Integration of the Vetiver System within Conventional Erosion Control Technologies in Brazzaville, Republic of the Congo

Alain N'Dona
Kinshasa, Democratic Republic of the Congo

Abstract

Brazzaville, the capital of the Republic of Congo, has experienced worsening damage caused by soil erosion in the last decade.

The conventional engineering efforts to halt the progression of this erosion have remained unsuccessful as the works constructed for this purpose are quickly destroyed after one or two rainy seasons.

In this context, the idea of integrating vetiver technology with conventional engineering techniques, has proven to be an effective new approach not only to halt the progression of erosion, but also to ensure the protection and structural durability of conventionally constructed erosion control structures.

To demonstrate this, three sites in the northern part of Brazzaville (Casis, Pylône and Boukeni) were chosen to test this new anti-erosion integrated approach. Thus, the combination of bioengineering techniques (planting of vetiver) and conventional techniques of erosion control (construction of drains, terramesh retaining walls, gabions, slope benching and reshaping, the use of sandbags etc…) provided a more effective anti-erosion control system as well as a means to protect the conventional engineering works.

At the Casis site, the conventional engineering work included the construction of a drain, terramesh retaining walls, gabion protected embankments and a regraded slope. The integration of the bio-engineering vetiver technology was used primarily to protect these structures and stabilize the slopes by planting vetiver hedgerows.

At the other two sites (Pylône and Boukeni), the conventional engineering work done consisted of stacked sandbags in the lower part of the ravine and where the water flows into the ravine to halt the progressive slippage of the ravine walls due to erosion. The vetiver-based bio-engineering system in this case involved the planting of vetiver hedges directly into these sandbags to not only provide vegetative protective cover of the sandbags, but more importantly, to anchor them in place using the deeply rooted vetiver plants.

Observations on these three sites in April 2011 show that the vegetative cover using vetiver and its subsequent development of deep root system has stabilized all the slopes, provided sustainable protection of the drain built in September 2008 as well as anchoring all the sandbags. This combined system has thus for the first time stopped the progression of erosion despite the high intensity rainfall (100mm or more per day) frequently recorded there. This high rainfall would have created much more destruction of the conventional measures (thus much more erosion) if it had not been for the use of this vetiver-based integrated approach for erosion control.

1. INTRODUCTION

Several publications on worldwide climate change report that drought, flooding and erosion are a few of the convincing signs of climate change in sub-Saharan Africa. In Brazzaville, the capital of the Republic of Congo, there has been for over a decade, high intensity rainfall. This high level of rainfall has caused and continues to cause more erosion and massive property damage, including destruction of roads, homes, etc.

During the same period, conventional engineering efforts to halt erosion damage have remained ineffective. Indeed, conventionally engineered works such as drains, Terramesh-constructed walls, retaining gabions, sandbags, etc. deteriorate quickly and frequently do not last for a long time, all due to excessive rainwater runoff. Conventional works are therefore vulnerable due to the lack of vegetative protective measures implanted at the time the sites were constructed.

Given these difficulties, Egis International, an engineering and consulting company, proposed to the Congolese authorities in charge of public works, the idea of integrating bio-engineering technology, including the Vetiver System into their conventional technology. This proposal is a very effective new approach in the city of Brazzaville as it will not only halt the progression of erosion, but will also ensure the protection and sustainability of conventional structures to be built in the future, confirming the statements of Dr. Paul Truong, a member of the Vetiver Network International (TVNI) Board of Directors (Truong al. 2008a).

To implement this proposal, three erosion sites in the northern part of Brazzaville (Pylône, Boukeni and Casis) were chosen to demonstrate this new integrated anti-erosive approach that combines bio-engineering (vetiver planting) and conventional anti-erosion methods (drain construction, the use of Terramesh retaining walls, slope reconstruction and the use of stacking sandbags).

After planting vetiver, observations on these three sites focused on the extent of vetiver establishment and the level of damage to structures recorded after significant rains.

2. MATERIALS AND METHODS

2.1. Erosion sites

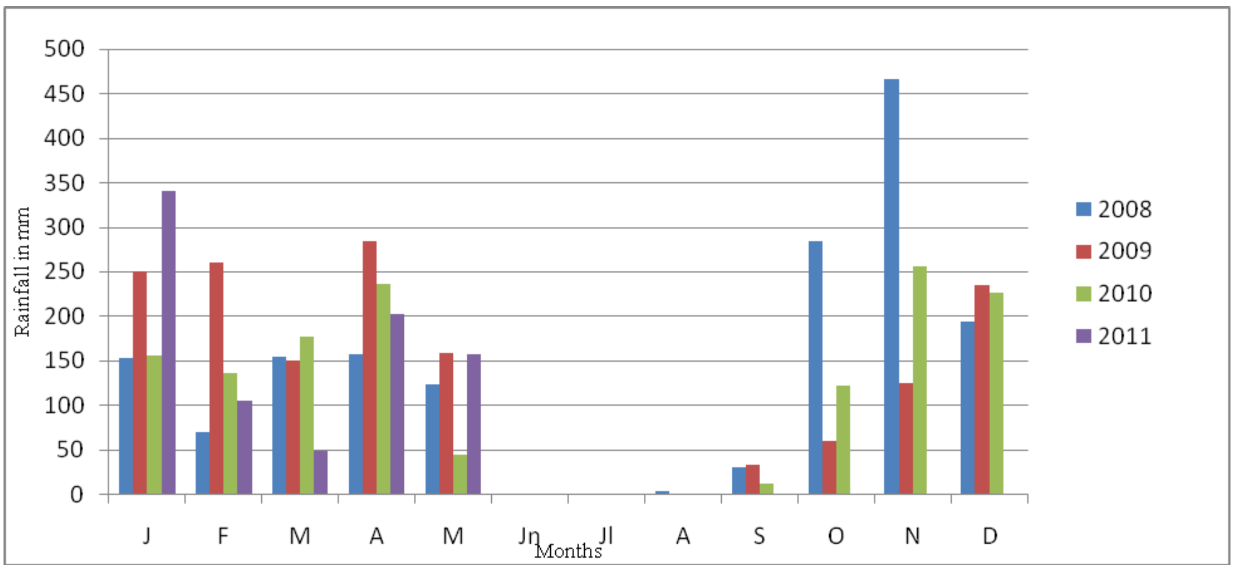
Three sites were chosen in northern Brazzaville, given the seriousness of their erosion threats to both public infrastructure and private dwellings. The Pylône site had erosion that threatened the medium voltage electric power transmission tower between Brazzaville and the northern part of the country, therefore there was a sense of urgency to halt the progression of this ravine. The erosion at Boukeni destroyed over 300 homes in the Mongali residential district. By contrast, the most devastating of the three is found at Casis where nearly a thousand homes had been destroyed by an ever advancing erosion ravine reaching to within 2 miles of the national highway, NR2, the only road at the time that connected the capital, Brazzaville and the northern part of the Republic of Congo.

With respect to the geology and the geomorphology of these sites, all are located within 3 kilometres of each other, at the edges of the small plateau containing the city of Brazzaville, which is part of the larger Batékés plateau on the bank of the Congo River.

The Batékés plateau forms a vast area reaching 700 metres in elevation in some places and subdivided into smaller plateaus by deep waterways that move in a direction parallel to the plateau locations. The geological stratification of this area has in the lower levels lagoon-based, fossil-rich clay layers. Within each stratum, the most common materials are made of fine white feldspar sandstone, forming the "Makélékélé slabs". Finally, the stratified upper level is formed by white, very soft sandstone combined with harder white-yellowish sandstone.

Regarding rains, the figure I below shows the monthly average rainfall in Brazzaville from 2008 through May 2011 (ANAC, 2008, 2009, 2010 and 2011).

Figure I: Monthly rainfall, 2008 through May 2011



The average monthly rainfall amounts as shown in the above graph do not give any indication of the rainfall intensity within each rainfall event capable of creating erosive damage. For this reason, Table II below shows for each year, the number of rain events with the corresponding quality of rainfall per event measured in millimetres (mm).

Table I: Number of rainfall events per year sorted by the amount of rainfall per event

	Quantity of rain per rainfall event in mm		
	< 30	30-50	>50
2009	94	12	7
2010	71	9	8
2011, (though May)	33	8	3
TOTAL	198	29	18

It is important to note that from our observations, rainfall events of less than 30 mm have low erosive capability if they are spread throughout the day. However, it is also noted that while being considered less erosive in nature individually, the succession of rainfall events in two or three consecutive days, or if the rain falls in two or three hours, will cause significant damage in some places because of the high soil moisture saturation level, thus increasing the amount of runoff and the intensity of the erosive forces of those events.

2.2. Plant material

The plant material used was vetiver (*Chrysopogon zizanioides*, formerly known as *Vetiveria zizanioides*). This material came from vetiver nurseries initially set up by some community-based associations at the end of a training program organized in February 2004 in Kinshasa, Democratic Republic of Congo, led by TVNI with support from USAID/DRC (United States Agency for International Development, Democratic Republic of the Congo). On the other hand, vetiver has been planted since the 1960s on sites for the purpose of the delimiting certain land parcels and for embankment protection of aquaculture and rice perimeters along the Congo River.

Vetiver is a perennial grass within the Gramineae family, Panicoideae subfamily of the Andropogonideae, species and sub-Andropogoneae sorghinae species. It is a native of Northern India(National Research Council, 1993). Compared to other grasses, the *C. zizanioides* cultigen of vetiver has the advantage of having special features in the fight against erosion. Vetiver's roots are vertically oriented, dense and long, and can penetrate up to 3 to 4 metres deep into the soil, which helps stabilize the soil against erosion (Truong, 2000, Rachmeler, 2003).

The stems are stiff and vertical in nature. When they are planted close together, they grow together to form a dense, thick hedge. This hedge can withstand winds and blowing sand and acts as a filter that retains soil particles or other sediments found in runoff waters. It also helps to dissipate and slow the velocity of surface water runoff thus promoting water infiltration (National Research Council, 1993, Julliard et al, 2001; and Truong, 2004). Vetiver tolerates a wide range of climatic conditions, with the exception of the slow growth encountered under shady conditions as it grows optimally in full sun (Goudiaby, 2003).

Before planting, the clumps of vetiver were divided into slips for February-March planting, the roots are pruned and leaves are cut down to 10 cm to 20 cm in length to facilitate planting and to promote a healthy recovery. These slips are subsequently planted in furrows previously filled with topsoil or humus to improve the initial soil fertility thus accelerating the vetiver plant recovery after pruning in preparation for bare root planting. The vetiver plants grown in hedges form successive rows on slopes and embankments along the contour lines. Two to three slips of vetiver are spaced 10-15 cm apart within the row, giving a density of 20-30 individual slips per linear meter. The space between rows is a function of the slope upon which the hedgerows are established. The rule of thumb is: for every increase of 1 to 1.5 metres of elevation increase up a slope, another hedgerow should be planted. Thus on a 30-45º slope, the space between rows is approximately 1- 1.5 meters.

To obtain rapid growth of vetiver, a mixture of mineral fertilizer NPK 17-17-17 or 15-15-15 and 46% Urea was applied in two replications. The first application took place 90 days after planting and the second application between 4 and 5 months after the first application.

Watering was needed due to the absence of rain during the week of planting, as this is especially important for newly planted vetiver slips in order to reduce slip mortality. During the dry season, planting and watering was suspended as a result of logistical and financial constraints.

2.3. Determination of area coverage

According to the Nature Prairie Museum, (2005), specific land coverage corresponds to the surface area that is covered by a given plant species. As part of this work, to assess the specific vetiver coverage of slopes and embankments, twenty samples of 2 square metres each were randomly assigned and used as the sampling unit at each observation site. This coverage is expressed as a percentage of the area occupied by the biomass of vetiver on the surface of the sample (2 square metres). The coverage was estimated on the basis of observations made directly within each sample area planted every three months from initial planting until May 2011, when the development of the coverage had reached its maximum, i.e., completely covering the land surface making it impossible to see bare ground.

2.4. Observations of damage during the rainy season

There are several methods for determining soil loss caused by water erosion. Among these methods, the universal equation of soil loss (UESL) is widely known. However, Zaher (2011) indicates that the use of these different methods depends on the objectives and technical resources available. Within this project, we did not have the scientific means to quantify soil loss due to splash erosion. Therefore, we limited ourselves to observation and we identified the signs and effects of visible physical damage caused by different rainfall amounts/frequency on slopes and embankments protected by vetiver hedgerows. After each rainfall event the following signs and their respective categories were used:

A = rain without runoff on slopes and embankments
B = rain that caused runoff without stripping off surface soils
C = rain causing runoff and stripping off of surface soils
D = rain that causes the creation of small channels
E = rain that caused the creation of gullies ≥ 1metre deep

Based on the rainfall event frequencies that caused physical signs of erosion and signs of damage that were regularly visible, rainfall of 30 millimetres or more, is considered in the context of this work as a threshold to cause visible damage.

3. RESULTS AND DISCUSSION

3.1. Vegetative coverage

Table II below shows the evolution of the vegetative coverage (%) for each site sampled every three months from initial vetiver planting until May 2011. These values are the quarterly average across samples within each site.

Table II: Evolution of vetiver vegetative coverage on embankments and slopes at 3 sites (%)

	1st year 2009				2d year 2010				3d year 2011			
	1st Qtr	2d Qtr	3d Qtr	4th Qtr	1st Qtr	2d Qtr	3d Qtr	4th Qtr	1st Qtr	2d Qtr	3d Qtr	4th Qtr
Casis	0	0	0	2	20	60	60	90	100	100	-	-
Boukeni	2	30	30	100	100	100	100	100	100	100	-	-
Pylône	0	10	10	40	60	70	70	80	100	100	-	-

From Table II the vetiver vegetative coverage of the slopes and embankments has significantly increased from 0 to 100% on all three sites beginning in the first quarter of the first year (2009) through the first quarter of the third year (2011). For the Boukeni site, coverage was very fast 2% at planting in the first quarter 2009 to 100% at the end of the 4th quarter of that same year. This is portrayed in Photos 2, 3 and 4 below.

Photo 1: Initial status at the Boukeni ravine, before placing sandbags and planting vetiver

Photo 2: Placing bags containing topsoil and vetiver planting on the Boukeni site (February 2009)

Photo 3: The Boukeni site 2 months after planting vetiver directly into the bags of topsoil (April 2009)

Photo 4: Status of the vetiver cover at Boukeni 10 months after planting (November 2009)

This rapid development compared to the other two sites is attributed not only to the fact that the Boukeni vetiver planting occurred earlier (in the middle of the first quarter of 2009) as compared to the other two sites (Pylône Q2 and Casis Q4), but also because of the presence of topsoil in the bags into which the vetiver slips were planted. There was also more organic matter after the decomposition of garbage that was frequently thrown into the ravine by Boukeni residents. The decomposition of such waste created humus of very good quality at Boukeni, unlike the very poor soils at both Casis and Pylône, both devoid of organic matter to a large extent. Indeed, a soil that is rich in organic matter and nitrogen allows for rapid vetiver development (Ndona et al., 2006, Ndona, 2009).

None the less, despite the poor soil quality at Casis and Pylône, the plant cover development increased to 100% between Q1 2010 and Q1 2011 as shown in Photos 5, 6 and 7 for the Casis site and between Q4 2009 and Q1 2011 for the Pylône site, illustrated by Photos 8 and 9. It should be noted that the Casis and Pylône sites received fertilizer applications (NPK 17-17-17) and urea (46% N). This further confirms the recommendations made by Ndona et al. (2006) and Ndona, (2009) on the positive effects of fertilization on low fertility soils and the good vetiver response to these treatments with respect to biomass formation.

Photo 5: Planting vetiver at the Casis site Nov. 2009

Photo 6: The Casis site five months after planting vetiver on part of the site (April 2010)

Photo 7. The Casis site 17 months after planting vetiver on parts of the site (May 2011)


Photo 8: The Pylôn site two months after planting vetiver on parts of the site (June 2009)


Photo 9: The Pylône site 23 months after planting vetiver (May 2011)

It should be noted that in each site vetiver development slowed down during the dry season. Table II points this out as occurring between the late 2nd quarter and early 3rd quarter in both the first and second year of observation. In the dry season, it does not rain (ANAC, 2008, 2009 and 2010) and water stress occurs seems to affect the development of the vetiver vegetative cover. This has been confirmed in other work done in other countries as cited in the literature, Truong et al. (2008a). Slow growth occurs in the first months of planting vetiver on these sites and when there is no rainfall in the dry season between 2nd and 3rd quarters. The slow growth is due to the fact that the vetiver root system has not yet fully developed and is not able to find deep sub-soil moisture when water stress occurs in the dry season.

3.2. Frequency of rain causing damage to the 3 sites

For all three observation sites, starting in the first year (2009) until the third year (May 2011), the frequencies of damage recorded after each rainfall event of 30 millimetres or more are presented in Table III below.

Tableau III: Observation frequency of signs and visible effects of damage after a rainy day on the embankments and slopes

Sites	Observations	*1st year (2009)*		*2d year (2010)*		*3d year (2011) (through May 2011)*	
	Rainfall amount	30-50 mm (N=12)	>50 mm (N=7)	30-50 mm (N=9)	>50 mm (N=8)	30-50 mm (N=8)	>50 mm (N=3)
Casis	A= rain without runoff on slopes and embankments	0	0	4	2	8	3
	B= rain that caused runoff without stripping off surface soils	0	0	0	3	0	0
	C= rain causing runoff and stripping off of surface soils	4**	1**	3	5	0	0
	D= rain that causes the creation of small channels	4**	1**	3	2	0	0
	E= rain that caused the creation of gullies ≥ 1metre deep	3**	1**	1	2	0	0
Boukeni	A= rain without runoff on slopes and embankments	2	0	9	8	8	3
	B= rain that caused runoff without stripping off surface soils	10	7	0	0	0	0
	C= rain causing runoff and stripping off of surface soils	0	0	0	0	0	0
	D= rain that causes the creation of small channels	0	0	0	0	0	0
	E= rain that caused the creation of gullies ≥ 1metre deep	0	0	0	0	0	0
Pylône	A= rain without runoff on slopes and embankments	0	0	1	3	6	3
	B= rain that caused runoff without stripping off surface soils	0	0	5	4	2	0
	C= rain causing runoff and stripping off of surface soils	7	4	3	5	0	0
	D= rain that causes the creation of small channels	6	3	3	3	0	0
	E= rain that caused the creation of gullies ≥ 1metre deep	2	3	0	1	0	0

N = Number of rains recorded during the year (see Table I)
*****: For the 3d year (2011) observations stopped in May
**: The observations were done only in November and December as the Casis site was planted at the beginning of November

Casis site

The results shown in Table III above indicate that during the first year of observation (2009), 12 rains with 30 to 50 mm and 7 with more than 50 mm of rain fell on the 3 sites. At Casis, in this first year we only consider the rains starting from November, which is the beginning of vetiver planting on the site. According to ANAC, (2009), the city of Brazzaville recorded 4 rains with 30 to 50 mm and one of more than 50 mm of rain in November and December 2009.

In view of the observations in Table III, all 4 rains with 30 to 50 mm caused runoff and stripping off of surface soils (C) and the creation of small channels (D). However at the Casis site, the 3 to 4 rain showers of 30-50 mm fell between November and December caused the formation of gullies ≥ 1metre deep (E). During the same period (November and December 2009), only one rain occurred with over 50 mm and that rain caused all by itself the three categories of damage (C, D and E) and illustrated by the photograph 10 below.

Photo 10: Damage on the slopes and embankments adjacent to the Casis drain site (Dec. 2009)

This kind of damage occurred frequently and reoccurred during each rainfall event at Casis, because vetiver grass planting had just started, the cover was almost zero (2%) as shown in Photo 10 above and this cover was not yet able to provide effective protection of slopes and embankments at Casis.

However, during the second year (2010), nine rainfall events of 30 to 50 mm occured. Observations at the Casis site indicated that of the nine events, 4 showed no sign of runoff on slopes and embankments (A) and 3 caused runoff and stripping off of surface soil (C) and the creation of small channels (D). Among these 9 rainfall events, only one caused the creation of gullies above 1 metre in depth (E).

For the same second year, 8 rainfall events of over 50 mm fell at on the sites. Two rains showed no sign of runoff (A), 3 caused runoff without stripping off the surface soil (B), 5 caused runoff with stripping off of surface soil (C) and 2 rains caused the creation of small channels (D) followed by deep gully erosion (E).

It is however important to note that all the rain that caused Category C, D and E damage (as illustrated by the Photos 11 and 12 below), fell between the 1st and 2nd quarters of 2010, when the cover was not sufficiently developed. Table II shows that in this period the vegetation was estimated between 20 and 60% on this site, at which point the vetiver hedges had not yet formed a dense vegetative cover that can effectively protect the slopes and embankments of the site against erosion. To be effective in protecting against soil erosion and insuring the stabilisation of infrastructure, Greenfield (2008) mentions that vetiver must form very dense hedgerows.

Photos 11 and 12: Damage on the slopes at the Casis site (April 2010)

In addition, despite an exceptional rainfall of 96 mm and three rains of 48, 46 and 56 mm that fell in December 2010 (ANAC, 2010), no damage was recorded, even in areas previously degraded by light rain in April 2010. These 4 rains did not even cause any runoff damage (see Photo 13), also the lack of damage is shown in Table III data, thanks to the improvement of the vegetative cover on this site from the end of fourth quarter 2010, up through 2011, as shown in Photos 13 and 14 below.

Photos 13 and 14: Same site as in photos 11 and 12 (May 2011), the vetiver hedges having prevented all erosion despite record rainfall exceeding 70 mm

The spectacular results of these observations were obtained in the first and second quarter of the 3rd year (2011). Indeed, as shown in Table III above, even though ANAC (2011) already recorded 8 rains of 30 to 50 mm and 3 rains over 50 mm in the first and second quarter 2011, no signs or visible damage effects were recorded on the Casis site. The deep roots along with rigid and dense stems and leaves of the vetiver hedges ensured the stability of slopes and embankments (Ndona et al., 2006, Truong et al, 2008b, 2008c, Greenfield, 2008). All these rains caused no damaging runoff following the development of very dense vetiver hedge rows, giving a slope vegetative cover estimated at 100%, as shown in Photo 16 below. Indeed, the vegetative cover protects the soil from raindrop impact (splash), it slows and dissipates surface runoff and thus promotes the infiltration (Ndona et al., 2006, Truong et al, 2008b, 2008c, Greenfield, 2008, Zaher, 2011).

Photo 15. The Casis site during planting, Nov. 2009

Photo 16. The same site 17 months later in May 2011

Thus, vetiver vegetative cover really demonstrated its effectiveness as no signs of runoff damage were observed due to greatly increased infiltration as a result of the development of abundant vetiver-based vegetative cover (Ndona et al., 2006, Paul Truong et al., 2008a).

Boukeni site

At the Boukeni site in the first year of observation (2009), ANAC recorded 12 rains from 30 to 50 mm and 7 rains of over 50 mm. Of the 12 rains from 30 to 50 mm that fell on this site, only 2 did not cause rain runoff (A) and 10 rain-induced runoffs occurred without stripping off the surface soil (B). By contrast, all 7 of the rains over 50 mm created runoff without stripping off of the surface materials. This performance is due partly to the fact that the vetiver planting on this site was done earlier and the vegetative cover developed rapidly due to the presence of humus and the original high fertility of the soil on this site. At the end of the fourth quarter of the first year, the rapid development of vetiver hedges resulted in heavy cover, capable of stabilizing the site against the progression of any erosion damage. The role of good ground cover for protection against erosion is also confirmed by Ndona et al. (2006), Truong et al (2008b and 2008c), Greenfield, (2008) and Zaher (2011).

On the other hand, stacking sandbags helped block surface soil movement thus preventing damage from runoff. The runoff was also limited by the space gaps between the sandbags that also increased the infiltration of runoff. In addition, after a few months, these sandbags decomposed and broke down easily and the soil in the bags was then stabilised in place by the dense, deep vetiver root system from the plants planted on top of the original sandbags.

During the second and third year of observation (2010 and 2011), of all the rain that fell on this site, whether they were of 30 to 50 mm or over 50 mm, no signs of runoff damage on slopes and backfill at Boukeni were seen. The rapid development of vetiver hedges provided 100% vegetative cover beginning in the fourth quarter of the first year (2009). This well established plant cover did not allow any surface runoff because of significantly increased infiltration, as repeatedly confirmed in the literature by Ndona et al. (2006), Truong et al (2008b and 2008c), Greenfield, (2008) and Zaher (2011).

Pylône site

In the first year (2009), for 12 rains with 30 to 50 mm recorded, 7 rains caused runoff and the stripping off of surface soil (C), 6 rains caused more than just surface damage but created small channels as well (D). Two rains generated deep gullies (E). By contrast, of the 7 rains with more than 50 mm rain in 2009, 4 rains caused the surface stripping damage (C) and 3 rains caused more extensive damage (D) and (E).

Much of this damage was recorded between the first and second quarter, when vetiver hedges were not yet able to provide effective protection because vetiver hedges were in the first months of their development. However, beginning the second year, one rain of 30 to 50 mm produced no runoff at all (A), 5 rains had some runoff but without stripping off any surface material (B) and 3 rains caused runoff with some stripping off of surface soils (C) and the creation of some small channels (D). As was the case in the first year, the C and D type damage in the second year was largely caused by the rains during the first and second quarters.

In contrast to the first year, we noticed that from the 2nd year (2010) until the third year, there was a reduction of severe damage (D) and (E) caused by rains over 50 mm and there were more rains which did not cause any runoff (A) and those rains that did cause some runoff did not create any damage. This remarkable result is attributed to the development of the vetiver hedges, thus creating the vegetative cover that can protect the slopes and embankments at this site just like what was observed at the other two sites.

4. CONCLUSION

The work described above involves an experiment in the city of Brazzaville in the Republic of Congo with a new approach to fight against erosion and mitigate storm damage by investigating the integration of the Vetiver System into conventional methods used to prevent erosion.

These conventional anti-erosion methods have their limits as demonstrated in the past where expectations were not met using these methods and as such, damage to infrastructure and to the land continues unabated to this day. Since the designers of this infrastructure did not include bio-engineered mitigation systems such as using the Vetiver System, it is important to prove the effectiveness of such integration now.

The integration of this vetiver-based bio-engineering technology involved the planting of vetiver hedgerows along land contours to protect embankments, slopes and man-made conventional anti-erosion structures (drains, gabions, and Terramesh retaining walls) at three erosion sites in the northern part of Brazzaville, specifically on the sites at Casis, Boukeni and Pylône.

Observations made over three years (2009, 2010 and 2011) showed that the development of vetiver hedges produced dense vegetative cover and was effective in preventing erosion damage on these three sites. The vetiver vegetative cover and the deep penetration of the dense root system into the soil contributed greatly to effective erosion protection of man-made structures, as well as protecting the slopes and embankments on these sites. They also helped to stop the progression of existing erosion and it prevented any new damage due to erosion from occurring despite exceptionally high rainfall during those three years of observation. Without the existence of these vetiver hedges, the damage would have been very extensive and would have probably destroyed the existing man-made structures.

BIBLIOGRAPHY

ANAC 2011. Histogramme pluviométrique, Station d'observations synoptiques de Brazzaville, Agence Nationale de l'Aviation Civile, Brazzaville, République du Congo

ANAC, 2009. Histogramme pluviométrique, Station d'observations synoptiques de Brazzaville, Agence Nationale de l'Aviation Civile, Brazzaville, République du Congo

ANAC, 2010. Histogramme pluviométrique, Station d'observations synoptiques de Brazzaville, Agence Nationale de l'Aviation Civile, Brazzaville, République du Congo

Goudiaby, V. 2003. Le Système Vétiver, une solution efficace pour protéger et pérenniser les bassins de rétention. DynaEntreprise, CEES, Dakar, Sénégal

Greenfield, J.C. 2008. The vetiver system for soil and water conservation, 1st edition 2008, The Vetiver Network International, USA.

Juliard, C., Truong, P., Diatta, M., et Goudiaby, V. 2001. Pourquoi le vétiver (espèce herbacée) utilisé avec succès dans une centaine de pays pour la reforestation ne pourrait pas jouer le même rôle au Sénégal? Colloque International sur la désertification et la reforestation; Dakar.

Musée-Nature de la prairie, 2005. Au fil des paysages. Consulted on 29 may 2011, internet website, www.livingprairie.ca/fr/livinglandscape/quadrats/methology.html

National Research Council. 1993. Vetiver Grass: A Thin Green Line Against Erosion. National Academy Press, Washington, D.C.

Ndona, A. 2009. Vetiver system for highway batter and gully stabilisation in the Democratic Republic of the Congo. Extended abstract presented at National Workshop on the Vetiver System for Soil and Water Conservation, Environment Protection and Land Rehabilitation, Adis Ababa, Ethiopia. www.vetiver.com/ETH_WORKSHOP_09/ETH-S3a.pdf.

Ndona, A., Truong, P. and Rachmeler, D. 2006. Rehabilitation of ravines on the Congolese flood plain. PRVN Tech. Bull. N°2006/1, ORDPB, Bangkok, Thailland.

Rachmeler, D. 2003. Le Système vétiver: Applications dans toutes les activités humaines. D'où son très grand intérêt. Communication à l'occasion de la session de formation organisée à Kinshasa du 9-12 Février, dans le cadre du projet CLIFS/USAID.

Truong, P. 2000. Vetiver Grass for Mine Site rehabilitation and Reclamation. Extended Abstract of the paper presented at the Remade Lands International Conference, Fremantle, Washington, November 2000.

Truong, P. 2004. Vetiver System. A Green and Clean Solution. Potential Applications and Benefits for The Democratic Republic of Congo. Veticon Consulting, Brisbane, Australia

Truong, P., Van, T. T., Pinners, E. 2008a. The vetiver system for slope stabilization. An Enginner's Handbook, 1st Edition 2008, The Vetiver Network International, USA.

Truong, P., Van, T. T., Pinners, E. 2008b. The vetiver system for agriculture, 1st Edition 2008, The Vetiver Network International, USA.

Truong, P., Van, T. T., Pinners, E. 2008c., Vetiver system applications. Technical Reference Manual, 2nd edition 2008, The Vetiver Network International, USA.

Zaher, H. 2011. Erosion. Campus numérique francophone de Rabat, Maroc.