The method of material flow analysis, a tool for selecting sustainable sanitation technology options: the case of Pouytenga (Burkina Faso)

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Abstract

Like many other cities in Sub Saharan Africa, Pouytenga in Burkina Faso has sanitation problems characterized by poor public health. Pouytenga is located upstream of the dam of Yitenga, and the pollution of this city is drained into this dam, which is used to supply drinking water. The city has no strategic sanitation plan. So, the objective of the study is to assess the dynamics of material flows and pollutant (nitrogen) through different technological sanitation options of Pouytenga. The method of material flow analysis (MFA) is used to assess the matter and nutrients fluxes. The methodology includes literature review, household surveys and chemical analyses of wastewater and fecal sludge. Several scenarios of sanitation options have been assessed. The results show that Pouytenga currently discharges about 61,824 tons of material, including 36 tons of nitrogen per year in surface water and 373 098 tons of materials, including 282.6 tons of nitrogen on groundwater per year. The promotion of diverted urine toilets in the city and solid waste composting is expected to recover 194 tons of nitrogen for agriculture.
Keywords: poor public health, pollution, nitrogen, material flow analysis.

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1 Introduction

Pouytenga is a middle sized city of Burkina Faso in West Africa with a population of about 72,000 inhabitants. This city does not have any Strategic Sanitation Plan for managing wastewater, fecal sludge, solid waste and rainwater. About 66% of households discharge their grey water on the street; 14% don't have on-site sanitation facilities and practice open defecation. About 27% of households discharge their solid waste in the environment without any treatment. The rainwater is drained by natural channels and discharges into a dam located in the city upstream (fig. 1). This dam is used for supplying the city drinking water. In this paper, we describe how material flow analysis (MFA) can be used as a tool for selecting sustainable sanitation technology options. MFA is a systematic assessment of flows and stocks of materials within a system defined in space and time (Brunner and Rechberger [1]; Montangero [2]; Yiougo *et al.* [3]). It can be used for designing and testing different materials management systems in order to compare the flows to the environment, or against some acceptance criteria for environmental loading. So, any strategy of materials management can be discussed through the results of an MFA system (Lu *et al.* [4]). This paper recommends MFA as a tool for decision making that allows comparing different sanitation technology options.

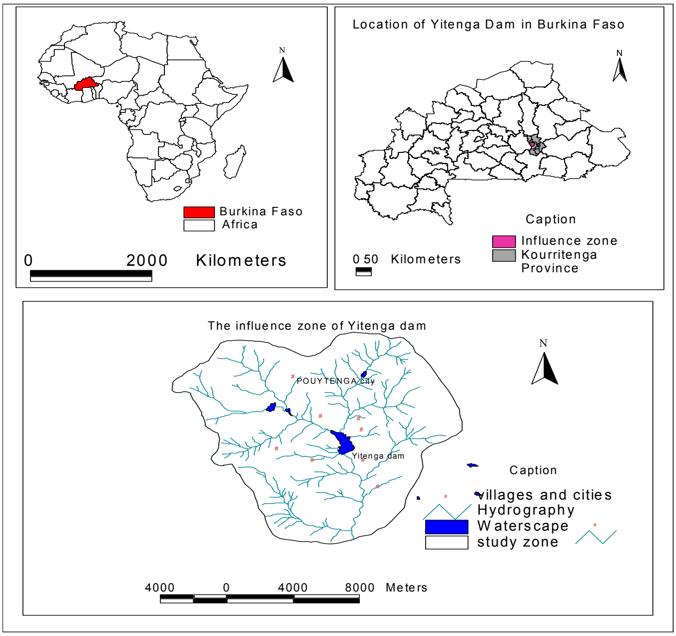

Figure 1: Location of study zone.

2 Methodology

2.1 Principles of the material flow analysis method

Material Flow Analysis (MFA) is the assessment of matter mass flow (water, food, excreta, wastewater...) or pollutant mass flow (nitrogen, phosphorus, carbon...) which going through a system (city, country...) during a defined period (fig. 2). The principle of MFA is based on the law of matter conservation. MFA has four mains steps (Binder *et al.* [5]): (i) system analysis; (ii) quantification of mass of matter and indicator flow; (iii) identification of the current situation weak points and (iv) development and assessment of the technology scenario.

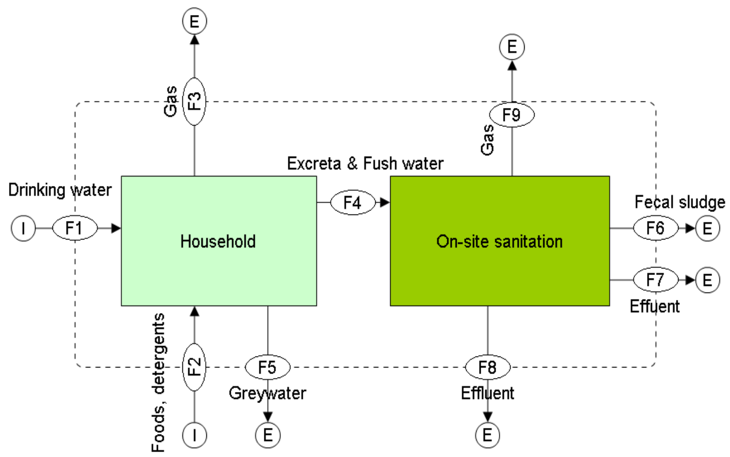

Figure 2: Example of system analysis. The boxes designate processes and the arrows represent the flows.

2.2 System analysis

The system border of this study was the geographic limit of the city of Pouytenga (80 km^2). The indicator flow is Nitrogen (N). Nitrogen is a pollutant linked to sanitation problems and can be reused in agriculture. According to Binder *et al.* [5], the choice of indicator should take into account the availability of measuring devices and the link with human activities, representative of pollution and nutrients. The system is composed by 12 processes and 44 flows. The 12 processes are:

1. Households: they consume water, food (input) and reject excreta, wastewater, garbage, and biogas (output) ;
2. On-site sanitation which is represented by different types of technology as simple pit latrines, septic tank, urine diverted toilet. The inputs are wastewater and excreta and the outputs are fecal sludge and effluent ;
3. Drainage channels and natural drainage receive wastewater and rainwater with a part of household garbage and fecal sludge;

4. Open dumps receive household and market solid waste partly used as organic manure in peri-urban agriculture;
5. Water supply process concerns running water, water from fountains and from alternative resources such as wells and dams. The input is untreated water (raw water from the dams and the groundwater) and the output is drinking water;
6. Markets where foods, livestock and mineral fertilizers pass through;
7. Abattoir (slaughterhouse) which receives one part of livestock and water (input) and rejects meat, liquid and solid waste ;
8. Stock of fecal sludge on the street: sludge removed from the pit is sometimes discharged on the street;
9. Peri-urban agriculture including market gardening, urban agriculture and urban livestock ;
10. Atmosphere;
11. Surface water;
12. Groundwater.

2.3 Quantification of mass of material and nitrogen flow

Matter flow was expressed in kg/capita/year and nitrogen flow in g/capita/year. Data which are used come from four sources: bibliography, survey, chemical analysis and estimated data. The software Excel was used for mass flow calculation and STAN (Software for Substance Flow Analysis) was used for the graphic representation (Cencic and Rechberger [6]).

2.3.1 Bibliography data

Data about nutrition come from the Food and Agriculture Organisation database. Data from several study on Material Flow Analysis in other contexts are been used in particular from Ghana (Belevi [7]), Ethiopia (Meinzinger *et al.* [8]), Zimbabwe (Gumbo [9]), and Vietnam (Montangero *et al.* [10]).

2.3.2 Collected data

A survey among the population of Pouytenga was carried out. About 250 (4%) households were interviewed about the current status of sanitation. Nitrogen values in fecal sludge, grey water come from analysis. Grab sampling is used to collect wastewater samples (35 samples) during two sampling campaigns. Samples of fecal sludge were taking during empting operation of pit latrines and septic tanks. Samples were collected in polyethylene bottles containing nitric acid in order to have a pH<2 and stored at approximately 4°C. N has been determined by Kjeldah method according to Standard Methods for the Examination of Water and Wastewater (2005).

2.4 Evaluated scenarios

The tested technologies are the Ventilated Improved Pit (VIP), the urine diverted toilet and the organic matter composting. The VIP latrine is promoted by the National Water and Sanitation Agency (ONEA), and the urine diverted toilet is promoted by the Regional Center for Water and Sanitation (CREPA). Table 1 summarizes the four tested scenarios (S).

Table 1: Evaluated scenarios.

	Current situation	S1	S2	S3	S4
Simple pits latrine	83%	-	-	83%	-
VIP latrine	-	97%	-	-	-
Urine diverted toilet	-	-	97%	-	97%
Septic tank	3%	3%	3%	3%	3%
Open defecation	14%	-	-	14%	-
Solid waste composting	67%	67%	67%	100%	100%

3 Results and discussion

Technological proposals have been tested to improve the current situation of sanitation. These technologies aim to reduce the flow of pollutants (nitrogen) that are lost through the existing sewerage system. Table 2 presents the results of the current situation and the tested scenarios.

Table 2: Results of the current situation and the tested scenarios.

	Current situation	**S 1**	**S2**	**S3**	**S 4**
Raw water consumption (kg/year/cap)	7,016	-	-	-	-
Matter flow in surface water (kg/year/cap)	1,030.4	1,010.4	1,010.4	974.4	958.4
Matter flow in groundwater (kg/year/cap)	6,218.3	6,174.5	5,921.3	6,093.53	5,796.53
Nitrogen flow in surface water (kg/year/cap)	0.6	0.27	0.27	0.36	0.26
Nitrogen flow in groundwater (kg/year/cap)	4.71	4.4	3	4.61	2.64
Nitrogen reused in agriculture (t/year)	37.65	48.37	149.3	66.65	194

3.1 Current situation analysis

The main matter flow is drinking water, of which from the main source is surface water. Each year, one person uses on average 7,016 kg of raw water including 6,542 kg from the dam. The results show that each person every year stores an average 6,218 kg of matter in the soil or groundwater and rejects 1,030 kg in surface water systems through sewage infiltration and runoff (fig. 3). These matters represent wastewater, excreta, fecal sludge and solid waste. The results

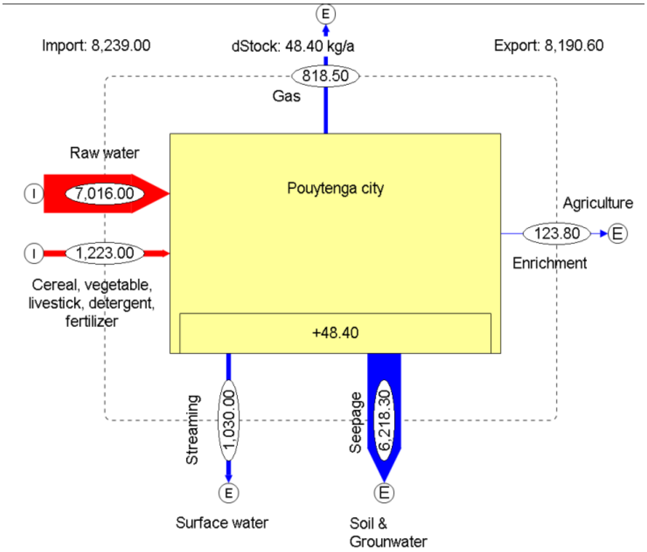

Figure 3: Annual matter flows in kg/cap./year in current situation.

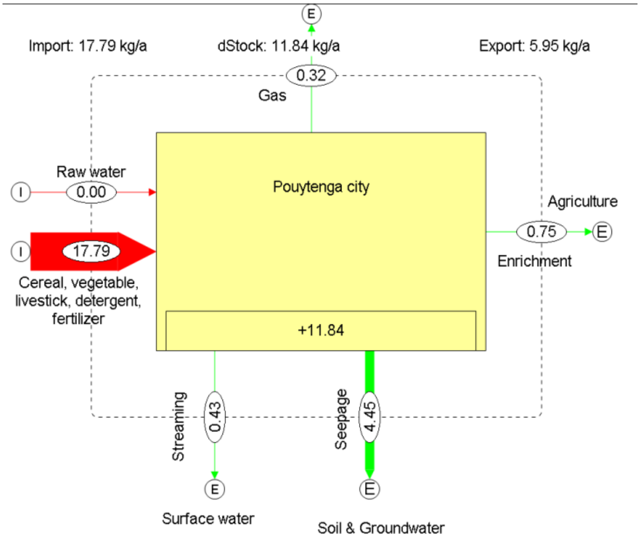

Figure 4: Annual nitrogen flows in kg/cap./year in current situation.

also indicate that the main source of nitrogen comes from food, which is subsequently dismissed with excreta. In the city of Pouytenga, 36 tons of nitrogen per year is discharged into surface waters through wastewater. About 175 tons of nitrogen (4.71 kg / cap / year) are infiltrated into the soil through simple pit latrines and septic tanks. On average, only 37.6 tons of matte from sanitation systems (fecal sludge and organic waste composting) is reused in agriculture each year, which is only 10.6% of the nitrogen produced by the system (fig. 4). The amount of nitrogen obtained is comparable to that found by Meinzinger *et al*. ([8]) in the town of Arba Minch (70 000 inhabitants) in Ethiopia in the current situation gives a value of 270 tons per year of nitrogen store in the soil. The amount of nitrogen stored (282.6 tons) in the soil in Pouytenga each year poses a risk of groundwater pollution.

3.2 Scenario 1: VIP latrines implementation

This test scenario was the adoption of the double pit VIP latrine by97% of households. This technology allows the reuse of sludge after a storage period of two (02) years after filling the first pit. The implementation of this scenario shows that the flows of matter and nitrogen into the soil and ground water remain high averaging 5,583 kg /cap/ year for matter and 4.4 kg/cap/year for nitrogen. About 48 tons per year is reused in agriculture. In this scenario, the nitrogen flow remains high due to the duration of fecal sludge storage in the pit (2 years for filling and 2 years for storage before reusing). This fact favours maximum leachate infiltration.

3.3 Scenario 2: Urine Diverted Toilet (UDT) implementation

The tested scenario was the adoption of urine diverted toilets by 97% of households. The adoption of this scenario allows for a reduction of matter flows to groundwater (5,921 kg / cap / year) and a noticeable reduction of nitrogen flow to this compartment (3 kg /cap/ year on average). An average of 2.49 kg / cap / year of nitrogen are reused in agriculture. The rate of reused nitrogen is about 42%.

3.4 Scenario 3: solid waste composting implementation

The third scenario involves the settlement of a system for collecting solid waste from households and the market with the organic fraction to be reused for compost in agriculture. This is a biodegradation of organic matter by microorganisms in the presence of oxygen. This process reduces the amount of solid waste and produces humus that farmers can use for their field enrichment. The adoption of such a scenario leads to a small reduction in matter and nitrogen flows into soil and surface water. However, the reuse rate of nitrogen increased from10.6% in the current situation to18.7% in this case.

3.5 Urine Diverted Toilet and solid waste composting implementation

This scenario couples the settlement of urine diverted toilet with the system for solid waste composting. In comparison with the current situation, this scenario leads to lower the amount of matter and nitrogen flows into the environmental compartments (surface water and groundwater). Matter and nitrogen flows into surface waters are respectively on average958.3 kg/cap/ year and 0.26 kg/cap/year. This scenario allows the reuse of the total nitrogen of the system to54.5%, which corresponds to 3.23kg /cap/year on average. The nitrogen flow deposits about 57% to surface water and 44% to the groundwater. As a result, the reuse of the nitrogen peaks for this scenario. The study conducted in Hanoi in Vietnam shows that the replacement of the septic tank through the urine diverted toilet reduces by 42% the amount of phosphorus discharged into surface waters (Montangero and Belevi [11]). In Arba Minch, Ethiopia, a study on material flow analysis showed that the adoption of urine diverted toilets by 33% of households would meet the demand of fertilizers in urban agriculture (Meinzinger *et al.* [8])

3.6 General discussion

This study showed that the flows of matter and nitrogen into the soil and groundwater are greater than those to surface waters. In the case of Pouytenga, the free groundwater level is about 10 meters and the average depth of the pit latrines is 3.5 meters. In this situation, the risk of groundwater pollution is significant. The reuse of nutrients is maximized in case of using urine diverted toilet as on-site sanitation technology and the settlement of composting process as a solid waste management system. MFA application has some constraints. These constraints are socio-cultural and economic. One of the factors limiting the implementation of this scenario is the sociological barrier on the principle of reuse of excreta in agriculture. Promotion and extension of sanitation technology has a cost. However, the MFA method does not take into account this aspect which is nevertheless a decisive parameter. Other economic aspects that are not taken into account include (i) earnings generated by the reuse of byproducts in agriculture including the savings by reducing the purchase of chemical fertilizers and (ii) the environmental costs generated by pollution of water resources or the gain from preventing the pollution. One limitation of the method is not taking into account the form of nitrogen produced through the system. The amount of nitrogen obtained is not necessarily the quantity easily mobilized for agriculture. Indeed, nitrogen is assimilated by plant roots in the form of nitrate or ammonium ions. However the proportion of nitrate and ammonium absorption varies with the type of plant and soil (Gaudry 1997cited by Mimouni *et al.* [12]).

4 Conclusion

The MFA method applied to Pouytenga city allows for analysis of the current situation of sanitation and testing some scenarios for improvement. In the current situation, Pouytenga rejects on average each year 61,824 tons of matter which 36 tons of nitrogen is deposited in the dam Yitenga, which is used for drinking water supply. It also infiltrates on average 373,098 tons of which 282.6 tons of nitrogen is deposited into groundwater. Thereby, sewage, solid waste and fecal sludge disposal in Pouytenga contribute to the filling, the pollution, and the eutrophication of Yitenga dam and the groundwater pollution. The tested scenarios show that the adoption of urine diverted toilet as an excreta management technological option and the settlement of a composting system for solid waste will optimize the reuse of nutrients in agriculture as the nitrogen (194 tons per year). We can thus conclude that MFA can be used for selecting sustainable sanitation technology options by assessing the current situation and comparing sanitation technological options.

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