\delta^{18}O$ vs SMOW moved from negative to positive values.

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REFERENCES

[1] PRETTY, J., Sustainable agriculture, people and the resource base: Impacts on food production. Forum for Development Studies 1 7-32 (1997).

[2] MAGUNDA, M.K., TENYWA, M.M., Soil and Water Conservation in Uganda. In: J. Mukiibi (Ed.), Agriculture in Uganda; Volume I-General Information. Copyright: NARO, Published by Fountain Publishers LTD, ISBN 9970-02-243-1, (2001) 145-168.

[3] ULLRICH, A., VOLK. M., Application of the Soil and Water Assessment Tool (SWAT) to predict the impact of alternative management practices on water quality and quantity. Agricultural Water Management 96(8) 1207–1217 (2009).

[4] IAEA. Use of isotope and radiation methods in soil and water management and crop nutrition (Manual), FAO/IAEA Agriculture and Biotechnology Laboratory 247 (2001).
[5] MAJALIWA, J.G.M, MAGUNDA, M.K., TENYWA M.M., Non-point pollution loading in a selected micro-catchment of the Lake Victoria basin, In the proceedings of the Ninth International Symposium on river Sedimentation (9th ISRS) Yichang, China, 2206-2211 (2004)
[6] DUNNE, T., Sediment yield and land use in tropical catchments, Journal of Hydrology 42 (1979) 281-300.
[7] EI-SWAIFY SA., Research needs and applications to reduce erosion and sedimentation in the tropics (1990).
[8] BREUGELMANS, W., The influence of soil, land use and deforestation on the occurrence of landslides in Mount Elgon area, Eastern Uganda, Unpublished MSc thesis, Catholic University Leuven, Belgium (2003).
[9] KNAPEN, A., Spatial and temporal analysis of landslides in Manjiya County, Mount Elgon area, eastern Uganda, Unpublished MSc thesis, Catholic University Leuven, Belgium (2003).
[10] KNAPEN, A., KITUTU, M.G, POESEN, J., BREUGELMANS, W., DECKERS, J., and A., MUWANGA, Landslides in a densely populated county at the foot slopes of Mount Elgon (Uganda): characteristics and causal factors. Geomorphology 73, (2006) 149–165.
[11] CLAESSENS L., A. KNAPEN, M.G. KITUTU, POESEN J., DECKERS, J.A., Modelling landslide hazard, soil redistribution and sediment yield of landslides on the Ugandan foot slopes of Mount Elgon, Geomorphology 90 (2010) 23–35.
[12] WATERS, T.F., Sediment in streams: sources, biological effects, and control. American Fisheries Society Monograph 7 (1995).
[13] DIETER, C.D., Water turbidity in tilled and untilled prairie wetlands, Journal of Freshwater Ecology 6 (1991) 185-189.
[14] JURIK, T.W., WANG S.C. and A.G., VAN DER VALK, Effects of sediment load on seedling emergence from wetland seed banks, Wetlands 14 (1994) 159-165.
[15] WANG, S.C., JURIK, T.W., and A.G. VAN DER VALK, Effects of sediment load on various stages in the life and death of cattail (Typha x glauca), Wetlands 14 (1994) 166-173.
[16] KRULL, J.N., Aquatic plant-macroinvertebrate associations and waterfowl, Journal of Wildlife Management 34 (1970) 707-718.
[17] MURKIN, H.R., The basis for food chains in prairie wetlands, In A. van der Valk, ed. Northern Prairie Wetlands, Iowa State University Press, Ames, Iowa, (1989) 316-338.
[18] NEWCOMBE, C.P., and D.D, MACDONALD, Effects of suspended sediments on aquatic ecosystems, North American Journal of Fisheries Management 11 (1991) 72-82.
[19] MERRITT, R.W., CUMMINS, K.W. and T.M. BURTON, The role of aquatic insects in the processing and cycling of nutrients, In Resh, V.H. and D.M. Rosenberg, ed. The Ecology of Aquatic Insects, Praeger Publishers, New York, NY, (1984) 134-163.
[20] FRITZELL, E.K., SWANSON, G.A., and M.I. MEYER, Fall foods of migrant common snipe in North Dakota, Journal of Wildlife Management 43 (1979) 253-257.
[21] EULISS, N.H.JR. and S.W. HARRIS, Feeding ecology of northern pintails and green-winged teal wintering in California, Journal of Wildlife Management 51 (1987) 724-732.
[22] GILLER, K.E. and CADISCH, G., Future benefits from biological nitrogen fixation: an ecological approach to agriculture. Plant and Soil. 174 (1995) 255-277.

[23] KANTRUD, H.A., Duck nest success on Conservation Reserve Program land in the prairie pothole region. Journal of Soil and Water Conservation 48 (1993) 238-242.
[24] KAIZZI, C.K., The potential benefit of green manures and organic fertilizers in cereal production on contrasting soils in eastern Uganda. PhD Desertation submitted to the University of Bonn and German Centre for Development Research (ZEF) 64-69.
[25] TIMSINA, J., SINGH, U., BADARUDDIN, M., MEISNER, C., and AMIN, M.R. 2001. Cultivar, nitrogen and water effects on productivity and nitrogen use efficiency and balance for rice-wheat sequences of Bangladesh. Field Crop Research. 72 (2001) 143-161.

INTEGRATED WETLAND CHARACTERIZATION AND MANAGEMENT FOR NUTRITIONAL, HEALTH AND ENVIRONMENTAL ISSUES – A CASE STUDY OF EKITI STATE, NIGERIA

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Abstract

Wetlands in Nigeria are important for livelihood as they provide a wide range of social, economic and environmental services to rural farmers and they play a major role in rice production. Currently wetlands occupy about 7.2% of land area in Nigeria. The current trend in rice production in Nigeria showed that there has been a gradual shift from upland to wetland rice production. In addition, wetlands are used for growing high value leafy vegetable during non-rice growing season. The management of wetlands for increasing the productivity of rice based cropping system and nutrient use efficiency is important to provide economic and environmental benefits to farming communities. The objectives of the project were to assess yield and fertilizer use efficiency of leafy vegetable crops and rice in lowland wetlands in Nigeria. Results showed leafy vegetable yields for A. cruentus (28.9 tons ha^{-1}) and C. argentea (35.8 tons ha^{-1}) were significantly increased with fertilizer application along with the quality of vegetables (total carotenoids, crude protein and calcium contents) suggesting that fertilizer recommendations based on soil test is necessary for determining the adequate level of nutrients for leafy vegetables. For rice production under wetlands, fertilizer management impacted grain yield, nitrogen uptake and nitrogen use efficiency. Economic analysis of rice production in wetlands showed that farmer income also increased with improved fertilizer management. The studies showed that wetlands in Nigeria can be used for agriculture by appropriately managing the water and nutrient.

1. INTRODUCTION

The occurrence of wetland soils in Nigeria has been associated with three landforms namely; inland depressions, floodplains and coastal plains [1]. The major wetland soils in Nigeria have been classified into Gleysols/Fluvisols and Alfisols, Inceptisols, Entisols, Histosols and Vertisols [2]. Wetlands are grossly underutilized in Nigeria. Rice and sugar cane are grown in wetlands during the rainy season. Wetlands in Nigeria may be appropriately described as the breadbasket in the land because they serve as the main source for growing crops and water supply to livestock.

The unsustainable use of wetlands as a whole has led to the disruption of natural hydrological cycles. Wetlands are, however, very fragile ecosystems and their conversion to cropland has resulted in many cases of severe ecological and environmental deterioration and degradation. This has often resulted in higher frequency and severity of flooding, drought and pollution [3]. The most common and direct consequences of conversion are severe erosion of the wetland soils, disruption of water flow regulation and deterioration of environmental quality, all leading to biodiversity losses. In most parts of Ekiti State, poorly managed cultivation has already resulted on the abandonment of wetlands by cultivators as fertility has become exhausted and the soils have become eroded and desiccated. Appropriate protection and allocation of water to wetlands is essential to enable these ecosystem survive and continue to provide important goods and services to local communities [4].

It is therefore necessary that policy makers carefully, determine appropriate strategies for the sustainable use and management of wetlands for agriculture or other purposes. Development of such policies and strategies can only possible with information on the characteristics and functioning of wetlands is carefully collected, assembled and analysed. It was in view of this background that this research proposal was designed. This proposal was designed to generate information on soil and water for Ekiti wetlands required by planners and policy makers in order to develop a sustainable land and water management plan for this ecosystem. The research output will also contribute to the database required for the precise characterization, classification, evaluation and understanding of wetland resources in Ekiti State, Nigeria. Therefore, the major objective of this research proposal is to carry out a detail study on wetland characterization and management with emphasis on nutritional, health and environmental issues using wetlands in Ekiti State in Nigeria as a case study.

Fertilizer management issue in rice production is drawing attention among farmers, especially under current climate change condition. Appropriate amount of fertilizers applied onto soils reduce greenhouse gas emissions, NO_3 leaching and eutrophication. Fertilizer N use efficiency of lowland rice is relatively low due to loss of applied N through leaching, volatization and denitrification in soil flood water system ([5]. It has been observed that the recovery efficiencies of 30-50% of applied N are typical in field experiments at research stations for lowland rice in the tropics ([6]. Fageria and Baligar [7] obtained an average nitrogen use efficiency of 58 kg of grain per kg N utilized by rice in the Philippines. They discovered that nitrogen use efficiency decreased with increasing rates of application.

Annual rice production in Nigeria is about 4 million tones. However, Nigeria has emerged as a major importer of rice which cost the country about ₦155 billion and ₦350 billion in 2010 and 2011, respectively ([8]. Rice production in Nigeria is characterized by low yield due to lack of efficient fertilizer application and utilization, cultivation of low yielding varieties, problem of soil fertility, poor management of wetland soils [9].

One of the management options available to mitigate against the effects of climate change on wetland rice fields is to properly monitor the utilization and timing of the use of nitrogen fertilizers on wetland rice field. Nuclear techniques, especially stable isotopes of nitrogen (^{15}N) can be used to quantity N fertilizer use efficiency on wetland rice fields [10].

The objective of the study was to characterize and classify three major wetlands (inland valley) soil of Ekiti State, evaluate the potentials of these wetlands for irrigated rice vegetable production and identify soil characteristics controlling yield of rice on these wetlands with the view of advising farmers on how to manage these properties.

2. MATERIALS AND METHODS

2.1. Wetland sites

Three wetland sites included in the study are (1) Ado-Ekiti I, (2) Ado-Ekiti II, and (3) Ado-Ekiti III. The location and morphological characteristics of these wetlands are provided in Table 1.

TABLE 1. SITE CHARACTERISTICS OF SELECTED WETLANDS [11]

Wetland	Geographic Location	Slope %	Parent material	Landuse	Vegetation	Topography
Ado-Ekiti I	07°42'49.026N 05°1523.634°E	3-6	Granitic	leafy vegetables	Ferns, *mucuna* spp.	Valley bottom
Ado-Ekiti II	07°42'37.218°N 05°1446.38°E	3-6	Granitic	rice and vegetables	*andropogon gayanus*, mucuna spp and *Elaeis guinensis*	Valley bottom
Ado-Ekiti III	07°4216.536°N 05°1505.7°E	2-4%	Granitic	Wetland rice, yam and vegetables	*Elephant, grass, Gliricidia sepium, Chromolaena* odoratum	Valley bottom

The following three studies were carried out at these sites: (1) land evaluation, land degradation and environmental issues of wetland sites, (2) soil and crop nutrient dynamics of vegetable crops, (3) evaluation of the potentials of wetland (Ado-Ekiti II) for Small Scale Irrigation Vegetable Production, and (4) rice yield response to fertilizer application and climate change in wetlands. Soil classification, morphological and physical characteristics are provided in Table 2.

2.2. Field studies

The wetland soils were classified into land suitability classes for wetland rice production using [12] land evaluation system. Land degradation assessment studies were carried out on Ado-Ekiti II wetland site. Soil samples were taken from three land use types including rice (WR), vegetable (WV) and fallow (WF)) located on the same soil type [13]. The system of land degradation assessment was used to compare the levels of degradation. This was done to determine factors responsible for land degradation study the effects of land use on the physico-chemical properties and heavy metal content of the wetland and evaluate the effects of two management practices (local and improved) on soil physical and chemical properties and rice yield [14].

(1) Studies were conducted during the late 2009 and early 2010 seasons to determine the leaf yield and chemical composition of Amaranthus Cruentus L (V1) and celosia argentea (V2) as affected by land use types and fertilizer regimes. The land use types were, (1) fallow upland (LI), fallow wetland (L2), cultivated upland (L3), and cultivated wetland (L4). The fertilizer regimes for all land use and crops include control (no fertilizer application), blanket (application based on previous general recommendation) and fertilizer factor (FF application based on soil test values). Fertilizer sources were Urea (46% N), single super phosphate (7% P) and muriate potash (55% K). The crops included in the study are Amaranthus Cruentus L (V1) and celosia argentea (V2).
(2) Field studies were also carried out to assess nitrogen fertilizer response to rice yield in three wetland locations. All three sites were characterized for soil physical and chemical properties. The experiment was carried out using ^{15}N labelled urea.

Statistical analyses were carried out for all data collected from field sites to examine the effect of different management practices.

3. RESULTS AND DISCUSSION

Results of land degradation assessment showed that all land use types were found to be 70% none to slightly degraded physically and above 70% moderately to very highly degraded chemically while biological degradation was none to slight (Tables 3 and 4). The content of the heavy metal was generally low. On the effects of land use types on soil degradation, it was discovered that all the land use types were more than 55% wetland highly degraded chemically. The fallow plot was the least degraded, followed by the wetland rice plot.

The wetland vegetable plot was the most degraded of all the land use types. Factors identified to be responsible for degradation are continuous cultivation, erosion, leaching, inappropriate cropping system and crop management. The heavy metal content of the wetland land use types was found to vary according to the organic matter content and the concentration

TABLE 1. SOIL CLASSIFICATION, MORPHOLOGICAL AND PHYSICAL CHARACTERISTICS OF WETLAND SITES

wetland	Depth (cm)	Soil Colour (dry)	Texture	Structure	Drainage	Soil Classification		Land Suitability Evaluation for Wetland and Appropriate Landuse
						USDA	FAO	Limitations and recommendations
Ado-Ekiti I	30	7.5YR 7/2	Clay 1oam	Fine sub-angular blocky	Poorly drained	Typic Endoaquent	Dystric fluvisol	Soil fertility problem, low pH, Available P, Ca, mg and CEC. High ESP value, Use of appropriate organic and inorganic fertilizers
Ado-Ekiti II	100	10YR 7/1	Loam to sandy clay	Fine subangular blocky	Poorly drained	Fluvaquentic Endoaquept	Dystric fluvisol	Soil fertility problem. low nutrients. Use appropriate organic and inorganic fertilizers
Ado-Ekiti III	86	10YR 6/2	Loamy sand to sandy clay	Medium subangular blocky	Poorly drained	Typic Endoaquent	Eutric Gleysol	Soil fertility problem. Low Ca, Mg, Available P. Low clay content Application of appreciable organic and inorganic fertilizer

was in the order Mn > Zn > Cu. The trace metal content of the landuse types were also in the order WF > WR > WV.

Management Practices (Local and Improved) on rice field have significant effects on soil organic matter, N, Mg, Ni, Cu, Pb, exchangeable acidity and base saturation. With twenty – two soil properties in regression, the soil properties that contributed most to rice yield were Zn, Mg, Pb, Cd, Mn, Cu, Clay and silt.

Rice grain yield per hectare under the two management practices were significantly different ($P < 0.01$) with improved practices increasing yield by 24.2% and 28%. Rice yield correlated significantly with some soil properties (pH, Sand, Silt, Mg, Zn, Cu, Na and Ca).

TABLE 2. EFFECT OF MANAGEMENT PRACTICES ON THE PHYSICO-CHEMICAL PROPERTIES OF THE SELECTED WETLAND SOILS

Properties	Improved	Local	t-test	Significance
pH	4.86	5.06	1.39	ns
Organic Matter	10.81	11.88	2.09	**
Sand	58.63	54.34	1.51	ns
Silt	19.68	23.32	1.82	ns
Clay	21.61	20.84	1.16	ns
N	0.54	0.59	2.05	**
P	5.55	6.33	1.3	ns
K	0.27	0.25	0.7	ns
Ca	0.11	0.97	1.28	ns
Mg	0.04	0.03	2.87	*
Na	0.1	0.09	0.9	ns
Zn	0.23	0.05	10.17	
Fe	0.17	0.01	1.49	*
Ni	0.028	0.01	2.73	ns
Cu	0.02	0.01	2.84	*
Mn	2.87	2.96	0.93	*
Pb	0.15	0.11	3.14	ns
Cd	0.009	0.01	0.62	*
EA	0.92	1.04	2.03	ns
EB	0.51	0.47	1.28	**
CEC	1.43	1.52	1.17	ns
BS	35.54	31.42	2.2	ns
ESP	19.75	19.72	0.03	**

ns= non significance, * = significance and ** = highly significance

TABLE 3. DUNCAN TEST GROUPING FOR THE EFFECT OF LAND USE TYPES ON SOIL PHYSICAL AND CHEMICAL PROPERTIES FOR WETLAND RICE (WR), WETLAND VEGETABLE (WV) AND WETLAND FALLOW (WF)

Properties	Land use		
	WR	WV	WF
pH	b	a	b
Organic matter	a	a	b
Organic carbon	ab	b	a
Sand	a	b	a
Clay	a	b	a
Nitrogen	ab	a	a
Available	a	b	a
Exch. K	a	a	a
Exch. Ca	a	a	a
Exch. Mg	a	a	a
Exch. Na	a	a	a
Zn	b	b	b
Fe	a	a	a
Ni	a	a	a
Cu	ab	b	a
Mn	a	b	a
Pb	b	b	a
Cd	a	a	a
EA	b	b	a
EB	a	a	a
CEC	b	b	a
BS	a	b	a
AWH	a	b	a
TP	a	a	a
EC	a	b	a
ESP	a	a	a
Silt	a	a	a

3.1. Fertilizer response yield of leafy vegetables

Results of yield response showed that significantly ($P<0.05$) higher leaf yields were recorded for A. Cruentus (28.9 tons/ha) and C. argentea (35.8 tons ha^{-1}) under L2 using the Ff compared to other land use types and fertilizer regimes (Tables 5 and 6). The least leaf yields were recorded for the two vegetables under the control (no fertilizer) regime. Statistical analysis ($P<0.05$) showed that total carotenoids, crude protein and calcium contents of V1 were significantly higher than that of V2 under all land use types. The oxalate and other extract composition of the two vegetables in all land use types and fertilizer regimes did not differ significantly. Except for the oxalate and other extract contents, the plants under Ff had significantly higher contents of carotenoids, calcium, ascorbic acid, crude protein and crude fibre compared to plants under blanket and control treatments. The result of the study showed that higher leaf yields and optimum nutrient composition of A. Cruentus and C. argentea can be realized by a proper combination of landuse types and fertilizer rates. The use of fertilizer factor (Ff) in determining nutrient amendment required for a particular soil provides a better picture of actual fertilizer rate required and also promotes higher vegetable leaf yield and quality.

TABLE 4. INFLUENCE OF LAND USE TYPES ON LEAF YIELD AND CHEMICAL COMPOSITION OF AMARANTHUS CRUENTUS (V1) AND CELOSIA ARGENTEA (V2)

Land use Type	Carotenoid (mg/100g)	Leaf yield ($t\ ha^{-1}$)	Calcium (mg/100g)	Protein (g/100g)	Fiber (g/100g)	Acid (mg/100g)	Oxalate (mg/100g)
$L_1 V_1$	26.3	28.2	395	5.8	0.8	58.8	5.1
V_2	21.1*	35.6*	361*	4.1ns	0.6ns	57.4ns	6.7ns
$L_2 V_1$	21.1	24.6	371	4.2	0.8	41.4	5.2
V_2	17.4*	31.6*	335*	3.2ns	0.7ns	40.9ns	6.6ns
$L_3 V_1$	20.2	18.4	345	3.4	0.7	33.6	5.5
V_2	26.8*	27.5*	311*	2.3ns	0.6ns	32.4ns	6.8ns
$L_4 V_1$	17.1	13.6	314	3.3	0.8	27.6	5.3
V_2	12.8*	20.4*	305*	2.1ns	0.6ns	27.1ns	6.4ns

* & ns indicate significant and non-significant at 5% level of probability, respectively by Least Mean Square Analysis. All values are means of triplicates analyses

TABLE 5. INFLUENCE OF FERTILIZER REGIMES ON THE LEAF YIELD AND CHEMICAL COMPOSITION OF AMARANTHUS CRUENTUS (V1) AND CELOSIA ARGENTEA (V2)

Landuse Type	Carotenoid	Leaf yield	Calcium	Protein	Fiber	Acid	Oxalate
	(mg/100g)	($t\ ha^{-1}$)	(mg/100g)	(g/100g)	(g/100g)	(mg/100g)	(mg/100g)
Blanket V_1	20.4	22.6	362	5.8	0.6	41.8	5.1
V_2	18.2*	30.8*	341*	4.1*	0.6ns	41.4ns	6.7ns
Ff V_1	28.4	26.6	398	7.2	0.8	59.4	5.2
V_2	24.1*	37.6*	365*	5.2*	0.7ns	58.9ns	6.6ns
Control V_1	16.4	14.9	334	3.8	0.4	37.6	5.3
V_2	12.6*	18.4*	305*	2.1*	0.4ns	37.1ns	6.4ns

* & Ns: indicate significant and non significant at 5% level of probability, respectively by Least Mean Square Analysis. All values are means of triplicates analyses

3.2. Potentials of Wetland for Small Scale Irrigation Vegetable Production

Detailed soil survey was carried out on a 1.03 Hectares of Wetland to evaluate the suitability of the soils for irrigation agriculture and to examine the influence of three different soil types, water and fertilizer rates on the yield of Amaranthus cruentus. All the soils evaluated were considered not suitable for gravity irrigation but soil A was considered highly suitable, soils B and C were considered moderately suitable for drip irrigation respectively.

The results (Table 7) showed that soil types greatly influenced Amaranthus yield significantly (P < 0.05). Soil A gave the highest total biomass yield (4597 kg/ha), followed by soil C (3152 kg/ha) and soil B (3111 kg/ha). Fertilizer regime based on soil test gave the highest biomass yield of 4051.6 kg/ha followed by the control with 3636 kg/ha and lastly the blanket with 3173 kg/ha. The study showed that watering the crop daily gave the highest biomass yield of 30703 kg/ha followed by once in two days with 3632 kg/ha and twice daily with 3527 kg/ha. The study confirmed that fertilizer recommendations based on soil test is necessary for determining the adequate level of nutrients that could replenish the soil as well as satisfy the need of the crop. The study suggests the use of drip irrigation rather than gravity irrigation in terms of water use.

TABLE 6. INFLUENCE OF SOIL TYPES, WATER AND FERTILIZER RATES ON YIELD (KG/HA) AND YIELD COMPONENTS OF *AMARANTHUS CRUENTUS* IN ADO-EKITI, SOUTHWESTERN, NIGERIA IN KG/HA

A. WATER RATE	Total biomass	Fwt	Rwt	FLwt	FSwt
Once daily (11 litres)	3703.1a	835.56a	438.00a	448.00a	497.19a
Once in 2 days (11 litres)	3632.0a	788.74a	341.93a	443.26a	469.93a
Twice daily (22 litres)	3527.0a	859.26a	404.15a	510.22a	533.93a
B. FERTILIZER					
Recommended	4051.6a	783.40a	347.26a	518.52a	548.74a
No fertilizer	3636.7a	964.10a	435.56a	479.41a	513.19a
Blanket	3173.9a	736.0a	401.78a	403.96a	439.11a
C. SOIL TYPE					
A	4597.9a	692.15b	175.41b	318.81b	306.37b
B	3111.1b	904.30a	466.96a	546.96a	602.67a
C	3153.2b	887.11a	542.22a	535.70a	592.50a

Means with the same letters are not significantly different at P (<0.05)

Fwt: Fresh weight, Rwt: Root weight, FLwt: Fresh Leave weight, FSwt: Fresh Stem weight.

3.3. Fertilizer response to rice yield

Rice yield results showed that fertilizer application to wetland rice significantly increased rice yield compared to unfertilized rice wetlands (Table 8). The number of panicles and tillers were also influenced by fertilizer application. However among the fertilizer application even though there was a positive response to soil test based application and 150 kg/ha, the difference is not significant.

Rice grain yield, N uptake and fertilizer use efficiency of rice wetlands under different fertilizer management practice showed that grain yield significantly increased with N uptake also increased (Table 9). Farmer income also increased with fertilizer application. However, site one provided more yield and economic return compared to compared to sites 2 and 3. As yield increased fertilizer use efficiency also increased along with yield.

TABLE 7. RICE YIELD RESPONSE TO FERTILIZER APPLICATION IN WETLANDS

Wetland/Soil Type (USDA)	Fertilizer (kg/ha)	No of tillers at 14 weeks /m^2	No of panicles at 14 weeks	Dry matter (kg/m^2)	Grain yield (t/ha)
Site 1 Typic Endoaquent	0	18b	15c	3.2c	2.67b
	ST	18b	18b	4.2c	4.39a
	100	19a	21a	9.6a	3.94a
	150	19a	21a	6.0.b	4.55a
Site 2 Typic Fluvaquentic Endoaquept	0	19c	15.c	0.10b	1.55b
	ST	25b	19.b	0.16a	1.94a
	100	24b	23.a	0.18a	2.22a
	150	25a	23.a	0.18a	2.22a
Site 3 Typic Endoaquent	0	24.d	15.c	0.33c	2.31c
	ST	23.c	19.b	0.42b	3.05a
	100	27.b	23.a	0.47a	3.22a
	150	29.a	21.a	0.55a	3.50a

TABLE 8. RICE GRAIN YIELD, NITROGEN UPTAKE, FERTILIZER USE EFFICIENCY AND NET FARM INCOME UNDER WETLAND RICE PRODUCTION

Wetland Site	Crop N %	N Fertilizer ($g\ kg^{-1}$)	NFUE %	N Uptake (kg/ha^{-1})	Net Farm Income (US \$ ha^{-1})
Site 1	1.8	0	-	-	2730
		ST	49.2	89	5244
		100	55.4	33.9	4575
		150	56.9	126	5218
Site 2	2.9	0	-	26	1.463
		ST	12.1	33.9	1973
		100	33	63	2282
		150	36	-	2244
Site 3	1.3	0	-	8.5	2476
		ST	57	125	3457
		100	52.9	156	3615
		150	45.3	171	3951

The results obtained from the study showed that nitrogen fertilizer application (0, ST, 100, 150 Kg N/ha) had significant ($P < 0.05$) effect on rice dry matter yield, number of tillers, number of panicles and grain yield.

The use of 150 kg N/ha produced the maximum number of tillers (m^2-29) at site 3 than all other treatments. The no of tillers per unit area is the most important component of yield. The more the tillers especially fertile tillers, the more the yield. More no of tiller (m^2) in the 150kg N/ha treatment might be due to more N availability that played a vital role in cell division. Significantly higher dry matter accumulation (0.60 and 0.55kgm^2) was obtained on plots treated with 150 and 100kg/N/ha respectively.

The best economic rice yield (4.39+/ha) was obtained using fertilizer rate based on soil test at site 1. The recovery by rice of ^{15}N labeled was much higher using 150kg N/ha at sites 1 and 2, while it was higher using 100kg N/ha at site 3. This is expected because the total nitrogen for each of the sites differed. The higher N use efficiency (57%) at site 3 can be attributed to the considerably low soil fertility obtained at that site. An important reason for the low N use efficiency at site 2 when compared to sites 1 and 3 may be due to the high total nitrogen content obtained at this site

The result obtained in this study for NFUE at site 3 and 1 showd that when input (fertilizer) is properly managed, rice grown on wetland soils usually make use of higher proportion of N applied from isotopic dilution method. The economic analysis of rice production result showed that site 1 using fertilizer rate base on soil test gave the highest net from income of USD 5244 per hectare. The NFUE values measured (43.3 to 63.3%) in this study are comparable to those reported for soil with low fertility [15]. The percentage of N recovery varies with soil properties/type, methods amounts and timing of fertilizer applications and other management practices as evidenced in this study. Nitrogen fertilizer use efficiency is usually ranges between 30 to 50% in the tropics [16].

4. CONCLUSION

The N rates applied in this experiment significantly influenced no of panicles, no of tillers, dry matter yield (t/ha) and Grain yield of rice on these three wetland soils. The best economic yield of 4.39t/ha of rice was obtained on a Typic Endoaquept soil using fertilizer application based on soil test value. N Recovery of rice of ^{15}N labeled was much higher using the soil test fertilizer application rate at site 3. Results obtained for NFUE at site 1 and 3 shows that when input (fertilizer) is properly managed, rice grown on wetland soils usually makes use of higher proportion of N applied.

REFERENCES

[1] FASINA, A.S., 2005. Properties and classification of some selected wetland soils in Ado Ekiti, Southwest Nigeria. Applied Tropical Agriculture, 10:76-82

[2] OLALEYE, A.O.. Characterization, Evaluation, Nutrient dynamics and Rice Yields of Selected Wetland soils in Nigeria. PhD Thesis, Department of Agronomy, University of Ibadan (1998) 202.

[3] BABALOLA T.S., ET AL., Land evaluation studies of two wetland soils in Nigeria. International Research Journal of Agricultural Science and Soil Science 1 (2011) 193-204.

[4] FASIN A.S., ADEYANJU, A., Comparison of three land evaluation systems in evaluating the predictive value of some selected soils in Ado-Ekiti, Southwest Nigeria. J. Soil Sci. 17 (2007) 113-119.

[5] PENG, S., R.J., BURESH, J., HUANG, J., YANG, Y., ZOU, X., ZHONG, G., WANG, and F., ZHANG,. Strategies for overcoming low agronomic nitrogen use efficiency in irrigated rice systems in China, Field Crops Research 96 (2006) 37-47.

[6] DE DATTA, S.K., Improving Nitrogen Fertilizer, Efficiency in Lowland Rice in Tropical Asia Fert. Res. 9 (1996)171-186.

[7] FAGERIA, N.K. and BALIGAR, V.C.. Lowland Rice Response to Nitrogen Fertilization. Commun. Soil Science. Plant Analy 32 (2001) 1405-1429.

[8] FASINA, A.S., Policy and Agricultural Development in Nigeria. Proc. 26th Annual Conference of Farm Management Association of Nigeria (FAMAN) held at Federal College of Agriculture, Akure, (2011) 15.

[9] BAMBA, I., DIAGNE, A., MANFUL, and J. AJAYI. O.,. Historic Opportunities for Rice Growers in Nigeria. Special Report. Grain de sel. No. 51, July – September 2010
[10] CHEN, AD, H. SUTER A. A. ISLAM A, R. EDIS A, J. R. FRENEY A B, C. N. WALKER C. 2008. Prospects of improving efficiency of fertiliser nitrogen in Australian agriculture: a review of enhanced efficiency fertilisers. Soil Research 46(4) 289–301.
[11] AKINBOLA, G. E. 2001. Characterization and classification of some valley bottom soils on basement complex of southwestern Nigeria. In Proceedings of the 27th Annual Conference of Soil Science Society of Nigeria. Calabar. Pp. 100 - 111.
[12] FAO 1976. Framework for land evaluation. Soil Bulletin No. 32, FAO, Rome, pp. 19.
[13] FAO 1979. A Provisional Methodology for Soil Degradation Assessment. FAO, Rome
[14] NACHTERGAELE F. A., Riccardo Biancalani B, Sally Bunning C and Hubert George D. 2010 Land Degradation Assessment: the LADA approach. Proceeding: 19th World Congress of Soil Science, Soil Solutions for a Changing World. 72-75.
[15] ASAGIE, N.H., VENO AND A. EBID 2007: Effects of Sewage Sludge Application in Rice growth, Soil Properties and N-rate in Low Fertile Soil. Int. J. Soil Science 2:171-181.
[16] PRASAD, R. AND DE DATTA, S.K. 1979. Increasing fertilizer nitrogen in wetland rice. Pages 465-484 in International Rice Research Institute. Nitrogen in rice. Las Banos, Philippines.

DYNAMICS OF GREENHOUSE GAS EMISSIONS FROM RIPARIAN BUFFER ZONES AND WETLANDS AS HOT SPOTS IN AGRICULTURAL LANDSCAPES

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Abstract

The study considers various aspects of riparian buffer zones and wetlands for greenhouse gas emissions in agricultural landscapes of northern and north-eastern Europe. In particular, the impact of pulsing water regime, continuous loading and several alterations of environmental conditions on greenhouse gas emissions are taken into the consideration. In two case studies the isotopologue technique was used to distinguish between N_2O sources in both riparian zones and constructed wetlands. Nitrous oxide (N_2O) and nitrogen (N_2) emissions, isotopic signatures of N_2O and nitrate (NO_3^-) in groundwater of two differently loaded riparian grey alder stands in southern Estonia were investigated over a period of nine months. One area was a 38-year-old stand in Porijõgi (PJ), where uphill agricultural activities had been abandoned since the middle of 1990s, and the second area was a 55-year-old alder stand in Viiratsi (Vi), which still receives polluted lateral flow from uphill fields applied with pig slurry. Gas fluxes were measured in six sampling sessions, and water samples were analysed for NO_3^-, N_2, N_2O, and isotopic signatures of oxygen-18 (delta ^{18}O, $\delta^{18}O$) and nitrogen-15 (delta ^{15}N, $\delta^{15}N$) in N_2O and NO_3^- in four of the six sessions. The N_2O and N_2 fluxes from both riparian zones did not differ significantly, being 9.6 ± 4.7 and 14.5 ± 3.9 µg N_2O–N m^{-2} h^{-1}, and $2\,466 \pm 275$ and $3\,083 \pm 371$ µg N_2–N m^{-2} h^{-1} in PJ and Vi sites respectively, suggesting that gaseous N_2 is the dominant gas emission from these alder stands. The isotopic signatures of N_2O and NO_3^- were not significantly different between PJ and Vi study sites suggesting possible conversion of NO_3^- to N_2O in both areas. The greater prevalence of N_2 emissions over N_2O in both areas, and the strong relationship between NO_3^- and N_2O concentrations ($r2= 0.846$, with $p < 0.01$) further suggested that denitrification is the main source of N_2O and N_2 fluxes in these grey alder stands. The dominant emission of N_2 over N_2O showed that these riparian zones play an important role in reducing the emissions of N_2O while removing NO_3^- from water and improving the water quality.

1. INTRDOUCTION

Riparian ecosystems are important landscape in agricultural catchments that control water quality in rivers and other water bodies but they are also potential hot-spots of nitrous oxide (N_2O) emission to the atmosphere [1]. Nitrous oxide plays an important role in altering stratospheric chemistry, including depletion of the ozone layer. The radiative forcing of N_2O is 296 times higher than that of the same amount of carbon dioxide (CO_2), and is therefore a potent greenhouse gas (GHG). Despite its relatively minor contribution to global warming (6 percent), a small increase in emissions can lead to a large accumulation of N_2O in the troposphere, a phenomenon resulting from the long residence time of N_2O, approximately 120 years [2]. Nitrous oxide is produced by (i) reduction of nitrate (NO_3^-) to nitrogen gas (N_2), and (ii) oxidation of ammonium hydroxylamine (NH_2OH) to nitrite (NO_2^-), and the reduction of NO_2^- to N_2O and N_2 under aerobic conditions. Apportioning N_2O to these source oxidation-reduction processes is a challenging task. A better understanding of the N_2O processes is, however, required in order to improve mitigation strategies [3].

Considerable NO_3^- reduction is possible, especially in agricultural areas with high N fertilizer inputs. Dinitrogen (N_2), the main gaseous component of Earth's atmosphere, is the final product of this process, and thus the quantification of groundwater N_2 arising from denitrification (excess N_2) can facilitate the reconstruction of historical N inputs, because NO_3^- loss is derivable from the sum of denitrification products [4]. The concentration of excess N_2 produced by denitrification in groundwater is estimated by comparing the measured concentrations of argon (Ar) and N_2 with those expected from atmospheric equilibrium, assuming that the noble gas argon (Ar) is a stable component [4]. It is also very important to consider the excess N_2 value when calculating indirect N_2O emission from the aquifer resulting from NO_3^- leaching [4].

It has been suggested that the information obtained from measuring the intra-molecular distribution of ^{15}N on the central (α) and the end (β) position of the linear N_2O molecule is crucial for a better understanding of the apportioning of N_2O between nitrification and denitrification, but also source and sink processes [5]. The N_2O site-specific ^{15}N signatures from denitrification and the NH_2OH to N_2O pathway of nitrification have been shown to be clearly different, making this signature a potential tool for N_2O source identification. Most published studies have been dedicated to the analysis of ^{15}N and ^{18}O isotope and isotopic signature ($\delta^{15}N_\alpha$ and $\delta^{15}N_\beta$) of emitted N_2O [5], while there are only a limited number of studies dedicated to the analysis of dissolved N_2O in groundwater [6].

Alders are typical tree species in riparian zones (known as common species of symbiotic dinitrogen (N_2) fixing bacteria (actinobacteria) from the Frankia group) and grey alder stands dominate in riparian zones in agricultural landscapes of North and North-Eastern Europe. Due to high rates of N_2 fixation, some authors have seen alder forests as sources of water body pollution with excess nitrogen (N) [7]. Several other studies consider riparian alder stands to be effective N removal ecosystems [8]. This contradiction is mainly due to the position of alder stands in the landscape: in riparian zones the excess N is mainly denitrified, whereas in the more aerated conditions of higher altitude locations [7], leaching takes place.

On the other hand, alder stands showed the highest N_2O emission values of riparian forests [8]. The percentage of N_2O flux of N input to the riparian ecosystem varied from 0.02% in a riparian wetland [9] to 5.5% in a riparian forest [10].

Nitrous oxide flux appears to be the greatest among the GHG studied: from −1.8 kg N_2O–N ha^{-1} yr^{-1} in riparian mixed forest/grass vegetation [11] to 6390 kg N_2O–N ha^{-1} yr^{-1} in intensively managed riparian grassland in New Zealand [12]. Riparian created marshes showed significantly lower N_2O emissions [13] than natural fens and grasslands [14].

Apportioning N_2O to these source processes is a challenging task that has been analysed in several studies ([15]. A better understanding of the processes is, however, required in order to improve mitigation strategies.

Quantification of groundwater N_2 arising from denitrification (excess N_2) can facilitate the reconstruction of historical N inputs, because NO_3^- loss is derivable from the sum of denitrification products ([4]. It is also very important to consider the excess N_2 value when calculating indirect N_2O emission from the aquifer resulting from N-leaching [4].

Several researchers suggest that information obtained from measuring the intramolecular distribution of ^{15}N on the central (α) and the end (β) position of the linear N_2O molecule is crucial for a better understanding of the apportioning of N_2O between nitrification and denitrification, but also source and sink processes ([5]. The N_2O site-specific ^{15}N signatures from denitrification and the NH_2OH-to-N_2O pathway of nitrification have been shown to be clearly different, making this signature a potential tool for N_2O source identification [16]. The majority of studies have been dedicated to the analysis of $\delta^{15}N$ and $\delta^{18}O$ isotope and isotopomer ($\delta^{15}N_\alpha$ and $\delta^{15}N_\beta$) values of emitted N_2O [5], while there are only a limited number of studies dedicated to the analysis of dissolved N_2O in groundwater. Especially, isotopologue-based data on the relative contribution of the saturated and unsaturated zones to total fluxes and on lateral N_2O fluxes with groundwater flow to open water bodies are provided by very few studies.

A pulsing hydrological regime is often used in horizontal subsurface flow (HSSF) constructed wetlands (CW) to enhance removal of BOD, COD, NH_4 and total N [17] utilization by bacteria and to support more effective NH_4, total N and total P removal. Little is known of the impact of intermittent loading on greenhouse gas (GHG) emissions from CWs. Several studies have shown that a pulsing regime decreases both CH_4 and N_2O emissions from created riverine wetlands have found that the lower water table level in the HSSF bed of the Paistu-Sultsi hybrid CW in Estonia caused a significant increase in CO_2 and N_2O emission and a decrease in CH_4 emission. However, no systematic experiments have been performed in HSSF CWs to study the impact of a fluctuating water table.

The main objective of this study was therefore to compare gaseous N_2O and N_2 fluxes with the isotopic signatures of N_2O and NO_3^- in the groundwater of two differently loaded riparian alder stands in southern Estonia. The specific objectives of the study were to: (1) assess and analyse N_2O fluxes from the main land-use types of agricultural landscapes to compare N_2O trends and determine hot spots for N_2O, (2) clarify the impact of the change in land use intensity (abandonment from one side and intensification from another) on fluxes of N_2O from riparian buffer zones (RBZ) on different soils; (3) determine the N_2O fluxes influenced by the change of water regime in both RBZs and various wetlands within agricultural landscapes; (4) test the isotopologue technique for the distingusishing between the N_2O sources (denitrification vs nitrification) in both PBZs and CWs for wastewater treatment; and (5) analyse opportunities for optimal siting and management of RBZs and CWs to minimize N2O emission (e.g., biomass production for sustainable energy consumption);

It was hypothesize that: (1) in continuously and long-term loaded RBZs and small constructed wetlands the saturation effect can appear, i.e., both the rate of denitrification and nitrification will decrease, and thus emissions of N_2O will decrease as well; (2) changes in water regime influence N_2O emissions differently: on Gleysols and Histosols drainage causes an increase the N_2O emission, re-wetting of RBZs on automorphic soils will result in increase of N_2O flux; (4) the energy forest plantations in RBZs with no significant fertilization level will help decrease N_2O fluxes.

2. MATERIALS AND METHODS

2.1. Experimental study areas

The measurement of GHG emission from riparian zones, constructed wetlands, drained wetlands and experimental sites within the agricultural landscapes [18] was carried out in 8 areas with 17 different sites (Figure. 1).

The Aardlapalu drained fen grassland is 1018 ha in size and is situated in south-eastern Estonia (Tartu County, Reola; 58°18´N, 26°44´ E). The whole area, a formerly intensively managed polder, is covered with a drainage system. In April and May, the site is flooded with water from the winter snow thaw. The water level is approximately 75–100 cm above ground. In midsummer, usually at the end of July, it is drained, and the resulting grassland is used mainly for haying.

The Porijõgi study area is a grey alder stand situated in the moraine plain of south-eastern Estonia (Tartu County, Sirvaku; 58º 13` N, 26° 47` E), in the riparian zone of a small river, the Porijõgi, which flows in a primeval valley where agricultural activities ceased in 1992. The landscape study transect in this valley crosses an abandoned arable land area and an abandoned cultivated grassland. In the grey alder stand, two microsites namely (1) a wet riparian forest on hydromorphic soil, and (2) a dry riparian forest on automorphic soil, were chosen for gas and soil analyses.

The Viiratsi study area is situated in the Sakala uplands (Viljandi County, 58º 20` N, 25° 39` 20'' E), consisting of moraine hills and undulated plains with a variety of glacial deposits. The study area is located on the moraine plain in the vicinity of a pig farm (30,000-80,000 pigs at the time of the study). Almost all of the slurry from the pig farm is spread on the neighbouring fields, and the whole area is heavily impacted by the pig slurry. The site includes a land transect located in a cultivated field where slurry is spread almost every growing season. From this site, two microsites (1) a wet riparian forest on hydromorphic soil, and (2) a dry riparian forest on automorphic soil, were chosen for gas and soil analyses.

The Pudivere study area is located in northern Estonia (Liivaaugu, Lääne-Viru County, 59°5´N, 26°22´E). The area is mainly used for agricultural purposes, and the study sites are surrounded with arable fields or grasslands. From this site, three microsites were chosen including (1) fertilized arable land, (2) grassland on automorphic soils, and (3) semi-natural grassland on hydromorphic soil.

The Rõhu study area is located in south-eastern Estonia (Tartu County, 58°21´N, 26°31´E). The area is very actively used for agricultural purposes. The main cultivated crops are corn (for silage) and oil rape. In the first year of research, there were two study sites in this area namely (1) one that had a manipulated, high groundwater level and (2) one with normal drainage. Since 2009, water-level manipulation ended and these two microsites are considered to be one.

The Rõka Study area is situated in Tartu County (Rõka, 58°14´N, 27°18´E), in the east of Estonia. At Rõka, two microsites have been chosen including (1) a former arable field on automorphic soil that was abandoned during the last decade, and (2) a riparian black alder (*Alnus glutinosa*) forest on hydromorphic soil.

The Sangla study area is situated in Tartu County (Rannu, 58°19´N, 26°13´E), in south-eastern Estonia. The whole neighbouring area is a former peat extraction field. From Sangla, two microsites were chosen including (1) a grassland area on the slope of a mineral soil (the downslope of an arable field) that is influenced by a drainage downslope and is used only for haying (no herding), and (2) a drained transition fen forest at the border of the peat extraction area.

The Holvandi grey alder plantation (0.1 ha) was established on abandoned farmland in spring 1995, in the southeastern part of Estonia, 58◦3' N and 27◦12' E. According to the data of the closest meteorological station, mean annual temperature, amount of precipitation and length of the vegetation period are 6 ◦C, 653mm and 191 days, respectively. The soil is classified as Eutric Podzoluvisol. One-year-old transplants of natural origin were used for planting. Initial density was 15,750 trees per hectare. No weed control, fertilization or other treatment was employed. The establishment, survival and growth of the plantation have been described earlier [19]. A complex study of all forest stand parameters, below-ground biomass, soil chemical and physical parameters, as well as GHG emission were measured with various frequency during the period 1990-2006.

The Kambja riparian forest sites of groundwater manipulation. We studied the effect of changing groundwater depth on the emission of CO_2, CH_4, and N_2O in two riparian grey alder (*Alnus incana*) stands in Kambja, southern Estonia (58°11'18''N, 26°37'40''E.), using the closed static chamber method. The older alder (OA) stand (ca 40 yrs) is situated on the alluvial soil of a small stream. The younger alder (YA) stand (5-6 yrs) is growing in patches in combination with common reed, at the dry bottom of a former peat extraction site in which 0-10 cm of raw humus covers till, and a small stream passes through the sites.

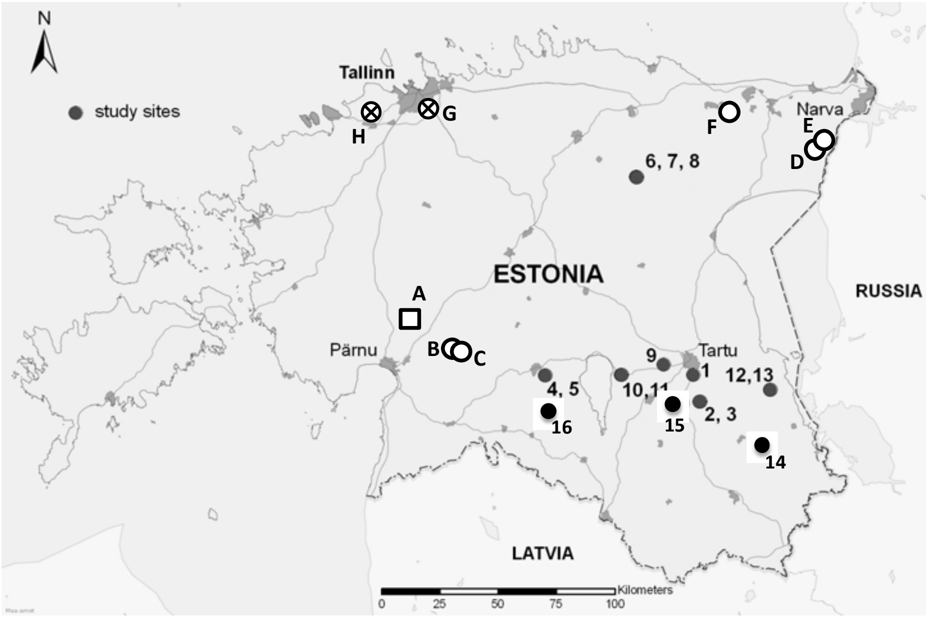

FIG. 1. Location of study areas in Estonia. 1 - Aardlapalu drained fen grassland, 2- Porijõgi riparian forest on automorphic soil, 3- Porijõgi riparian forest on hydromorphic soil, 4 - Viiratsi riparian forest on automorphic soil, 5 - Viiratsi riparian forest on hydromorphic soil, 6 - Pudivere fertilized arable land on automorphic soil, 7 - Pudivere grassland on automorphic soil, 8 - Pudivere semi-natural grassland on hydromorphic soil, 9 - Rõhu fertilized arable land on automorphic soil, 10 - Sangla fertilized grassland on automorphic soil, 11 - Sangla drained transition fen forest, 12 - Rõka abandoned land on automorphic soil, 13 - Rõka riparian forest on hydromorphic soil, 14 – Holvandi grey alder forest on an abandoned arable land, 15 – Kambja forest with experimental groundwater depth manipulation; 16 – Sultsi-Paistu horizontal subsurface flow constructed wetland for schoolhouse wastewater treatment. Study sites for the measurement of GHG emissions in natural, drained, and disturbed (actually used and abandoned), and restored peatlands: A – Lavassaare peat extraction area complex (active, abandoned, and Phalaris-cultivated peatlands), B – Kuresoo natural and drained raised bog, C – Valgeraba natural transitional bog and drained bog forest, D – Kasesoo peat extraction area with active, abandoned and natural sites, E – Puhatu peat extraction area with active, abandoned and natural sites, F – Hiiesoo peat extraction area with active, abandoned and natural sites, G – Seli abandoned peat extraction area with Sphagnum-layer-restored experimental sites, H – Ohtu abandoned peat extraction area with Sphagnum-layer-restored experimental sites.

The Sultsi-Paistu hybrid wetland system (constructed in 2002; 58°14'30.63''N, 25°35'33.70''E) treats the wastewater of 140 people (about 64 PE) and consists of a two-chamber VSSF filter bed (12 m × 18 m) and a 216 m^2 HSSF filter bed. The latter has a depth of 0.9 m and is filled with 2–4 mm light-weight aggregates (LWA) and covered with reed (see Öövel et al 2007 *Ecol Eng* for a detailed description). The whole system showed outstanding purification effect: for BOD_7 the average purification efficiency is 91%; for total suspended solids (TSS) 78%, for total P 89%, for total N 63%, and for NH_4-N 77%.

2.2. Gas sampling and analyses

The closed chamber method was used for the measurement of CO_2, CH_4 and N_2O fluxes, and the He-O method [20] for the measurement of N_2 emissions. For gas sampling we used closed chambers with a conical cover made of PVC, height 50 cm, Ø 50 cm, volume 65 l, sealed with a water-filled ring on the soil surface, painted white to avoid heating during application at 0, 10, 20, 30 and 60 minutes the gas samples were taken from the enclosures of samplers with previously evacuated gas bottles. Gas samplers were installed in 3-5 replicates During each gas sampling session in each microsite, the depth of the groundwater table (cm) in observation wells (∅ 50 mm, 1.5 m deep PVC pipes perforated and sealed in a lower 0.5 m part) and soil temperature was measured at 3 depths (0-10, 20-30 and 30-40 cm). Also the NH_4-N and NO_3-N concentration in soil samples was analysed using the Kjeldahl method.

Intact soil cores (diameter 6.8 cm, height 6 cm) for use with the He-O method were taken from the topsoil (0-10 cm) at the gas sampler sites each time gas sampling was completed. Soil samples were weighed, kept at low temperature (4^oC) and transported to the laboratory of the Institute of Primary Production and Microbial Ecology of the Centre for Agricultural Landscape and Land Use Research (ZALF) in Germany. At the lab, the soil cores were introduced into special gas-tight incubation vessels. In these vessels, N_2 was removed using 3 subsequent slight evacuation/flushing cycles with an artificial gas mixture (21.3% O_2, 78.6% He, 337 ppm CO_2, 374 ppb N_2O, 1882 ppb CH_4 and approximately 5 ppm N_2). This was followed by the establishment of new flow equilibrium by continuously flushing the vessel headspace with the gas mixture at 10 ml per minute for 12 hours. For the start value, N_2 and the greenhouse gas concentration in the gas mixture was measured. The gas concentrations in the incubation headspace were measured (final value) after closing the incubation headspace for one hour to accumulate the emission of N_2 and the greenhouse gases. The final accumulation value minus the start continuous flow value served as the basis for the calculation of the emission rates. During the flushing, the redox potential of the soil cores was regularly measured and regulated so that it was comparable with the field conditions. The gas concentration in the collected air was determined by using the gas chromatographic system (electron capture detector and flame ionization detector; in the lab of the Institute of Primary Production and Microbial Ecology at the Centre for Agricultural Landscape and Land Use Research (ZALF) in Germany. Since October 2008 the gas concentrations were measured in the laboratory of the Institute of Technology of the University of Tartu using the same equipment as at ZALF.

2.3. Gas sampling protocol and location of gas samplers in various case studies

Gas samplers were installed in 3-5 replicates at the following sites: in Edge, Wet and Dry positions in the Porijõgi riparian buffer zone and in Wet, Slope and Dry positions in the Viiratsi study area (Figure. 2). Gas sampling was carried out according to the following schedule: (1) in Porijõgi – once a month in October and November 2001, March, May to December 2002, January to March, July, November and December 2003, March 2004, April and May 2005, November and December 2006, April, June and August 2007, April, May, July, August, October and November 2008, January to October 2009; (2) in Viiratsi – once a month at the same dates as in Porijõgi, but starting in November 2003.

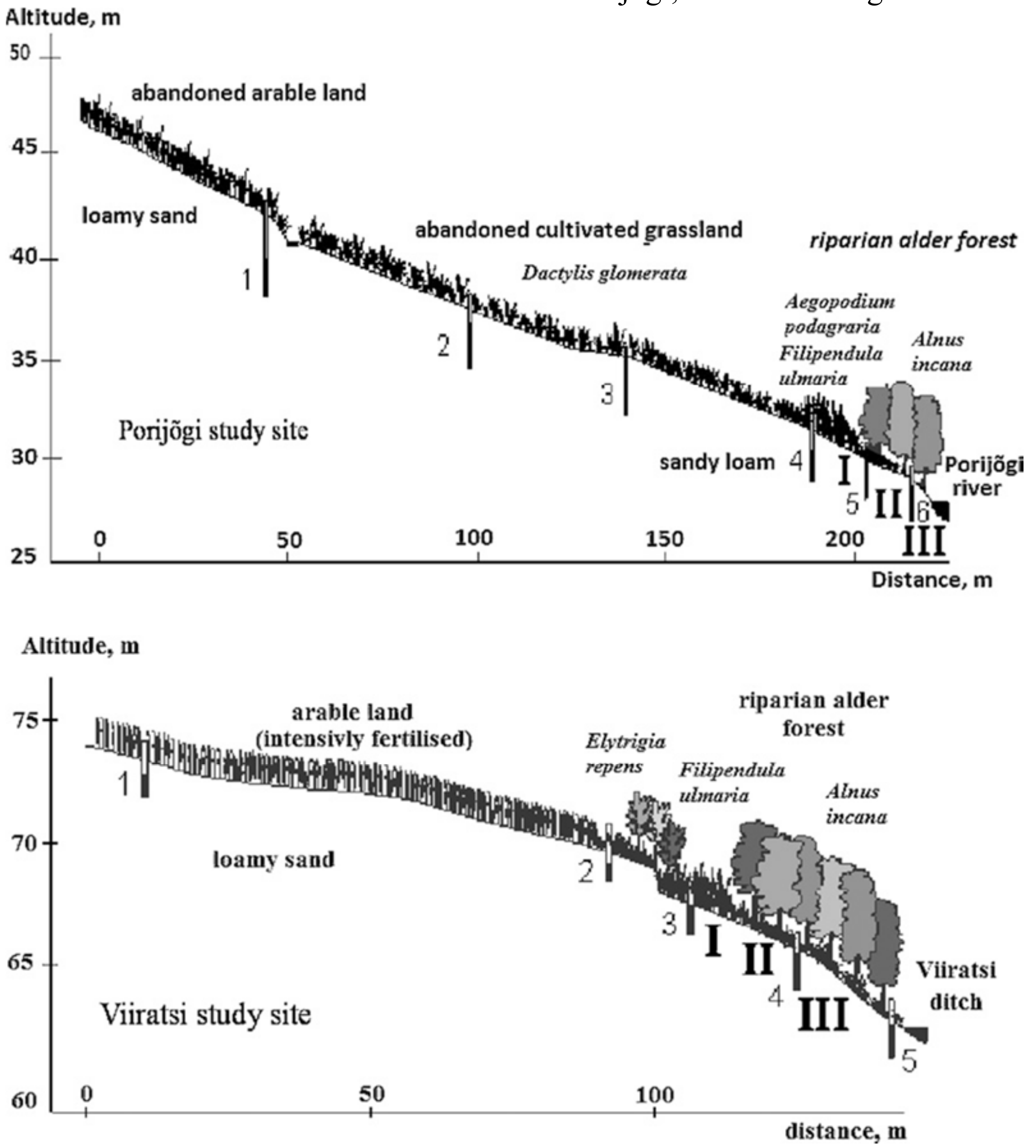

FIG. 2. Study transects in complex riparian buffer zones in southern Estonia. Microsites in Porijõgi: I – edge, II – dry, III – wet; in Viiratsi: I – wet, II – slope, III – dry. 1–5(6) – groundwater observation wells.

2.4. Peatlands

In all 13 microsites of 5 study areas (Figure 1), gas samplers were installed in 5 replicates and the sampling lasted from October 2008 until December 2009 with the frequency of 1-2 sampling sessions a month. All supporting field studies were the same like in the riparian forests studies.

2.5. Experiments conducted in an experimental forest site with groundwater table manipulation

In both areas (one representing and older alder (OA) stand (ca 40 years), situated on the alluvial soil of a small stream, and the second one, a younger alder (YA) stand (5-6 years), growing in patches in combination with common reed, at the dry bottom of a former peat extraction site in which 0-10 cm of raw humus covers till), one site was chosen for water table manipulation (Manip) and another remained unchanged with a stable and deeper groundwater table (15 to 17 cm below ground in YA, and 45 to 50 cm in OA, later called as Dry sites). In July and August 2011 we twice changed the water table at the Manip sites, closing the streams with temporary dams for two days and measuring gas emission two days after the flooding. At all sites, 5 replicate gas samplers and two replicate groundwater observation wells were used. At dry sites the chambers were located outside the flooded area. Gas samples were taken in 10 sampling sessions 0, 10, 30 and 60 minutes after installing the chambers on rings and analyzed for GHG in the lab using the Shimadzu 2014 GC.

2.6. Experiments conducted in a subsurface flow constructed wetland for wastewater treatment

In the period 2008-2010 the depth of the water table in the HSSF bed fluctuated from 0 to 70 cm. Since that period the water table has been kept constantly at a depth of 0-10 cm. In October and November 2012, an experiment with fluctuating water table depth from 0-12 (high level) to 17-25 cm (low level) was conducted. Gas fluxes were measured in 12 sampling sessions in 2008-2010 from the inflow, middle and outflow parts of the HSSF bed, and in 16 sessions during the experimental period (7th October to 7th November 2012) from the inflow and outflow parts of the HSSF bed (5 replicates from each location). During the experimental period, water samples were taken from the inflow and outflow of the HSSF once a week, during both high and low water table level and analysed for pH, TOC, BOD_7, NH_4^+-N, NO_2^--N, NO_3^--N, total N (TN), PO_4^{3-}-P and total P (TP) in the lab of Estonian Environmental Research Ltd. Water samples for analyses of NO_3^-, N_2 and N_2O and isotopologues of N_2O were taken in four sessions from April to December 2008. CO_2, CH_4 and N_2O emission was measured using the closed-chamber/gas-chromatographic technique [21]. Isotopologue signatures of N_2O such as $\delta^{18}O$, average $\delta^{15}N$ ($\delta^{15}N^{bulk}$) and ^{15}N site preference (SP = difference in $\delta^{15}N$ between the central and peripheral N positions of the asymmetric N_2O molecule) were measured using an enhanced IRMS in the Centre for Stable Isotope Research and Analysis, University of Göttingen, Germany [22]. The SP value has been used as an indicator of N_2O from denitrification.

2.7. Isotopologue studies

2.7.1. Water sampling and analyses

Shallow groundwater depth in upper aquifer was measured once a month from piezometers installed with 2-3 replicates on the borders of plant communities. Groundwater discharge was estimated on the basis of both Darcy's law and through gauging with weirs installed in groundwater seeping sites within the alder stand.

For the analysis of nitrogen gases, NO_3^-, and their isotopologue signatures, water samples were taken in 4-9 replicates from water sampling wells using a peristaltic pump. Water was pumped through the probes into 115-mL serum bottles. To discard water with atmospheric contamination, an overflow of > 115 mL water was allowed before the bottles were immediately sealed without trapping air bubbles using butyl rubber septa (Altmann, Holzkirchen, Germany) and crimp caps [4]. The samples were stabilized with 0.1 mL of saturated $HgCl_2$ solution.

In the laboratory of the Büsgen-Institute at the University of Göttingen in Germany, a He-headspace of 8 mL was created and the liquid and gas phases of the water samples were then equilibrated at constant temperature (2°C) by agitating on a horizontal shaker for 3 h. To analyse N_2 and Ar, 1 mL of headspace gas was injected manually into a gas chromatograph (GC; Fractovap 400, CARLO ERBA, Milano) equipped with a thermal conductivity detector and a packed column (1.8m length, 4mm ID, molecular sieve 5Å) and using helium as carrier gas. To determine dissolved N_2O and CO_2 concentrations, the headspace volume was augmented to 40 mL through the additional injection of 32 mL of helium and an equivalent amount of groundwater was replaced. After equilibrating the liquid and gas phases at constant temperature (25°C), 24 mL of the headspace gas was equally distributed to 2 evacuated septum-capped exetainers® (12 mL, Labco, Wycombe, UK). N_2O and CO_2 were analyzed using a Fractovap 400 GC equipped with a thermal conductivity detector, an ECD and an autosampler. NO_3^- concentration was determined on 0.45 μm membrane filtered samples by using a gas chromatograph (ICS-90, DIONEX, Idstein, Germany) equipped with an IC-AIS column. NH_4^+ concentration was measured using the standard procedures. A more detail characterization of the analyzing procedures is given in [23].

N_2 from denitrification ($\mathbf{X}_{\mathrm{excessN2}}$) was calculated using the following equation:

$$X_{excessN_2} = X_{N_2T} - X_{N_2EA} - X_{N_2EQ} \qquad (1)$$

where $\boldsymbol{X}$ denotes the molar concentration of the parameters, $\boldsymbol{X}_{\mathrm{N2\ T}}$ represents the molar concentration of the total dissolved N_2 in the groundwater sample, $\boldsymbol{X}_{\mathrm{N2\ EA}}$ is N_2 from "excess air", and $\boldsymbol{X}_{\mathrm{N2\ EQ}}$ is the molar concentration of dissolved N_2 in equilibrium with the atmospheric concentration

Initial NO_3^- concentration (**c**$NO_3^-{}_{t0}$**)** at a given location on the aquifer surface is defined by the NO_3^- concentration of the recharging water before alteration by denitrification in the groundwater. From the assumption that NO_3^-consumption on the groundwater flow path between the aquifer surface and a given sampling spot originates from denitrification and results in the quantitative accumulation of gaseous denitrification products (N_2O and N_2**)**, it follows that **c**$NO_3^-t_0$ can be calculated from the sum of the residual substrate and accumulated products. Thus **c**$NO_3^-t_0$ is given by the following equation:

$$cNO_3^-\ t_0 = excess\ N_2 + cNO_3^- - N + cN_2O{-}N \qquad (2)$$

Reaction progress (RP) is the ratio between the products and the starting material of a process, and can be used to characterize the extent of NO_3^- elimination by denitrification. RP is calculated as follows:

$$RP = \frac{excess\ N_2 + cN_2O-N}{cNO_3^- - N_{to}} \qquad (3)$$

In this study, all of the concentration values are recalculated to mg L^{-1}.

2.7.2. Isotope analyses

The isotopologue signatures of N_2O, i.e. $\delta^{18}O$ ($\delta^{18}O$-N_2O), average $\delta^{15}N$ ($\delta^{15}N^{bulk}$-N_2O) and $\delta^{15}N$ from the central N position ($\delta^{15}N^{\alpha}$), were analysed after cryo-focussing using isotope ratio mass spectrometry, as described by [22]. The analysis was conducted at the Centre for Stable Isotope Research and Analysis (University of Göttingen, Germany) using a Delta XP IRMS (Thermo–Finnigan, Bremen, Germany), allowing simultaneous detection of m/z 30, 31 of N_2O fragments and m/z 44, 45 and 46 of intact N_2O molecules. The IRMS was connected to a modified Precon (Thermo–Finnigan, Bremen, Germany) equipped with an auto sampler (model Combi-PAL CTC-Analytics, Zwingen, Switzerland) [3].

^{15}N site preference (SP; ‰) was obtained as:

$$SP = 2 \times (\delta^{15}N^{\alpha} - \delta^{15}N^{bulk} - N_2O) \qquad (4)$$

The isotopologue ratios of a sample (R_{sample}) were expressed as the deviation from the $^{15}N/^{14}N$ and $^{18}O/^{16}O$ ratios of the reference standard materials (R_{std}), atmospheric N_2 and standard mean ocean water (SMOW) respectively:

$$\delta X = \left(\frac{R_{sample}}{R_{std}} - 1\right) \times 1000 \tag{5}$$

where X = $^{15}N^{bulk}$-N_2O, $^{15}N^{\alpha}$, $^{15}N^{\beta}$, or ^{18}O

2.7.3. Statistical analysis of data

Normality of variable distributions was checked using the Kolmogorov–Smirnov, Lilliefors and Shapiro–Wilk tests. In most cases with the gas analyses, the distribution differed from the normal, and hence non-parametric tests were performed. Medians, 25 and 75% percentiles and non-outlier range values of variables are presented. We used the Kruskal–Wallis ANOVA and Wilcoxon Matched Pairs test to check the significance of differences between the gas fluxes at different sites, and the Spearman Rank Correlation to analyse the relationship between GHG fluxes and environmental conditions. The Mann–Whitney U-test was used to check the difference between gas fluxes in different periods. The statistical analysis was carried out using Statistica 7.1 (StatSoft Inc.). The level of significance of $p < 0.05$ was accepted in all cases.

In addition, the soft modeling approach called redundancy analysis (RDA) was applied to relate gas emission data to environmental parameters (Legendre and Legendre, 1998). The soil temperature and depth of groundwater data were used in the redundancy analysis as explanatory variables, and the land-use categories and microsites were considered as a categorical variable. The forward selection option with 1000 permutation was applied for variable selection. RDA was implemented using the CANOCO 4.52 program. The Global Warming Potential (GWP) of N_2O and CH_4 was calculated by converting the measured flux values into CO_2 equivalents (eq; 1 kg CH_4 =25kg CO_2 eq; 1kg N_2O= 296 kg CO_2 eq; IPCC, 2007).

3. RESULTS AND DISCUSSION

3.1. Comparative study of two differently loaded riparian alder stands

The temporal and spatial variations in N_2O and N_2 fluxes in both Porijõgi and Viiratsi were remarkable. Local differences in GHG fluxes between micro-sites ("Edge", "Dry" and "Wet" in Porijõgi, and "Wet", "Slope" and "Dry" in Viiratsi) were sometimes greater than those between sites. Median values of N_2O and N_2 fluxes from both sites over the whole study period and all microsites did not differ significantly, being 2.1 mg N_2–N m^{-2} h^{-1}, and 5 and 9 g N_2O–N m^{-2} h^{-1}, in Porijõgi and Viiratsi, respectively (Figure 3)

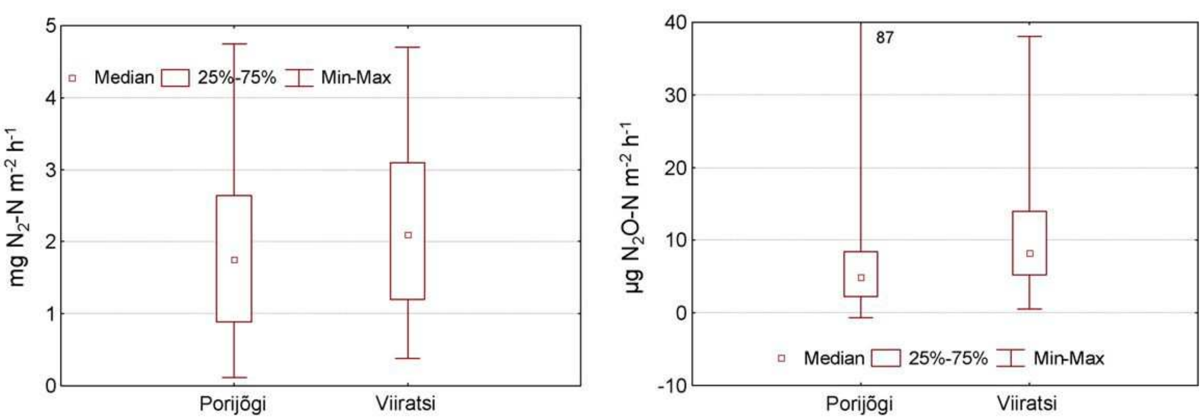

FIG. 3. Comparison of N_2 and N_2O fluxes in Porijõgi and Viiratsi study sites. Data represent fluxes from all sites within the test area. No significant differences in fluxes between two study areas have been found (Wilcoxon Matched Pairs test).

The N_2:N_2O ratio in Viiratsi (40–1200) was lower than in Porijõgi (10–7600). The median values-based estimation of the Global Warming Potential of N_2O was 185 kg CO_2 equivalents (eq) ha^{-1} yr^{-1} in Porijõgi and 336 kg CO_2 eq ha^{-1} yr^{-1} in Viiratsi, respectively. A significant Spearman rank correlation was found between the mean monthly air temperature and N_2 fluxes in Porijõgi, and N_2O flux in Viiratsi, (Figure 4).

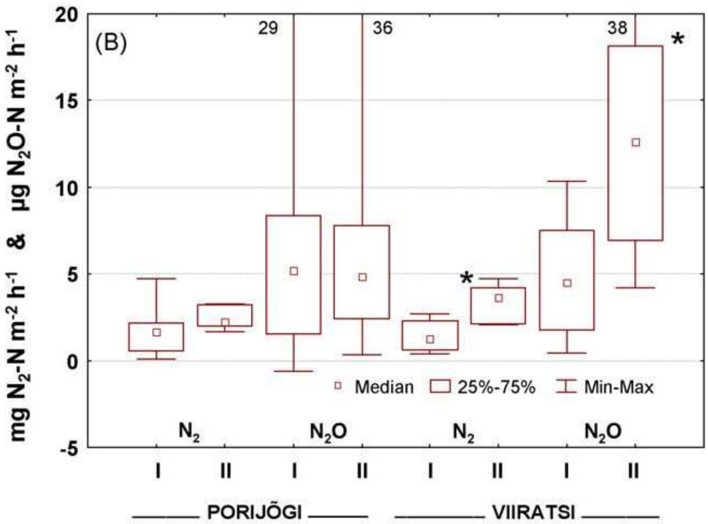

*FIG. 4. Comparison of N_2 and N_2O fluxes in 2003–2007 (period with colder winters and long-term average precipitation) and 2008–2009 (warmer winters and higher precipitation). I – 2003–2007, II – 2008–2009. * – significantly differing values ($p < 0.05$; Mann–Whitney U-test).*

In Viiratsi a significant correlation was found between the CO_2 and N_2 emission (upper part) and N_2 and N_2O fluxes. In the same time in Porijõgi no significant relationship was observed (Figure 5). This may also indicate on long-term higher initial loading in Viiratsi.

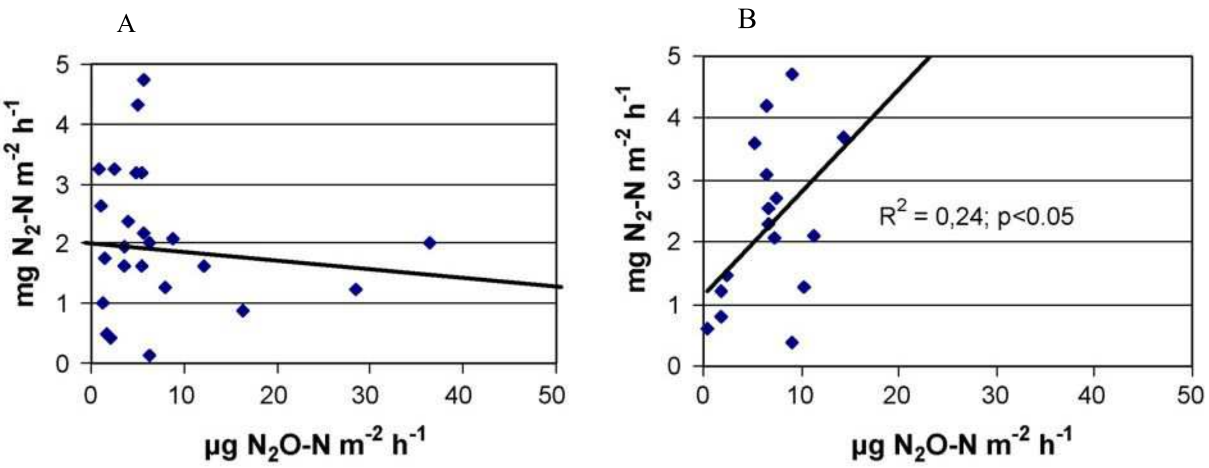

FIG. 5. The relationship between CO_2 and N_2 emission (upper part) and N_2 and N_2O fluxes (lower part) in the Porijõgi (A) and Viiratsi (B) study areas.

3.2. Isotopologue studies in riparian grey alder stands

The average values of N_2O and N_2 fluxes from both Porijõgi (PJ) and Viiratsi (Vi), riparian zones did not differ significantly, being 9.6±4.7 and 14.5±3.9 µg N_2O–N m^{-2} h^{-1}, and 2466±275 and 3083±371 µg N_2–N m^{-2} h^{-1} in PJ and Vi respectively (Figure 6). The N_2:N_2O in Vi (278±60) was lower than in PJ (995±360).

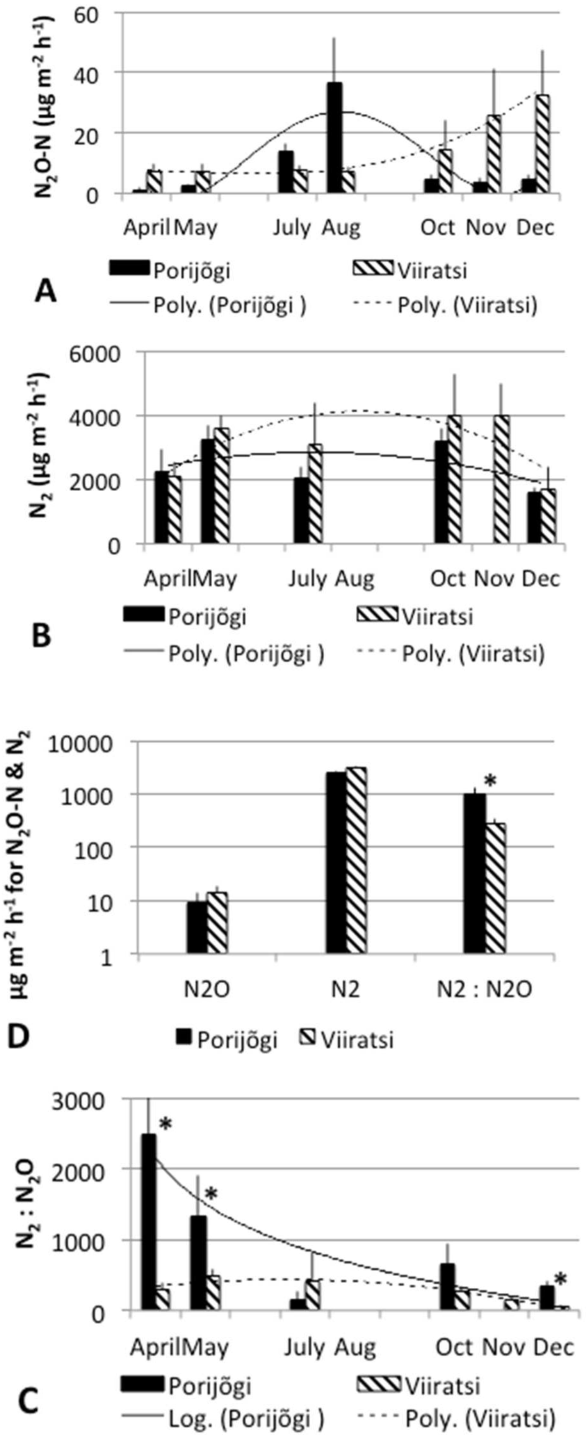

*FIG. 6. Monthly average emission ± standard error values of N_2O (A) and N_2 (B) emission, and N_2:N_2O ratio (C) in PJ and Vi riparian grey alder forests. D – N_2O and N_2 emission and N_2:N_2O ratio values averaged over the whole study period. *significantly different values ($p < 0.05$).*

The excess N_2 concentration and the reaction progress (RP) value in the groundwater of both

the upper (U) and lower (L) sites of both areas were quite similar, varying from 2.43±0.19 to 3.01±0.31 mg L^{-1} and from 0.55±0.08 to 1.0±0.05 for excess N_2 and RP respectively.
None of the measured isotopologue values were also significantly different between the two study areas and also between the sites (Figure 7). The PJ upper site had somewhat higher values than those in the PJ lower site for $\delta^{18}O\text{-}NO_3^-$, $\delta^{18}O\text{-}N_2O$ and $\delta^{15}N^{bulk}\text{-}N_2O$. The SP-$N_2O$ value was lower at the PJ upper site (12.6±1.3 and 24.1±6.5 ‰ in upper and lower sites respectively).

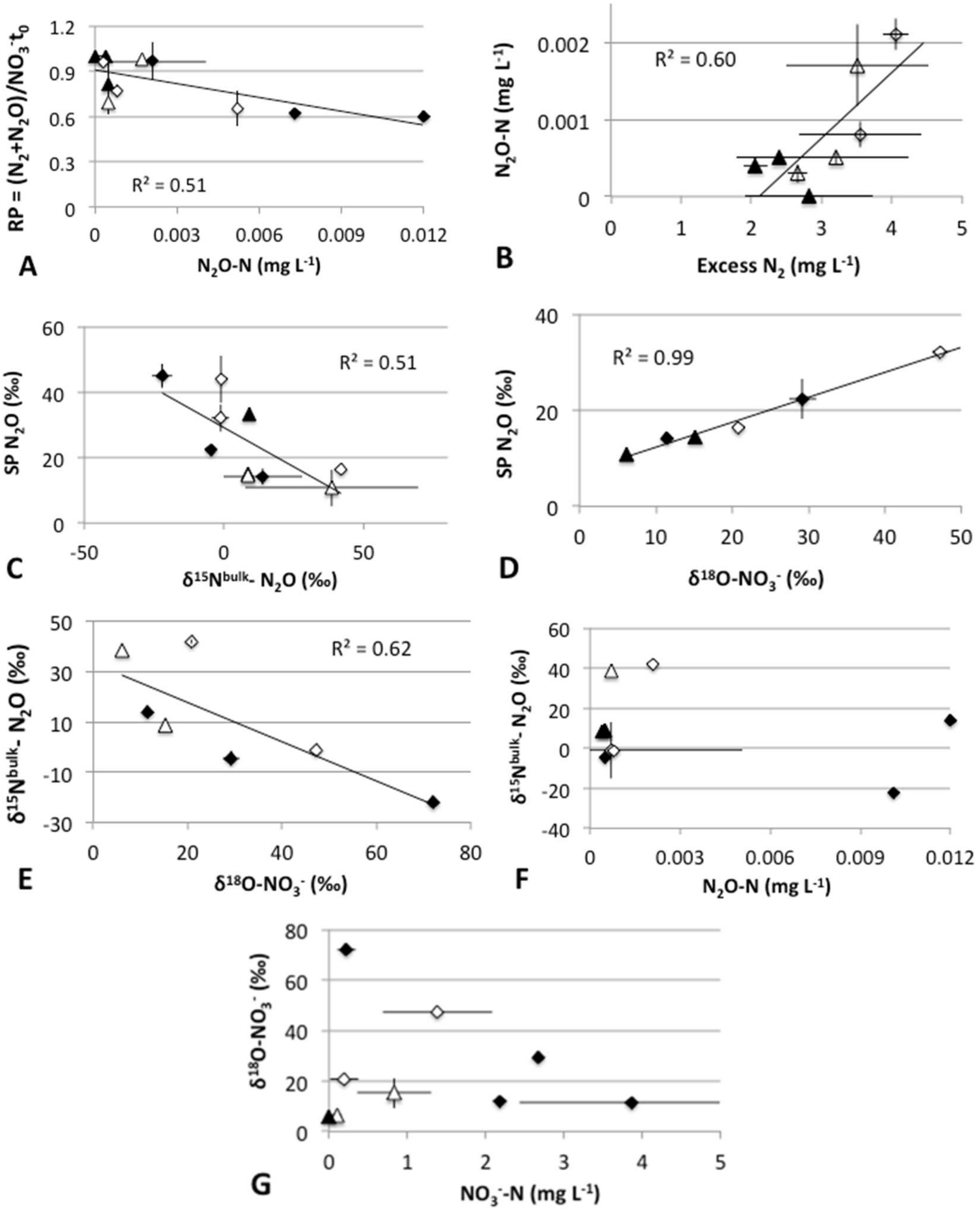

FIG. 7. Groundwater N_2O vs reaction progress (RP) (A), excess N_2 vs N_2O (B), $\delta^{15}N^{bulk}N_2O$ vs SP (C), $\delta^{18}O\text{-}NO_3^-$ vs SP (D), $\delta^{18}O\text{-}NO_3^-$ vs $\delta^{15}N^{bulk}N_2O$ (E), N_2O vs $\delta^{15}N^{bulk}N_2O$ (F), and NO_3^- vs $\delta^{18}O\text{-}NO_3^-$ (G) in the riparian grey alder forests of Porijõgi (triangles) and Viiratsi (diamonds) in Estonia. White symbols refer to the upper sites, and black symbols to the lower sites (see Table 1). Average and standard error values are shown.

A significant negative linear correlation was determined between the groundwater N_2O-N concentration and RP, between $\delta^{15}N^{bulk}N_2O$ and SP N_2O and between $\delta^{18}O$-NO_3^- and $\delta^{15}N^{bulk}N_2O$ values, while excess N_2 and N_2O-N concentration and $\delta^{18}O$-NO_3^- and SP N_2O values were positively correlated. N_2O and N_2 emission values were positively correlated with NO_3^--N, N_2O-N and the sum of NO_3^- and excess N_2 concentrations (NO_3^--t_0) in groundwater (Figure 7).

The strong prevalence of N_2 emission over N_2O fluxes, SP N_2O values, as well as the correlation pattern between the isotopologue and water quality characteristics corroborate that the main source of N_2O fluxes in both riparian grey alder stands is denitrification.

3.3. Dynamics of nitrogen and carbon in soil and gaseous nitrogen emissions in a short-rotation grey alder forest on abandoned agricultural land

Short-rotation energy forestry is one of the potential ways for management of abandoned agricultural areas. It helps sequestrate carbon and mitigate human-induced climate changes. Owing to symbiotic dinitrogen (N_2) fixation by actinomycetes and the soil fertilizing capacity and fast biomass growth of grey alders, they can be suitable species for short-rotation forestry. In the study of a young grey alder stand (*Alnus incana* (L.) Moench) on abandoned arable land in Estonia the following hypotheses were tested: (1) afforestation of abandoned agricultural land by grey alder significantly affects the soil nitrogen (N) status already during the first rotation period; (2) input of symbiotic fixation covers an essential part of the plant annual N demand of the stand; (3) despite a considerable N input into the ecosystem of a young alder stand, there will occur no significant environmental hazards (N leaching or N_2O emissions).

The first two hypotheses can be accepted: there was a significant increase in N and C content in the topsoil (from 0.11 to 0.14%, and from 1.4 to 1.7%, respectively) (Figure 8 and Figure 9), and N fixation (151.5 kg N ha^{-1} yr^{-1}) covered about 74% of the annual N demand of the stand.

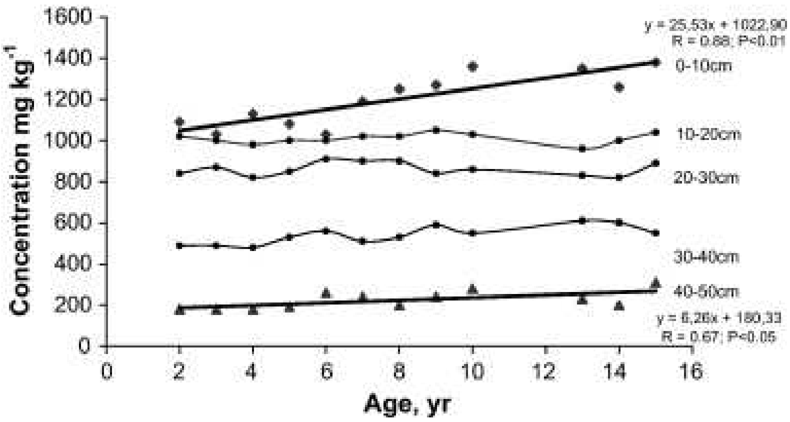

FIG. 8. The dynamics of soil nitrogen concentration in different soil layers of grey alder stand.

The third hypothesis met support as well. N_2O emissions (0.5 kg N ha^{-1} yr^{-1}) were low, while most of the annual gaseous N losses were in the form of N_2 (73.8 kg N ha^{-1} yr^{-1}) (Figure 10). Annual average NO_3–N leaching was 15 kg N ha^{-1} yr^{-1} but the N that leached from topsoil accumulated in deeper soil layers. The soil acidifying effect of alders was clearly evident; during the 14-year period soil acidity increased 1.3 units in the upper 0–10 cm topsoil layer.

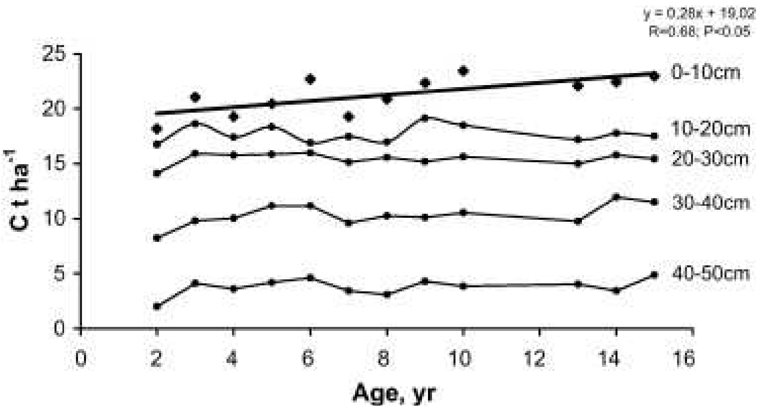

FIG. 9. The dynamics of soil carbon storage in different soil layers in grey alder stand.

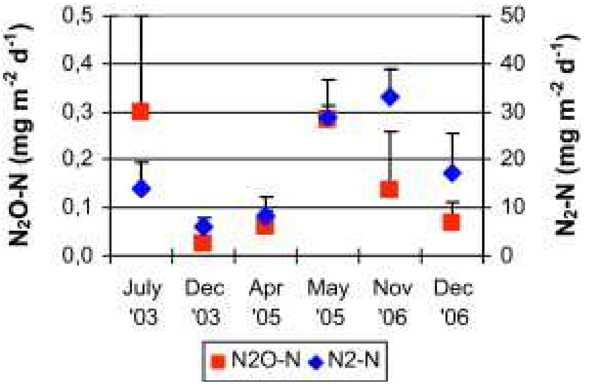

FIG. 10. Average and standard deviation values for nitrous oxide and dinitrogen fluxes from the study sites in 2003, 2005 and 2006.

3.4. The impact of a pulsing groundwater table on greenhouse gas emissions in riparian grey alder stands

The study showed that the groundwater table manipulation significantly decreases N_2O emission (Figure 11). There was no significant difference in CO_2 and CH_4 emission between the OA and YA sites, whereas in OA sites with higher N concentration in the soil, the N_2O emission was significantly higher than in the YA site. We found a significant correlation between groundwater depth and the emission of all GHGs.

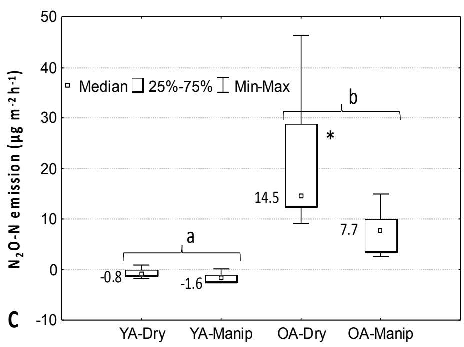

*FIG. 11. Median, 25 and 75% quartile and min-max values of N_2O emission in grey alder stands at the Kambja study area in Estonia. YA – young alder stand, OA – old alder stand, Dry – stable deep water table, Manip – changing groundwater table. Different lower-case letters (a, b) indicate significant ($p < 0.05$) differences between study sites, o-o - no significant differences. *significant difference between the dry and manipulated sites. Numbers show median values.*

The deeper groundwater table significantly increases N_2O emission (Figure 12).

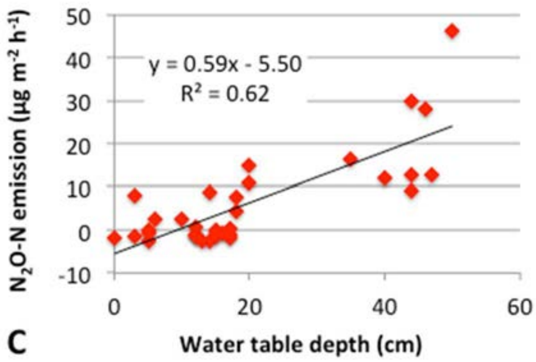

FIG. 12. The correlation between groundwater depth (cm from the surface) and emission N_2O (C) in all sites in the Kambja study area.

The effect of drainage and radiative forcing of Estonian peatlands on N_2O emission showed that annual emission of greenhouse gas is estimated to be 278 to 1,056×103 of CO_2 equivalent (eq), of which N_2O contributes 3 to 5%. The annual efflux is 419 to 676×103 CO_2 eq year^{-1} from drained peatlands, and 2141 to 380×103 CO_2 eq year^{-1} from the undrained peatlands. The annual loss of C from peatlands is estimated to be 38 to 86 tons C×103 year^{-1}. Thus due to drainage, Estonia's transitional fens and ombrotrophic bogs have gone from being sinks to sources of C. Nitrous oxide emission from undisturbed, drained and mined peatlands showed that N_2O from abandoned and active peat mining areas were significantly higher than natural and drained areas (Figure 13),

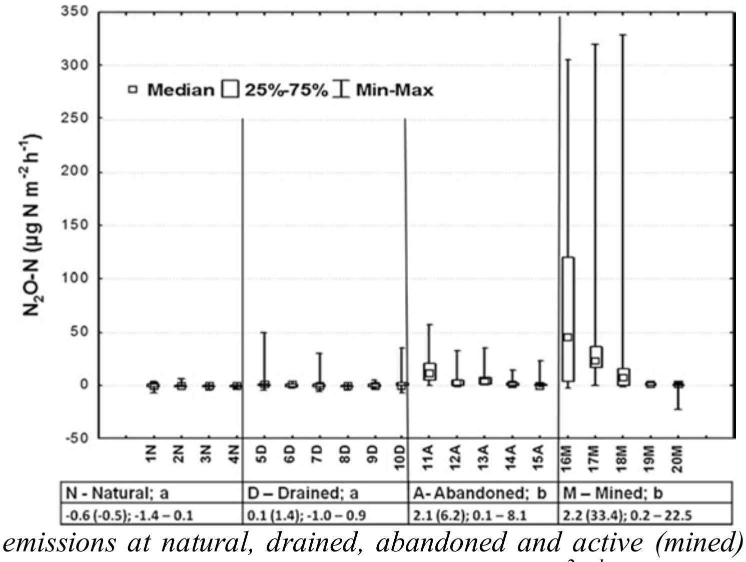

FIG. 13. N_2O-N emissions at natural, drained, abandoned and active (mined) peat extraction sites. Median, average (in brackets) and interquartile range (µg N $m^{-2}h^{-1}$) are given. a and b, significantly differing values

Nitrous oxide emissions from intensively fertilized arable land, abandoned arable land, semi-natural grasslands, fertilized grasslands and riparian alder forests, showed that no clear differences were found between colder and warmer periods and N_2O was emitted throughout the whole year. Relatively higher N_2O emissions were measured from the fertilized arable land, the riparian forest on automorphic soil, and the drained transition fen forest median values 1.4, 1.1, and 0.9 kg N_2O-N ha^{-2} y^{-1} respectively (Figure 14).

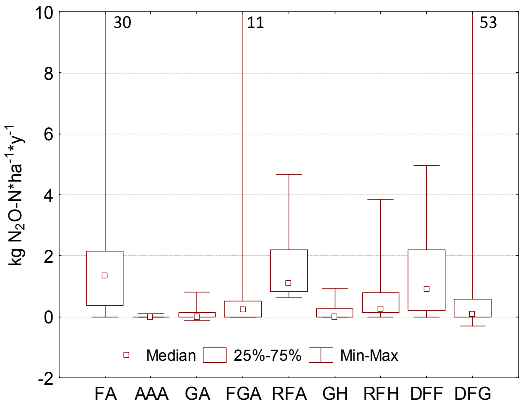

FIG. 14. Methane (left) and nitrous oxide (right) emissions from all of the study site groups.. FA – fertilized arable land on automorphic soil, AAA – abandoned arable land on automorphic soil, GA – grassland on automorphic soil, FGA – fertilized grassland on automorphic soil, RFA – riparian forest on automorphic soil, GH – grassland on hydromorphic soil, RFH – riparian forest on hydromorphic soil, DFF – drained transition fen forest, DFG – drained fen grassland.

During the experimental period of a pulsing water table, water quality parameters did not differ significantly between the inflow and outflow parts. Likewise, in the inflow part, there were no significant differences between high and low water table periods. In the outflow part, however, TOC and TN values were significantly higher at the deep water table. Average ± standard values of TN and TP in the outflow (18±2.3 to 25±2.0, and 1.5±0.9 to 3.7±2.1 mg L-1, respectively) were notably higher than during the normal management regime.

While N_2O emission varied between 1.6±1.5 and 4.9±2.0 µg N_2O-N m^{-2} h^{-1} in the inflow and from 3.0±0.6 to 3.2±1.2 µg N_2O-N m^{-2} h^{-1} in the outflow, the inflow emission values at the deeper water table (in better aerated conditions) were significantly higher than at the higher water table (in saturated conditions) (Figure 15).

The value of $\delta^{15}N^{bulk}N_2O$ and $\delta^{18}O$-N_2O in water samples ranged from -2 to 32 ‰ and between 41 and 78 ‰, whereas the SP N_2O value ranged from 15-41 ‰. There was a significant positive correlation ($p < 0.05$) between the $\delta^{18}O$-N_2O and $\delta^{15}N^{bulk}N_2O$ values (R^2 = 0.35) and between the $\delta^{18}O$-N_2O vs SP N_2O values ($R^2 = 0.77$). No significant relationship was found between other isotopologue values. The SP N_2O values, as well as the correlation between the isotopologue parameters corroborate that the main source of N_2O fluxes is denitrification. One can say that the short-term (one month) and short-range (up to 35 cm) fluctuation of the water table can enhances N_2O emission. (Figure 16)

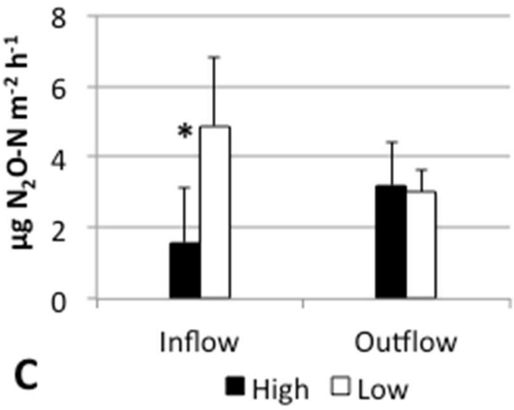

FIG. 15. Emission of N_2O (C) from input and output sites of wetlands

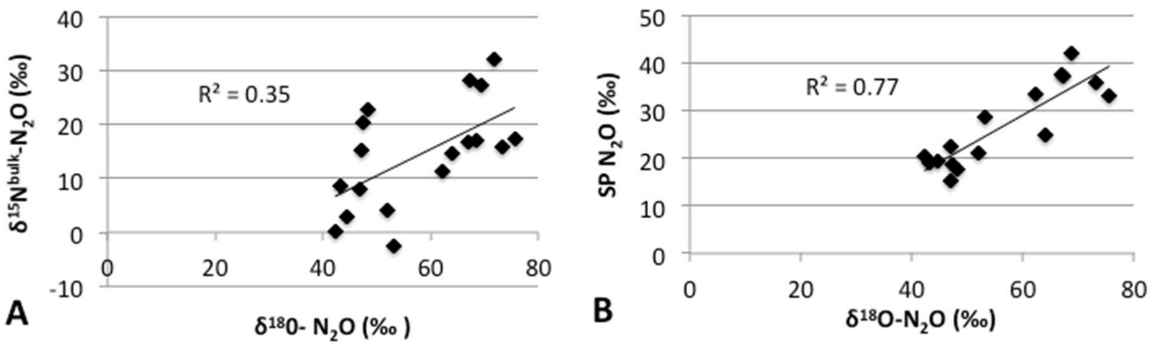

FIG. 16. Treated wastewater $\delta^{18}O$-NO_3^- vs $\delta^{15}N^{bulk}N_2O$ (A) and $\delta^{18}O$-NO_3^- vs SP N_2O (B) in the Sultsi-Paistu HSSF CW.

4. CONCLUSIONS

The main gaseous flux from both riparian alder stands was in the form of N_2, which was 278 (Viiratsi) to 995 times (Porijõgi) higher than the amount of N_2O emitted. Nitrous oxide accumulation in the groundwater was moderate, i.e. not higher than typical values in NO_3^- contaminated denitrifying aquifers. Therefore the fluxes of N_2O along with water from both study areas were small in comparison with surface fluxes. The dynamics of N_2O turnover are similar to denitrifying aquifers, with the lowest N_2O accumulation at the start and end of the reaction progress. Site preference signatures are higher than those of N_2O from unsaturated soils, confirming that denitrification in the saturated zone exhibits a broad range of SP with most values > 30‰. Both N_2:N_2O ratios and isotope data suggest that the main source of N_2O in both areas is denitrification. Due to the more fluctuating groundwater depth in Porijõgi, a significant part of N_2O may be produced by nitrification, at least temporarily. This study also confirms that isotopic signatures of N_2O may be used to distinguish N_2O fluxes from ecosystems with unsaturated and saturated groundwater situations. Further, the study showed that in riparian alder stands saturated with water, N_2 is the predominant denitrification product compared with N_2O which is a significant boost to N_2O emissions to the atmosphere.

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REFERENCES

[1] VILLAIN, G., GARNIER, J., TALLEC, G., J., TOURNEBIZE, Indirect N_2O emissions from shallow groundwater in an agricultural catchment (Seine Basin, France). Biogeochemistry 111, (2012) 253-271.

[2] FORSTER, P., RAMASWAMY, V., ARTAXO, P., BERNTSEN, T., BETTS, R., FAHEY, D.W., HAYWOOD, J., LEAN, J., LOWE, D.C., MYHRE, G., NGANGA, J., PRINN, R., RAGA, G., M., S., VAN DORLAND, R. Changes in Atmospheric Constituents and in Radiative Forcing. In: S. Solomon et al. (Editors), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K. (2007).

[3] WELL, R., ESCHENBACH, W., FLESSA, H., VON DER HEIDE, C., D., WEYMANN, Are dual isotope and isotopomer ratios of N_2O useful indicators for N_2O turnover during denitrification in nitrate-contaminated aquifers? Geochimica et Cosmochimica Acta 90, (2012) 265-282.

[4] WEYMANN, D., WELL, R., VON DER HEIDE, C., DEURER, M., MEYER, K, KONRAD, C., W., WALTHER, Denitrification and nitrous oxide accumulation in nitrate-contaminated aquifers estimated from dissolved nitrate, dinitrogen, argon and nitrous oxide. Biogeosciences 5, (2008) 1215–1226.

[5] TOYODA, S., YANO, M., NISHIMURA, S., AKIYAMA, H., HAYAKAWA, A., KOBA, K., SUDO, S., YAGI, K., MAKABE, A., TOBARI, Y., OGAWA, N., OHKOUCHI, N., YAMADA, K., N. YOSHIDA, Characterization and production and consumption processes of N_2O emitted from temperate agricultural soils determined via isotopomer ratio analysis. Global Biogeochemical Cycles 25, No GB2008, (2008).

[6] WELL, R., FLESSA, H., XING, L., JU, X.T., ROEMHELD, V., Isotopologue ratios of N_2O emitted from microcosms with NH_4^+ fertilized arable soils under conditions favoring nitrification. Soil Biology and Biochemistry 40, 9, (2008) 2416-2426.

[7] BINKLEY, D., SOLLINS, S., BELL, R., SACHS, D., D., MYROLD, Biogeochemistry of adjacent conifer and alder-conifer stands. Ecology 73, (1992) 2022–2033.

[8] MANDER, U., LÕHMUS, K., TEITER, S., URI, V., J., AUGUSTIN, Gaseous nitrogen and carbon fluxes in riparian alder stands. Boreal Environ.Res. 13, (2008) 231–241.

[9] JACINTHE, P.A., GROFFMAN, P.M., GOLD, A.J., A., MOSIER, Patchiness in microbial nitrogen transformations in groundwater in a riparian forest. J. Environ. Qual. 27, (1998) 156–164.

[10] JORDAN, T.E., WELLER, D.E., CORRELL, D.L., Denitrification in surface soils of a riparian forest: effects of water, nitrate and sucrose additions. Soil Biol. Biochem. 30, 7,

(1998) 833–843.
[11] DHONDT, K., BOECKX, P., HOFMAN, G., O., VAN CLEEMPUT, Temporal and spatial patterns of denitrification enzyme activity and nitrous oxide fluxes in three adjacent vegetated riparian buffer zones. Biol. Fertil. Soils 40, (2004) 243–251.
[12] SCHIPPER, L.A., COOPER, A.B., HARFOOT, C.G., DYCK, W.J.. Regulators of denitrification in an organic riparian zone. Soil Biol. Biochem. 25, (1993) 925–933.
[13] HERNÁNDEZ, M.E., W.J., MITSCH, Denitrification in created riverine wetlands: Influence of hydrology and season. Ecol. Eng. 30, (2007) 78–88.
[14] OEHLER, F., BORDENAVE, P., DURAND, P., Variations of denitrification in a farming catchment area. Agr. Ecosyst. Environ. 120, (2007) 313–324.
[15] PARK, S., PEREZ, T., BOERING, K.A., TRUMBORE, S.E., GIL, J., MARQUINA, S., S.C., TYLER, Can N_2O stable isotopes and isotopomers be useful tools to characterize sources and microbial pathways of N_2O production and consumption in tropical soils? Global Biogeochemical Cycles 25, No GB1001 (2011).
[16] JINUNTUYA-NORTMAN, M., SUTKA, R.L., OSTROM, P.H., GANDHI, H., OSTROM, N.E. Isotopologue fractionation during microbial reduction of N_2O within soil mesocosms as a function of water-filled pore space. Soil Biology and Biochemistry 40, 9, (2008) 2273-2280.
[17] VYMAZAL J., M., MASA. Horizontal sub-surface flow constructed wetland with pulsing water level. Water Sci Technol 48 (2003) 143–148.
[18] MANDER, U., KUUSEMETS, V., LÕHMUS, K., MAURING, T., TEITER, S., AUGUSTIN, J., Nitrous oxide, dinitrogen, and methane emission in a subsurface flow constructed wetland. Water Science and Technology 48, (2003) 135–142.
[19] URI, V., LÕHMUS, K., MANDER, Ü., OSTONEN, I., AOSAAR, J., MADDISON, M., HELMISAARI, H. S., and Augustin, J.: Long-term effects on the nitrogen budget of a short-rotation grey alder (Alnus incana (L.) Moench) forest on abandoned agricultural land, Ecol. Eng., 37, 920–930, doi:10.1016/j.ecoleng. 01.016, (2011).
[20] TEITER, S. AND MANDER, Ü.: Emission of N_2O, N_2, CH_4 and CO_2 from constructed wetlands for wastewater treatment and from riparian buffer zones, Ecol. Eng., 25, (2005), 528–541.
[21] MANDER, U., KUUSEMETS, V., LÕHMUS, K., MAURING, T., TEITER, S., and J., AUGUSTIN, Nitrous oxide, dinitrogen, and methane emission in a subsurface flow constructed wetland, Water Sci. Technol., 4, (2003) 135–142.
[22] WELL, R., HÖPER, H., MEHRANFAR, O., and K., MEYER, Denitrification in the saturated zone of hydromorphic soils-laboratory measurement, regulating factors and stochastic modeling, Soil Biol. Biochem., 37, 1822–1836, doi:10.1016/j.soilbio.2005.02.014 (2005).
[23] WEYMANN, D., GEISTLINGER, H., WELL, R., VON DER HEIDE, C., and H. FLESSA, Kinetics of N_2O production and reduction in a nitrate-contaminated aquifer inferred from laboratory incubation experiments, Biogeosciences, 7, 1953–1972, doi:10.5194/bg-7-1953-2010, (2010).

INVESTIGATION OF NITROGEN PATHWAYS IN TYPICAL ENTROPIC-MODIFIED RIPARIAN ZONES OF THE ARGES RIVER CATCHMENT'S AREA, ROMANIA

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Abstract

Surface and groundwater pollution by nutrients from agriculture is a major environmental problem in Romania. Agricultural intensification with excess use of fertilizer and pesticide, more than crop need contributed to such pollution. This pollution problem can continue into the future even if improved practices are implemented. Therefore it is necessary to find viable solutions that can be applied at large spatial scale and with relatively low costs. Use of natural areas located along the rivers and other surface waters as a buffer in retention and removal of excess nutrients used in agricultural areas, is a solution which can be widely applied with extremely low cost. The scope of paper is to estimate the different types of riparian zones in nutrient acquisition and storage using carbon and nitrogen isotopes; with a role in reducing pollution of surface water, ground water and increase agricultural production. The study was carried out in a small catchment (45 km^2) located in the Romanian Plain, in southern Romania, in an area with high potential for nutrient pollution from agricultural. Within this riparian zone five vegetation zones (agriculture (A), pasture (P), querceta forest (F_1), mixed forest (F_2), and wetland (W) were selected for nutrient and biomass accessions. The average annual rainfall for the catchment is 570 mm with a potential, evaporation of 717 mm. The soils of the catchment belong to two classes such as clayed and land bill. Agriculture is practiced in the majority of the land (73%) with rest occupied by forests, wetlands, other surface waters and urban development. Within agriculture wheat is the predominant crop (86%) with sunflower and maize occupy the rest. vegetation present in riparian zones of the rivers is the most important structure for nutrient uptake and to reduce nutrients into water resource. The results showed that the largest quantities of biomass are produce by mixed forest following by querceta forest, a significant contribution it has a layer of trees. The least productive herbaceous layer is grass mixed with forest and the most productive is the agriculture (4.241 g/m^2/year).The least efficient in nutrient uptake and storing herbaceous layer is mixed forest (F_1). The most efficient type of vegetation in taking N was the crop in agriculture land, followed by querceta forest, pasture, mixed forest and wetland. The uptake gradient is the same with the soil moisture gradient, which means that, in areas with low humidity, dominate oxygen forms that are more accessible of plants compared to the reduced forms accessible of denitification processes. The largest amount of litter was produced in agricultural land almost 860 g/m^2, and the smallest amount was produced in pasture 380 g/m^2. The study showed that this riparian zone mosaic provides on one hand a high diversity, a source of natural resources (wood, biomass, food) and on the other hand great areas to reduce diffuse pollution from agriculture (riparian areas that function as buffer zones).

1. INTRODUCTION

Romania is relatively poor in available water resources. The country has approximately 75 km^3 of water of which surface water accounts for 67 km^3 and the remaining is ground water. Per-capita water availability in the country is 3246 m^3/inhabitant/year, but without Danube River it will be only 1650 m^3/inhabitant/year. One can notice that more than half (68 %) of the surface water of Romania is suitable for domestic and industrial consumption while 11% is not suitable for such purposes and are degraded. The average amount of water used in Romania annually is of 9.051 km^3 of which industry, domestic, agriculture uses 4.823, 2.887, 1.299 km^3, respectively and remaining 0.042 km^3 is used by others.

Before 1989, intensive application of fertilizers and pesticides for agriculture has been practiced in Romania. This practice historically discharged nutrients and pesticides in large amounts to surface and ground waters. Since 1989, this practice has largely been discontinued and more than 50 per cent of agricultural land has been abandoned in Romania. Since 2007 the political context was changed and Romania became a member of the European Union and must to oblige the European legislation regarding agrarian community policy, water quality and other agro-environmental measures (including the European Union Water Directives).

The aim of European Union water directive is to establish a framework for the protection of internal surface waters, transitional waters, coastal waters and groundwater. This is a challenge for farmers whose aim is to increase agricultural production. As a state member of European Union, Romania must conform to the water directive targets and comply with EU agricultural policy by adopting agro-environmental measures. A good support necessary to harmonize these two areas of European policy is finding a technical solution that allows son the one hand protecting water quality and increase agricultural production. The most important issue for this harmonization is to find solutions to adapt to Water Framework Directive conditions with the agro-environmental measures. One solution is to reduce diffuse pollution from agriculture using riparian buffer zones. To quantify the buffering capacity of these areas we have conducted a case study in the south of Romania, in Romanian plain, an important agricultural region. The Glavacioc catchment area that involves high levels of agriculture nutrients input and covered by agriculture land and different natural ecosystems was selected for this assessment.

2. MATERIAL AND METHOD

2.1. The Catchment

Glavacioc is a small catchment (45 km^2) situated in southern part of Romania (44º 27’ 8.07” N; 25º 16’ 33.35” E) and is a part of the Câlniştea basin (87.2 km^2) (Figure 1).

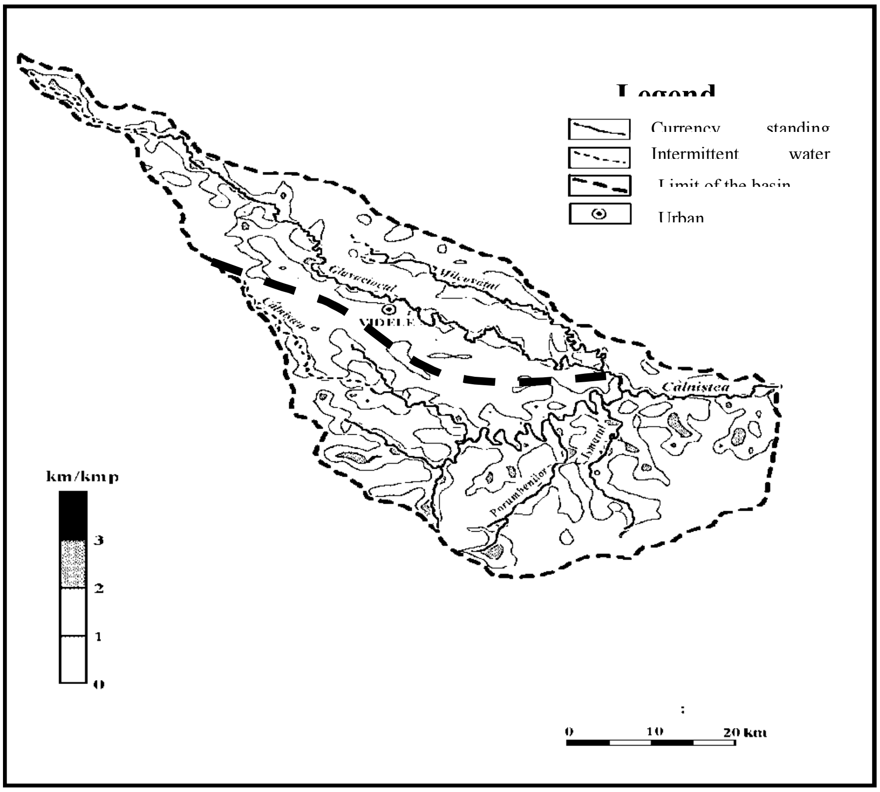

FIG. 1. Glavocioc Catchment

Mean slope of the terrain is 1° and elevation varies between 85 m and 145 m. It is rich in precipitation; the average is over 1500 mm (Figure 2) and average monthly temperatures between - 4 °C and 26° C (Figure 3) Relative humidity in the center of the basin had 72% (annually mean values) and annually potential evapo-transpiration varies between 598 mm and 718 mm.

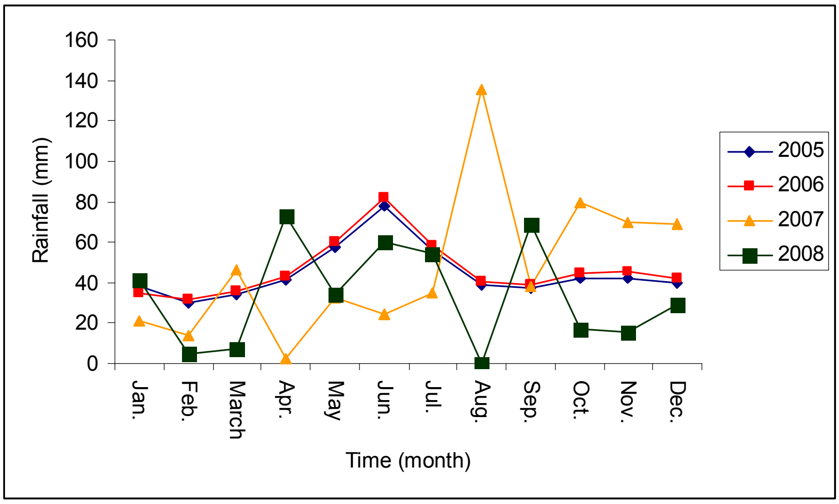

FIG. 2. Monthly rainfall for the Glavocioc catchment for four years from 2005-2008.

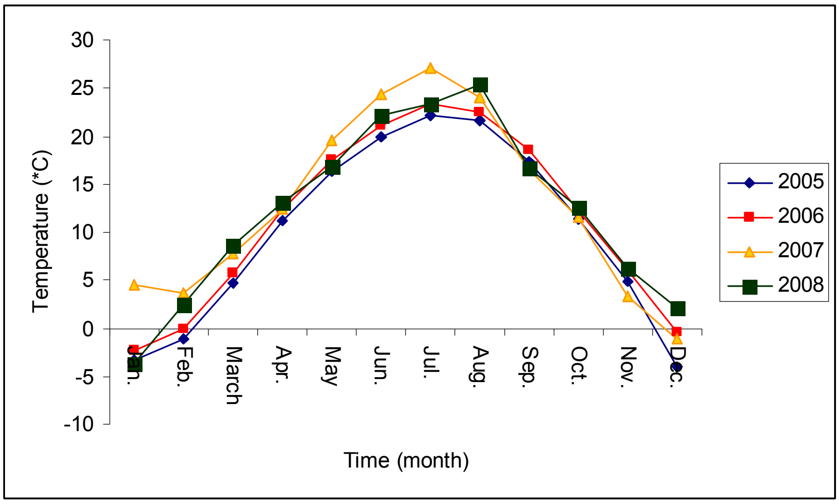

FIG. 3. Mean monthly temperature for the Glavocioc catchment for four years from 2005-2008

During winter (between December and February) evapo-transpiration value is close to zero. The highest value of evapo-transpiration is recorded in June (average of 145/month).

2.2. Soils of Glavocioc catchment

Pedological studies showed that two class (clayey soils, land bill) with three types (brown red, brown red luvic and brown eumesobazic) soils have been present in the catchment (Table 1).

Typical red brown soils are present in areas with southern exposition and slope of 15-20^o and land-form switches from meadows to the river terraces. Red brown soils of luvic-vertic are present on terraces and in areas with deficient rainfall. Red brown soils of luvic-pseudo-glezic are present on the plains of average height and river terraces. Moliceum-ezobasic red, brown soils are found in thermopile forests of oak, elm, maple. Gleizat red brown soils were found in forests of meadow consisting of poplar and willow. About 60% of agriculture soils are eroded and 15% are prone to leaching.

TABLE 1. MAIN SOIL TYPES OF GLAVVOCIOC CATCHMENT

Soil class	Soil type	Soil Sub type
Clayey soils	brown red	Typical
	brown red luvic	Vertic
		Pseudo gleizic
Land bill (cambiosoils)	brown eu-mezo-bazic	Molic

2.3. Land use

About 75% of the Glavacioc‘s basin area is covered with agricultural land (72.5%) the majority of the crops are represented by wheat (86%), maize (11%) and sunflower (3%). Of the remaining about 13% has been used for urban development. Forests occupy 12% of the land mass, wetland 2%, rivers and lakes 0.5%. The number of types of crops at the national level is 36 of which 25 (69.4%) are found in the Glavacioc catchment, which represents a great diversity (Table. 2).

TABLE 2. LAND AREA COVERED BY CROP TYPES

Type of crop	Surface (km^2)	Surface (%)	Sowing period – type of the plants (annual, biannual, perennial)
Cereals for grains			
Wheat	8.32	25.5	Autumn, biannual
Rye	0.07	0.22	Autumn, biannual
Barley	1.37	4.2	Autumn, biannual
Oats	0.82	2.5	Autumn, biannual
Maize grains	10.43	31.96	Spring, annual
Sorghum	0.21	0.65	Spring, annual
Rice	0.05	0.15	Spring, annual
Dried pulses			
Peas	0.32	0.97	Spring, annual
Dried beans	0.34	1.04	Spring, annual
Root crops			
Potatoes	1.01	3.10	Spring, annual
Sugar beet	0.38	1.18	Spring, annual
Fodder roots	0.13	0.4	Spring, annual
Industrial crops			
Sunflower	4.10	12.57	Spring, annual
Rape	0.80	2.45	Spring, annual
Soya beans	0.45	1.39	Spring, annual
Vegetables			
Tomatoes	0.47	1.45	Spring, annual
Dry onion	0.15	0.45	Autumn, biannual
Dry garlic	0.08	0.23	Autumn, biannual
Cabbage	0.44	1.36	Spring, biannual
Green peppers	0.67	2.04	Spring, annual
Water melons and melons	0.35	1.06	Spring, annual
Green fodder from arable land			
Annual green fodder	0.48	1.47	Spring, annual
Pastures	0.72	2.2	Perennial herbaceous
Lucerne	0.69	2.11	Autumn, perennial
Clover	0.32	0.98	Autumn, perennial
Vineyards and nurseries	0.20	0.61	Perennial

The largest land area is occupied by grain cereals, most crops are annual, and sowing period is mostly in spring. Agriculture in the area is mainly rain fed and predominantly uses organic fertilizers (animal manure) and rarely uses chemical fertilizers. Synthetic fertilizer is mainly used for maize, wheat and sunflower. The amount of animal manure used varies between 10 to 15 t/ha.

Although forest area is not very large there is a great diversity of types of forest (24 typologies). Dominant tree species are of the genera *Quercus, Salix, Populus, Alnus, Acer*, *Ulmus, Fraxinus*, etc.

2.4. Field measurements

At the beginning of April 2009 a field trip was carried out with the aim of selecting the study area. After visiting the entire basin, Glavacioc catchment was selected as study area. In the study area one transect (T) perpendicular to the direction of flow of water was selected. The length of the transect was approximately 500 m. Within the transect 5 sampling points were determined within different vegetation including (A in agriculture land, P in pasture, F_1 in querceta forest, F_2 in mixed forest and wetland) (Figure 4).

FIG. 4. The transect of sampling points under different vegetation

General climate data for the site was provided by the local meteorological station of National Institute of Meteorology and Hydrology. The information's site scale, elevation, distances, geographical coordinates were obtained by processing topographic map and photo-aerogramme Google Earth maps. The geographical coordinates (latitude, longitude, altitude) were also measured using Garmin GPS Etrex summit model.

Information about the cropping system was taken from National Statistical Yearbook for 2007 [1] of Agency Payments and Interventions in Agriculture and the Land Register Book. The soil maps (scale 1:200 000) were obtained from Research Institute of Soil Science and Agro-chemistry. The pointer to level bar Recta Ds-50 was used to measure the land slope. Data on elevation and groundwater level were digitized using software Surfer 8, 2002.

2.4.1. Groundwater

The depth of groundwater aquifers and piezometric levels were determined using the field piezometer. The direction and speed of flow of groundwater was determined using KCl as a tracer. Groundwater flow velocity was calculated using Darcy law [2].

2.4.2. Soil

The drop method was used for soil texture determination. Bulk density of soil was determined on core soil samples which are taken by driving a metal corer into the soil at the desired depth and horizons. Soil nitrogen and carbon content were determined using the CN analyzer.

2.4.3. Vegetation

Vegetation structure was analyzed in herbaceous layer, trees and shrubs. Structure of vegetation, dominant species, biomass, primary productivity, C, N stocks and C, N uptake for each zone were estimated. Plant nutrient uptake for each of the vegetation type was determined using ^{15}N stable isotope. The herbaceous and shrubs layers biomass was performed using quadrat method [3] and primary productivity was assess used the McClaugherty method ([4];[5]). The trees stem production and productivity was estimated according to Whittaker and Woodwell ([6];[7]).

2.4.3 Litter

Litter production was assessed using traps method and litterbag technique was used to determine the litter decomposition rate and the following equation was used to determine the rate of decomposition [8].

$$ln\frac{M_o}{M_t} = \text{kt} \quad (1)$$

Where M_o and M_t are mass of litter at times 0 and t

2.4.5 Water balance

The water balance for the catchment was estimated using the following equation

$$D + P = Q + ET + \Delta S \quad (2)$$

$$P = R + I + P_e \quad (3)$$

Where:
P is precipitation
Q is runoff
ET is evapo-transpiration
ΔS is the change in storage (in soil or the bedrock)
D is groundwater recharge
R is runoff
I is infiltration
Pe, is percolation [9]

2.5. ^{15}N isotopic signatures of soil and plant

The isotopic signatures of ^{15}N was determined for soil and plant samples from all five vegetation types was calculated measuring ^{15}N in soil and plant using mass spectrophotometry. The equation used to estimate the signatures is as follows:

$$\delta^{15}N‰ = \left(\frac{R_{sample}}{R_{standard}} - 1\right) \times 1000 \quad (4)$$

Where: R_{sample} and $R_{standard}$ are ratios of $^{15}N/^{14}N$ for sample and standard.

3. RESULTS

3.1. Nutrient input

The Galvacioc River has two major sources of nutrient pollution which are untreated sewage water from urban households and fertilizers (both organic and inorganic) used in agriculture. Fertilizers are used for three main crops (maize, wheat and sunflower), only some of these areas are fertilized. 3% of the cultivated area of maize area is fertilized with mineral NPK (the content in NPK fertilizer is: 75 kg N/t, 130 kg P/t and 175 kg K/t respectively,) and 10% with organic fertilizer (manure). Surface of the wheat crop fertilized with NPK is about 20% and with the manure 5%. For sunflower crops NPK fertilizer of was used and 30% of cultivated area being fertilized. Manure comes from raising cattles and has a nitrogen content of 5 kg N/t and 0.49 kg P/t (mean values in dry matter). From fertilization with NPK the farmers use between 250 and 300 kg/ha, and amount of manure used as fertilizer is between 10 and 15 tons/ha. Total nutrients input introduced by fertilization of crops was 15 483 kg N and 13 206 kg P (Table 3).

TABLE 3. QUANTITY OF NUTRIENTS INPUT IN GLAVACIOC CATCHMENT BY FERTILIZERS.

Crop	Fertilizer type	Area (ha)	Fertilizer Applied (t/ha)	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Total fertilizer (t)	Total N (kg)	Total P (kg)
Maize	NPK	31.3	0.28	20.62	35.8	8.6	645	1119
	manure	104.3	10	50	4.9	1043	5215	511
Wheat	NPK	166	0.3	22.5	39	49.8	3735	6474
	manure	41.6	15	75	7.4	624.	3120	306
Sunflower	NPK	123	0.3	22.5	39	36.9	2768	4797
Total input						1762.3	**15483**	**13206**

There are six villages (Negrişoara, Glavacioc, Şelaru, Cătunu, Buteşti, Purani) and one small town (Ştefan cel Mare, ScMare) situated along the river in Galvacioc catchment. The population is supplied with water from the river and the groundwater aquifers. Nitrogen content in both sources is an average of 15 mg N/ and the P is 2.5 mg/l. After use in the household the N and P contents increases reaching values of 25 mg N /l and 3.5 mg P/l, because the water is discharged into the river without being purified. Sewage contributes 8577 kg N and 1299 kg P annually to the Glavacioc river made an annual intake of approximately 3169 kg N and 632 kg P are contributed by the population (Table 4), a small quantity to compare with the nutrients input (15 483 ka N and 13 206 kg P).

TABLE 4. QUANTITY OF NUTRIENTS INPUT IN GLAVACIOC CATCHMEN BY UNTREATED SEWAGE

Locality	Population	Water used (m^3/year)	N and P content in sewage and the difference with water supply mean values				Total N and P input			
			mg N/l		mg P/l		Kg N/year		Kg P/year	
Negrişoara	796	16238	24	9	3.05	1.2	390	146	50	19
Glavacioc	814	20513	26	11	3.35	1.5	533	226	69	31
Şelaru	2140	79608	28	13	3.65	1.8	2229	1035	291	143
Cătunu	927	23360	24	9	3.45	1.6	561	210	81	37
Buteşti	885	21240	21	6	3.15	1.3	446	127	67	28
Purani	1685	56616	25	10	4.15	2.3	1415	566	235	130
ScMare	3405	143010	21	6	3.55	1.7	3003	858	508	243
Total	10652	272639					8577	3169	1299	632

Comparing the two sources of input of nutrient intake observe that most is made by the fertilization of crops. Although a small area of agricultural crop land is fertilized and the amount of fertilizer used is relatively small these fertilizers made a significant increase in soil nutrients. Intake of nutrients coming from fertilizers compared with intake of domestic water is 5 times higher in case of N and 20 times for P. Therefore the policy of protection of surface water should be focusing on the sources of diffuse pollution from agriculture and not on the wastewater. In Romania's strategy to reduce pollution of surface water is focusing on the requirements of European Water Framework Directive. Under this directive, diffuse sources in agriculture are not taken into account in Romania, although they made the greatest contribution.

3.2. Vegetation biomass, the nutrient stocks

The vegetation present in riparian zones of the rivers is the most important structure to nutrient uptake storage and for reducing the discharge of nutrients from agricultural land. The capacity of vegetation to retain the nutrients is different for different types and dictated by its internal structure and function.

Biomass estimated for the vegetation present in straw, on agricultural lands, has recorded a spectacular growth. In forest was observed a decline in plant biomass as they entered the competition for light with the leaves of trees. Most productive vegetation area is wetland. The ratio of belowground and aboveground biomass belowground biomass has a higher value which indicates a slight tendency to dryness.

The largest quantities of biomass are produce by mixed forest following by querceta forest, a significant contribution it has a layer of trees. The least productive herbaceous layer is grass which was present in mixed forest (Figure 5).The most efficient plant layer for C and N uptake is the wheat crop, but the stock is low because the plant stems and grains are removed.

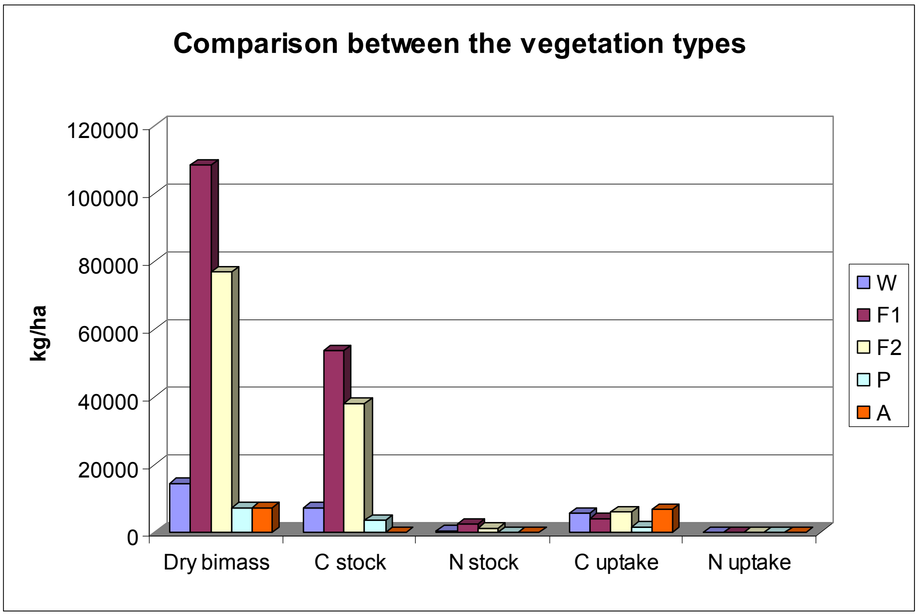

FIG. 5. The biomasses, C, N stocks and C, N uptake in all five type of vegetation, in July 2010

The C stocks represent approximately 49 % of the biomass and the N stock about 3.5 %. The carbon fixation rate, through photosynthesis, was much higher than that of nitrogen uptake by roots absorption**.**

3.3. Soil nitrogen availability and uptake by plants

The most efficient vegetation type for C and N uptake was in agricultural crop land, followed by querceta forest, pasture, mixed forest and wetland (Figure 6). The uptake gradient was same with the soil water gradient. This is probably due to the fact that, in areas with low soil water content N availability for plant may be limited by non-availability of nitrates and water stress.

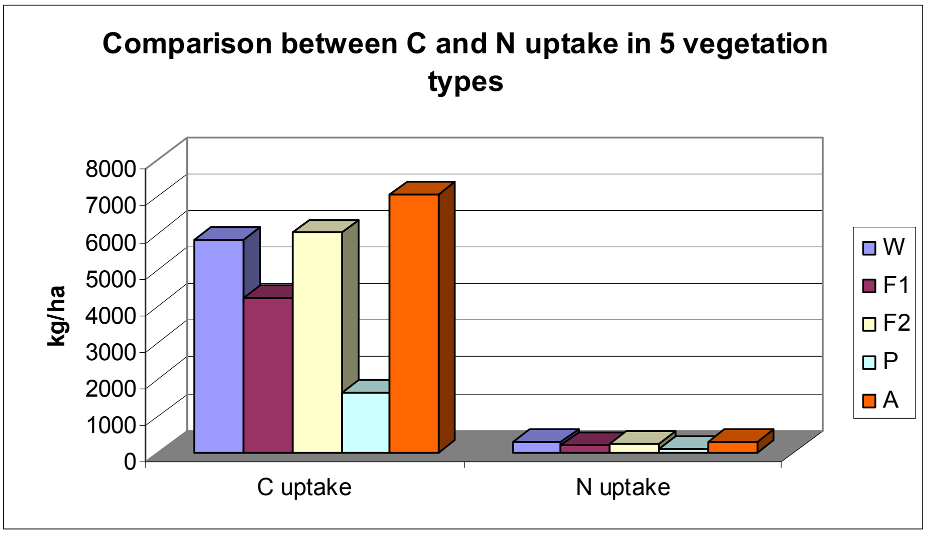

FIG. 6. Carbon and nitrogen uptake by different vegetation

In all zones except wetland, the isotopic signature (δ^{15}N‰) flowing the same rules. The δ^{15}N‰ is present in soil in high quantity; part of this is absorbed by roots and is present in belowground biomass like nitrogen in nutrients and NH_2- groups, and only part of this come in aboveground biomass like nitrogen in NH_2- groups and other organic compounds (Figure 7). In wetland the signature of δ^{15}N‰ in soil to compare the aboveground biomass is similar; the root absorption and other physiological and biochemical process are very intensely to compare agricultural land.

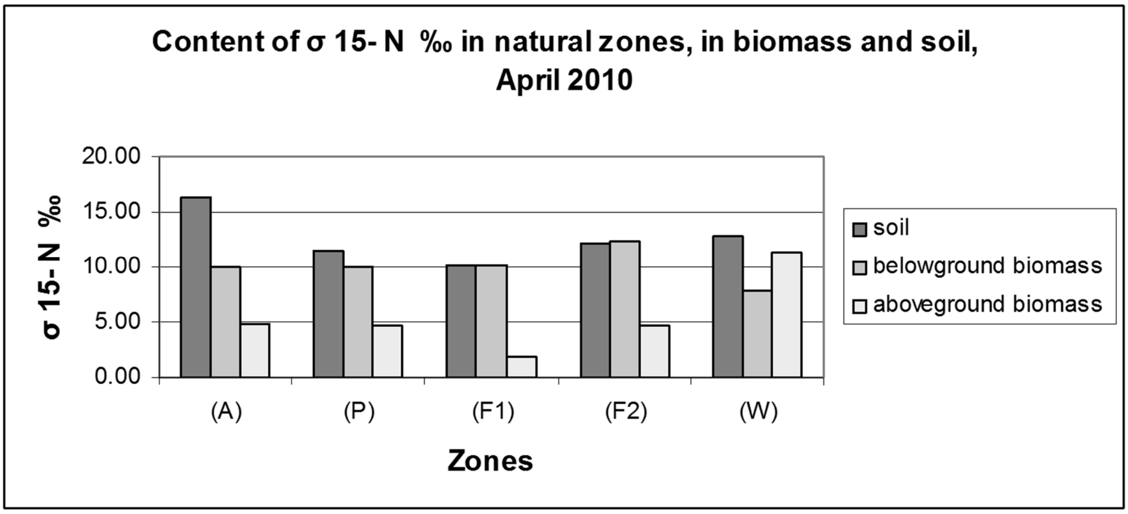

FIG. 7. The content of δ^{15}N‰ in aboveground and belowground biomass, soil , for all 5 zones (agriculture land - A, pasture - P, mixed forest – F_1, querceta forest – F_2 and wetland- W), in April 2010.

3.4. Litter

The amount and quality of litter produced in each type of vegetation was different for different vegetation types. The largest amount of litter was produced in agricultural land (860 g/m^2) and the smallest amount was produced in pasture (380 g/m^2). The decomposition rate of litter depends upon the quality of litter and it can be slower or more intense. The indicator that reflects the best, the intensity of decomposition is decomposition rate constant (k). The values of decomposition rate constant (k) calculated for each type of vegetation present in Glavacioc site are comparable with values present in literature (Table 5). The highest value of the constant decomposition rate (k) was recorded in mixed forest (F_1), here the decomposition process is most intense. In querceta forest (F_2) the k value is close to that of F_1.

TABLE 5. COMPARISON BETWEEN AVERAGE VALUES OF K WITH AVERAGE VALUES PRESENT IN LITERATURE

Vegetation	k(days^{-1})	k(days^{-1}) literature	reference
W	2.281×10^{-2}	2.464×10^{-2}	Gessner & al. 1991 [10]
F_1	5.327×10^{-2}	2.354×10^{-2}	Nelson & al.1990 [11]
P	4.283×10^{-2}	1.044×10^{-2}	Nelson & al.1990 [11]
A	2.578×10^{-2}	0.332×10^{-3}	Salamanca et al. 1998 [8]
F_2	5.061×10^{-2}	0.367×10^{-3}	Aerts 1997 [12]

High rate of decomposition in F_1 is due the saturation of soil by water (sufficient water necessary for bacterial exo-enzymes activity) and the nature of litter (the quantity of lignin and cellulose in trees and shrubs leafs is low compared to that of wheat stems and *Scyrpus sp*).The lower value of k occurred in wetland; plant species present here are due to high soil water status; tissues structure of these plants are impregnated with silica salts that are difficult to break down in small fragments. The wheat straws were also similar in structure that tissues are impregnated with silica salts; therefore the value of k in agriculture land is low and similarly with wetland. In both agricultural land and in wetland the decomposition process takes place slowly and very fast in the forests (Figure 8).

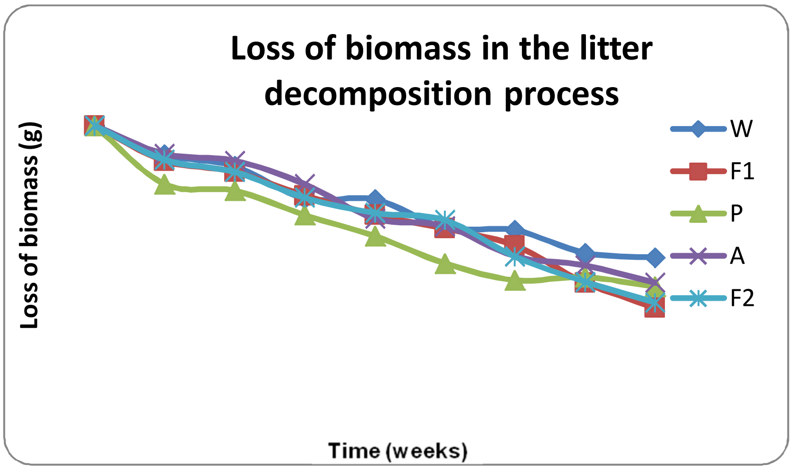

FIG.8. Compared between the decomposition rates in the 5 areas at 8 moments.

3.5. Nutrients and water balance

3.5.1 Nutrients balance

Since the dynamics of vegetation stocks of herbaceous layer was different from tree layer (the time of the cycle of nutrients in the tree layer is much longer than herbaceous layer) nutrient balance was calculated separately for each layer. The nutrient balance was calculated from the rate of C and N accumulation in productivity process, the C and N stock present in standing biomass, the C and N loss in decomposition process and the C and N remained in stock. For example, in mixed forest F_1, the rate of accumulations for C was 2436 kg/ha/year and 877 kg/ha/year N, the stock in standing biomass was 51 153 C kg/ha and 2294 N kg/ha, the loss in decomposition process was zero for C and N and the stock remained was 51 153 C kg/ha and 2294 N kg/ha (Figure 9).

The most efficient herbaceous layer for nutrient uptake of was the wheat crop (A). This agriculture land is the most productive and registering the highest productivity (4.741 g/m^2/year) (Figure 11). Although the most productive is farmland, the highest value of standing crop was

wetland, because in agriculture land most of the biomass was removed with threshing. Also the wheat straw is being removed by the local population as they use this for bedding in stables.
The least efficient in nutrient uptake and storage was herbaceous layer in mixed forest F_1. This layer is very low productive due to competition for light, space and nutrients. Also, the pedo-climatic conditions in the forest (high humidity, organic matter in sufficient quantities, good oxygenation conditions) creates optimal conditions for litter decomposition, and recorded the highest rate of decomposition (5.327 x 10^{-2} g/m^2 day^{-1}).

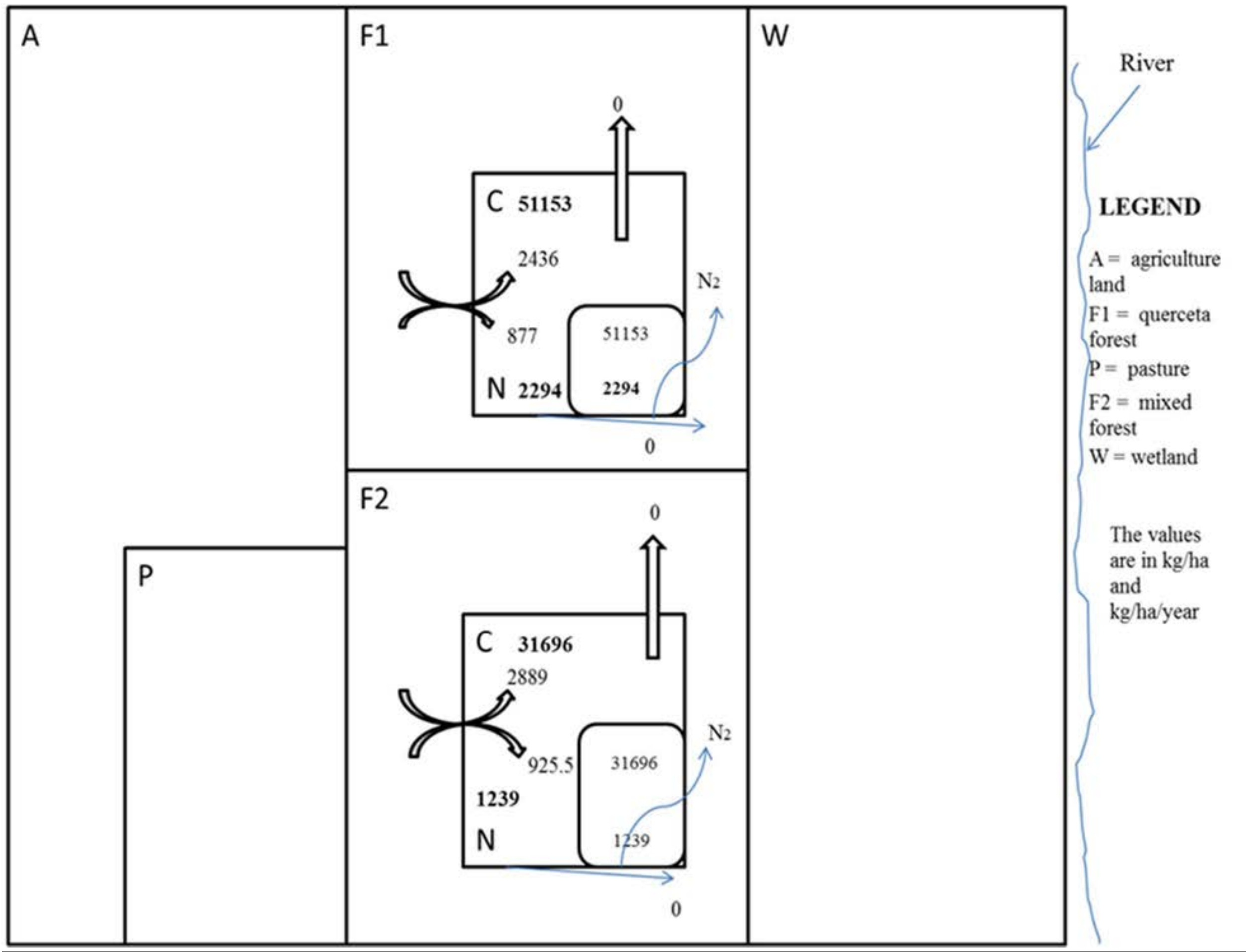

FIG. 9. Nutrients balance in trees layer wood

In tree layer amount of nutrients (C and N) stored in the wood, only in 2011, was 10 times greater than that stored in the leaves. In wood, the amount of nutrients taken as productivity, accumulate from year to year and only the leaves supplies the litter, which decomposes. In the two forest types (F_1 and F_2), about 80% of litter is decomposed, and 20% accumulates at the soil surface and supplies the top soil with organic matter (Figure 10). Organic matter plays a fundamental role in soil processes; this is an energy source of microorganisms and precursor in soil humic acids. Although part of N is lost in the process of denitrification, like a final stage of decomposition, a large amount of N returned to soil as nutrients from which is taken by plants. The analyses of Figure 9 show that the temperate forests are very important ecosystems in terms of the amount of carbon storage and fertility of the soils.

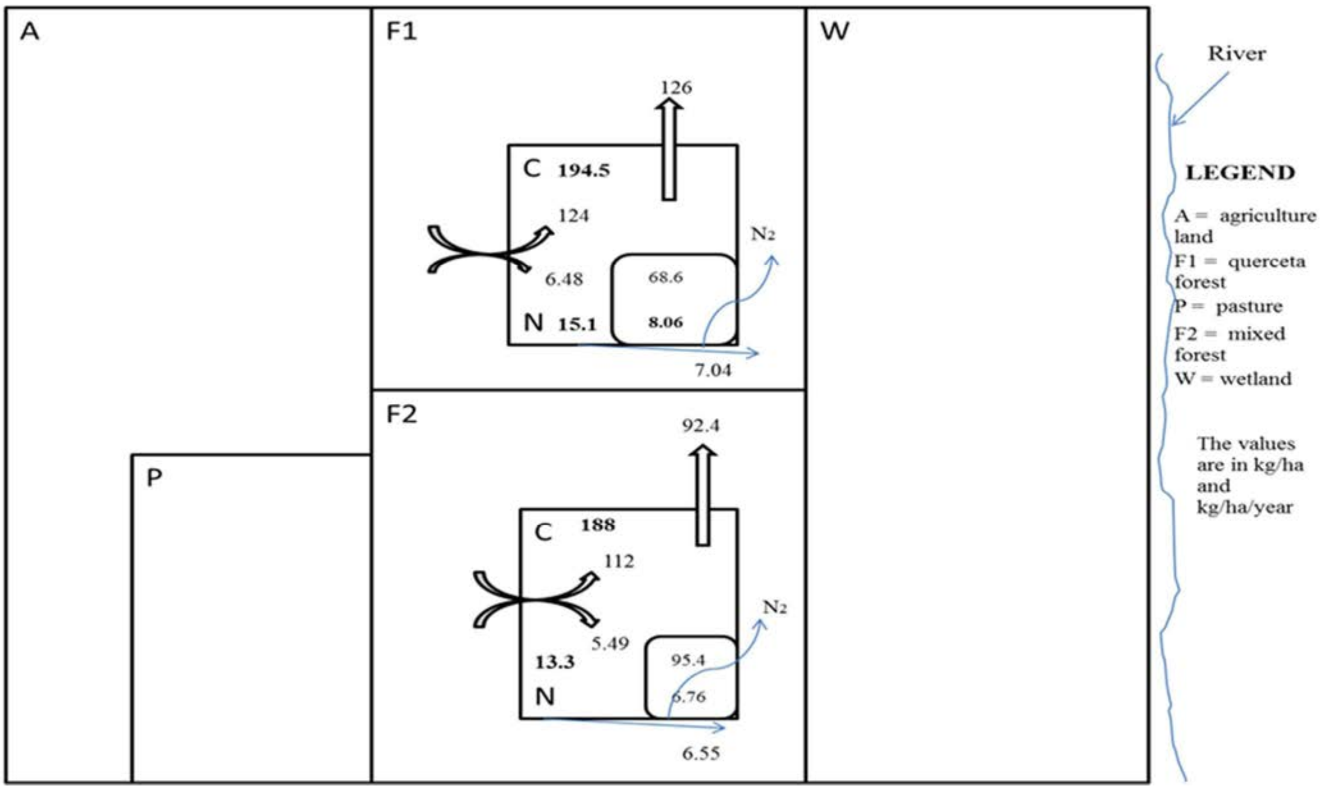

FIG. 10. Nutrients balance in trees layer leafs

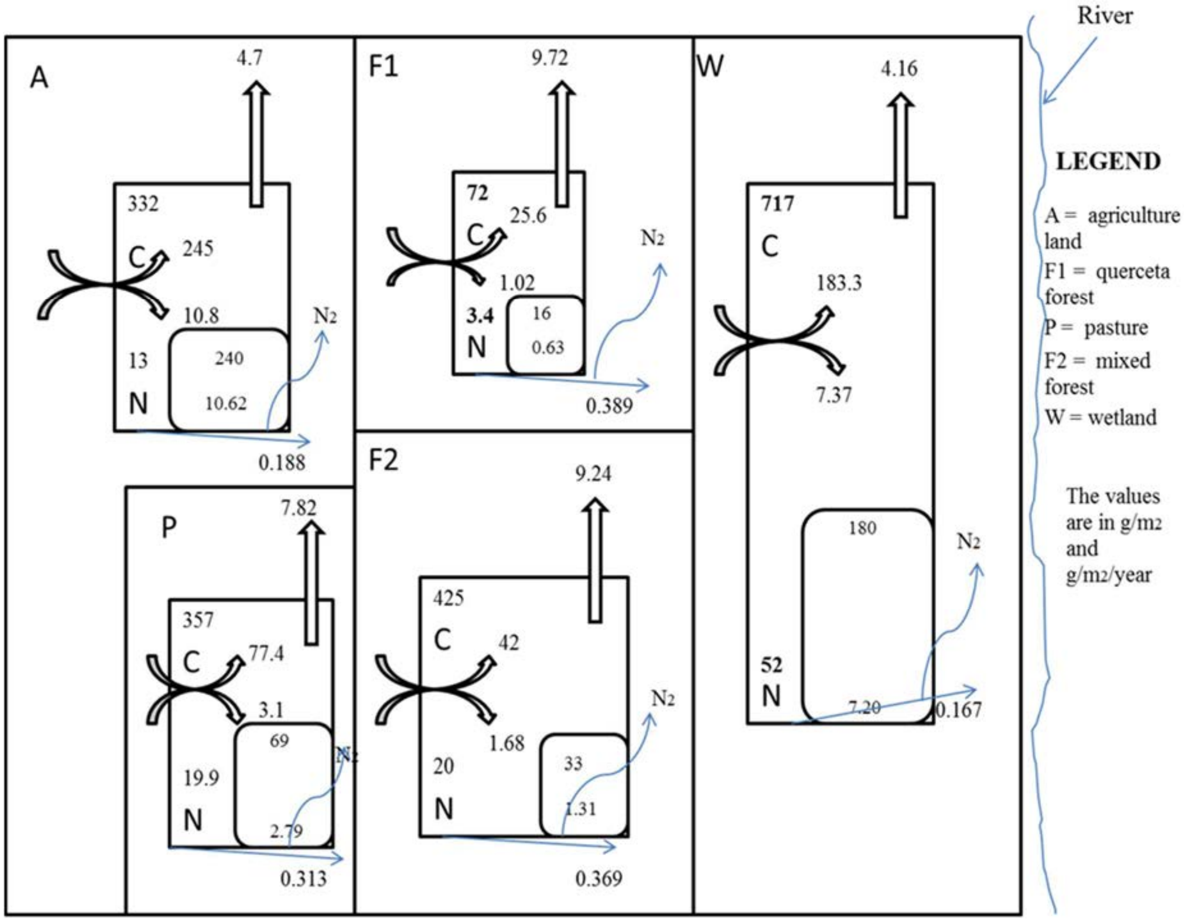

FIG. 11. Nutrients balance in herbaceous layer

Making a unilateral analysis regarding takeover efficiency and nutrient use by plants in crops we take the risk of leaving the role of other types of ecosystem in nutrients cycling. A holistic approach, with simultaneous analysis for all function of different types of ecosystem (reducing pollution, creating local microclimates, etc.) outside the production can give an overview and help making the best decisions in different types of land. Natural and semi-natural ecosystems are the main sources in the production of resources and energy generation and play an important role in reducing pollution. With resources and energy required are greater with both human pressures exerted on ecosystems and biodiversity is higher, which implies the need for preservation of these species and ecosystems. Residues arising from the use of resources that emphasize forms of pollution accentuate the anthropogenic pressure on natural resources. Keeping a mosaic structure is an ideal solution to harmonize the development of society with nature conservation. A green infrastructure with lacks and rivers, wetland, different types of forest, pastures, shrubs including different types of crops, it represent the ideal structure provide both energy and resources needs.

3.5.2. Water balance

For the year 2011, a normal year in terms of precipitation regime showed the following water fluxes:

ΔS (37.5 mm/year) = P (571 mm/year) + D (189 mm/year) – ET(717 mm/year) – ΔQ (63-57) (mm/year) where P (571.5 mm/year) = R (19 mm/year) + I (552 mm/year) + Pe (0.5 mm/year)

Although the area is deficient in precipitation, the river and groundwater supply manage to compensate the water losses by evapo-transpiration. The area is cultivated with various crops (corn, wheat, sunflower) without the need for irrigation. Higher values of precipitation are recorded in July, August and September. The phenomenon is manifested by frequent droughts, some lasting. The average intervals of drought, is 15 to 19 days and maximum of 50 days.

4. CONCLUSIONS

Green infrastructure in Glavacioc catchment is very heterogeneous land use. The catchment has the following ecosystems that include: rivers and lakes, wetland with *Carex sp. Lythrum sp. Scyrpus sp.*, wetland with *Salix sp.* and *Typha sp., Phragmites sp.*, pastures for animal grazing, nine types of forest that include mixed forests, 25 types of crops, and urban development. This mosaic of land use provides species diversity, a source of natural resources (wood, biomass, food) and great areas to reduce diffuse pollution from agriculture (riparian areas that function as buffer zones). The number of species in the vegetation mosaic was 74 and that of ecosystems types was 41 of which the most numerous were the semi-natural and anthropogenic. Forested area in Glavacioc basin occupies an area of 540 ha, and mean annual wood production is approximately 3 240 m^3/ha/year. The catchment inhabits population in the basin approximately 10 652 human being grouped in nearly 3 200 households and uses about 16 000 m^3 of firewood and 20% of which is obtained from local forests. Biomass production capacity of herbaceous layers at basin level is 15 656 tons (1 319.4 by wetland, 468 by herbaceous plant in mixed forests, 2 173 by herbaceous plant in querceta forests, 241 pasture and 11,453 by straw and debris from agricultural crops), providing a daily diet for 521 885 cows and annual food for 1 430. About one in two households obtained their food from animals. In Romania, grazing in forest is prohibited by law thus 13.4% of biomass available cannot be used.

The fixing capacity of C from carbon dioxide by photosynthesis at basin level is 4 712 tons (52 wetland, 1 269 mixed forest, 1 073 by querceta forest, 5.5 by pasture and 2 309 by crops), which is 0.000075‰ of total emissions of C estimated at global level (0.63×10^9 t) annually. The percentage seems insignificant but the vegetation covers a total area of only 3 896 ha, with is 0.000029% the global land surface ($13\ 400 \times 10^6$ ha) [13]. Nitrogen uptake capacity of green infrastructure at basin level is 104 072 kg (2 661 by wetlands, 5 546 by mixed forests, 6 230 by querceta forests, 292 by pastures and 89 341 by agriculture land). The amounts of N coming from fertilizers to the catchment is 15 483 kg/year and from untreated sewage is 8 577 kg/year and represent 23% of the uptake capacity of the vegetation in the basin, less than one quarter. Al though in the 2008 report of Ministries of Environment and Forests it says that is an area with high potential for N pollution originating from agriculture, in 2010 was observed that the mosaic of vegetation used as a buffer zone was benefit at a rate of 23% [13]. At present, in Glavacioc basin is sufficient as a natural buffer area. Such natural areas can to be used to retain the pollution with N coming from agricultural diffuse sources. In the future it should be noted that small amount of natural fertilizers can be applied to agricultural farms in the Glavocioc catchment to preserve this mosaic structure.

REFERENCES

[1] National Statistical Yearbook, National Institute of Statistics (2007).

[2] FITTS, C.R., Groundwater Science, Academic press (2002).

[3] GHEORGHE I.F.,"FitocenologieşiVegetaţiaRomâniei, Ed. Didacticăşi Pedagogică (2008).

[4] MCCLAUGHERTY C.A., et al., The role of fine root in the organic matter and nitrogen budgets of two forested ecosystems, Ecology 63 (1982) 1481-1490.

[5] MCCLAUGHERTY, C.A., BERG, B., Celluolose, lignin and nitrogen concentrations as rate regulating factors in late stages of forest litter decomposition, Pedobiologia 30 (1987) 101-112.

[6] WHITTAKER, R.H., MARKS, P.L., Methods of assessing terrestrial productivity in Leith, H. and Whittaker, R.H. (eds) Primary productivity of the Biosphere Spinger Verlag, New York, (1993).

[7] WHITTAKER, R.H., WOODWELL, G.M., Dimension and production relations of trees and shrubs in the Brookhaven forest, New York, Ecol. 56, (1968) 1-25.

[8] SALAMANCA, F.E., et al., Effect of leaf litter mixture on the decomposition of Quercusserrata and Pinusdensiflora using field and laboratory microcosm methods, Ecological Engineering 10, (1998) 53–73.

[9] OOSTERBAAN, R.J., The energy balance of groundwater flow applied to subsurface drainage in anisotropic soils by pipes or ditches with entrance resistance. On the web :. Paper based on:, The energy balance of groundwater flow. Published in V.P.Singh and B.Kumar (eds.), Subsurface-Water Hydrology, 153-160, Vol. 2 of Proceedings of the International Conference on Hydrology and Water Resources (1996), New Delhi, India, (1993).

[10] GESSNER, M.O., et al., Rapid processing of fresh leaf litter in an uplandstream, Verh. Int. Verein. Limnol. 24, (1991) 1846-1850.

[11] NELSON, W.J., et al., Seasonal comparison of weight for two types of Typhaglauca Godr. leaf litter Aquat. Bot. 37 (1990) 299-314.

[12] AERTS, R., Climate, leaf litter chemistry and leaf litter decomposition in terrestrial ecosystem: a triangular relationship, Oikos 79, (1997) 439 – 449.

[13] MINISTRIES OF ENVIRONMENT AND FORESTS, Water quality in Romania, Romanian National Report (2008).

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