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Greywater Characteristics In Rural Areas of the Sahelian Region for Reuse Purposes: The Case of Burkina Faso

Caractéristiques des eaux grises en milieu rural en zone sahélienne à des fins de réutilisation : cas du Burkina Faso

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Résumé de l'article

Les caractéristiques des eaux grises produites dans deux localités rurales (« Barkoundba » et « Kologoudiessé ») situées en zone sahélienne au Burkina Faso ont été évaluées à travers des observations dans des concessions sélectionnées, des échantillonnages et des analyses de laboratoire. L'étude visait à déterminer les caractéristiques qualitatives et quantitatives des eaux grises afin d'évaluer leur potentiel de réutilisation en agriculture en milieu rural. Les résultats ont montré que les eaux grises sont produites à partir de trois à quatre sources principales avec des productions moyennes de 8 ± 1 L•habitant^{-1}•j^{-1} à « Barkoundba » et 13 ± 3 L•habitant^{-1}•j^{-1} à « Kologoudiessé ». Malgré ces faibles taux, la quantité moyenne d'eaux grises produites a varié entre 67 et 344 L•concession^{-1}•j^{-1} pendant la saison sèche. Ces eaux grises peuvent être collectées pour l'irrigation de jardins familiaux de taille variant entre 10 et 43 m^2. La douche produit plus d'eaux grises avec des contributions de 56 % à « Barkoundba » et 70 % à « Kologoudiessé ». L'évaluation qualitative a montré que toutes les eaux sont contaminées par des polluants chimiques et microbiens à des niveaux ne permettant pas leur réutilisation directe en agriculture. C'est pourquoi il est recommandé de les traiter avant leur réutilisation. Sur la base des directives de l'Organisation Mondiale de la Santé (OMS), le système de traitement doit pouvoir éliminer plus de deux à quatre unités logarithmiques de bactéries selon que l'irrigation est restrictive ou non restrictive, respectivement. Comme les eaux grises des douches sont directement déversées sur le sol, l'unité de traitement devrait être reliée à la douche pour permettre la collecte et récupérer les quantités requises pour le jardinage. Un système de traitement « Slanted Soil » pourrait être envisagé. Les dangers d'une réutilisation directe pour les sols, les plantes et la santé humaine ont été discutés sur la base des multiples paramètres qualitatifs mesurés. Cependant, des mesures complémentaires, et notamment l'évaluation de la variabilité interannuelle de la qualité des eaux grises, seraient nécessaires dans la perspective d'une étude de risques.

RSE

GREYWATER CHARACTERISTICS IN RURAL AREAS OF THE SAHELIAN REGION FOR REUSE PURPOSES: THE CASE OF BURKINA FASO

Caractéristiques des eaux grises en milieu rural en zone sahélienne à des fins de réutilisation : cas du Burkina Faso

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ABSTRACT

The characteristics of greywater generated in two rural areas ("Barkoundba" and "Kologoudiessé") located in the Sahelian region in Burkina Faso were assessed through observations in selected concessions, sample collection and laboratory analyses. The study aimed at characterizing the qualitative and quantitative characteristics of greywater in order to evaluate its reuse potential for gardening in rural areas. The results showed that greywater is generated from 3 to 4 main sources with average daily productions of 8 ± 1 L•capita^{-1}•d^{-1} in "Barkoundba" and 13 ± 3 L•capita^{-1}•d^{-1} in Kologoudiessé". Despite these low rates, the average quantity of greywater production varied from 67 to 344 L•concession^{-1}•d^{-1} during the dry season. This greywater can be collected to provide additional water for irrigation in home gardens of size varying from 10 to 43 m^2. Shower activity is the major contributor of greywater with up to 56% in "Barkoundba" and 70% in "Kologoudiessé". The qualitative assessment of the greywater streams showed that every source is contaminated with chemicals and microbial pollutants at levels not suitable for direct reuse in agriculture. Therefore, it is recommended to treat the greywater before its use for irrigation purposes. Based on World Health Organization (WHO) reuse guidelines, the treatment system should be able to remove bacteria by more than 2 log units and 4 log units if restricted and unrestricted irrigation are considered respectively. Since shower greywater is directly poured onto the ground, the treatment unit should be adapted to the shower room to allow shower greywater collection, in order to collect the required quantities for gardening. A slanted soil treatment system could be investigated. Hazards of a direct reuse are discussed for soils, plants and human health on the basis of the various qualitative parameters. However, an accurate risk assessment would require further investigations with the evaluation of the interannual variability of greywater quality.

Keywords: greywater, gardening, rural area, Sahelian region, agricultural reuse.

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RÉSUMÉ

Les caractéristiques des eaux grises produites dans deux localités rurales (« Barkoundba » et « Kologoudiessé ») situées en zone sahélienne au Burkina Faso ont été évaluées à travers des observations dans des concessions sélectionnées, des échantillonnages et des analyses de laboratoire. L'étude visait à déterminer les caractéristiques qualitatives et quantitatives des eaux grises afin d'évaluer leur potentiel de réutilisation en agriculture en milieu rural. Les résultats ont montré que les eaux grises sont produites à partir de trois à quatre sources principales avec des productions moyennes de 8 ± 1 L•habitant^{-1}•j^{-1} à « Barkoundba » et 13 ± 3 L•habitant^{-1}•j^{-1} à « Kologoudiessé ». Malgré ces faibles taux, la quantité moyenne d'eaux grises produites a varié entre 67 et 344 L•concession^{-1}•j^{-1} pendant la saison sèche. Ces eaux grises peuvent être collectées pour l'irrigation de jardins familiaux de taille variant entre 10 et 43 m^2. La douche produit plus d'eaux grises avec des contributions de 56 % à « Barkoundba » et 70 % à « Kologoudiessé ». L'évaluation qualitative a montré que toutes les eaux sont contaminées par des polluants chimiques et microbiens à des niveaux ne permettant pas leur réutilisation directe en agriculture. C'est pourquoi il est recommandé de les traiter avant leur réutilisation. Sur la base des directives de l'Organisation Mondiale de la Santé (OMS), le système de traitement doit pouvoir éliminer plus de deux à quatre unités logarithmiques de bactéries selon que l'irrigation est restrictive ou non restrictive, respectivement. Comme les eaux grises des douches sont directement déversées sur le sol, l'unité de traitement devrait être reliée à la douche pour permettre la collecte et récupérer les quantités requises pour le jardinage. Un système de traitement « Slanted Soil » pourrait être envisagé. Les dangers d'une réutilisation directe pour les sols, les plantes et la santé humaine ont été discutés sur la base des multiples paramètres qualitatifs mesurés. Cependant, des mesures complémentaires, et notamment l'évaluation de la variabilité interannuelle de la qualité des eaux grises, seraient nécessaires dans la perspective d'une étude de risques.

Mots clés : eaux grises, jardinage, zone rurale, région sahélienne, réutilisation agricole.

INTRODUCTION

Wastewater reuse in agriculture is becoming increasingly necessary in developing countries located in Sahelian regions because of the scarcity of freshwater resources. In middle and low income countries, greywater is most often discharged untreated onto the ground and into open storm water drains. This unsanitary disposal is responsible for the transmission of a large number of water-related diseases (malaria, diarrhoea, etc.) and smelly stagnant waters (ROSA, 2007). Indeed, 19.4% of deaths in children under five are attributable to diarrheal diseases (WHO, 2004). Burkina Faso, like most of the countries in Sub-Saharan Africa, faces serious challenges with regard to water and sanitation services. This situation is more critical in rural areas, where only 1% of the population has access to sanitation services (DGRE, 2006). As in all Sahelian developing countries, Burkina Faso is also facing an increasing demand for freshwater. For a number of reasons, many rural areas develop the practice of gardening. Despite available land, finding and transporting water is generally the main barrier. This shift requires alternative sources of water to be identified. Greywater, which is household wastewater without feces, could be a cost effective alternative source of water. But greywater still contains pathogens and pollutants that can cause health and environmental issues and have adverse effects on soils and plants. Its treatment for reuse in agriculture assumes that the quantitative and qualitative characteristics are determined.

Previous studies have been carried out to characterize greywater but most of them have been conducted in European and North American countries (ERIKSSON *et al.*, 2003; WINWARD *et al.*, 2008). However, as the quantity and the composition of greywater depends on the quantity and type of available water supply, population structure and households activities (MOREL and DIENER, 2006), it is not possible to safely extrapolate the results reported to match greywater characteristics in rural areas of Sahelian regions located in low-income countries. Therefore, it is imperative to characterize greywater quality and quantity in rural areas in Burkina Faso, in order to choose adequate treatment technologies for safe reuse in agriculture.

This study aims at characterizing the greywater disposal situation and its qualitative and quantitative characteristics in order to evaluate its reuse potential in gardening in rural areas. The specific objectives are to:

- characterize the greywater disposal situation;
- determine the greywater sources in the households in rural areas;
- evaluate the amount of greywater generated in the studied rural areas; and
- evaluate the physico-chemical and microbiological quality of the different sources of greywater in rural areas.

1. MATERIAL AND METHODS

1.1 Study site

The vast majority of the population in Burkina Faso (77.3%), corresponding to 73% of the households, resides in rural areas (INSD, 2008). Therefore, the study was carried out in two villages, "Barkoundba" (12.66°N, 1.19°W) and "Kologoudiessé" (12.64°N, 1.23°W) located in the central part of Burkina Faso, the "Plateau Central Region" (Figure 1). With the aim of collecting greywater in rural households for reuse in gardening during the dry season, this region was chosen due to the fact that at least 90% of the households live in rural areas (INSD, 2008). In addition, the area is dominated by the Sudano Sahelian climate, characterized by two seasons, a dry season from October to May (8 months) and a rainy season from June to September (4 months). Annual rainfall is between 600 mm and 900 mm. "Barkoundba" is composed of around 920 inhabitants whereas "Kologoudjessé" is composed of around 700 inhabitants. These two villages were selected based on the ethnic and religious group membership and the activities carried out by the inhabitants. Indeed, in the studied region, "Mossi" and "Peul" are the main ethnic groups. More generally, "Mossi" is the main ethnic group in Burkina Faso (48.6%) followed by "Peul" ethnic group (7.8%) (MINISTÈRE DES AFFAIRES ÉTRANGERES ET DE LA COOPÉRATION RÉGIONALE, 2011). The population of "Barkoundba" belongs to the "Peul" ethnic group with Islam as main religion and cattle farming as the main livelihood activity, whereas the inhabitants of "Kologoudiessé" are members of the "Mossi" ethnic group, Christians in general and with crop farming as the main activity. Gardening is a secondary activity carried out in both villages.

1.2 Sampling and greywater characteristics assessment

The quantitative and qualitative characteristics of the greywater generated in both villages were assessed through observations in selected concessions, sample collection and laboratory analyses.

1.2.1 Selection of sample concessions

The influence of habitat type and neighbourhood affiliation that could be used for the selection of concessions does not arise in rural areas, because in both cases, dispersed traditional type buildings are common. Therefore, the number of concessions

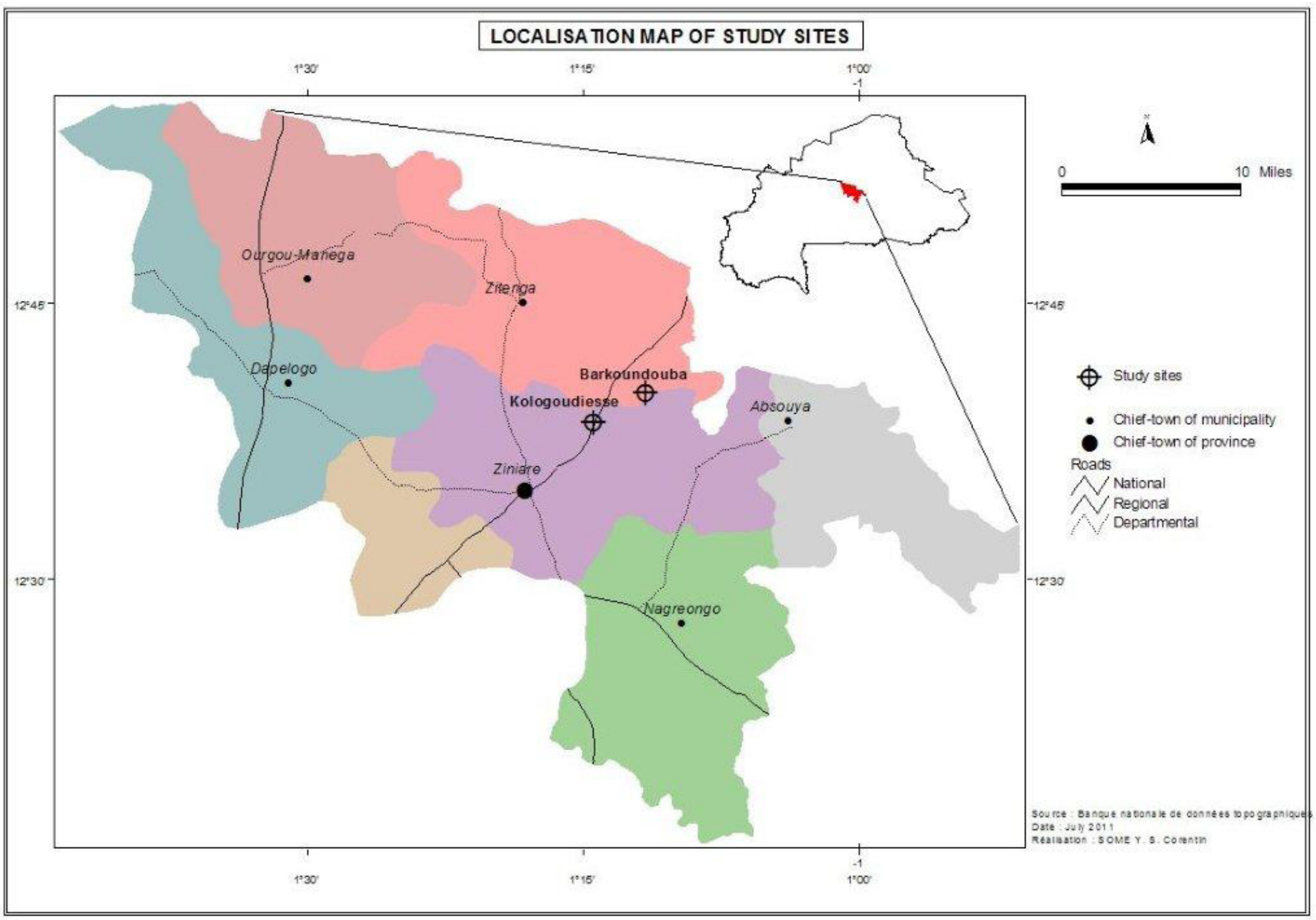

Figure 1. Localization map of the study sites.
Carte de localisation des sites d'études.

for observations was arbitrarily set at five in each village and the sampling was carried out based only on the number of persons in a concession using the stratified sampling method (LEVY and LEMESHOW, 2008). The following clusters were generated:

- cluster 1: concessions with a size of 1 to 10 persons;
- cluster 2: concessions with a size of 11 to 15 persons;
- cluster 3: concessions with a size of more than 15 persons.

The distribution of the five concessions among the three clusters was done based on the number of concessions in each cluster. Then, once the number of concessions to involve per cluster was determined, these concessions were randomly selected inside the cluster.

In "Kologoudiessé", a total of 43 concessions were enumerated of which 24 belong to cluster 1, 10 to cluster 2 and 9 to cluster 3. Based on this distribution, three of the five concessions involved in the observations were selected in cluster 1; 1 concession was selected in cluster 2 as well as in cluster 3. The three concessions selected in cluster 1 have sizes of 8, 9, and 9 persons, whereas those selected in clusters 2 and 3 have sizes of 14 and 23 persons respectively.

In "Barkoundba", a total of 56 concessions were enumerated of which 32 belong to cluster 1, 11 to cluster 2 and 13 to cluster 3. Based on this distribution, three of the five concessions involved in the observations were selected in cluster 1 and 1 concession was selected in cluster 2 as well as in cluster 3. The three concessions selected in cluster 1 have sizes of 8, 10, and 10 persons, whereas those selected in clusters 2 and 3 have sizes of 15 and 24 persons respectively.

1.2.2 Greywater collection

Greywater reuse is only required in the dry season because rainwater is available during the wet season. Therefore, this study was conducted in dry season, from March to May 2011.

Observations were made in the selected concessions in each village to quantify the greywater generated from laundry, dishwashing and showers, suspected to be the three main sources of greywater in rural areas. In addition, in "Barkoundba", greywater from ablutions was taken into account because most of the inhabitants are Muslims. In the selected concessions, assessment of water use consisted of doing observations during a week (7 consecutive days) from morning to early evening. The following parameters were monitored:

- the quantity of drinking water supplied to the concessions;
- the greywater sources;
- the quantity of greywater generated from the above mentioned sources;
- and the greywater disposal situation.

The amounts of water supplied and greywater generated were estimated from the containers used for water collection and greywater production.

In order to determine the greywater characteristics, one sampling was done in the selected concessions at the end of the observations. Because of one-day sampling, additional concessions have been involved in order to have more reliable results. Therefore, five additional concessions were randomly selected in each village among the concessions which are not involved in the observations (*i.e.* 38 in "Kologoudiessé" and 51 in "Barkoundba") for greywater collection. In each concession, samples were collected from laundry, dishwashing and showers. In addition, greywater samples were collected from ablutions in "Barkoundba".

1.2.3 Assessment of greywater quality

In situ measurements were made for pH, temperature and conductivity.

Escherichia coli, fecal coliforms and enterococci were used as indicator bacteria for microbiological pollution assessment. The spread plate method was used after an appropriate dilution of the samples in accordance with the procedure in Standard Methods for the Examination of Water and Wastewater (APHA, 1998). Chromocult Agar (Merck KGaA 64271, Darmstadt, Germany) was used as the culture medium for both *E. coli* and fecal coliform assessment whereas Slanetz and Bartley medium (Biokar Diagnostics, France) was used for enterococci assessment.

The physico-chemical characteristics were evaluated through assessment of chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD_5), total phosphorus (TP), ammonia nitrogen (NH_4), suspended solids (SS), calcium, magnesium, nitrate, sulphate, sodium and potassium. Suspended solids were determined by a gravimetric method using glass microfiber filters Whatman (porosity 1.5 µm). Calcium and magnesium were determined titrimetrically using a standard ethylenediamine tetraacetate (EDTA) technique. Nitrate, sulphate, sodium and potassium were evaluated using filtered samples. Sodium and potassium were measured by flame photometry whereas nitrate and sulphate were determined by spectrophotometry. All analyses were conducted according to Standard Methods (APHA, 1998).

The Sodium Adsorption Ratio (SAR) (Equation 1) was evaluated using the results from the Na, Ca and Mg measurements to determine the suitability of greywater for irrigation purposes.

$$SAR = \frac{Na^+}{\sqrt{\frac{Mg^{2+} + Ca^{2+}}{2}}} \quad (1)$$

where Na, Ca and Mg are expressed in milli-equivalents per litre (meq•L^{-1}) (ABU GHUNMI *et al.*, 2008; ALBERTA ENVIRONMENT, 2000).

2. RESULTS AND DISCUSSION

2.1 Quantitative assessment

2.1.1 Drinking water requirement and greywater production

In both villages, the drinking water is carried mainly by women and children on the head, bicycle or donkey cart using containers of 20 to 200 L, mainly from wells and boreholes.

The Total Water Supply (TWS) assessed in both villages is higher than the Total Water Consumption for human needs (TWC) which, in turn, is more than the Total Greywater Production (TGP) (Table 1; Figure 2). The drinking water collected and used for household activities in "Kologoudiessé" is higher than that collected in "Barkoundba". Indeed, the mean values of TWS ranged from 246 to 683 L•concession^{-1}•d^{-1} in "Kologoudiessé" and from 105 to 297 L•concession^{-1}•d^{-1} in "Barkoundba". The corresponding TWC ranged from 165 to 548 L•concession^{-1}•d^{-1} and from 80 to 197 L•concession^{-1}•d^{-1} whereas the TGP ranged from 67 to 344 L•concession^{-1}•d^{-1} and 70 to 147 L•concession^{-1}•d^{-1} (Table 1). These results show that the collected water is not used only for human needs. The difference between the TWS and TWC (Figure 2) can be explained by the fact that one part of the collected water is used for cooking local beer ("Kologoudiessé") or livestock watering ("Barkoundba"). In addition, the drinking water supplied to the households is stored in containers for the following days, while stocks last.

The water requirement and greywater production varied from concession to concession in both villages. Roughly, except for the TWS, when the concession size increases, the TWC and TGP increase (Table 1). Since greywater is generated from the households' activities, its production profile seems to be linked to the TWC profile more than the TWS. Indeed, previous results have reported that greywater production in a household is directly influenced by water consumption which is dependent on a number of factors including the existing water supply service and infrastructure, the number of household members, the age distribution, the lifestyle characteristics, the typical water usage patterns, etc. (CARDEN *et al.*, 2007; MOREL and DIENER, 2006). The TWC is higher than the TGP in both villages (Figure 2) because of differences in contributors. Indeed, in addition to the water required for activities producing greywater, the TWC includes water used for basic human physiological requirement to maintain adequate hydration (*i.e.* drinking water) and an additional requirement for food preparation (activities that do not generate greywater) (WHO, 2011).

In both villages, water collection and consumption as well as greywater production are subject to daily variation (Figure 2). This variation is also shown by the high standard deviation in Table 1. It can be explained by the variation of the household activities during the week. Furthermore, the results show that the weekend is not a period of intense greywater production in

Table 1. Mean values [litres per concession per day (L•concession^{-1}•d^{-1})] of water supplied, water used for human needs and greywater generated at the concessions level in rural areas in Burkina Faso.

Tableau 1. Valeurs moyennes [litres par concession par jour (L•concession^{-1}•j^{-1})] de l'eau fournie, de l'eau utilisée pour les besoins de l'homme et des eaux grises générées au niveau des concessions en zones rurales au Burkina Faso.

Rural settlement	Size of concession	Total water supply (L•concession^{-1}•d^{-1})	Total water consumption for human needs (L•concession^{-1}•d^{-1})	Total greywater production (L•concession^{-1}•d^{-1})
Kologoudiessé	8	330 (363)	165 (43)	67 (32)
	9	251 (104)	227 (96)	99 (23)
	9	246 (51)	241 (30)	144 (28)
	14	301 (80)	299 (80)	194 (39)
	23	683 (224)	548 (190)	344 (83)
Barkoundba	8	152 (18)	100 (15)	73 (5)
	10	105 (28)	80 (33)	70 (22)
	10	144 (45)	121 (40)	89 (17)
	15	297 (70)	188 (69)	129 (45)
	24	291 (136)	197 (138)	147 (37)

() = standard deviation; Data collected during 35 days in each village at the rate of one week per concession; size of concession = number of persons in the concession

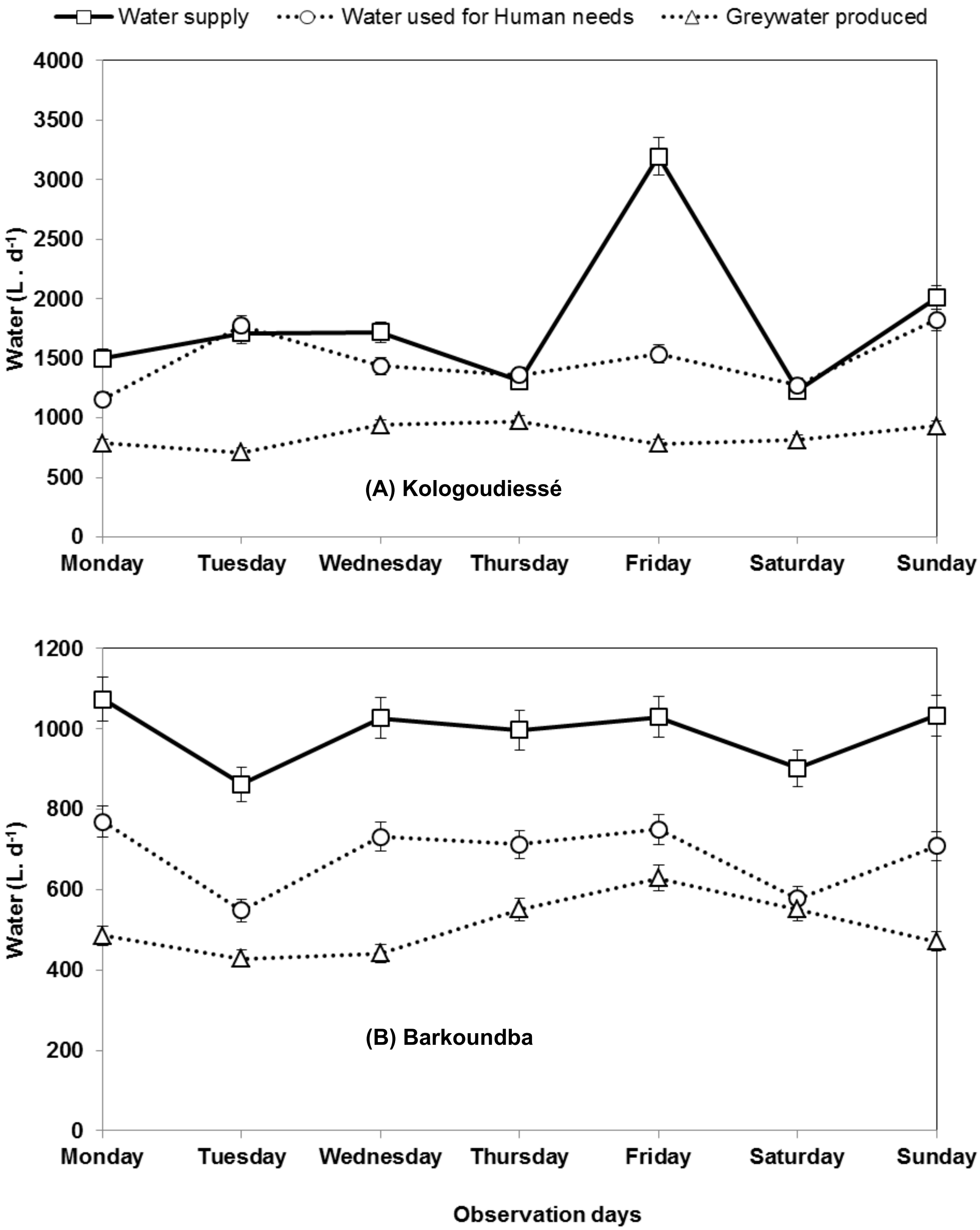

Figure 2. Profile of the total daily amount of water supply, water consumption and greywater production registered in five concessions during a week of observation in the study rural areas: (A = Kologoudiessé; (B) = Barkoundba.
Profil des quantités quotidiennes totales d'approvisionnement en eau, de consommation d'eau et de production d'eaux grises récoltées dans cinq concessions au cours d'une semaine d'observation dans les zones rurales étudiées: (A) = Kologoudiessé; (B) = Barkoundba.

rural areas as the highest quantities of greywater were produced in the middle of the week in both villages (Figure 2).

The average quantity of greywater produced per concession varies from 67 to 344 L•d^{-1} and from 70 to 147 L•d^{-1} in "Kologoudiessé" and "Barkoundba" respectively (Table 1). This greywater is generated from three main sources in "Kologoudiessé" (shower, laundry and dishwashing) and four main sources (shower, laundry, dishwashing and ablution) in "Barkoundba" (Table 2). The quantity of greywater generated is influenced by the concession size. Indeed, in both villages, the highest quantities of greywater are generated in the concessions

Table 2. **Mean values [Litres per capita per day (L•capita^{-1}•d^{-1})] of water supply, water consumption for human needs and greywater production and sources in rural areas in Burkina Faso.**

Tableau 2. ***Valeurs moyennes [litres par habitant par jour (L•habitant^{-1}•j^{-1})] de l'approvisionnement en eau, de la consommation d'eau pour les besoins de l'homme ainsi que la production d'eaux grises et les sources en zones rurales au Burkina Faso.***

Rural settlement	Kologoudiessé	Barkoundba
Total water supply (TWS) (L•capita^{-1}•d^{-1})	30 (7)	15 (4)
Total water consumption (TWC) for human needs (L•capita^{-1}•d^{-1})	24 (3)	11 (2)
Total greywater production (L•capita^{-1}•d^{-1})	13 (3)	8 (1)
Greywater contribution to the TWC in a given concession (%)	54 (11)	76 (7)
Greywater sources identified	Dishwashing Laundry Shower	Dishwashing Laundry Shower Ablution

() = standard deviation; TWC = Total Water Consumption for human needs; Total Water Supply (TWS); Data collected during 35 days in each village at the rate of one week per concession.

with the highest size. Moreover, these quantities decrease with the concession size (Table 1). The reported results indicate that the quantity of greywater generated could be reused for small garden watering. Since these greywaters are generated in batch-wise production, a storage tank is necessary to meet the volume and timing of vegetable watering in Burkina Faso estimated to be 8 L•m^{-2}•d^{-1} (WETHE *et al.*, 2001). Considering the needs for vegetable watering (8 L•m^{-2}•d^{-1}), the size of vegetable garden per concession varies approximately from 10 to 43 m^2. These small gardens could generate substantial income of 2,000 to 8,600 FCFA per culture if one considers estimates conducted in Niamey (Niger) in 2002, where a farmland of 4,200 m² generated about 850,000 FCFA (ABDOU, 2002). These rates should be revised upwards if one takes into account the global rise in food prices, particularly in the Sahel region (OXFAM ET SAVE THE CHILDREN, 2008). In addition, these vegetables could also be used for direct household consumption.

Since drinking water requirements and greywater production are influenced by the concession size, these parameters are analyzed on the basis of the number of persons in the concession (Table 2). The results show that the *per capita* drinking water requirements and greywater generated are higher in "Kologoudiessé" than in "Barkoundba". Indeed, the *per capita* drinking water supply and consumption were two times higher in "Kologoudiessé" (30 and 24 L•capita^{-1}•d^{-1}) than "Barkoundba" (15 and 11 L•capita^{-1}•d^{-1}). Previous studies reported that water consumption in low-income areas with water scarcity and rudimentary forms of water supply varies from 20 to 30 L•capita^{-1}•d^{-1}, whereas a household member in a richer area with piped water may generate several hundred litres per day (MOREL and DIENER, 2006). In France, for example, water consumption is estimated to be 150 L•capita^{-1}•d^{-1} (MONTGINOUL, 2002). Based on WHO guidelines for drinking water and the *per capita* TWC reported in Table 2, the service level in "Kologoudiessé" and "Barkoundba" is classified under "basic access" with approximately 20 L•capita^{-1}•d^{-1} (WHO, 2011). The daily *per capita* consumption of drinking-water is approximately 2 litres for adults, but it varies according to climate, activity level and diet. It is assumed that a minimum volume of 7.5 litres *per capita* will provide sufficient water for hydration and incorporation into food for most people under most conditions (WHO, 2011). This requirement could rise under the severe climatic conditions in both villages during the study (dry season), which could explain the differences between TWC and TGP.

The great difference between villages related to the *per capita* TWS and TWC is considerably reduced when dealing with greywater. Indeed, the quantity of greywater generated is estimated to 13 L•capita^{-1}•d^{-1} in "Kologoudiessé" and 8 L•capita^{-1}•d^{-1} in "Barkoundba". Moreover, statistical analysis (t test at $\alpha = 0.05$) showed that the *per capita* TWS, TWC and TGP estimated in the "Mossi" village ("Kologoudiessé") are significantly higher than those estimated in the "Peul" village ("Barkoundba"). These differences may find an explanation in the habits of the two ethnic groups. Unlike "Kologoudiessé", the inhabitants of "Barkoundba" are Muslims and activities such as cooking local beer are not carried out. In addition, in the "Peul" village, because of food habits and the availability of milk, kitchen activities are reduced.

2.1.2 Greywater contribution and contributors in rural area

The greywater contribution to the total water consumption is estimated to 54% in "Kologoudiessé" and 76% in

"Barkoundba" (Table 2). A contribution of 64% has been reported in rural areas in Jordan (ABU GHUNMI *et al.*, 2008). Figure 3 shows that shower, laundry and dishwashing contributions to greywater production ranged from 11% to 70% in "Kologoudiessé" and from 11% to 56% in "Bakoundba". In both rural settlements, shower activity is the main greywater contributor. Indeed, the bathroom contributed up to 56% and 70% of the total greywater produced in "Barkoundba" and "Kologoudiessé" respectively (Figure 3). The shower greywater is directly discharged onto the ground outside the concessions, causing smelly stagnant water. Laundry activity (contribution of 11%) is the minimum greywater contributor in "Kologoudiessé" whereas the minimum contributor in "Barkoundba" is ablution activity with the same ratio (11%). Shower activity is characterized by low daily frequency and high water volume consumption per use in contrast to ablution and dishwashing which were characterized by a high daily frequency use and low volumetric water consumption per use. MOREL

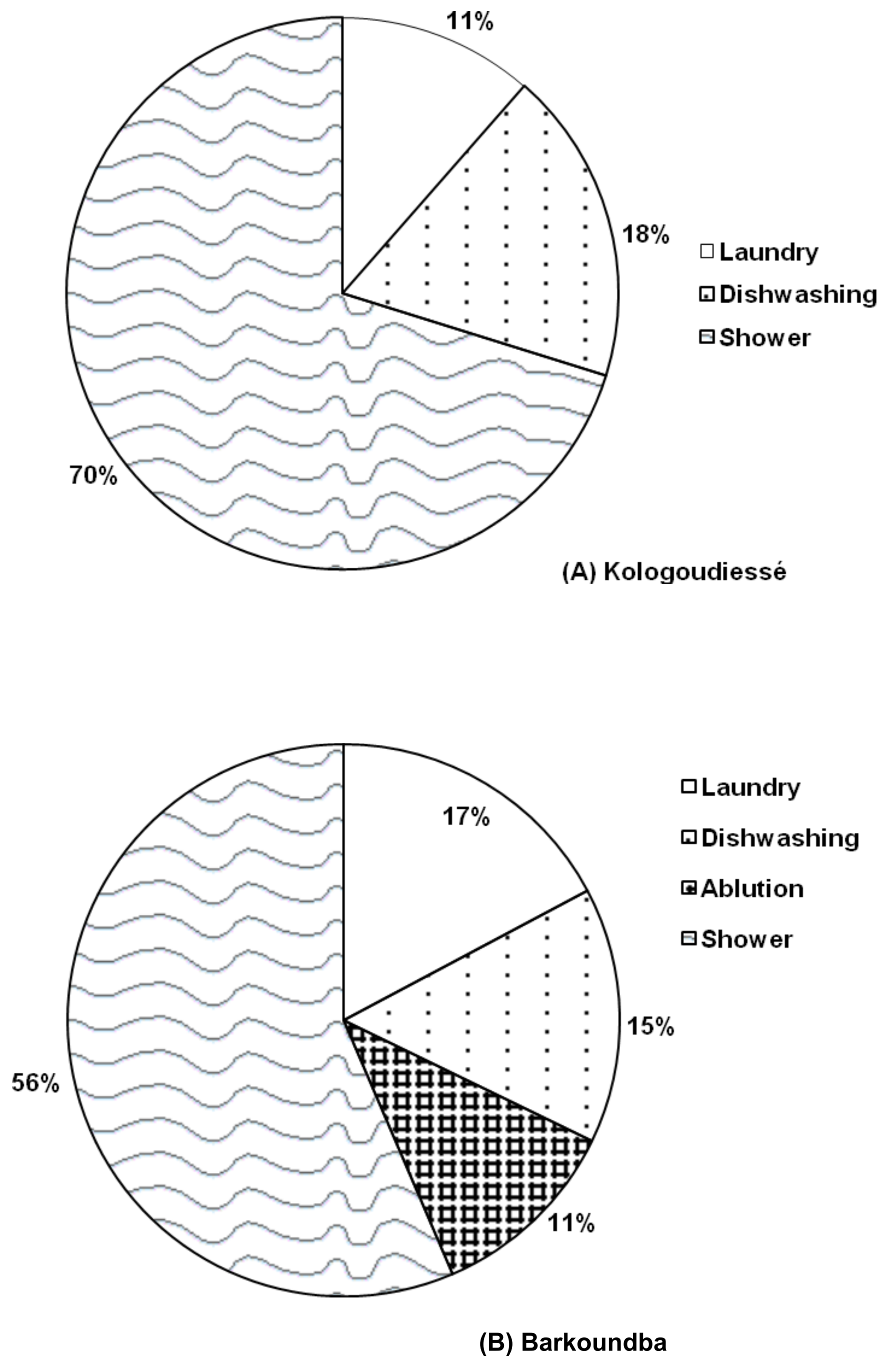

Figure 3. Greywater sources and their respective contributions in the study rural areas.
Sources d'eaux grises et leurs contributions respectives dans les zones rurales étudiées.

and DIENER (2006) reported that bathroom contributes up to 60% of the total greywater produced and that kitchen greywater represents generally the smallest fraction. Further, it has been reported that washbasin and shower activities were the main greywater contributors in urban areas whereas kitchen and laundry activities were the main greywater contributors in rural areas (ABU GHUNMI *et al.*, 2008).

2.2 Qualitative assessment and reuse potential

2.2.1 Physico-chemical parameters

The mean values of the physico-chemical parameters of the main greywater sources are presented in Tables 3 and 4.

The mean values of the temperature are above 30°C regardless of the greywater source. MOREL and DIENER (2006) reported that the temperatures of greywater samples generally vary from 18°C to 30°C. The results reported in this study could be explained by the high temperature of the water used to perform the activities. Indeed the samples were collected during daytime. The temperature is a very important environmental parameter since bacterial growth is influenced by its values. For example, in wastewaters in tropical and subtropical regions, most bacteria grow well at temperatures between 15 and 40°C (MARA, 2004).

The pH is also an important environmental parameter. Most bacteria prefer neutral or slightly alkaline conditions, around 6.5 to 8.5 (MARA, 2004). The normal pH range for irrigation water is 6.5 to 8 (WHO, 2006). All greywater sources exhibited alkaline conditions except that collected from ablution (Tables 3 and 4), due to the products used to perform these activities. Indeed, the ablution is performed with water without any product, whereas other activities are carried out using soaps and detergents such as "OMO" and "KLIN", which show an alkaline pH when diluted in water (OJO and OSO, 2008). Since greywater collected from ablution activity is generated from body washing without any use of soap or detergent, it exhibited neutral conditions. The dishwashing activity exhibited the highest mean pH with an average of 9 in "Kologoudiessé". This finding is explained by the use of potassium hydroxide for cooking in "Kologoudiessé" contrary to "Barkoundba" where milk is the most popular food.

Laundry greywater exhibited high COD and BOD_5 followed by dishwashing, showers and finally ablution (Tables 3 and 4). This finding is in accordance with the reported results. Indeed, maximal values of 300 mg•L^{-1} for BOD_5 and 633 mg•L^{-1} for COD have been reported for shower greywater whereas maximal values of 1460 mg•L^{-1} and 2050 mg•L^{-1} respectively were reported for kitchen greywater (LI *et al.*, 2009). Laundry greywater contains non-biodegradable fibres from clothing as

Table 3. **Mean* values of physico-chemical parameters of greywater collected from the three main sources in Kologoudiessé.**
Tableau 3. ***Valeurs moyennes des paramètres physico-chimiques des eaux grises collectées à partir des trois sources principales à Kologoudiessé.***

Greywater Source	pH	T°C	EC µS•cm^{-1}	SS mg•L^{-1}	BOD_5 mg•L^{-1}	COD mg•L^{-1}	NO_3 mg•L^{-1}	NH_4 mg•L^{-1}	TP mg•L^{-1}	SO_4 mg•L^{-1}	Na mg•L^{-1}	K mg•L^{-1}	Ca mg•L^{-1}	Mg mg•L^{-1}	SAR
Shower	8.0 (0.7)	33.0 (1.3)	868 (274)	1093 (720)	533 (429)	1240 (966)	13.4 (11.6)	22.6 (8.6)	8.8 (4.8)	73.0 (115)	290 (128)	87.5 (68)	3.0 (1)	6.6 (3.5)	16.4 (9.2)
Dishwashing	9.0 (0.7)	32.8 (1.3)	616 (169)	1533 (1080)	886 (402)	3410 (2070)	13.4 (10.5)	26.0 (62.6)	10.9 (4.8)	112 (180)	253 (151)	34.8 (25)	2.4 (1.4)	4.7 (2.2)	18.2 (14.0)
Laundry	8.8 (1)	31.9 (1.9)	578 (553)	3060 (2370)	2743 (1340)	6497 (2600)	46.4 (40.5)	57.6 (50.5)	27.8 (18.9)	171 (90)	448 (212)	227 (102)	4.0 (4.2)	7.9 (6.9)	26.9 (13.8)

EC = Electrical conductivity; T°C = Temperature; SS = Suspended Solids; BOD_5= 5-days Biological Oxygen Demand; COD = Chemical Oxygen Demand; SAR = Sodium Adsorption Ratio; TP = Total Phosphorus; () = standard deviation; * = for the different greywater sources, the mean values were estimated from data collected one time in 10 different concessions.

Table 4. **Mean* values of physico-chemical parameters of greywater collected from the four main sources in Barkoundba.**
Tableau 4. ***Valeurs moyennes des paramètres physico-chimiques des eaux grises collectées à partir des quatre sources principales à Barkoundba.***

Greywater Source	pH	T°C	EC $\mu S \bullet cm^{-1}$	SS $mg \bullet L^{-1}$	BOD_5 $mg \bullet L^{-1}$	COD $mg \bullet L^{-1}$	NO_3 $mg \bullet L^{-1}$	NH_4 $mg \bullet L^{-1}$	TP $mg \bullet L^{-1}$	SO_4 $mg \bullet L^{-1}$	Na $mg \bullet L^{-1}$	K $mg \bullet L^{-1}$	Ca $mg \bullet L^{-1}$	Mg $mg \bullet L^{-1}$	SAR
Shower	8.0 (0.5)	31.0 (2.8)	857 (194)	1160 (359)	848 (147)	1800 (813)	25.3 (11)	7.7 (6)	11.3 (7.2)	20.8 (18.4)	212 (69)	701 (1090)	34.5 (10)	19.0 (11.3)	5.3 (2.3)
Dishwashing	8.0 (1.4)	30.3 (1.8)	970 (314)	2280 (1010)	1330 (468)	4080 (992)	10.8 (5.8)	4.0 (2.3)	16.9 (8.2)	24.0 (31.9)	222 (111)	297 (124)	26.4 (10)	17.0 (4.7)	5.8 (2.6)
Laundry	8.5 (0.6)	31.7 (3)	2730 (1970)	2560 (831)	1300 (817)	6300 (3530)	49.0 (28.6)	12.7 (6.5)	22.7 (11.2)	61.1 (40.9)	459 (224)	983 (656)	24.8 (8.8)	15.6 (8.2)	12.3 (6.0)
Ablution	7.5 (0.3)	31.0 (3.8)	535 (111)	479 (192)	211 (136)	506 (166)	13.5 (4.2)	7.4 (7.8)	8.6 (7)	10.6 (10.4)	95.6 (23.7)	252 (192)	42.5 (12.6)	17 (5.7)	2.2 (0.5)

EC = Electrical conductivity; T°C = Temperature; SS = Suspended Solids; BOD_5= 5-days Biological Oxygen Demand; COD = Chemical Oxygen Demand; SAR = Sodium Adsorption Ratio; TP = Total Phosphorus; () = standard deviation; * = for the different greywater sources, the mean values were estimated from data collected one time in 10 different concessions.

suggested by MOREL and DIENER (2006) that can explain the higher COD values. The COD/BOD ratio of the greywater collected in "Barkoundba" ranged from 2.31 to 13.46, 1.67 to 5.46, and 1.31 to 3.31 for laundry, dishwashing and shower greywater respectively. In "Kologoudiessé", the same ratio ranged from 1.24 to 6.4 for laundry greywater, 1.12 to 6.18 for dishwashing greywater and 1.12 to 5.44 for shower greywater. As reported previously in low and middle income countries (MOREL and DIENER, 2006), greywater data indicate maximum COD/BOD ratios in laundry and dishwashing greywater. These ratios indicate that some of the effluents are barely biodegradable (TRUC, 2007) and confirm that laundry greywater can have more non-biodegradable elements. The high ratio (>4) is attributed to the fact that biodegradability of greywater depends primarily on synthetic surfactants used in detergents. Indeed, in low and middle-income countries, non-biodegradable surfactants are still used (in powdered laundry detergent) whereas Western countries have banned and replaced non-biodegradable by biodegradable detergents (MOREL and DIENER, 2006).

In both villages, laundry greywater exhibited the highest ammonia, nitrate, phosphorus and potassium contents (Tables 3 and 4). Regarding the NO_3 and NH_4 mean values reported in Tables 3 and 4, the corresponding $NO_{3-}N$ values ranged from 3 to 10.5 $mg \bullet L^{-1}$ $NO_{3-}N$ and 2.4 to 11 $mg \bullet L^{-1}$ $NO_{3-}N$ whereas the corresponding $NH_{4-}N$ values ranged from 20 to 44.7 $mg \bullet L^{-1}$ $NH_{4-}N$ and 3.1 to 9.8 $mg \bullet L^{-1}$ $NH_{4-}N$ in "Kologoudiessé" and "Barkoundba" respectively. Excessive nitrogen may delay maturity and reduce crop quality and quantity. Indeed AYERS and WESTCOT (1985) have reported that severe problems are expected with nitrogen sensitive crops (sugar beets, grapes) at more than 30 $mg \bullet L^{-1}$ N. For crops not sensitive, more than 30 $mg \bullet L^{-1}$ nitrogen may be adequate for high crop production or little or no fertilizer nitrogen may be needed.

Nitrogen, phosphorus and potassium are essential plant nutrients and in general have positive effects on plant growth unless excessively applied. According to the U.S. EPA, the most beneficial nutrient for plant growth is nitrogen (U.S. EPA, 2004). But excessive nitrogen may delay maturity and reduce crop quality and quantity. Greywater rich in nitrate can have a negative impact as nitrate is highly soluble and can move easily in soils irrigated with wastewater (IWMI and IDRC, 2010). Since the final objective is to reuse the greywater for irrigation purposes, the nitrogen, phosphorus and potassium contents in the greywater can be drastically reduced by plant uptake. Washing detergents are the primary source of phosphates found in greywater in countries that have not yet banned phosphorus-containing detergents (ERIKSSON *et al.*, 2002) like Burkina Faso.

2.2.2 Suspended solids, salinity, sodium, calcium and magnesium hazards

Except for ablution greywater, the SS content is high for all greywater sources regardless of the rural settlement (Tables 3 and 4). A previous study reported that the SS content of greywater ranged from 50 to 300 mg•L^{-1} but sometimes can reach values as high as 1500 mg•L^{-1} (DEL PORTO and STEINFELD, 1999). The high values reported in Tables 3 and 4 could be explained by the way the water is used to perform the activities. For example, for laundry activity, the same water is used to wash many clothes until saturated, allowing SS to accumulate.

The mean values of the electrical conductivity (EC) ranged from 535 µS•cm^{-1} (ablution) to 2730 µS•cm^{-1} (laundry) (Tables 3 and 4). A much higher value of 4540 µS•cm^{-1} has been reported in laundry greywater in Jordan (ABU GHUNMI *et al.*, 2008). The mode, the dose and frequency of irrigation have a direct influence on the process of soil salinization. Subsurface irrigation system increases the EC of the soil surface horizons whereas surface irrigation allows better leaching of the salts to the bottom layer (HEIDARPOUR *et al.* 2007). Further, SUAREZ *et al.* (2006) have reported that EC values varying from 1000 to 2000 µS•cm^{-1} do not affect infiltration of loam and clay soils. Permissible EC limits of greywater reuse for irrigation are strongly dependent on soil characteristics and the suggested limits differ in the literature reviewed (MOREL and DIENER, 2006). According to GRATTAN (2002), EC below 1300 µS•cm^{-1} should normally not cause problems whereas irrigation with more saline greywater (EC exceeding 1300 µS•cm^{-1}) requires special precautions (use of salt-tolerant plants). According to WHO guidelines, the recommended maximum value for greywater reuse in irrigation is 3000 µS•cm^{-1} (WHO, 2006). High EC in irrigated water can interfere with extraction of water by plants as it can result in an increase in osmotic potential in the soil solution (IWMI and IDRC, 2010). Salinity dominated by sodium salts not only reduces calcium availability but reduces calcium transport and mobility to growing regions of the plant, which affects the quality of both vegetative and reproductive organs. Salinity can directly affect nutrient (potassium and nitrate) uptake (GRATTAN and GRIEVE, 1999). However, other studies have shown a positive correlation between salinity and sodicity (BELAID, 2010; SAIDI *et al.*, 2004). Indeed, water with high SAR values has no effect on the structure of the irrigated soil when the corresponding EC is high, since EC and Exchangeable Sodium Percentage (ESP) have antagonistic effects related to the structural stability of the soil (PESCOD, 1992). Therefore, the effects of the high EC values reported in this study could be moderated and have to be considered with regard to the SAR values.

The SAR values estimated from the greywater produced in "Kologoudiessé" are higher than those determined from the greywater generated in "Barkoundba" (Tables 3 and 4). Laundry greywater exhibited the highest SAR values regardless of the rural settlement. Indeed, in "Barkoundba", a mean highest ratio of 12.3 is registered in laundry greywater whereas a mean lowest value of 2.2 is estimated from ablution greywater. In "Kologoudiessé", the highest value (26.9) is derived from laundry greywater. Except for ablution greywater, the reported SAR values are higher than those reported by SOU (2009) in Burkina Faso, where the treated wastewater used for irrigation showed SAR values ranging from 0.31 and 2.61 and the surface water, SAR values of 0.02 to 0.24. SAR values varying from 10 to 12 have been reported for irrigation wastewater in Tunisia (BELAID, 2010). An average SAR value of 4.8 has been reported for greywater used for irrigation in Israel (GROSS *et al.*, 2005). The same authors reported that a long-term irrigation using water with a SAR higher than 4 can negatively alter the soil properties.

The expected effect of the SAR values reported in Tables 3 and 4 could be lowered because other parameters of the greywater and the chemical content of the receiving soil have to be considered. Indeed, for a given SAR value, the adverse impacts on soil physical properties are reduced with the increasing salinity (SUAREZ *et al.*, 2006). BELAID (2010) has reported that water with high SAR values has no effect on the structure of the irrigated soil when the corresponding EC is high. Furthermore, when a receiving soil which is saturated with calcium anions has a low CEC, it facilitates percolation, reducing the effect of SAR.

The results reported in Tables 3 and 4 show that high concentrations of sodium are found in the laundry greywater with mean values of 448 mg•L^{-1} and 459 mg•L^{-1} respectively in "Kologoudiessé" and "Barkoundba". BELAID (2010) reported that sodium is responsible for salinization of soil irrigated with wastewater. A high sodium ion concentration in water affects soil permeability and causes infiltration problems (SUAREZ *et al.*, 2006). The adverse effect of sodium on soil depends on the SAR values of the water and the composition of the irrigated soil. Indeed, SUAREZ *et al.* (2006) examined water infiltration into loam and clay soils irrigated with water at EC = 1000 and 2000 µS•cm^{-1} and SAR of 2, 4, 6, 8 and 10 and concluded that the adverse impacts of sodium on infiltration were evident above SAR 2 for loam soils whereas for clay soils, adverse impacts occurred above SAR 4. Therefore the presumptive sodium effect of the raw greywater should vary depending on the soil type.

Calcium and Mg ions may be associated with soil aggregation and friability, and at high concentration in irrigation water, they can increase soil pH, resulting in a reduction of the availability of phosphorus (AL-SHAMMIRI *et al.*, 2005). For a semi-arid region with high evaporation, it has been reported that water containing concentrations of Ca and Mg higher than 200 mg•L^{-1} cannot be used in agriculture

(KHODAPANAH *et al.*, 2009). The results reported (Tables 3 and 4) show that all the greywater samples do not exceed this value. It is important, however, to take into account the cation exchange capacity (CEC) of the receiving soil. Indeed, BELAID (2010) has reported that, in a soil with good permeability and low CEC, wastewater components (K, Mg, Na) are leached with drainage water. In addition, high natural concentrations of Ca in the farm soil reduce the SAR and minimize potential negative harm to the plants (GROSS *et al.*, 2005).

2.2.3 Microbial aspects

The danger from pathogens in greywater results from direct contact, inhalation of aerosols and consumption of contaminated vegetables when greywater is used for irrigation (WHO, 2006). The microbiological quality of the greywater collected from ten concessions in both villages is presented in Table 5. The greywater produced is substantially contaminated with fecal indicators, regardless of the source. Previous results have reported substantial fecal contamination of greywater streams with fecal coliforms concentrations of 0 to 3.4×10^5 CFU•(100 mL)$^{-1}$ in Germany (LI *et al.*, 2009) and 1.5×10^8 CFU•(100 mL)$^{-1}$ in Costa Rica (DALLAS *et al.*, 2004). Since toilet waste is not included in greywater, fecal contamination is limited to activities such as washing fecally contaminated diapers, childcare, anal cleansing and showering (MOREL and DIENER, 2006; OTTOSSON, 2003; WHO, 2006).

The physico-chemical characteristics of the greywater can encourage the growth of bacteria. This is exacerbated by the relatively high temperature of the greywater sources. Indeed, the mean values of the temperature are above 30°C regardless of the greywater source. However, the pH values reported can have a negative effect on the bacteria since most bacteria prefer neutral or slightly alkaline conditions, around 6.5 to 8.5 (MARA, 2004). The nutrient content of the different greywater sources can have beneficial effects on bacteria since it has been reported that addition of nitrogen or phosphorus to real greywater resulted in stimulation of the biomass (JEFFERSON *et al.*, 2001).

The statistical analysis (t test at α = 0.05) of the microbiological data highlighted the following findings:

(i) All data collected in "Kologoudiessé" are compared to those collected in "Barkoundba". In terms of *E. coli* and fecal coliforms contents, there are no significant differences between all data collected in "Barkoundba" compared to those collected in "Kologoudiessé". However, enterococci content is significantly higher in "Kologoudiessé" than "Barkoundba".

(ii) Further, all data collected in both villages are grouped together on the basis of the greywater source and compared. When comparing the greywater sources using *E. coli* or enterococci as fecal indicators, it appeared that the greywater sources are not significantly different regardless of the rural settlement. However, when using fecal coliforms as indicator bacteria, it appeared that dishwashing greywater is significantly more polluted than shower and laundry greywater. This finding has been previously explained by the presence of large amounts of easily biodegradable organic substances in dishwashing greywater compared with the other streams (LI *et al.*, 2009). Fecal contamination in dishwashing greywater is due to contaminated vegetables and raw meat used during the cooking process (OTTOSSON, 2003).

Table 5. Microbiological characteristics of the greywater.
Tableau 5. Caractéristiques microbiologiques des eaux grises.

Rural settlement	Greywater sources	*E. coli* CFU•(100 mL)$^{-1}$	Fecal coliform CFU•(100 mL)$^{-1}$	Enterococci CFU•(100 mL)$^{-1}$
Kologoudiessé	Shower	10^3 - 2×10^6	1.4×10^4 - 4.4×10^7	2.3×10^4 - 2.2×10^7A
	Dishwashing	80 - 6.4×10^7	2.4×10^3 - 1.6×10^8	9.6×10^2 - 3×10^6A
	Laundry	10^2 - 9.1×10^5	3.1×10^3 - 9.5×10^6	6×10^2 - 3.5×10^6
Barkoundba	Shower	4.8×10^2 - 6.6×10^7	2.2×10^3 - 9.5×10^7	5.2×10^2 - 2.7×10^5B
	Dishwashing	1.3×10^2 - 2.3×10^7a	7.4×10^2 - 3×10^7a	2×10^2 - 2.7×10^5B
	Laundry	40 - 2.6×10^7	1.2×10^2 - 2.8×10^7	3.7×10^2 - 2.2×10^5
	Ablution	2×10^3 - 9×10^5b	2.2×10^4 - 1.7×10^7b	3.3×10^2 - 7.4×10^5

Data collected one time in 10 different concessions in each village.
For a given fecal indicator, values with different lower case letters are significantly different (unilateral *t-test* at α = 0.05).
When comparing the greywater produced in "Barkoundba" and "Kologoudiessé", for a given greywater source, the values with different upper case letters are significantly different.

(iii) When comparing the greywater collected in "Kologoudiessé" with that collected in "Barkoundba", it appeared that except for shower and dishwashing greywater, which have enterococci contents significantly higher in "Kologoudiessé" than in "Barkoundba", the other sources are not significantly different regardless of the fecal indicator (Table 5).

(iv) Furthermore, in each village, the greywater sources are compared. In "Kologoudiessé", there are no significant differences among the greywater sources (shower, dishwashing and laundry) in terms of fecal pollution, regardless of the fecal indicator. In "Barkoundba", dishwashing greywater is significantly more polluted than ablution greywater in terms of both *E. coli* and fecal coliform content (Table 5).

The maximum values of fecal indicators registered in the study site are 6.6 x 10^7 CFU•(100 mL)$^{-1}$, 1.6 x 10^8 CFU•(100 mL)$^{-1}$and 2.2 x 10^7 CFU•(100 mL)$^{-1}$ for *E. coli*, fecal coliforms and enterococci respectively (Table 5). Based on WHO guideline for greywater reuse for restricted (*E. coli* < 10^5 CFU•(100 mL)$^{-1}$) and non-restricted (*E. coli* < 10^3 CFU•(100 mL)$^{-1}$) agricultural irrigation (WHO, 2006), a substantial treatment would be necessary in the case of reuse in gardening. The treatment system should be able to remove bacteria by more than 2 log units and 4 log units if restricted and unrestricted agricultural irrigation are considered respectively.

2.3 Benefits and risk of greywater reuse in gardening in rural area

The estimated average greywater generation rates were 13 ± 3 L•capita^{-1}•d^{-1} and 8 ± 1 L•capita^{-1}•d^{-1} in "Kologoudiessé" and "Barkoundba" respectively (Table 2). These rates are low compared with average rates reported (30 ± 3.6 L•capita^{-1}•d^{-1}) in Jordan (AL-HAMAIEDEH and BINO, 2010). However, to provide additional water resources and avoid unpleasant disposal situations (smelly stagnant water) in the study area, the greywater produced can be collected and used for irrigation in home gardens. Considering the needs for vegetables watering (8 L•m^{-2}•d^{-1}) and the quantity generated per concession (67 - 344 L•concession^{-1}•d^{-1}), the size of the home garden may vary approximately from 10 to 43 m^2.

Although greywater reuse can mitigate the utilization of natural water resources, it may also result in environmental (increase of salinity and sodium content in soil) and health (diseases) issues (AL-HAMAIEDEH and BINO, 2010). The low water consumption in the study area is responsible for producing greywater characterized by high BOD_5, COD and SS values (Tables 3 and 4). GROSS *et al.* (2005) have reported that long-term irrigation of arid soil with greywater may result in the accumulation of salts and surfactants in the soil, causing changes in soil properties and toxicity to plants. High values of soil salinity and SAR may cause deterioration of soil structure, decreases in soil permeability and reductions of crop yields due to toxic and osmotic effects (HALLIWELL *et al.*, 2001). This aspect can be mitigated with soil leaching with drainage water (AL-HAMAIEDEH and BINO, 2010). Because of the arid conditions, a cleanup with rainwater could only be considered during rainy season. In addition, greywater reuse in agriculture may have negative impacts on the microbial communities of the receiving soil. Indeed, it has been reported that most bacteria prefer pH values from 6.5 to 8.5 (MARA, 2004). The pH values reported in Tables 3 and 4 are sometimes higher than 8.5. Furthermore, in the soil, ammonia is oxidized by bacteria to nitrite that can be toxic to plants, and to nitrate, which is not toxic. GROSS *et al.* (2005), using plots irrigated with greywater, reported that ammonia in greywater allows the development of nitrifying bacterial populations, leading to an accumulation of nitrite (an increase in nitrate was also noticed after eight days). Moreover, due to the high content of fecal indicators in both villages, the microbiological quality of the greywater does not fulfill the WHO reuse guidelines. Therefore, a treatment should be considered to mitigate the health and environmental issues.

A slanted soil treatment system could be investigated. It should be able to remove bacteria by more than 2 log units and 4 log units if restricted and unrestricted irrigation are considered respectively. However, further studies are necessary to assess the treated greywater quality and the physico-chemical characteristics of the receiving soils in the study area. The treatment by a slanted soil treatment system (SSTS) should lower the excess in nitrogen.

CONCLUSION

In the studied villages of "Barkoundba" and "Kologoudiessé", greywater is generated from three to four main sources with mean daily productions of 8 ± 1 L•capita^{-1}•d^{-1} and 13 ± 3 L•capita^{-1}•d^{-1} respectively. Despite these low rates, the average collected quantity is sufficient for irrigation in home gardens (the size varying from 10 to 43 m^2) to provide additional water and avoid unpleasant disposal situations.

However, the low water consumption and the products used are responsible for producing greywater characterized by high BOD_5, COD, SS, SAR and EC values. Using raw greywater for irrigation might cause environmental harm. Moreover, the greywater streams are characterized by high fecal indicator content, and hence pose public health risks. Therefore, treating greywater before its use for irrigation purposes is recommended.

Based on WHO reuse guidelines, the treatment system should be able to remove bacteria by more than 2 log units and 4 log units if restricted and unrestricted agricultural irrigation are considered respectively. In view of the basic objectives of a household or neighbourhood greywater management system, summarized by MOREL and DIENER (2006), the reported results and the end use of the effluents, a low cost treatment system using locally available materials should be investigated. A slanted soil treatment system (SSTS) could be a suitable option (USHIJIMA *et al.*, 2013). In order to meet the required amount for gardening, the SSTS should be adapted to collect and treat greywater from the three main sources, especially from shower (the major contributor: shower greywater is presently poured onto the ground outside of the concession). Gravel and sand filters could be investigated to find the suitable soil types and grain size. Because of the effect of treatment on the raw greywater, further studies are necessary to assess the opportunity of using the treated greywater in the study area as in other rural areas. In addition, since quantitative results were obtained from data collected during the dry season, further studies are necessary to estimate the annual variation.

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