WASTEWATER TREATMENT AND DISPOSAL IN MAHAJANGA, MADAGASCAR – SCIENTIFIC, MULTI-DISCIPLINAR COOPERATION

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This paper describes an 11-year experience of scientific cooperation between different partners for sustainable development and sound technologies, in the field of sanitation and wastewater treatment. The Faculty of Engineering (University of Trento, Italy), the Faculty of Science (University of Mahajanga, Madagascar) and other local NGOs and administrations cooperate to foster research, mainly for anaerobic treatment and practical, effective solutions. This work describes strategies, efforts and practical solutions developed to carry on a scientific research and practical solutions in Mahajanga as a result of a multi-sectorial cooperation. The aim of this kind of collaboration was also to foster local, independent research and to support the new specialization course in waste and wastewater treatment at the local Faculty.

Keywords: wastewater, sanitation, anaerobic treatment, international cooperation

1. Introduction

Wastewater (sewage and industrial) treatment and disposal is a priority problem in emerging and developing countries; emerging countries can take advantage of specific funds (structural funds) like the ones Romania and Bulgaria received from the European Union after their entrance in 2007. On the contrary, most of the regions in the World suffer from lack of economic resources, environmental regulations, and technical knowledge. Specifically, in Sub-Saharan African countries, wastewater collection, treatment and disposal are still at the moment an important challenge. Wastewater treatment and disposal will be one of

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the huge problems for Developing Countries in the following years. African countries suffer from inadequate wastewater treatment, if somewhere present [1].

Similarly, Madagascar has in practice no wastewater treatment plants, except for some experimental pilot-scale projects, and very limited sanitary sewers. As even sanitation coverage is very poor even if compared with other African countries [2], wastewater collection and treatment both from civil and industrial discharges is actually limited, generating critical problems [3].

In this context, the government will delineate the safeguarding politics for environment and biodiversity.

Madagascar has developed a wastewater legislation by the way of ONE (Office National pour l'Environnement), which is the “Code de l'Eau”, LOI n° 98-02, 1999 [4], applicative standard; it delineates parameters and limits for wastewater discharge into rivers and sea. Nevertheless it seems to be evident that Madagascar standards, as in many others Developing Countries, could be reached only by a stepwise treatment technologies implementation [5].

In this study, an integrated collaborative approach between the Civil and Environmental Engineering Department, Trento, Italy, the NGO Engineering without Borders Trento, Italy, and the Faculty of Science, Mahajanga, Madagascar, and some other specific partners is exposed. This sort of multi-disciplinary cooperation lasts for more than 12 years.

The city of Mahajanga is situated on the north – east coast of Madagascar. Its development has been strongly enhanced in the past 20 years, as the old colonial centre has been surrounded by new quarters; most of them are slums. This situation and the industrial development of the 80's have caused problems in the civil and industrial wastewater management; many cases of cholera, typhus, hepatitis and even human plague [6] have been reported. Undefined number of cases of several illness have been registered near industrial wastewater uncontrolled discharges by local community.

Local Faculty of Science joined, in 2002, a World Bank program for industrial, economical and research development, aiming at the rehabilitation of their laboratory, the implementation of local research and collaboration with local enterprises, national and international institutions.

The research was carried on from the very beginning with the active collaboration of the Faculty of Science, Mahajanga, and Engineering Without Borders – Trento, a voluntary association; the Faculty of Science received also the support of different organisations inside the project named “Contribute to the research for anaerobic wastewater treatment processes for the city of Mahajanga”.

Anaerobic treatments are an effective solution and in most cases is easy to maintain even in Developing Countries. An advantage is related to the generation of methane from streams that are considered basically a waste [7, 8]. This aspect can be used as an opportunity for starting a discussion/collaboration with companies that discharge concentrated biodegradable streams without any treatment, in areas where the regulation is absent. The control of the impact on the atmosphere does not require unconventional approaches [9]. Construction costs and land requirement are generally low [10, 11]; tropical climate conditions allow the energetic exploitation of the biogas for different uses, as to produce electrical power. The most convenient system seemed to be the Upflow Anaerobic Sludge Blanket (UASB) [12], which was experimented in pilot and full scale in several situations in many developing countries. We decided to plan an experimentation in Mahajanga with a pilot scale UASB reactor. This system appeared to be suitable both for industrial and for civil wastewater [10].

There was the need to obtain a pilot scale system easy to monitor, small, transparent and transportable. At the same time in Mahajanga the project previewed the rehabilitation of the laboratory, which is necessary for experimental analysis and for the monitoring phase of the wastewater quality.

The core of the whole project consisted in planning a sustainable approach for the technology transfer; this should also be able to be reiterated in different contexts in the city of Mahajanga, involving local actors such as NGOs, authorities and community leaders and promoting research and cooperation.

From one side pilot experimentation about industrial wastewater treatment was considered important to foster local research and enterprises collaboration. A different, maybe more dramatic problem was represented by sanitation, sewerage and civil wastewater treatment. In Mahajanga sewerage is limited, but also septic tanks, improved latrines and in some areas even traditional latrines are absent. Thus, from the beginning of the collaboration, in parallel with industrial wastewater treatment experimentation, effective studies and practical strategies have been considered. For sanitation, specifically, population was even more likely to be involved: a more holistic and multi-disciplinary approach was needed, taking into consideration social, economic, cultural and anthropological aspects. This lead to a participatory planning and construction of WCs and showers in two areas in Ambalamanga, with septic tank system and sub-superficial irrigation as drainage. This solution, according with local municipality, is also known to be effective and reliable [13].

The aim of the partnership was thus to study and implement strategies and activities to contribute to the more general objective, about the implementation of environmentally sound technologies (for waste, wastewater and air-flow treatment) in Mahajanga area.

Specific aims have been:

- planning, testing and transferring a pilot-scale anaerobic reactor for being used in Mahajanga for experimentation;
- helping local laboratory modernization and utilisation;
- contributing for partnership with local institutions and enterprises;

- planning and effectively implementing, in the framework of this cooperation, effective and sound infrastructures for wastewater collection, treatment and disposal.

Discussion and results of this work are mainly focused on the feasibility of such steps. Successful results could be useful for a following pilot scale research or, afterwards, for a full - scaling proposal; for the case of sanitation and civil wastewater treatment and disposal, the approach could be generalized for further application in similar districts.

2. Strategies implementation

Researchers chose a specific, well-defined area in Mahajanga, in order to concentrate the study and propose sustainable strategies. In this area (Ambalamanga sector in the quarter of Antanimasaja) both industrial and civil wastewater treatment and disposal represent a serious problem and, thus, have been afforded.

a) First step: pilot reactor and training, first experimentation

A 10-liter UASB pilot scale reactor was firstly tested in Trento to evaluate performances at different conditions of T, pH and organic loading rate. The reactor was made with no automatisms, in order to be as simple as possible, resistant and easy to transport. Encouraging performances were obtained in terms of COD removal efficiency and biogas production, thus leading to choose this system for local researchers' training and pilot-scale experimentation in Mahajanga.

Moreover, in Ambalamanga a local oil and soap factory, SIB, is fully operating, discharging wastes and wastewater heavily charged in suspended solids, phosphates and COD. The pilot plant was then carried to Mahajanga, for further testing and experimentation.

b) Laboratory recovery and experimentation in Mahajanga

The second phase was, thus, to study industrial wastewater characterization and possible solutions. The case study was SIB enterprise (cotton oil and soap production). Wastewater, after a sedimentation tank and the use of NaOH to help precipitation, is directly discharged into a mangrove lagoon.

The pilot plant layout was already in the laboratory. Some local students have to be trained, laboratory analysis for wastewater characterization had to be performed; moreover, the laboratory itself should grant security and continuity, thus it had to be rehabilitated and provided with new instrumentation.

Electrical power supply for the laboratory of the Faculty was already partly in use, but voltage oscillation and cuts-off were very frequent; moreover, the electrical system was in a very bad state and unsecured. To protect new laboratory instrumentation a new rehabilitation was necessary. This was made in collaboration with NGO Engineering without Borders, and the technical school in Trento, Istituto Tecnico Industriale M. Buonarroti, involving their students and professors. Laboratory was then secured with a simple generating power unit, mostly made with local materials. It was able to act as accumulator energy, and to provide energy for basic services, at the occurrence.

Various wastewater analyses have been performed in collaboration with local students and Faculty professors. UASB reactor was also tested and several runs have been performed to teach and train local personnel; SIB wastewater have been used for the testing. A preliminary study about wastewater characterisation and potential treatment could thus be performed. Over the base of preliminary data about chemical analysis and flow rates, a full-scale anaerobic treatment plant layout was also supposed, together with an economic analysis.

A feasibility study carried out on industrial wastewater characterization, flow-rates estimation and economic analysis revealed the reliability and the potential sustainability of the process in comparison with more conventional wastewater treatment systems [14].

c) Sewage – septic tanks and sub irrigation

The main work in this phase was the planning and realisation of a collective system of WCs for local community (1,800 inhabitants); this constitutes the "civil wastewater" (or sanitation) problem of the area.

The absence of adequate sanitary systems in Ambalamanga has caused in the last years a significant improvement of several diseases. Thus, finding a sustainable solution for the sanitary problem has become a practical task for life quality amelioration. Moreover, the choice was restricted by specific (social, cultural and technical) constraints.

All these problems and conditions have been monitored and analysed with constant confrontations in participatory meeting with population and local partners; finally, the willingness of the population was also considered.

The project has thus been oriented towards the realisation of double-pit septic tanks in two available areas of the village.

Drainage from the septic tanks has to be treated with sub- irrigation (drain infiltration), [13, 15]. The project also foresees the possibility to post treat septic tank flow with a UASB system, but due to the particular socio-economic conditions of the area, this solution has been abandoned.

Again, with a new agreement among different partners, a new project had begun. Toilet systems and wastewater treatment has been planned in 2 appropriate areas; several local partners have been involved in the participatory project, then the full-scale final project was finally implemented. The research has been intended for realisation, as after the project phase, construction and community sensitization would have followed at the same time, prior to the final use.

At the current state, the preliminary project have been realised thanks to the synergy between population, NGOs, institutions and academic partners. This phase of the project offered a realistic opportunity to share knowledge and confirm empowerment of local actors. Not surprisingly, different town districts are also interested in further implementations for the future.

3. Results and discussion

a) First step: pilot reactor and training, first experimentation

A10 litre, transparent Poly methyl methacrylate pilot scale UASB reactor was designed and constructed in Trento in 2002-2003. Experimentations were performed before transfer in Mahajanga. The reactor was equipped with an external water jacket for thermostatic baths. A sedimentation tank was also provided for post-treatment simulation. The UASB reactor had also a didactic aim, as it was thought to be used in the local laboratory in Mahajanga for different experimentations. A peristaltic pump was used for feeding; wastewater samples were manually collected; a simple volumetric system with an electro valve used as counter was used for biogas production.

Once constructed, the UASB was firstly used with synthetic wastewater (mean COD of 5 g/l), in order to test the system at different conditions (COD, pH, T, organic loading rate). Granular sludge was provided by a local industrial UASB treatment plant.

Wastewater was then progressively shifted to municipal wastewater from Trento Nord treatment plant (mean COD of 0.5 g/l), collected after coarse grit removal; in the last phase additional 1 g/l COD was added to maintain a sufficient organic loading rate. In this case, post treatment sedimentation tank was also used for total suspended solids (TSS) and phosphorous removal via precipitation ($FeCl_3$), due to the wastewater characteristics in Mahajanga (SIB factory).

Results were encouraging, both from COD removal and biogas production, and from system flexibility and facility to manage.

Table 1

Characteristics and performances of experimentations in Trento. COD: chemical oxygen demand. OLR: organic loading rate. SLR: sludge loading rate. VSS: volatile suspended solids. HRT: hydraulic retention time. Q: flow rate. P: total phosphorous. N: total nitrogen. Y: specific biogas production. *P and TSS removal in the 2nd phase achieved by chemical precipitation.

Range of parameters	Synthetic wastewater		Municipal wastewater	
	Start-up	Regime	Start-up	Regime
COD inflow [g/l]	5	5-5.2	5.2	1.8-1.9
N-Ntot inflow [mg/l]	40	50	40-80	40-80
P-Ptot inflow [mg/l]	8	10		30-40

OLR [$kgCOD \cdot m^{-3} \cdot d^{-1}$]	3	11	6.8	2.7
SLR [$kgCOD \cdot kgVSS^{-1} \cdot d^{-1}$]	0.4	0.9	0.68	0.28
HRT [h]	36	13	18	8.5
T [°C]	37	15-40	37	25-37
pH	7-8	5.5 – 8	7-8	7.5
CODremoval [%]	50-60	75-90	60-70	80-90
P removal [%]	15-25	15-25	-	60-85*
Y [$l(CH_4)/g(COD)rem$]	0.10	0.15-0.20	0.10-0.15	0.15-0.20
TSS removal [%]	-	-	-	60-70

At the same time Malagasy professors visited Italian and French laboratories and treatment plants; other visits in Mahajanga took place for training and technology transfer. In 2004 the pilot plant was transferred in Mahajanga, where the laboratory was going to be rehabilitated and equipped for analysis; in the local faculty a new waste and wastewater specialization course was opened and some MSCs theses were approved.

b) Laboratory recovery and experimentation in Mahajanga

In the second phase, reagents and all necessary instruments were provided, to permit experimentation in Mahajanga. Pilot plant was tested various times, but there was the need to grant a stable functioning of both pilot plant and analitical instrumentation.

As previously mentioned with the collaboration of Istituto Tecnico Industriale Buonarroti a new electric plant was partly implemented in Trento and completed in Mahajanga, by Italian students and professors. This system was necessary to ensure safety and regular utilisation of the laboratory, even in case of blackouts or voltage oscillations. No electronic devices have been installed, as traditional electric instrumentations have been used. Storage truck accumulators to store energy have been used in this case; electrical power from local distributor (JIRAMA) is used to charge batteries. Each accumulator is independent and the whole system was supplied by security devices (dischargers).

Those conditions allowed for a much safer and continuous experimentation. For didactical purpose, a brief characterization of SIB wastewater was carried on, and a small start-up period with the UASB reactor was performed. These studies allowed us to propose a layout for SIB wastewater treatment plant, and some economical considerations about anaerobic treatment.

Table 2

Mean values for SIB wastewater. COD fil: COD filtered (0.45 μm). VSS volatile suspended solids

Parameter	**Value**
COD [mg/l]	12,480
COD fil [mg/l]	3,648
N [mg/l]	46

P [mg/l]	10
ST [mg/l]	1.25
TSS [mg/l]	5,720
VSS [mg/l]	4,780
pH [mg/l]	6.6
Q [m^3/d]	32

In the last period of this phase (2005-2007) some bases (sociological studies in the community of Ambalamanga) have also been conducted in order to plan the last step: sanitation and civil wastewater treatment plant.

A more conventional aerobic treatment plant with trickling filters was once proposed by CNRE (Centre National pour la Recherce sur l'Environnement). This layout was compared from an economical point of view, with a UASB reactor (in a layout with sedimentation tank and trickling filters as post-treatment. The last solution, initially more expensive, is actually convenient, as using a dual-fuel engine for power production, the payback period could be less than 3 years. It is worth to notice that, in this context, even a small treatment plant like this should be very convenient, due to the extremely high electricity costs.

c) Sewage – septic tanks and sub irrigation

The final part of the cooperation had been focused on community-level sanitation, wastewater treatment and disposal. As mentioned, the goal was to create a strong net between partners to plan, construct and maintain a WC system in Ambalamanga, to be used as pour-flush toilets [13, 15] with septic tanks and a sub-superficial irrigation system for treatment and disposal. Narrow roads in the quarter, sea proximity and limited free spaces did not allow a more simple and conventional sanitation strategy as familiar latrines construction. At the end, 2 areas in the village were chosen to build the infrastructures.

Once again the project was the result of the link between NGOs, administration and Faculties (Trento and Mahajanga); in this case, community involvement via local associations was even more crucial; thus a large part of technical choices and strategies have been chosen and implemented in a continuous agreement with the population.

Toilet number was estimated on the basis of inhabitants, existing sanitation systems, and frequency of utilization.

The most important device was the double – pit latrine construction ("*fossa alterna*") for both areas [16]. This system allow a continuous use, as when needed, a pit can be emptied allowing the second one to be filled with a simple pipe diversion.

For each toilet, two tanks will be used: when the first is full, the WC can be connected to the second tank, while the first one is closed. After 2 years, the first pit can be emptied by specifically trained people in a safe way. For each area, water supply for toilets and lavatories will be provided by a mixed system: solar pumps from nearby well, and from SIB water main.

The sub-superficial irrigation system could be an effective, relatively simple method for wastewater treatment and dispersion. Soil characteristics and water table demonstrated the feasibility of this methodology [17].

After periods of study and negotiations (2007-2011), the project was done; construction in 2 areas of 16 latrines, 4 showers in the first site and 20 latrines, 5 showers in the second site have been planned.

The construction, which employed local labour and was conducted by local enterprises, ended in August 2013. The main goal of that part of the project was a completely autonomous management and maintenance by community via a net of local associations, which are trained and motivated. Community use WC and showers by paying a defined amount, as commonly in use in the municipality.

4. Conclusions

The co-operation with the Faculty of Sciences resulted in the creation of a new specialization course in Waste and Wastewater Treatment. This is an important result: indeed the evolution of the local expertise is a key factor for obtaining sustainable results in technical sectors and allows the generation of laboratory data useful for designing solutions.

The collaboration developed between the Universities of Trento and Mahajanga and the local company SIB for studying wastewater treatment options can act as a pilot experience that could be replicated locally not only at regional level.

The involvement of the local community and the municipality of the Ambalamanga area to identify a suitable location for the construction of the sanitation facilities can be seen locally as a first experience in terms of environmental planning.

The gradual involvement of local NGOs' delegates and community members in the decision-making process demonstrated that the local competences can be valorised.

In the multi-disciplinary project for sanitation the local community and authorities have been directly involved in management and maintenance; that is an additional result in terms of expected sustainability of the work.

The general participation in different phases of many actors allowed the enhancement of the expertise also of the high-income bodies.

The project at the moment is still active and has progressively involved all Ambalamanga associations and community leaders, local enterprises (SIB), local authorities.

R E F E R E N C E S

[1] *K.B. Showers*, 2002. "Water Scarcity and Urban Africa: An Overview of Urban-Rural Water Linkages". *World Development*, **vol. 30**, no. 50, pp. 621-648.

[2] *M. Stampini, A. Salami, C. Sullivan,* 2007. "The Water and Sanitation Index of Development Effectiveness (WIDE) in Sub-Saharan Africa: Overview of Country Performance". *Africa Economic Brief*, **vol. 3**, no. 2, pp. 1-7.

[3] *V. Foster, C. Briceño-Garmendia*, 2010. "Africa's Infrastructure. A Time for Transformation". The Word Bank. http://siteresources.worldbank.org/INTAFRICA/Resources/aicd_overview_english_no-embargo.pdf.

[4] Code de l'Eeau. Loi n° 98-029 du 20 janvier 1999 ; Ministère de l'Energie et de Mines. Madagascar. http://www.droit-afrique.com/images/textes/Madagascar/Madagascar%20-%20Code%20de%20Eau.pdf.

[5] *M. Von Sperling, C.A.L. Chernicharo*, 2002. "Urban wastewater treatment technologies and the implementation of discharge standards in developing countries". *Urban Water,* **vol. 4**., pp. 105-114.

[6] *S. Chanteau, M. Ratsitorahina, L. Rahalison, B. Rasoamanana, F. Chan, P. Boisier, D. Rabeson, J. Roux, 2000.* "Current epidemiology of human plague in Madagascar". *Microbes and Infection,* **vol. 2**, no. 1, pp. 25-31.

[7] *E.C. Rada, M. Ragazzi, V. Torretta, 2013.* "Laboratory scale anaerobic sequencing batch reactor for treatment of stillage from fruit distillation". *Water Science and Technology,* **vol. 67**, no. 5, pp. 1068 - 1074.

[8] *S.L. Martineza, V. Torretta, J.V. Minguela, F Siñeriz, M. Raboni, S Copelli, E.C. Rada, M. Ragazzi, 2014.* "Treatment of slaughterhouse wastewaters using anaerobic filters". *Environmental Technology,* **vol. 35**, no. 3, pp. 322-332.

[9] *E.C. Rada, M. Ragazzi, 2008.* "Critical analysis of PCDD/F emissions from anaerobic digestion". *Water Science and Technology*, **vol. 58**, no. 9, pp. 1721-1725.

[10] *M. von Sperling, C.A.L. Chernicharo, 2005.* "Biological Wastewater Treatment in Warm Climate Regions". **vol. 2,** 1400 pp. IWA Publishing. ISBN 1843390027.

[11] *A.C. van Haandel, G. Lettinga*, 1994. "Anaerobic sewage treatment: a practical guide for regions with a hot climate". 226 pp. J. Wiley ed. ISBN 978-0471951216.

[12] *G. Lettinga, A.F.M. Van Velsen, S.W. Hobma, W.J. De Zeeuw, A. Klapwijk*, 1980. "Use of Upflow Anaerobic Sludge Blanket (UASB) reactor concept for biological wastewater treatment, especially for anaerobic treatment". *Biotechnology and Bioengineering,* **vol. 22**, no. 4, pp. 699-734.

[13] *P. Harvey,* 2007. "Excreta Disposal in Emergencies: a Field Manual". WEDC Loughsborough University. 232 pp. ISBN 978-1-843801139.

[14] *A. Sandri, 2005.* "Design aspects for the application of a UASB process in a sub-Saharan context". MSc thesis. University of Trento – Faculty of Environmental Engineering (in Italian). 283 pp.

[15] *P. Harvey, S. Baghri, B. Reed, 2002.* "Emergency sanitation, assessment and programme design". WEDC Loughsborough University. 358 pp. ISBN 1-84380 0055.

[16] *E. Tilley. C. Lüthi. A. Morel. C. Zurbrügg. R. Scertenleib*. 20007. "Compendium of Sanitation systems and technologies". EAWAG Dübendorf publ. pp. 158.

[17] *F. Paolazzi, 2010.* "Partecipatory planning of wastewater treatment system in the city of Mahajanga. Madagascar. MSc thesis. University of Trento – Faculty of Environmental Engineering (in Italian). 175. pp.