zef
Center for
Development Research
University of Bonn

# Working Paper 163

Maksud Bekchanov

# Enabling Environment for Waste and Wastewater Recycling and Reuse Options in South Asia: the case of Sri Lanka

ISSN 1864-6638 Bonn, November 2017

ZEF Working Paper Series, ISSN 1864-6638
Center for Development Research, University of Bonn
Editors: Christian Borgemeister, Joachim von Braun, Manfred Denich, Till Stellmacher and Eva Youkhana

## Authors' address

Dr. Maksud Bekchanov
Center for Development Research (ZEF), University of Bonn,
Genscherallee 3
53113 Bonn, Germany
Tel. 0049 (0)228-73 1841: Fax 0228-731972
E-mail: mbekchan@uni-bonn.de
www.zef.de

# Enabling Environment for Waste and Wastewater Recycling and Reuse Options in South Asia: the case of Sri Lanka

Maksud Bekchanov

# Abstract

Mismanagement of waste and wastewater is a key reason behind the continuing environmental pollution and degrading livelihoods across the developing countries of South Asia such as Sri Lanka. Recovering nutrients and energy from waste and wastewater streams can not only address the challenging waste and wastewater management problems but also considerably substitute the imports of chemical fertilizers and fossil fuels. Considering these environmental and economic benefits of waste and wastewater recycling, this study aims at assessing investment climate for a broader implementation of recycling technologies such as composting, biogas generation, and electricity production through incineration process. For this purpose, a wide range of methods were implemented including a detailed review of scientific literature, laws and reports by governmental agencies, as well as key informant interviews and focus group discussions. For assessing technical potential of recovering nutrients from waste streams a simulation model was applied. As results indicated, since waste generation and thus potential for nutrient recovery is high in urban areas, while demand for recovered nutrients is much higher in rural areas, interregional trade of the recovered nutrients would considerably contribute to reducing the shortage of fertilizers, improving food security, and increasing export incomes in Sri Lanka. Recovering nutrients from recycling only half of total organic waste and wastewater may allow for meeting agricultural demands for phosphorus and potassium, and supply 75% of nitrogen requirements at the national level. The government would need to be the main facilitator of the change through improving the accounting and planning in the system, establishing effective institutional and regulatory frameworks, providing financial incentives for the implementation of the recycling technologies, and supporting educational programs for raising the environmental consciousness.

Keywords: Resources recovery and reuse (RRR), composting, biogas generation, incineration, fertilizer demand

JEL codes: Q42, Q53, Q55

# Acknowledgements

This study is financially supported by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) through the “Research and capacity building for inter-sectorial private sector involvement for soil rehabilitation project (CB4SoilReha)” led by International Water Management Institute (IWMI). The author is very thankful for Sudarshana Fernando, Miriam Otoo, Pay Drechsel, Mohamed Aheeyar, Herath Manthrithilake and numerous other people from IWMI for research and logistical support during the field research conducted in August and September in 2017. Special thanks go to Ben Basnayake (Uni-Peradeniya), Ajith de Alwis (Uni-Moratuwa), Wimala Wimaladasa (the Central Environmental Authority), Tuan Areefen (Biogas Lanka), Sunil Samarakoon (Jetwing Blue Hotel), Wasanthi Wickramasinghe (Marga Institute), and Aruna Hewage (HARTI) for their invaluable support for collecting information on waste and wastewater management and recycling system in Sri Lanka. The author is very grateful to Professor Joachim von Braun (ZEF) and Alisher Mirzabaev (ZEF) for a review and constructive comments.

# Introduction

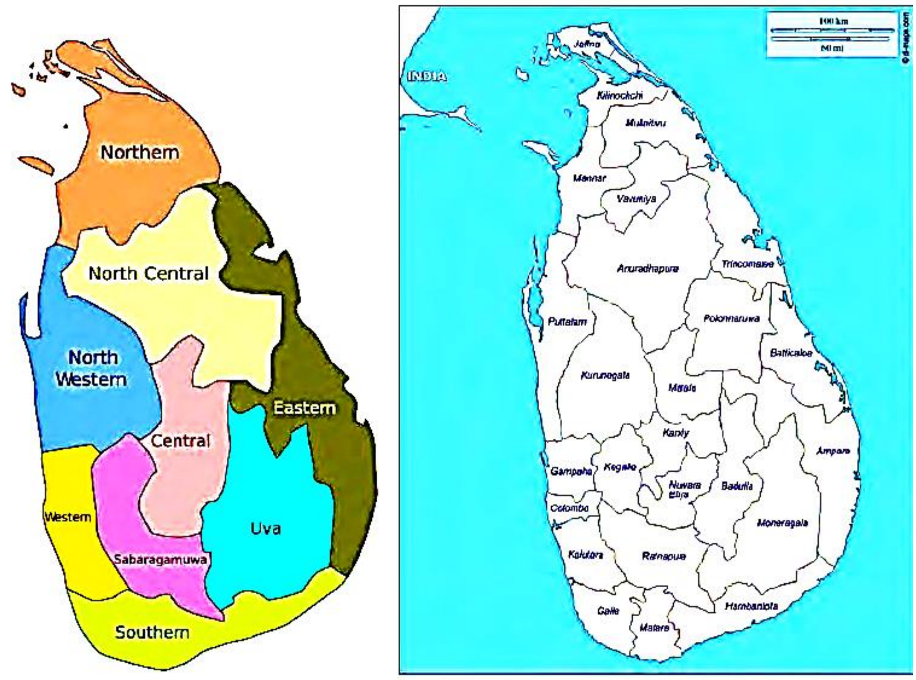
Waste and wastewater mismanagement are among major threats to environmental security across the developing countries, especially in South Asia (Visvanathan and Glawe, 2006; UN-HABITAT, 2010; WWAF, 2017). Poor understanding of the interlinkages between environment and economic systems may result in inefficient use of resources, generation of vast amounts of waste, and the consequent irreversible ecological damages. Recognizing these threats in advance, the implementation of the concepts of sustainable economy through the transformations towards a circular economy is gaining prominence across the world (Geissdoerfer et al. 2017). According to this concept, waste and wastewater can be perceived as an asset which can be recycled and recovered for further reuse in the production system. For instance, wastewater can be treated for augmenting water supply for irrigating croplands and landscapes (Bekchanov 2017). The sediments from wastewater treatment and slurry from anaerobic digestion can be used for reclaiming soils and improving crop productivity (Cordell et al. 2009). Advanced incineration and aerobic digestion technologies can be implemented for producing energy from organic waste and wastewater (Bekchanov 2017). In addition to multiple economic benefits through recovering energy and nutrients from waste, the recycling technologies would also largely contribute to the mitigation of environmental pollution. Given the lower emission of hazardous gases due to the reduced disposal of organic waste into open dumping sites, the companies engaged in waste and wastewater treatment may also apply for Certified Emission Reduction units (CERs) through the Clean Development Mechanism (CDM).

This study focuses on the case of Sri Lanka where inappropriate treatment of waste and wastewater has increased disease risks, leading to environmental pollution, biodiversity loss, and, consequently, threatening long-run socio-economic security (UNEP 2001). The environmental pollution problems are especially crucial in heavily populated and industrialized municipal areas of the country such as Colombo and Kandy because of the lack of facilities for appropriate treatment or safe disposal of waste and wastewater (Bandara 2003). Due to the lack of proper wastewater disposal system, almost 90% of heavily polluted wastewater joins fresh water streams further exacerbating the environmental and human health risks (Vandeweerd et al. 1997, Sudasinghe et al. 2011). Similarly, uncontrolled dumping of municipal and household waste along the roads, waterways, and natural sites degrade living conditions, spread pollution and diseases, increase flooding risks and contaminate potable water sources. Lack of technologies, technical skills and financial capability impedes wider implementation of waste recycling technologies throughout the country. In the example of Sri Lanka, this study discusses main problems of waste and wastewater mismanagement, options of recovering useful assets from waste streams, and barriers and opportunities (enabling environment) for wider implementation of Resource Recovery and Reuse (RRR) technologies.

# Geographical and socio-economic conditions in Sri Lanka

Sri Lanka is an island country located in the Indian Ocean (Fig. 1). The population of the country is about 21 million (as of 2015). Capital of the country, Colombo, located in the Western part is an industrialized port city with rapid economic development. The access of the country to the major trading sea routes play a key role in the integration of the country to global economic system. Current renovations and new constructions of an international harbor, sky-scrapers, highways and bridges aim at turning Colombo into a Megapolis with modern infrastructure and technological facilities in recent future. The expansion and modernization of the capital may also enhance economic growth country-wide. However, waste and wastewater management issues can be exacerbated in parallel with the modernization unless a proper attention is paid to the preparation of the professionals in this field and allocation of adequate financial resources for the implementation of RRR technologies.

Figure 1: Location, and administrative provinces and districts of Sri Lanka




Source: JICA (2013)

Kandy (in the Center) and Galle (in the South) are other two big cities with considerable potential for agro-processing and touristic industry. In contrast to modernization and development in the major urban areas, rural lifestyle is dominant in vast areas of the country. Despite the small size of the country, its landscape is also very diverse comprising rainforests, grasslands, lagoons, rivers, tropical coastal areas, marine ecosystems, dry zones, and mountains. Sudden change in the scene of landscapes and lifestyles from one end of the road towards the other provides the impression of time and space travel.

Sub-tropical climate in the country is characterized by hot temperature and high air humidity. Throughout a year, the temperature varies between 24-32 $^{0}$C in lowlands and between 18-27 $^{0}$C in mountainous zones. Average precipitation in the country is 1,674 mm per annum but the precipitation is very heterogeneous across the country and over time. Heavy rainfall (*monsoon*) occurs in the period between October to March (*maha* season) in northeast and between April to September (*yala* season) in southwest (Amarasinghe et al. 1999). The spatial and temporal variability in precipitation divides the country to wet and dry zones. The wet zone includes the south-western part of the country where annual precipitation is between 2,500 and 5,100 mm in contrast to annual precipitation of 1,100-1,600 mm in dry zone.

GDP per capita is about USD 4,000 (as of 2015). Given its favorable geographic location (access to the sea), and developed infrastructural facilities, the Western Province contributes more than 40% of national GDP (CBSL 2016). The agriculture was the main sector previously contributing more than 50% of GDP (as 1950s) but its share reduced to less than 10% at present (as of 2015). Nevertheless, majority of population lives in rural areas and 33% of economically active population (7.7 million) is engaged in the farming sector. Migration of workers from primary sectors into secondary and tertiary sectors may create labor shortage in agriculture (including organic farming), unless agricultural mechanization does not take place. Insufficient wages, lack of social security schemes, low social status accrued to the job also reduce labor availability for farming (Gamage et al. 2009).

The textiles and garments dominate in the exports, accounting for more than 40% of total exports despite the fact that cotton, a main input for the production of textiles, is largely imported to the country from India and China (CBSL 2016). Tea which is commonly perceived as a main component of the national exports contributes to 13-17% of total exports. Agricultural commodities producible in tropical areas such as rubber and coconut account for an inconsiderable share of total exports. Recycling organic wastes for producing compost perhaps may positively effect on the production and exports of tea, rubber, and coconuts.

Investment goods account for 20-24% of total imports (CBSL 2016). In contrast, since paddy production is strongly supported to maintain national food self-sufficiency and receives enormous amounts of subsidies for fertilizer, rice imports are not considerable. Fuel is fully imported and account for more than 14% of total imports (as of 2015) despite its declining share over time. Following the decreased trend of solar power panel prices (from China), the wider adoption of waste-to-energy recovery technologies, and increased use of hybrid cars (from Japan), the share of fuel exports is expected to decrease even further. Fertilizer is largely imported (from China) rather than produced domestically. Increased use of compost through recycling organic waste may reduce demand for importing chemical fertilizers.

As a main potential consumer of compost from organic waste and supplier of animal dung, the magnitude, structure and locations of the agricultural production are of particular interest for analyzing the feasibility of waste and wastewater recycling. Currently, Sri Lanka owns more than 2 million ha croplands, of which more than 50% is used for the cultivation of food crops such as paddy rice (CBSL 2016). Cultivation of plantation crops such as tea, rubber and coconut accounts for more than 35% of total croplands. About 38% (744.1 thousands) of the croplands are irrigated across the country (Amarasinghe 2012). 91% of these irrigated lands are located in the dry-zone. Paddy rice is the most common crop and are cultivated in more than 90% of the irrigated lands. Thus, the dry-zone districts account for 80% of paddy rice production. Plantation crops such as tea, rubber and coconut are cultivated in rainfed areas.

Livestock sector is essential source of organic fertilizer and information on the scope, type and locations of livestock farming allows for assessing the potential capacities of compost production across the country. Livestock rearing, especially fishery, is one of the key agricultural production activities in Sri Lanka. Although meat (beef) consumption is low in Sri Lanka because of low income levels and cultural reasons, consumption of fish, chicken meat, and eggs is common in daily diet. Due to the slaughter ban that prevented buffalo rearing for meat production and reduced use of cattle and buffalo as draught animals (Gamage et al. 2009), the population of these animals is decreasing across the country (CBSL 2016).

Further integration of crop production, livestock rearing, and waste management sectors across the country may allow for more productive and sustainable agricultural production in Sri Lanka. Recycling and safe disposal of organic wastes through composting can reduce the negative externalities of waste generating sectors. Composts locally produced may replace expensive fertilizer imports for agricultural uses and thus reduce the pollution of soil and water bodies by chemical fertilizers. However, the unbalanced demand for and supply of compost in locations may require improved inter-regional transportation and marketing systems across the country.

# Natural resources availability and use

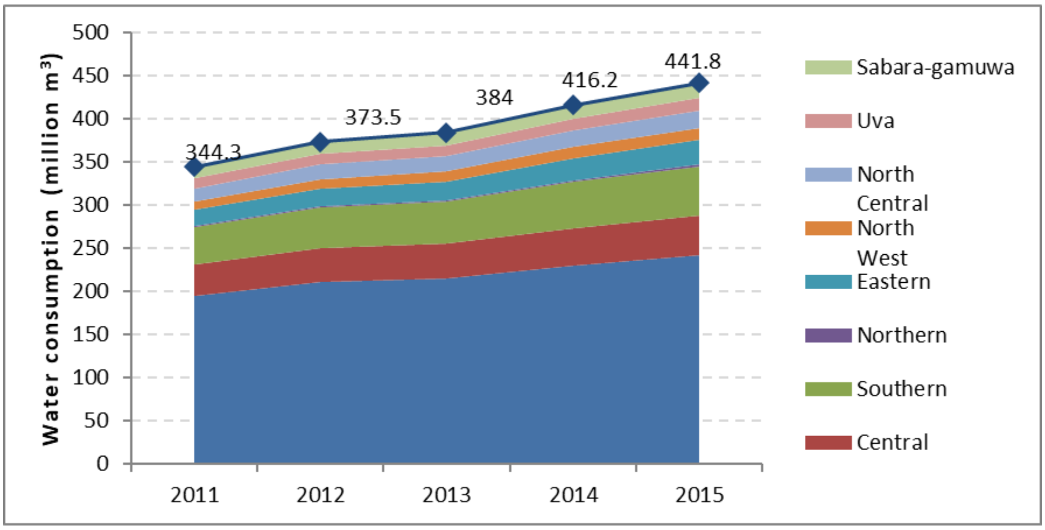
## Water supply and demand

Water is an essential resource for farming. The assessment of water supply and return flows may help for understanding the need for water augmentation for production sectors or ecosystems for example through an advanced wastewater treatment. As reported earlier, Sri Lanka has more than hundred small and medium rivers, which together supply over 50 $km^3$ water annually (Amarasinghe 2010). This will yield per capita water availability of 2,200 (as expected in 2050) to 2,800 $m^3$ (as of 2001). This is higher than threshold water requirement level of 1,700 $m^3$ per capita according to international standards (Amarasinghe 2010). Although water supply seems abundant when per capita distribution of annual water supply at country level is considered, water is scarce in non-monsoon seasons and in dry-zone.

Agriculture uses over 11 $km^3$ or 22% of total water resources (Amarasinghe et al. 1999). Paddy rice production in dry zone is the dominant consumer of agricultural water withdrawals while rice production in rainfed areas is very limited (Amarasinghe et al. 1999). Consequently, dry zone accounts for 95% of total water withdrawals for irrigation. Thus, water scarcity in dry zone may have severe impacts on rice production and thus on national food security in Sri Lanka.

At present, total municipal and industrial water withdrawals amount to 440 million $m^3$. Only some parts of the Western, Southern and Central provinces are equipped with a pump-borne water supply and sanitation network while the remaining parts of the country do not have pump-borne infrastructure. These three provinces account for 80% of nationwide municipal water withdrawals together (Fig. 2). Especially, the Western province accounts for about 55% of these withdrawals. Majority of population in the remaining parts of the country rely on surface and groundwater sources for potable water. However, the government plans the renovation and expansion of pump-borne water supply and sanitation network in major residential areas across the country with the support of international agencies (Ministry of Finance and Planning 2010). Although the establishment of pipe-borne water supply network improves access to safe water, it may also increase wastewater generation and thus may exacerbate wastewater related pollution. Consequently, there will be increased need for additional wastewater treatment facilities, recycling wastewater, and recovering energy and nutrients from wastewater streams.

Figure 2: Municipal (industrial and domestic) water consumption by provinces




Source: CBSL 2016

## Fertilizer demand and supply

Information on demand for and supply of chemical fertilizer is important for adequate assessment of the marketability of compost. Historically, the applications of manure, organic waste and waste streams from households were common to rehabilitate soils in Sri Lanka. Usage of chemical fertilizers such as urea, ammonium sulphate, and superphosphate by farmers became common for improving crop yields after 1950s (Weeraratna 2013). For attaining food self-sufficiency, especially self-sufficiency in rice production, the government has subsidized the supply of chemical fertilizers over long period of time (Wickramasinghe et al. 2010). However, chemical fertilizers are largely imported from other countries since Sri Lanka does not have the mines of minerals and ores sufficient to meet its domestic fertilizer demand. Reportedly, the imports of nitrogen fertilizers increased from 160 to 227 thousand tons during the period between 2005 and 2014 (Table 1). Meantime, the imports of the phosphorus fertilizers increased from 23 to 45 thousand tons. Ceylon Fertilizer Company Ltd under the Ministry of Agriculture is a main state-run enterprise which imports and distributes fertilizers throughout the country.

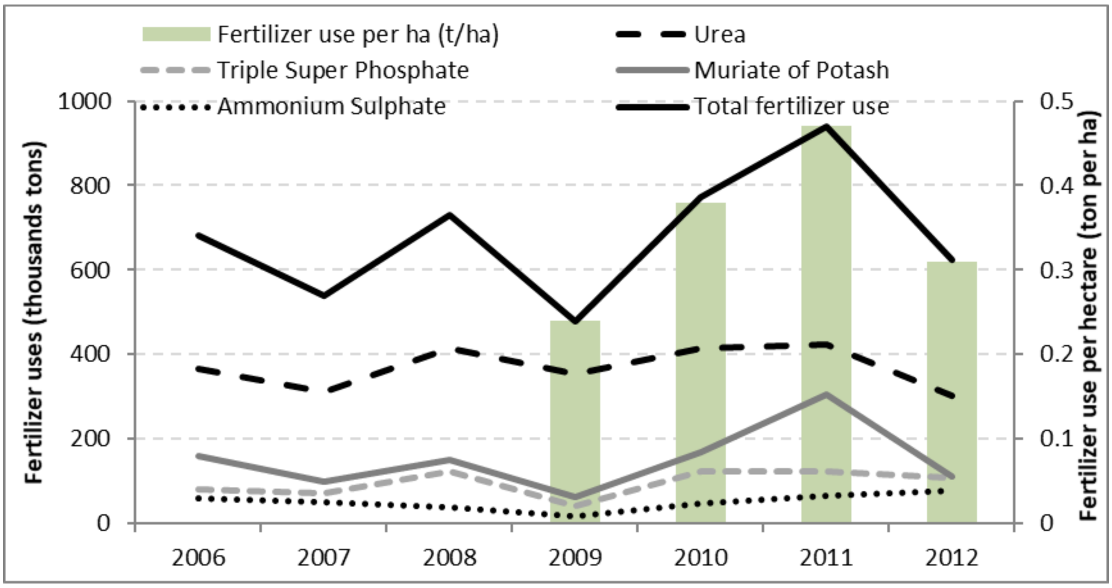
Table 1: Fertilizer production, exports and imports (1000 tons nutrients) in Sri Lanka

| Year | Production | Exports | Imports |
|---|---|---|---|
| Nitrogen fertilizers | | | |
| 2005 | 0.0 | 0.0 | 159.6 |
| 2010 | 0.0 | 0.0 | 166.1 |
| 2014 | 0.0 | 0.0 | 227.4 |
| Phosphate fertilizers | | | |
| 2005 | 11.0 | 0.0 | 22.6 |
| 2010 | 10.0 | 0.0 | 40.7 |
| 2014 | 1.0 | 0.0 | 45.4 |

Source: FAO database

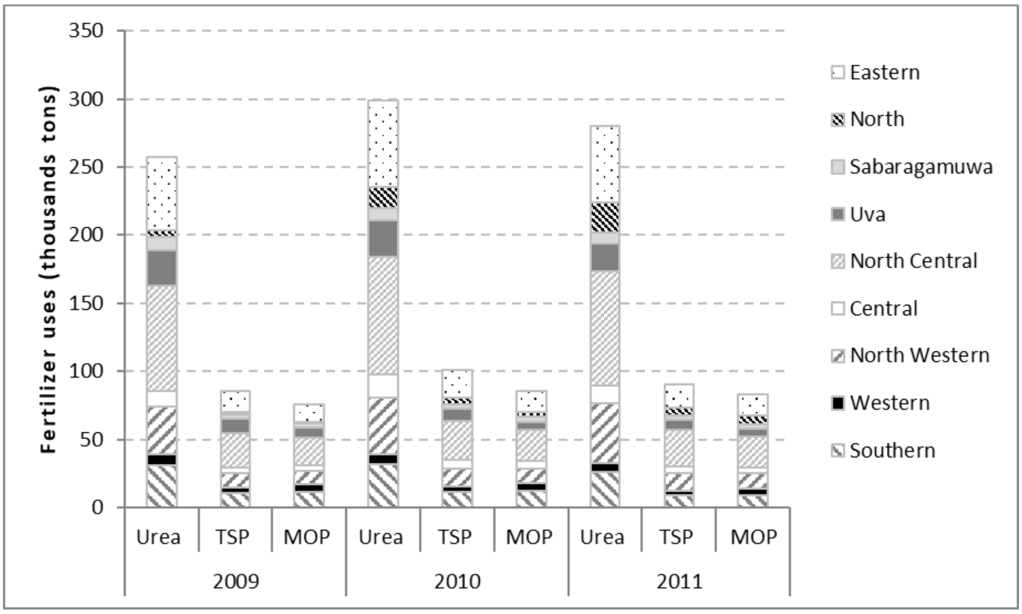
Total fertilizer use in Sri Lanka is between 600 to 800 thousand tons per annum (Fig. 3). The use of urea at the level of about 400 thousand per annum is the highest among all types of fertilizers. Ammonium Sulphate uses are between 40 to 60 thousand tons per annum and Triple Super Phosphate uses are 90 to 110 thousand tons per annum. Average fertilizer use per cropped area varies between 300 and 450 kg per ha. Depending on the fertilizer application rate, crop pattern structure, and total irrigated area the uses of fertilizers across the provinces vary (Fig. 4). The North-Central province which is specialized in paddy rice production dominates in the consumption of all types of fertilizers. Since Sri Lanka is heavily relied on fertilizer imports and the world market prices for fertilizers are expected to increase, the ways of recycling waste and wastewater for recovering nutrients (Nitrogen, Phosphorus, etc.) may gain prominence in future.

Figure 3: Fertilizer uses in Sri Lanka (2006-2012)




Source: Weeraratna (2013)

Figure 4: Fertilizer uses by provinces of Sri Lanka




Source: Weeraratna (2013)

Heavy application of chemical fertilizers is also a key reason for the contamination of surface and groundwater sources with nitrogen, phosphates, and toxic metals. Since only 30% of population in Sri Lanka has an access on water supply and the remaining population is using surface and groundwater sources for daily consumption and sanitation, water contamination may bear also serious health risks (MoE 2002). Increasing rates of Chronic Kydney Disease with Unknown Ethimology (CKDu) in major farming areas (especially in North-Central Province) are often explained with the increased uses of chemical fertilizers in paddy farming (Bandarage 2015). Since high levels of arsenic in phosphate fertilizer are often blamed for having adverse health effects, substituting chemical fertilizers with organic fertilizers such as compost can be more advisable (Jayasumana et al. 2015).

## Energy supply and demand

Demand for and supply of gas and electricity is essential for understanding the need for additional recovery of energy from waste and wastewater. Sri Lanka lacks fossil fuel resources and therefore largely imports these resources. However, the country has substantial potential for producing renewable energy through hydropower generation and solar power plants. Annual hydroelectricity production varies between 6,000-8,000 GWh depending on annual water availability (CBSL 2016). Electricity demand unmet by hydropower production will be supplied through additional electricity generation by the thermal plants which supply about 3,000-6,000 GWh per annum.

Lightening energy demands are largely met by electricity. At present, more than 90% of energy demand for lightening is supplied through electricity across the provinces in Sri Lanka (CBSL 2016). Liqued Petroleum Gas (LPG) accounts for over 40% of energy usage for cooking in the Western province but firewood use is more common for cooking and accounts for over 80% of energy used for cooking in the remaining parts of the country (CBSL 2016). In the less developed parts of the country such as North-Central Province, firewood usage accounts for more than 95% of total energy for cooking. Burning firewood in poorly ventilated environments while using inefficient cookstoves cause the indoor air pollution (MoE 2011). Harmful substances such as carbon monoxide, sulfur oxides, nitrogen oxides, formaldehyde, and benzopyrene in the polluted air increase the incidents of serious respiratory and cardiovascular diseases (MoE 2011). Perhaps, the usage of biogas based on organic waste recycling can be a more ecologically and health friendly alternative to firewood use for cooking in the houses. It could also reduce demand for firewood and consequently lessen the deforestation problems in some regions (Bajgain and Shakya, 2005).

# Waste and wastewater management sector

## Economic importance

Water, waste, and wastewater management sector contribute to a small share of total industrial employment and industrial value added in Sri Lanka at present despite its high relevance and importance for environmental protection (Table 2). In addition to subsidized water supply and waste collection fee rates, low demand for water supply services because of high precipitation levels may reduce the significance of the water and sanitation sector in the economic system. Underdevelopment of waste and wastewater treatment systems can be another reason for the weak linkages of this sector with the remaining sectors of the economy. Nevertheless, the importance of the water and sanitation sector is unquestionable for preventing heavy environmental pollution driven by urbanization, population growth, and production expansion.

Table 2: The share of water, waste, and wastewater sector in total industrial employment and economic value added in 2013

| | Persons engaged | | Value added | |
|---|---|---|---|---|
| | Number | (%) | (in Billion Rs) | (%) |
| Water collection, treatment and supply | 9,930 | 1.1 | 32.1 | 2.0 |
| Waste collection, treatment, and disposal | 1,005 | 0.1 | 0.7 | 0.0 |
| Remediation and waste management services | 184 | 0.0 | 0.2 | 0.0 |
| Remaining sectors of the manufacturing | 905,049 | 98.8 | 1579.6 | 98.0 |
| Total of manufacturing sector | 916,168 | 100.0 | 1612.6 | 100.0 |

Source: Department of Census and Statistics (2017)

## Wastewater availability and management in Sri Lanka

Industrial zones across the country generate 250-300 million $m^3$ wastewater annually (assuming that return flows are 80% of municipal water withdrawals). The piped sewerage network in Colombo city was built between 1906 and 1920 (ADB, 2015). Later in the period between 1983 and 1987, the sewerage system was extended to the areas of Dehiwala, Mount-Lavinia and Kollonnawa. The sewerage network covers only some parts of the city and comprises 320 km of sewers, 18 pumping stations, and two long outfalls into the deep sea (ADB, 2015). Thus, large amounts of wastewater produced by industries and urban areas are discharged into the deep sea without proper treatment (Jayalal and Niroshani, 2012). Disposal of wastewater and sewage sludge without proper treatment is a key reason for eutrophication and the spread of diseases in inland water bodies and coastal areas.

Increased eutrophication may also damage coral reefs in the coastal zone and negatively effect on fishing industry (Sunday Times, 2017a).

With the increased environmental consciousness and strict regulations for environmental protection, the establishment of wastewater treatment plants is increasing. Given the lack of pipe-borne sanitation infrastructure in many parts of the country, fecal sludge is collected by special trucks in some areas to deliver them into treatment plant. Wastewater is recycled through passing several ponds in wastewater treatment plants (Fig. 6). In some places like Rathmalana, a very modern wastewater treatment plant functions using advanced computer technologies for monitoring and managing wastewater treatment process. Treated wastewater is safely released into the sea or lagoon, thus without polluting the coastal area and damaging the fishery. Sediments are dried several days before being delivered to a compost plant for co-composting together with organic waste (food waste, crop residues, etc.) or dumped into landfills. In some cases, dried sediments were supplied to cement production factories for burning (Maheshi et al. 2015).

Figure 6: Treating wastewater in a small-scale plant in Colombo Municipal Area

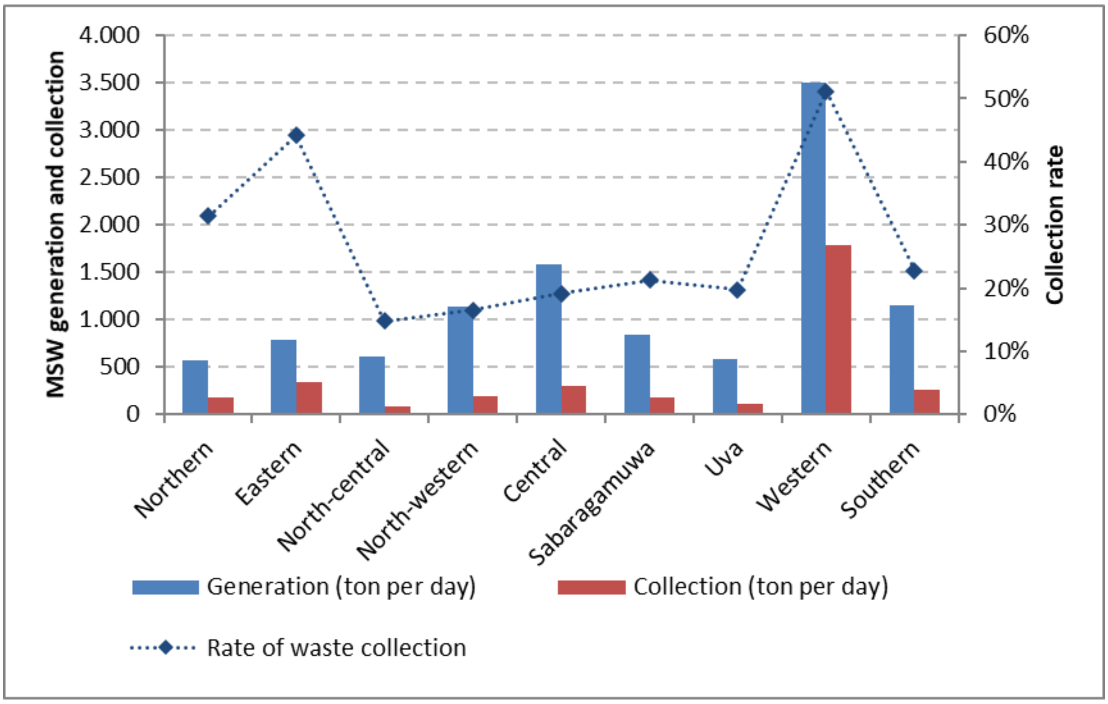
Source: Photo by the author (30.08.2017, wastewater treatment plant in Negombo)

Use of wastewater for irrigation is a common practice in some rural areas of Sri Lanka but no data is available about the extent of wastewater reuse given the multiple number of farmers with small sizes (less than a hectare) (Jayalal and Niroshani 2012). However, the uses of wastewater for irrigation without treatment over years also may be harmful for crops because of the accumulation of toxic salts and heavy metals such as mercury, lead, and copper in soil. Some low-cost methods of wastewater treatment before irrigation reuse are a reed-beds and stabilization ponds which considerably reduce the harmful content of wastewater (Jayalal and Niroshani 2012). Sludge formed in the reed-bed can be used as a fertilizer and treated water can be used for irrigating crops. Given that water is abundant in the growing season due to high rainfall levels in many areas except in the dry-zone, the scope for wastewater reuse is limited (Mr B. Golpakrishnan, personal communication, 07.09.2017). Therefore, the studies on wastewater management in Sri Lanka are not many and mainly focused on treatment and environmentally safe disposal issues rather than the re-uses.

## Waste generation and management

Daily rate of municipal waste generation per capita is 0.4 to 1 kg. The generation of municipal solid waste throughout the country is at the level of 9,000-10,000 tons per day and is expected to increase rapidly following the developments in Colombo Municipality (Fig. 7). The Western Province accounts for more than 30% of total waste generation in Sri Lanka. About 30% of total municipal solid waste or 3,000-4,000 tons of waste is collected in the country. Waste collection rates are higher in the Western and Eastern provinces where half of the waste generated is collected for a disposal or partial recycling. In the remaining provinces except the Northern province, waste collection rates are lower than 20%. Thus, this uncontrolled waste is usually disposed by households into low-lying areas, along the roads, or waterways (Vidanaarachchi et al. 2006). Even 85% of the collected waste is disposed of in open dumping sites without any pre-treatment or soil cover (Visvanathan et al. 2004).

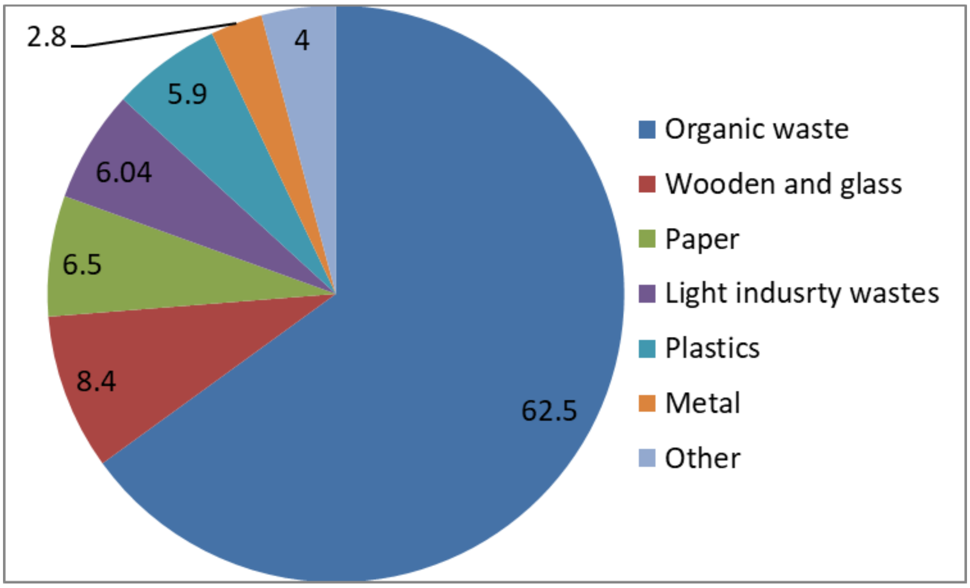
Figure 7: Municipal solid waste (MSW) generation and collection by provinces




Source: JICA (2006)

Less than 40% of municipal solid waste are inorganic waste which consists of wood, glasses, paper, textile, leather, rubber and polythene. The remaining 60% of total municipal waste is bio-degradable waste which can be used for composting (Fig. 8). Given that currently large amounts of municipal solid waste, including biodegradable waste, are dumped into landfilling sites or wetlands, losses of recoverable resources such as soil nutrients and biogas are substantial (Vithanage 2017). The waste consisting of paper, wood, and textile can be used in combustion plants for generating heating energy or electricity.

Figure 8: Content of municipal solid waste




Source: DCS (2015)

Management of waste and wastewater is a challenging issue in urban areas where disposing large amounts of waste requires finding suitable places for dumping (UNEP 2001). Given the underdeveloped capacity of waste and wastewater treatment, a safe disposal is limited and open dumping into low-lying areas such as abandoned paddy fields and marshy lands is prevalent (Gunawardana et al. 2009). Examination of 41 dumping sites existed in the surroundings of the capital city in 2000 revealed that almost all of them were open dumps and waste was buried only in a single site (UNEP 2001). Unfortunately, pollutants from these sites were not controlled by any engineering facilities. Some few sites were partially covered with soil only if there was public pressure or a projection to further use the land for agriculture. Consequently, haphazard dumping intensified environmental and health issues. Particularly, flood retention areas were reduced further increasing flooding risks. Some wetlands such as Muthurajawela were heavily polluted making them less convenient for habitation. Lands and water bodies in the surroundings of the dumping sites were degraded because of the seepage of the harmful substances from these sites (Menikpura et al. 2008). Life quality also decreased due to unpleasant odor and the spread of litter and waste from open dumping sites (MoE 2002). Additionally, open dumping increased the air pollution through increased emission of carbon dioxide and other hazardous gases (Maheshi et al. 2009). Given the mismanagement in the sector, some fatal problems such as landsliding in the garbage mountains which may destroy the neighboring houses and takes the lives of several people also occur as recently observed in the Meethotamulla dumping site in Colombo Municipality (Sunday Times, 2017b).

In some municipalities, solid waste is dumped into areas close to rivers consequently polluting potable water resources for downstream (Gunawardena et al. 2017). For instance, the Kelani river which is a main source of potable water supply for the capital city is polluted because of several dumping sites on its banks (UNEP 2001, Gunawardena et al. 2017). The consequences of pollution could be heavier in case the pollutants from medical waste enter into water streams. Especially, workers in the waste dumping sites and habitants in its surroundings may be exposed to higher health risks since they are more likely come to contact with contaminated needles, fecal matter, hazardous wastes, and various hazardous pathogens.

Waste was often burned open further excacerbating air pollution. Open dumping wastes along the roadside and on low-lying natural areas may also increase the risk of ingestion of plastics and other harmful substances by domestic and wild animals and damage their health (van Zon and Siriwardena

2000). Scattered garbage does not only destroy natural view of landscape but also cause offensive odors. It may also block water flow and cause flooding during heavy rainy season. A human pathogen Mosquito, fly and insects breeding in stagnant water bodies and streams blocked by waste may also cause the spread of disease and epidemics.

# Legal and institutional framework

## Key stakeholders involved in waste and wastewater management

The Central Environmental Agency (CEA) established in 1981 is a main organization in implementing environmental policy and measures (Jayalal and Niroshani 2012). National Water Supply and Drainage Board together with provincial councils are responsible for providing potable water and sanitation services across the country. The Board constructs and manages large-scale, pipe-borne water supply and sanitation projects. Small-scale, local water supply and sanitation projects require a community level participation and thus are managed by local authorities such as Municipal, Urban Councils and Prabeshiya Sabha. When local authorities do not have the required expertise in designing and implementing water supply and sanitation projects, the Board gets involved for providing the required support.

Ministry of Local Government and Provincial Councils is responsible for the implementation of policies and coordination of relationships between the central government and provincial councils (JICA 2016). The ministry also provides technical assistance, funds related research, and trains personnel for maintaintnig good governance. Ministry of Health, Nutrition and Indigenous Medicine oversees policies, monitoring and management of waste from medical facilities (JICA 2016). The Ministry appoints Public Health Inspectors to all municipalities and some rural residential areas. Public Health Inspectors are responsible for monitoring appropriate disposal of waste and wastewater and obedience to the environmental protection regulations.

National Solid Waste Management Support Center was established to provide guidelines and various technical assistance on proper waste management to local authorities. Ministry of Power and Energy is in charge of formulating national energy policies and strategies in Sri Lanka (JICA 2016). The Ministry envisages a gradual expansion of alternative energy sources including biofuel production and conversion of waste into energy. According to its plan at least 10% of total energy consumption should be satisfied through alternative sources in near future. Although there were several agreements or initiations of constructing plants to generate biogas or electricity from waste since 2000s, majority was failed due to financial or technical reasons or still under planning process. In contrast, the implementation of composting plants planned under a governmental *Pilisaru Program* worked better despite many technical, financial and institutional barriers.

## Legislation and Policies

National Environmental Act adopted in 1980 and amended in 1988 and 2000 is a key legislative document regarding not only wastewater management but also wider environmental protection and pollution control issues (Jayalal and Niroshani 2012). Particularly, the Act determines the tolerance limits for discharging effluents from industry sectors and municipal areas into inland surface water bodies and coastal zones. Main policy measures in the wastewater management sphere aim at improving water use efficiency, protecting water quality and maintaining optimal use of water through integrated management of all types of water. Moreover, the national policy and reforms consider ensuring environmental accountability and social responsibility of people and companies involved in waste generation, collection, transportation, treatment, disposal and coordination, minimizing adverse environmental effects of waste disposal, and ensuring human and environmental health.

For instance, National Environment Policy (2003) aims at promoting a balanced economic development with the consideration of environmental sustainability needs, integrated approach taking into account the interests of multiple stakeholders, and enforcement of environmental accountability. Objective of the supportive National Air Quality Management Policy (2000) is maintaining proper air quality to prevent and reduce air-borne disease incidents and death rates due to air pollution. Similarly, National Watershed Management Policy (2004) underlined sustainable and efficient use of water resources and rehabilitation of watersheds through inclusive decision making. According to the National Policy on Solid Waste Management, environmental accountability and social responsibility of all stakeholders involved in waste management sector should be ensured, recovery of resources should be maximized, and adverse health and environmental effects of waste disposal should be minimized.

Sri Lanka as a member of the Basel Convention developed National Strategy for Waste Management which is used for drafting guidelines for managing waste and wastewater and their disposal. The Central Environmental Authority is supposed to play a key role for the overall coordination of the strategy. Meantime, local authorities are expected to be active in the implementation of the strategy. Ministry of Finance developed implementation and investment plans and is in charge of raising funds.

Like in many developing countries, a proper waste and wastewater disposal was not prioritized and the enforcement of laws was relatively weak in Sri Lanka (UNEP 2001). No legislation and guidelines exist on reuse of wastewater for irrigation purposes (Jayalal and Niroshani 2012). An option of treating wastewater for further sale for farmers have not been practiced since there is no adequate development of legislation and mechanisms on controlling the quality of wastewater reuse in irrigation. However, all large scale enterprises need an Environmental Protection License (EPL) from CEA to operate. For obtaining the license, the companies and medium to large scale entities should provide a plan how they are managing their waste. Similar permissions are required also for constructing new houses. As a result of this strict regulation, the scope of the biogas plants and compost production facilities are gradually expanding.

# Major technologies of recycling waste and wastewater in Sri Lanka

## Composting plants for recycling organic waste

For preventing the negative outcomes of waste and wastewater mismanagement, various methods of waste and wastewater treatment such as composting, anaerobic digestion, and incineration have been applied or planned to be implemented in some municipal areas (UNEP 2001). Composting is a process of decomposing biodegradable waste into humus like matter - compost - which is rich in nutrients useful for crop growth (Fig. 9). A compost is a dark-colored matter with earthy odor and similar to organic top soil though the grades of the compost quality may vary depending on its nutritious value and hazardous content (Fig. 10). A good composting process allows for the elimination of the seeds of weeds and pathogenic organisms in the compost. Adding compost to soil is important for better soil structure and texture which reduces soil erosion, improves moisture holding capacity, allows for better movement of cations in soil, and improves water and air infiltration in the root zone (Samarasinghe et al. 2015). Consequently, this improves nutrient retention in the soil and also allows for improved growth of plant roots that in turn contributes to better nutrient intake by plants. Compost can be used for cultivating all types of crops including paddy rice, coconut, tea, and rubber.

Figure 9: Composting organic waste

Source: Photo by the author (30.08.2017, a composting plant in Negombo)

Figure 10: Packing the ready compost

Source: Photo by the author (30.08.2017, a composting plant in Negombo)

Compost production allows for multiple economic benefits such as increased employment opportunities, lowered state expenditures for operating and maintaining the dumping sites, reduced reliance on the fertilizer imports, hard currency savings, and reduced health expenditures for taking care of the CKDu patients (Samarasinghe et al. 2015). Reduced open dumping also improves the scenes of natural landscapes and environmental health, consequently increasing the attractiveness of the touristic services. Since demand for organic food is increasing all across the world, agricultural commodities grown using organic fertilizer can boost export revenues (Vidanapathirana and Wijesooriya, 2014).

National strategies on waste management aim at treating 19% of the collected waste for producing compost and thus reducing the imports of chemical fertilizers (Table 3). In districts such as Kurunegala, Anuradapura, Polonnaruwa, and Badulla where agriculture is a backbone for rural livelihoods, the targeted rates of waste recycling are even higher. Following the *Pilisaru Program* adopted by the national government in 2008, over 110 compost plants were planned to be established throughout the country (JICA 2016). Investments for this project provided by the government budget for the first three years of the implementation amounted to over Rs 5.7 Billion (over € 30 Million, Samarasinghe et al., 2015). 94 composting plants out of 119 are under operation at present and 17 are under construction (JICA 2016). Though the construction works were finished in the remaining plants these plants did not start producing compost given the problems related to electricity, water and road access. Most of the centralized composting facilities recently built in Sri Lanka use windrow composting technology (Samarasinghe et al., 2015).

Table 3: Municipal solid waste collection and composting rates across Sri Lanka

| Provinces | Waste collection (tons per day) | Number of compost plants | Targeted waste (tons per day) | Targeted waste (%) |
|---|---|---|---|---|
| Northern | 78.5 | 3 | 11 | 14.0 |
| North-Central | 82.2 | 16 | 58.5 | 70.9 |
| North-Western | 200.9 | 21 | 118 | 58.7 |
| Central | 314.8 | 0 | 30 | 9.5 |
| Western | 1783 | 17 | 116.8 | 6.6 |
| Southern | 249.5 | 24 | 94 | 37.7 |
| Sabaragamuwa | 153.5 | 8 | 36 | 23.5 |
| Uva | 110.6 | 7 | 56 | 50.6 |
| Eastern | 278.5 | 6 | 22 | 7.9 |
| Sri Lanka | 3,424 | 119 | 656.8 | 19.2 |

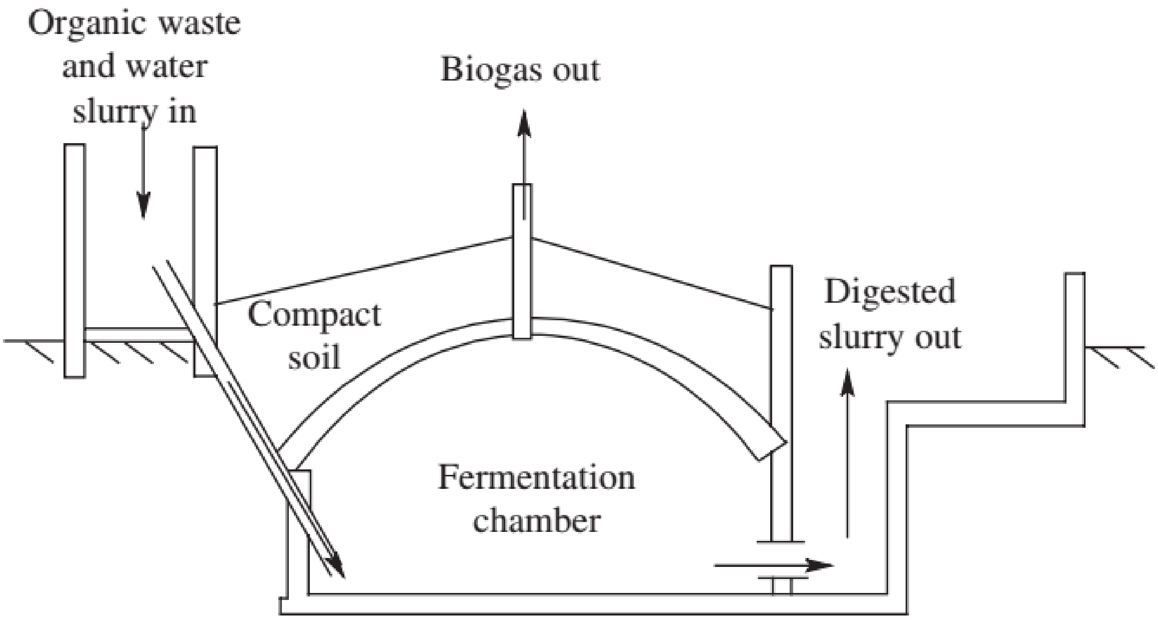
Source: Central Environmental Authority (2015).

## Biogas generation facilities for recycling waste and wastewater

Biogas plants are effective options for recycling organic waste. In developing countries of Asia, anaerobic technology is becoming common to recycle manure, food waste and crop residues (Pandyaswargo and Premakumara 2012). Biogas plant consists of an underground cylindrical tank for storing the organic matter and the fixed hemispherical dome for storing gas (Fig. 11). Different types of waste including livestock manure, toilet waste and food can be used for generating biogas in these digesters. Anaerobic digestion technology allows for recovery of energy in the form of methane from organic waste (UNEP 2001). Anaerobic bacteria or effective indigenous microorganisms (EM) help in the degradation of organic waste and consequent generation of biogas. The produced biogas which is primarily consists of methane and carbon dioxide can be used for cooking (Fig. 12) or generating electricity for lightening. The residuals after biodigestion such as slurry are rich in macro and micro nutrients and thus can be used as bio-fertilizer for organic farming. In Sri Lanka, biogas can be effectively generated from the food waste or manure of pigs, cattle, horse, and poultry, and is an effective substitute to firewood and fossil fuel (Gamage et al. 2009).

Biogas production by using waste allows for households a substantial reduction of the expenditures for LPG. Biogas produced at large scale can be also used for producing electricity and selling it through the electricity grid. Slurry from the biodigestion plant can be used as a biofertilizer which considerably improve crop yields. In addition to improving energy security and employment opportunities, biogas production has multiple environmental benefits such as reduced carbon dioxide emissions, prevention of deforestation, decreased amount of waste and reduced environmental pollution (de Alwis, 2002). In rural areas where women uses inefficient cookstoves, firewood, and animal dung for cooking, biogas uses would reduce the smoke during cooking and thus prevent indoor air pollution and air-borne disease incidents. Reduced firewood collection would also contribute to the prevention of deforestation. Women could save substantial amount of time spent for firewood collection and cooking. Consequently female children would have more time for education and would also get an access on improved electricity for lighting in the evening for preparing their homework.

Figure 11: Biogas plant design (Chineese type)




Source: Gautam et al. (2009)

Figure 12: Biogas use for boiling water and cooking


Source: Photo by the author (01.09.2017, in the Premises of Biogas Lanka)

Initial experimental projects of implementing aerobic digestion technology in Sri Lanka primarily aiming at energy recovery took place as early as 1970s upon the sky-rocketed energy prices in the world market (de Alwis, 2002). However, the scale of the adoption was very limited at that time and the implementations did not progress much as affected by the start of the civil war. With increased need for reducing waste and environmental pollution, the government has been widely supporting waste recycling technologies recently. In result, currently over 7000 biogas plants have been established across the country. Chinese type biogas plants are more commonly implemented (over 80% of the plants) than SriLakUmaga and Sri Lankan types of biogas plants. Hotels, schools, hospitals, farms and upper mid-income households considered the construction of biogas plant as a way of recycling their organic waste and thus reducing the payments to waste collection services. New houses consider the construction of biogas plant since the permission to construction by the government requires the plan of obligatory management of household wastes (Mr Tuan Areefen, Personal communication, 01.09.2017). Hotels and catering services also using biogas digesters for recycling food waste and for supplying staff kitchen with biogas (Mr Samarakoon, Personal communication, 07.09.2017).

Biogas plants are primarily established as waste management option since demand for gas is low and LPG is available at affordable price. However, the use of biogas in crematoriums is increasing thus creating incentives for biogas sector expansion. Biogas based electricity generation is very rare due to energy losses in turning biogas energy into electricity. Despite very effectiveness of the slurry from the biogas plants as biofertilizer, almost in 95% cases the slurry is not used for gardens due to unawareness of its benefits for soil productivity improvement (Mr Tuan Areefen, Personal communication, 01.09.2017). Perhaps, the use of biochar for soaking the slurry and marketing the enriched biochar would improve the demands for the slurry as biofertilizer. Systematic studies are required on the use of the slurry from biogas plant for improving soil productivity (Professor Ajith de Alwis, Personal communication, 06.09.2017).

## Waste-to-energy (incineration) plants to recycle waste

The incineration is a controlled process in which combustible waste is burned and changed into gases and heating energy; the residual ashes can be safely dumped into landfills. Incineration of waste has been less common in Sri Lanka since this process might require supplementary fuel because of low calorific value and high moisture content of waste in the country (UNEP 2001). Thus, the implementation of incineration plants was limited only for a few hospitals and industries and at small scale. Due to low financial capability of these enterprises, even these incineration plants are not well maintained and lacks emission control devices. Yet, with the increased tensions, public protests against open waste dumping sites and heavy environmental pollution, some positive change towards environmental safeguarding have been taking place.

The government recently approved the construction of the first large-scale waste-to-energy plant in Karadiyana dumping site in Colombo area which is planned to recycle 450-500 tons of the collected waste per day (Daily Mirror, 2017). The plant uses the advanced German and Danish technology for sustainable waste management. It is the first large-scale waste processing facility in the island meeting all international sanitary and sustainability standards and based on the proven and commercially viable technologies.

The plant requires investments amounted to Rs 27 Billion (over € 150 Million) and is proposed to recycle at least 500 tons of waste per day. The collected municipal solid waste is initially separated into organic and non-degradable content at the gate of the plant to maximize the energy production and recovery of bio-fertilizers. A hybrid system consists of a biological plant and an incineration plant. The biogas plant recycles 200 tons of degradable waste per day to produce bio-fertilizer using fast fermentable anaerobic digestion technology. About 40-50 thousand tons of liquid bio-fertilizer and 7.5 thousand solid fertilizer are expected to be produced within the system. The incineration plant with the recycling capacity of 300 tons per day serves for mass burning the remaining non-degradable waste and generating energy. Electricity generated in the incineration plant is expected to meet the energy demands of over 24 thousand households. The waste to be dumped at the site will be reduced by 90% at least while carbon dioxide emissions are reduced by 120 thousand tons.

# Modeling the potentials of recovering soil nutrients from waste and wastewater

## Model description

Recovering soil nutrients from biodegradable waste can be an effective option for rehabilitating degraded cropland soils and reducing the reliance on chemical fertilizer inputs. For assessing the nationwide potential of recovering soil nutrients from waste streams, a simple simulation model was applied by using observed data on livestock number, population number, manure per head, toilet waste per capita, wastewater and municipal organic waste (MOW) amount, nitrogen, phosphorus, and potassium (NPK) content of waste material, and recycling rates. Data was obtained from various statistical and governmental agencies (Gamage et al. 2009, DCS 2015, CBSL 2016, JICA 2016).

Availability of nutrients from livestock waste ($S_{r,l,k}^{LIV}$) was calculated as:

$$S_{r,l,k}^{LIV} = N_{r,l}^{LIV}\ q_l^{MNR}\ c_{r,l}^{LIV}\ n_{l,k}^{LIV} \tag{1}$$

where, $N_{r,l}^{LIV}$ is the head of livestock type *l* in region *r*, $q_l^{MNR}$ is the amount of manure per head of livestock, $c_{r,l}^{LIV}$ is the rate of recycling, and $n_{l,k}^{LIV}$ is nutrient (type *k*) content of manure.

Availability of nutrients from toilet waste ($S_{r,k}^{TOI}$) was determined:

$$S_{r,k}^{TOI} = N_r^{POP}\ q_r^{URN}\ c_r^{URN}\ n_k^{URN} + N_r^{POP}\ q_r^{FEC}\ c_r^{FEC}\ n_k^{FEC} \tag{2}$$

where, $N_r^{POP}$ is the number of population, $q_r^{URN}$ and $q_r^{FEC}$ are total amount of urine and feces per capita per annum, respectively, $c_r^{URN}$and $c_r^{FEC}$ are the rates of recycling urine and feces, respectively, $n_k^{URN}$ and $n_k^{FEC}$ are nutrient (type *k*) contents of urine and feces, respectively.

Availability of nutrients from MOW ($S_{r,k}^{MOW}$) is estimated as:

$$S_{r,k}^{MOW} = QG_r^{MOW}\ g_r^{MOW}\ c_r^{MOW}\ n_k^{MOW} \tag{3}$$

where, $QG_r^{MOW}$ is the amount of the generated MOW, $g_r^{MOW}$ is the collection rates of MOW, $c_r^{MOW}$ is the rate of recycling, $n_k^{MSW}$ is nutrient (type *k*) contents of MOW.

Availability of nutrients from wastewater ($S_{r,k}^{WWT}$) is determined as:

$$S_{r,k}^{WWT} = QG_r^{WWT}\ g_r^{WWT}\ c_r^{WWT}\ n_k^{WWT} \tag{4}$$

where, $QG_r^{WWT}$ is the amount of the generated wastewater, $g_r^{WWT}$ is the collection rates of wastewater, $c_r^{WWT}$ is the rate of recycling, $n_k^{WWT}$ is the nutrient contents of wastewater.

Total availability nutrients from different types of organic waste ($S_{r,k}^{TOT}$) is calculated by summing the availability of nutrients from manure, toilet waste, MOW, and wastewater:

$$S_{r,k}^{TOT} = \sum_l S_{r,l,k}^{LIV} + S_{r,k}^{TOI} + S_{r,k}^{MSW} + S_{r,k}^{WWT} \tag{5}$$

Demand for nutrients across the regions was estimated as equal to the total amount of nutrients embedded in different types of chemical fertilizers applied for crop production:

$$D_{r,k}^{TOT} = \sum_{f} \left( n_{f,k}^{FER} \, Q_{r,f}^{FER} \right) \qquad (6)$$

where, $Q_{r,f}^{FER}$ is total amount of chemical fertilizer (*f*) applied, and $n_{f,k}^{FER}$ is the nutrient content of fertilizer type *f*.

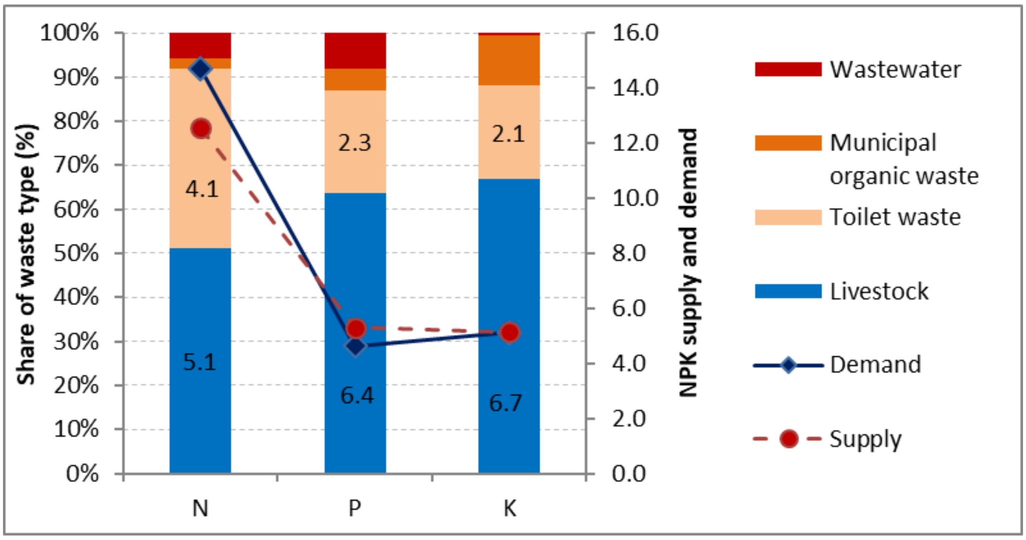
Balance (deficit or proficit) of nutrients (*k*) for each region (*r*) as a difference between the available amount of and demand for nutrients:

$$B_{r,k}^{TOT} = S_{r,k}^{TOT} - D_{r,k}^{TOT} \qquad (7)$$

## Results

According to the calculations, when 50% of different types were recycled in Sri Lanka, this would allow for recovering 125, 53, and 52 thousand tons of nitrogen, phosphorus and potassium, respectively (Fig. 13). This additional supply of nutrients from waste and wastewater recycling would allow for fully meeting domestic agricultural demand for phosphorus and potassium and satisfying more than 85% of demand for nitrogen fertilizers. Recycling animal and toilet waste would account for substantial share of total nutrients recovery.

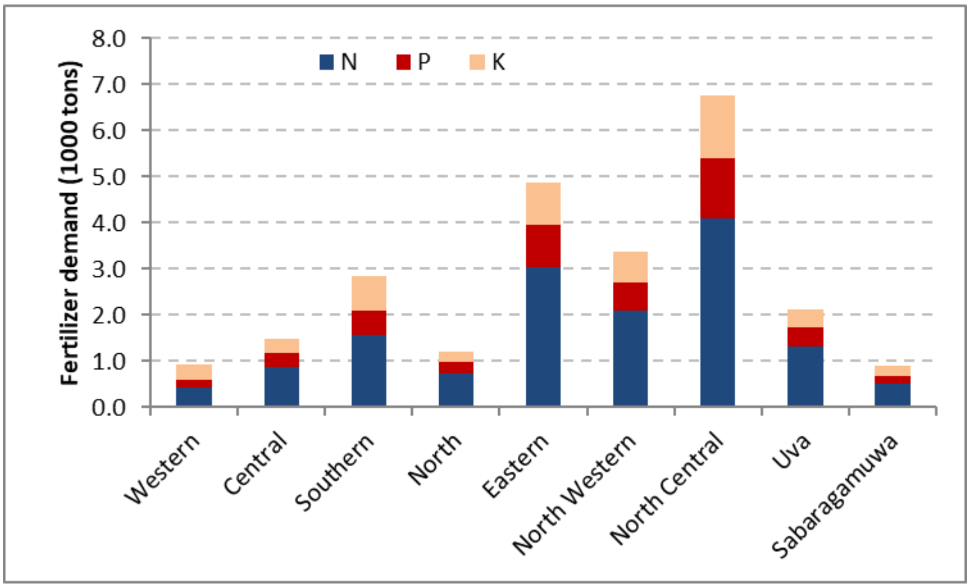
Figure 13: Potential of nitrogen (N), phosphorus (P), and potassium (K) recovery from waste assuming 50% of available waste recycled in Sri Lanka (2010)




Source: Author's estimation

Although at national level total nutrients supply can meet substantial part of total nutrients demand, at sub-national level demand and supply unbalances may exist since waste and wastewater is generated mainly in urban areas while demand is higher in rural areas. Fertilizer demand assessments across the provinces indicated that there is much higher demand for fertilizers in the North-Central and Eastern provinces (Fig. 14). The North-Western and Southern provinces also require substantial amount of fertilizers for agricultural production. In contrast, demand for nutrients is much low in the Western Province which is the main region with high urbanization level and generates most of the waste and wastewater.

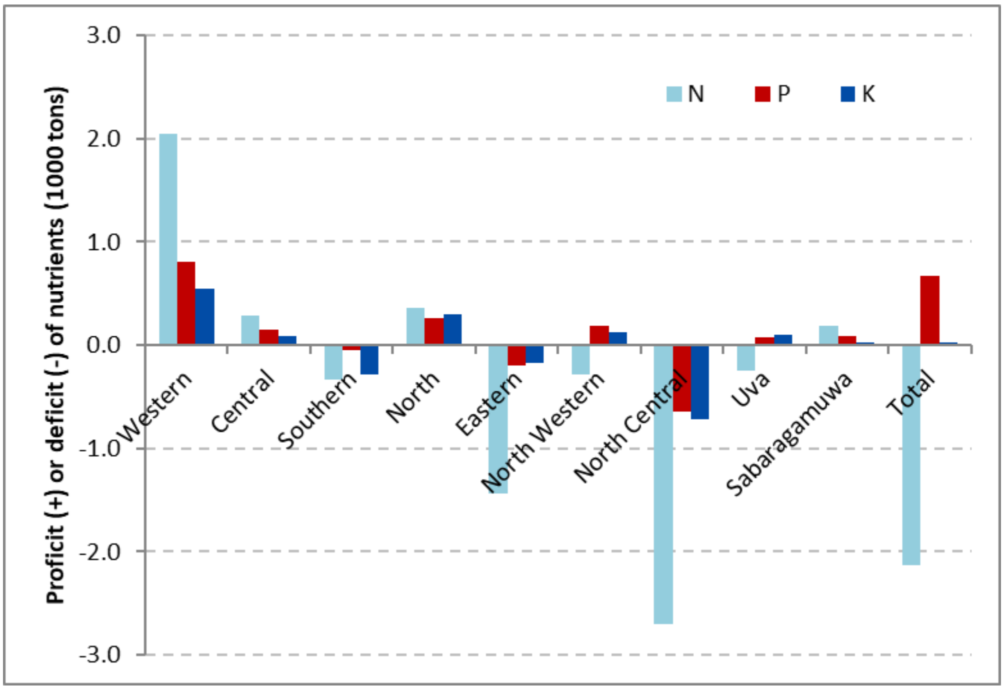
Figure 14: Netto demand for nitrogen (N), phosphorus (P), and potassium (K) across provinces (2010)




Source: Based on National Fertilizer Secretariat (2013)

The comparison of demand and supplies across the provinces allowed for determining the regions with proficit or deficit of nutrients when the possibility of recycling soil nutrients from waste and wastewater streams is considered. As calculations indicated, all types of nutrients can be recovered in much larger amounts than internal demand in the Western and Northern provinces (Fig. 15). Meantime, recovered nutrients from waste is not sufficient to meet agricultural demand in the North-Central and Eastern provinces. The trade of recovered soil nutrients among the regions may not only enhance environmental protection in urbanized areas but also solve crop yield reduction issues in rural areas. However, the costs of transportation and application of the recovered soil amendments should be additionally considered for proper assessment of the economic feasibility of this option.

Figure 15: Demands and potential supplies of recoverable nitrogen (N), phosphorus (P), and potassium (K) nutrients across the provinces of Sri Lanka (2010)




Source: Author's estimation

# Pros and cons for adopting RRR technologies in Sri Lanka

Despite substantial potential for recovering nutrients and strong governmental support of composting plants across Sri Lanka, the compost production and uses are hindered by many technical, financial and institutional factors. Particularly, compost plant managers may face the lack of lands for the expansion of the compost plants or dumping the unrecyclable waste and bureaucratic difficulties in obtaining permission for land uses (Samarasinghe et al., 2015). The gap between the laws and their real implementation also imped wider implementation of recycling. Neighboring houses to the compost plants also complain for malodor and leachate from the plants and frequently organize public protests (Samarasinghe et al., 2015). For instance, despite successful performance of the composting because of good compost quality and high market demand by farming in Walimada, Badulla and Kegala regions, the plants were closed because of public opposition due to malodor and disturbing insects (CEA, private communication, 08.08.2016).

Lack of sufficient funds due to low subsidy rates and low marketability of composts because of low quality may hinder the continuation of the composting activities (Samarasinghe et al., 2015). Particularly, low technical skills of the hired personal, receiving mixed and unsorted waste, lack of improved technologies for segregating the waste, and the plants unsuitably designed for the local conditions may prevent a proper composting. Especially, during monsoon seasons with heavy rainfall, the composting process will be very difficult. High levels of toxic matter, broken glasses, and heavy metal in improperly prepared compost from municipal solid waste may increase the hazardous effects of compost application. High levels of sand content may reduce yield improvement effects of compost. Consequently, the demand by farmers for low quality compost tends to decrease.

The visibility of the effects of compost application on crop growth also take much longer time than seeing the results from chemical fertilizer application. Especially large-scale commercial farmers may prefer the application of chemical fertilizers rather than because of its faster and stronger effects on crop growth (CEA, private communication, 08.08.2016). Majority of the farmers unfortunately are not well aware of the proper implementation methods of organic compost (CEA, private communication, 08.08.2016). The bulky mass of compost also increase its transportation, implementation and labor costs making it less attractive compared to chemical fertilizers (Samarasinghe et al., 2015). As the results of the surveys across Sri Lanka indicated the majority of the farmers also consider that the price for compost is higher than its real worth in farming (CEA, private communication, 08.08.2016). Meantime, artificially reduced prices to chemical fertilizers through government subsidies over decades substantially reduced the marketability of the composts (Wickramasinghe et al., 2010). Thus, in addition to lack of technical skills to operate the plant and low quality of compost, underdeveloped marketing system also hinders successful performance of composting plants (Pandyaswargo and Premakumara 2012).

Because of low salaries in the farming sector and increasing opportunities of employment in the non-agricultural sectors and abroad, reduced labor availability in agriculture hinder the increased application of compost which is labor consuming activity (Henegedara et al. 2008) unless investments take place in the delivery of the proper agricultural machinery for compost application. In composting plants, low salaries, lack of promotions and low social status of being hired in this job may reduce the availability of labor, especially skilled labor force in the sector (CEA, private communication, 08.08.2016). Only very poor people without skills to find job in urban areas and non-farming sectors may agree to work in the composting plants.

For addressing most of these issues, first of all a comprehensive accounting, planning and organization of waste and wastewater management sector is essential. Given the enormous costs of waste and wastewater recycling, the government remains a key actor for supporting the recycling programs. Increased rates of on-site recycling could considerably reduce waste collection and recycling costs by the LAs. Yet, raising the awareness of people on environmental benefits of recycling is essential for a wider involvement of the society in the environmental safeguarding. For preventing public protests, the compost plants should be additionally equipped with the facilities for dust control, leachate storage, and adequate ventilation. Installation of mechanical sorting facilities in the gates of the compost plants could help reducing inorganic matter from the waste, consequently improving compost quality. In compost factories, improved salaries and mechanization of the processes may help not only improving the quality of the services but also address labor shortage problems.

The reasons for low marketability of compost and increasing complaints over compost uses are often related to its low quality rendered by high sand content, low nutritional value and harmful elements. The control and certification of compost quality by trusted state organization can tackle this issue (Samarasiunghe et al. 2015). Organizing online platforms for compost marketing where farmers can find information on the quality, available amounts and the costs of compost can be helpful reducing information asymmetry and enhancing the wider uses of the compost for cultivating crops. Given the labor shortage for farming and heavy requirements for labor to apply compost in the crop fields, the mechanization of compost application or organizing special community-level companies to provide compost application services would improve the demand for compost even further.

Given the extra supply of the recoverable materials from waste in urban areas, the transportation of the recovered nutrients to the areas specialized in farming can improve soil quality and prevent degradation in the rural regions. Interregional trade of compost would decrease the chemical fertilizer use costs. The reduced costs of transportation would further enhance the interregional trade of compost. For instance, using railways or waterways for transporting compost can be cheaper than the transportation by trucks when complex landscapes and heavy traffic problems are taken into account. Particularly, given the surroundedness of the island by sea from all sides and its small size, a ship transportation route around the island which connects the different parts of the country can be an option for reducing the inter-regional transportation costs.

When chemical fertilizers were heavily subsidized (up to 90%) it was not beneficial at all considering compost as a soil ameliorative previously. However, the elimination of the government support for chemical fertilizer uses may improve the demand for compost. Instead, given the multiple environmental benefits of composting, subsidies can be increased to compost production and organic farming. Improved marketing of organic crops in foreign markets would also substantially increase the economic feasibility of compost uses in agriculture.

Composting can also reduce increased CKDu incidents which are generally believed as the result of overuses and improper applications of chemical fertilizers. Indeed, increased replacement of chemical fertilizer with organic compost should not fully diminish the role of chemical fertilizer for crop growth. Integrated Plant Nutrition System which considers the application of both organic and chemical fertilizers yet in an optimal ratio could enhance crop yield and improve fertilizer use productivity (Wickramasinghe 2010). For implementing this soil rehabilitation plan based on integrated nutrition management, rapid soil assessments can be conducted across the country to determine the hot spots of soil erosion, pollution, and land degradation (Professor Ajith de Silwa, personal communication, 06.09.2017). Then, based on the nutrition requirement of soils in particular locations, appropriate levels of organic and chemical fertilizers can be applied.

# Conclusions

Recycling waste and wastewater is a win-win option from both environmental and economic perspective. Recycling technologies such as composting and biogas generation from waste not only allow for environmental safeguarding but also for recovering valuable assets such as fertilizer for farming and energy for cooking. Options of recovering energy and fertilizer from waste is especially important to the countries such as Sri Lanka where waste mismanagement is a challenging issue and energy resources (fuel, LPG, and fertilizers) are almost fully imported, absorbing enormous amount funds in hard currency. Compost production expansion and integrated nutrition management through the optimal application of both organic and inorganic fertilizers would be essential for improving food security in the country. Given that tea and rubber are main export commodities from Sri Lanka, improved fertilizer application would also improve export revenues of the country. Yet, proper planning of waste management and compost production, fertilizer applications considering the nutrients demand of soils as determined through rapid soil assessments, mechanization of the compost production and application, improving the transportation and trade infrastructure within the country, and wider implementation of ICT technologies for establishing market and inter-sectoral cooperation platform are essential for realizing the benefits of the composting. Furthermore, compost quality monitoring and certification is important for reducing information asymmetry, establishing trust between compost producers and farmers, and thus enhancing the compost markets. The government plays an essential role for an improved environmental management by establishing appropriate institutional regulations, promoting education programs to raise environmental consciousness, and providing financial incentives through subsidies to recycling.

# References:


Asian Development Bank (ADB), 2012. Supply and use tables for selected economies in Asia and the Pacific: A research study. ADB, Mandaluyong, Philippines.

Asian Development Bank (ADB), 2015. SRI: greater ColomboWater and Wastewater Management Improvement Program (Project 3) – Wastewater Improvement Project. ADB, Colombo, Sri Lanka.

de Alwis, A., 2002. Biogas – a review of Sri Lanka's performance with a renewable energy technology. Energy for Sustainable Development, 6(1), 30-37

Amarasinghe, U.A., Mutuwatta, L., Sakthivadivel, R., 1999. Water scarcity variations within a country: a case study of Sri Lanka. Research Report No. 32. IWMI, Colombo, Sri Lanka.

Amarasinghe, U.A., 2010. Spatial Variation of Water Supply and Demand in Sri Lanka. In: Jinapala, K., De Silva, S. and Aheeyar, M.M.M. (Eds.). National Conference on Water, Food Security and Climate Change in Sri Lanka. Volume 3, Policies, Institutions and Data Needs for Water Management.

Bandara, N.J.G.J., 2003. Water and wastewater issues in Sri Lanka, Water Sci. and Technol. 47(12), 305-312.

Bandarage, A., 2013. Political Economy of Epidemic Kidney Disease in Sri Lanka, SAGE Open, 3(4), doi:10.1177/2158244013511827

Bekchanov, 2017. Potentials of Waste and Wastewater Resources Recovery and Re-use (RRR) Options for Improving Water, Energy and Nutrition Security. ZEF Working Paper No 157. Center for Development Research (ZEF), Bonn University, Bonn, Germany

Central Bank of Sri Lanka (CBSL), 2016. Sri Lanka: socio-economic data. Data Report. CBSL, Colombo, Sri Lanka

Cordell, D., Drangert, J.-O., White, S., 2009. The Story of phosphorus: global food security and food for thought. Global Environmental Change 19, 292–305.

Daily Mirror (Newspaper), 2017. Karadiyana Waste to Energy Project Inaugurated With Fairway Waste Management, Issue on 26.08.2017.

Department of Census and Statistics (DCS), 2012. Census of Population and Housing 2012. DCS, Colombo, Sri Lanka.

Department of Census and Statistics (DCS), 2015. Economic census for 2013/2014: Final report for formal industries. DCS, Colombo, Sri Lanka.

Gamage, D., Gamage, D.V.S.S., Gunaratne, A.N.D., Subsinghe, D.H.A., Perera, B.M.A.O., Puchpakumara, P.G.A., Gajanayaka, Sh., Seresinhe, Th., Pathirana, K.K., 2009. Livestock for rural development and poverty reduction: Sri Lankan experience. HARTI, Sri Lanka, Colombo.

Gautam, R., Baral, S., Herat, S., 2009. Biogas as a sustainable energy source in Nepal: Present status and future challenges. Renewable and Sustainable Energy Reviews, 13, 248–252.

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J., 2017. The Circular Economy – A New Sustainability Paradigm?, Journal of Cleaner Production, 143, 757–768.

Gunawardana, E.G.W., Basnayake, B.F.A., Shimada, S., Iwata, T., 2009. Influence of biological pre-treatment of municipal solid waste on landfill behaviour in Sri Lanka. Waste Manag. Res. 27 (5), 456–462.

Gunawardena, A., Hailu, A., White, B., Pandit, R., 2017. Estimating marginal abatement costs for industrial water pollution in Colombo. Environmental Development, 21, 26–37.

Henegedara, G.M., 2008. Recent Labour Market Trends in the Food Crop Sector in Sri Lanka, HARTI Research Report 127, HARTI, Sri Lanka, Colombo.

Japan International Cooperation Agency (JICA), 2006. Data collection survey on solid waste management in Democratic Socialist Republic of Sri Lanka. Final Report.

Japan International Cooperation Agency (JICA), 2013. Democratic Socialist Republic of Sri Lanka: Data Collection survey on Agricultural Network and Marketing. Final report.

Jayasumana C., Fonseka S., Ferando A., Jayalath K., Amarasinghe M., Siribaddana S., Gunatilake S., Paranagama P. 2015. Phosphate fertilizer is a main source of arsenic in areas affected with chronic kidney disease of unknown etiology in Sri Lanka. SpringerPlus, 4(90). doi: 10.1186/s40064-05-0868-z.

Jayalal, T.B.A., Niroshani, S.L.N., 2012. Wastewater production, treatment and use in Sri Lanka. Paper presented at 2nd regional workshop on “Safe use of wastewater in agriculture” jointly organized by FAO, UNEP, UNU-INWEH, and UNW-DPC, 16-18 May 2012, New Dehli, India.

Maheshi, D., Steven, V.P., Karel, V.A., 2015. Environmental and economic assessment of ‘open waste dump’ mining in Sri Lanka. Resources, Conservation and Recycling, 102, 67–79.

Menikpura, S.N.M., Basnayake, B.F.A., Pathirana, K.P.M.N., Senevirathne, S.A.D.N., 2008. Preediction of present pollution levels in Gohagoda dumpsite and remediation measures: Sri Lanka. In: 5th Asian-Pacific Landfill Symposium (APLAS Sapporo 2008), Sapporo, Hokkaido, Japan.

Ministry of Environment (MoE), 2011. Progress report 2011 and action plan 2012: Indoor air pollution. Colombo, Sri Lanka.

Ministry of Environment (MoE), 2002. National action plan for combatting land degradation in Sri Lanka. Colombo, Sri Lanka. Available online at: www.unccd.int/ActionProgrammes/sri_lanka-eng2002.pdf.

Ministry of Finance and Planning, 2010. Sri Lanka: the emerging wonder of Asia, Mahinda Chintana – vision for the future. Colombo, Sri Lanka.

Pandyaswargo, A.H., Premakumara, D.G.J., 2012. Financial sustainability of modern composting: the economically optimal scale for municipal waste composting plant in developing Asia. Int J Recycl Org Waste Agricult, 3, 66.doi: 10.1007/s40093-014-0066-y.

Samarasingha, G.G.L.W., Bandara, M.A.C.S., Karunarathna, A.K., 2015. Municipal solid waste composting: potentials and constraints, HARTI Research Report 174, HARTI, Colombo, Sri Lanka.

Sudasinghe M.I., Galagedara L.W., Gunawardena E.R.N. 2011. Performance evaluation of selected sewerage treatment plants in Sri Lanka. Tropical Agricultural Research, 22(2), 154-164.

Sunday Times (A Newspaper), 2017a. Marine Pollution around Sri Lanka and the inevitable environmental disaster, Issue on 09 April 2017.

Sunday Times (A Newspaper), 2017b. Meethotamulla – where to next? By Dr. Bandunee Athapattu, Issue on 23 April 2017.

UNEP, 2001. Annual report: Sri Lanka: State of the environment 2001. Regional Resource Centre for Asia and the Pacific UNEP, Pathumthani, Thailand.

UN-HABITAT, 2010. Solid waste management in the world’s cities: water and sanitation in the world’s cities 2010. London, Earthscan.

Van Zon, L., Siriwardena, N., 2000. Garbage in Sri Lanka: an overview of soild waste management in the Ja-Ela area. Report, Free University of Amsterdam, Netherlands.

Vandeweerd, V., Cheatle, M., Henricksen, B., Schomaker, M., Seki, M., Zahedi, K., 1997. Global Environment Outlook (GEO), UNEP Global State of Environment Report 1997, 121-132.

Vidanaarachchi, C., Yuen, S., Pilapitiya, S., 2006. Municipal solid waste management in the Southern Province of Sri Lanka: problems, issues and challenges. Waste Management, 26, 920–930.

Vidanapathirana, R., Wijesooriya, N., 2014. Export market for organic food: present status, constraints and future scope, HARTI Research Report 167, HARTI, Colombo. Sri Lanka.

Visvanathan, C., Glawe, U., 2006. Domestic Solid Waste Management in South Asian Countries – A Comparative Analysis. Paper presented at 3 R South Asia Expert Workshop, 30 August - 1 September, 2006 Kathmandu, Nepal.

Visvanathan, C., Trankler, J., Joseph, K., Chiemchaisri, C., Basnayake, B.F.A., Gongming, Z., 2004. Municipal solid waste management in Asia. In: Asian Regional Research Program on Environmental Technology (ARRPET). Asian Institute of Technology.

Vithanage, M., 2017. Mini review on solid waste management research in Sri Lanka. Paper presented at National Forum on Solid Waste Management, organized by Coordinating Secretariat for Science, Technology, and Innovations (COSTI), 23-24 June 2017, Colombo, Sri lanka.

Weeraratna, C.S., 2013. Fertilizer use in Sri Lanka with special reference to Chronic Kidney Disease of unidentified etiology (CKDu). Paper presented at the Symposium on "Chronic disease of uncertain origin (CKDu): a scientific basis for future action" organized by the National Academy of Sciences of Sri Lanka, 10 December 2013. Colombo, Sri Lanka.

Wickramasinghe, W., 2010, Alternative approaches to substitute chemical fetilizers in the food crop sector: integrated farming system approach and beyond, Working Paper 04, HARTI, Colombo, Sri Lanka.

Wickramasinghe, W., Samarasinha, G., Epasinghe, S., 2010. Fertiliser policy on paddy farming: an evaluation of 2005 subsidy programme. HARTI Research Report 135, HARTI, Colombo, Sri Lanka.

WWAP (United Nations World Water Assessment Programme). 2017. The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource. Paris, UNESCO.

**ZEF Working Paper Series, ISSN 1864-6638**
**Center for Development Research, University of Bonn**
**Editors: Christian Borgemeister, Joachim von Braun, Manfred Denich, Till Stellmacher and Eva Youkhana**

**1.** Evers, Hans-Dieter and Solvay Gerke (2005). Closing the Digital Divide: Southeast Asia's Path Towards a Knowledge Society.
**2.** Bhuiyan, Shajahan and Hans-Dieter Evers (2005). Social Capital and Sustainable Development: Theories and Concepts.
**3.** Schetter, Conrad (2005). Ethnicity and the Political Reconstruction of Afghanistan.
**4.** Kassahun, Samson (2005). Social Capital and Community Efficacy. In Poor Localities of Addis Ababa Ethiopia.
**5.** Fuest, Veronika (2005). Policies, Practices and Outcomes of Demand-oriented Community Water Supply in Ghana: The National Community Water and Sanitation Programme 1994 – 2004.
**6.** Menkhoff, Thomas and Hans-Dieter Evers (2005). Strategic Groups in a Knowledge Society: Knowledge Elites as Drivers of Biotechnology Development in Singapore.
**7.** Mollinga, Peter P. (2005). The Water Resources Policy Process in India: Centralisation, Polarisation and New Demands on Governance.
**8.** Evers, Hans-Dieter (2005). Wissen ist Macht: Experten als Strategische Gruppe.
**8.a** Evers, Hans-Dieter and Solvay Gerke (2005). Knowledge is Power: Experts as Strategic Group.
**9.** Fuest, Veronika (2005). Partnerschaft, Patronage oder Paternalismus? Eine empirische Analyse der Praxis universitärer Forschungskooperation mit Entwicklungsländern.
**10.** Laube, Wolfram (2005). Promise and Perils of Water Reform: Perspectives from Northern Ghana.
**11.** Mollinga, Peter P. (2004). Sleeping with the Enemy: Dichotomies and Polarisation in Indian Policy Debates on the Environmental and Social Effects of Irrigation.
**12.** Wall, Caleb (2006). Knowledge for Development: Local and External Knowledge in Development Research.
**13.** Laube, Wolfram and Eva Youkhana (2006). Cultural, Socio-Economic and Political Con-straints for Virtual Water Trade: Perspectives from the Volta Basin, West Africa.
**14.** Hornidge, Anna-Katharina (2006). Singapore: The Knowledge-Hub in the Straits of Malacca.
**15.** Evers, Hans-Dieter and Caleb Wall (2006). Knowledge Loss: Managing Local Knowledge in Rural Uzbekistan.
**16.** Youkhana, Eva; Lautze, J. and B. Barry (2006). Changing Interfaces in Volta Basin Water Management: Customary, National and Transboundary.
**17.** Evers, Hans-Dieter and Solvay Gerke (2006). The Strategic Importance of the Straits of Malacca for World Trade and Regional Development.
**18.** Hornidge, Anna-Katharina (2006). Defining Knowledge in Germany and Singapore: Do the Country-Specific Definitions of Knowledge Converge?
**19.** Mollinga, Peter M. (2007). Water Policy – Water Politics: Social Engineering and Strategic Action in Water Sector Reform.
**20.** Evers, Hans-Dieter and Anna-Katharina Hornidge (2007). Knowledge Hubs Along the Straits of Malacca.
**21.** Sultana, Nayeem (2007). Trans-National Identities, Modes of Networking and Integration in a Multi-Cultural Society. A Study of Migrant Bangladeshis in Peninsular Malaysia.
**22.** Yalcin, Resul and Peter M. Mollinga (2007). Institutional Transformation in Uzbekistan's Agricultural and Water Resources Administration: The Creation of a New Bureaucracy.
**23.** Menkhoff, T.; Loh, P. H. M.; Chua, S. B.; Evers, H.-D. and Chay Yue Wah (2007). Riau Vegetables for Singapore Consumers: A Collaborative Knowledge-Transfer Project Across the Straits of Malacca.
**24.** Evers, Hans-Dieter and Solvay Gerke (2007). Social and Cultural Dimensions of Market Expansion.
**25.** Obeng, G. Y.; Evers, H.-D.; Akuffo, F. O., Braimah, I. and A. Brew-Hammond (2007). Solar PV Rural Electrification and Energy-Poverty Assessment in Ghana: A Principal Component Analysis.

**26.** Eguavoen, Irit; E. Youkhana (2008). Small Towns Face Big Challenge. The Management of Piped Systems after the Water Sector Reform in Ghana.
**27.** Evers, Hans-Dieter (2008). Knowledge Hubs and Knowledge Clusters: Designing a Knowledge Architecture for Development
**28.** Ampomah, Ben Y.; Adjei, B. and E. Youkhana (2008). The Transboundary Water Resources Management Regime of the Volta Basin.
**29.** Saravanan.V.S.; McDonald, Geoffrey T. and Peter P. Mollinga (2008). Critical Review of Integrated Water Resources Management: Moving Beyond Polarised Discourse.
**30.** Laube, Wolfram; Awo, Martha and Benjamin Schraven (2008). Erratic Rains and Erratic Markets: Environmental change, economic globalisation and the expansion of shallow groundwater irrigation in West Africa.
**31.** Mollinga, Peter P. (2008). For a Political Sociology of Water Resources Management.
**32.** Hauck, Jennifer; Youkhana, Eva (2008). Histories of water and fisheries management in Northern Ghana.
**33.** Mollinga, Peter P. (2008). The Rational Organisation of Dissent. Boundary concepts, boundary objects and boundary settings in the interdisciplinary study of natural resources management.
**34.** Evers, Hans-Dieter; Gerke, Solvay (2009). Strategic Group Analysis.
**35.** Evers, Hans-Dieter; Benedikter, Simon (2009). Strategic Group Formation in the Mekong Delta - The Development of a Modern Hydraulic Society.
**36.** Obeng, George Yaw; Evers, Hans-Dieter (2009). Solar PV Rural Electrification and Energy-Poverty: A Review and Conceptual Framework With Reference to Ghana.
**37.** Scholtes, Fabian (2009). Analysing and explaining power in a capability perspective.
**38.** Eguavoen, Irit (2009). The Acquisition of Water Storage Facilities in the Abay River Basin, Ethiopia.
**39.** Hornidge, Anna-Katharina; Mehmood Ul Hassan; Mollinga, Peter P. (2009). 'Follow the Innovation' – A joint experimentation and learning approach to transdisciplinary innovation research.
**40.** Scholtes, Fabian (2009). How does moral knowledge matter in development practice, and how can it be researched?
**41.** Laube, Wolfram (2009). Creative Bureaucracy: Balancing power in irrigation administration in northern Ghana.
**42.** Laube, Wolfram (2009). Changing the Course of History? Implementing water reforms in Ghana and South Africa.
**43.** Scholtes, Fabian (2009). Status quo and prospects of smallholders in the Brazilian sugarcane and ethanol sector: Lessons for development and poverty reduction.
**44.** Evers, Hans-Dieter; Genschick, Sven; Schraven, Benjamin (2009). Constructing Epistemic Landscapes: Methods of GIS-Based Mapping.
**45.** Saravanan V.S. (2009). Integration of Policies in Framing Water Management Problem: Analysing Policy Processes using a Bayesian Network.
**46.** Saravanan V.S. (2009). Dancing to the Tune of Democracy: Agents Negotiating Power to Decentralise Water Management.
**47.** Huu, Pham Cong; Rhlers, Eckart; Saravanan, V. Subramanian (2009). Dyke System Planing: Theory and Practice in Can Tho City, Vietnam.
**48.** Evers, Hans-Dieter; Bauer, Tatjana (2009). Emerging Epistemic Landscapes: Knowledge Clusters in Ho Chi Minh City and the Mekong Delta.
**49.** Reis, Nadine; Mollinga, Peter P. (2009). Microcredit for Rural Water Supply and Sanitation in the Mekong Delta. Policy implementation between the needs for clean water and 'beautiful latrines'.
**50.** Gerke, Solvay; Ehlert, Judith (2009). Local Knowledge as Strategic Resource: Fishery in the Seasonal Floodplains of the Mekong Delta, Vietnam
**51.** Schraven, Benjamin; Eguavoen, Irit; Manske, Günther (2009). Doctoral degrees for capacity development: Results from a survey among African BiGS-DR alumni.

**52.** Nguyen, Loan (2010). Legal Framework of the Water Sector in Vietnam.

**53.** Nguyen, Loan (2010). Problems of Law Enforcement in Vietnam. The Case of Wastewater Management in Can Tho City.

**54.** Oberkircher, Lisa et al. (2010). Rethinking Water Management in Khorezm, Uzbekistan. Concepts and Recommendations.

**55.** Waibel, Gabi (2010). State Management in Transition: Understanding Water Resources Management in Vietnam.

**56.** Saravanan V.S.; Mollinga, Peter P. (2010). Water Pollution and Human Health. Transdisciplinary Research on Risk Governance in a Complex Society.

**57.** Vormoor, Klaus (2010). Water Engineering, Agricultural Development and Socio-Economic Trends in the Mekong Delta, Vietnam.

**58.** Hornidge, Anna-Katharina; Kurfürst, Sandra (2010). Envisioning the Future, Conceptualising Public Space. Hanoi and Singapore Negotiating Spaces for Negotiation.

**59.** Mollinga, Peter P. (2010). Transdisciplinary Method for Water Pollution and Human Health Research.

**60.** Youkhana, Eva (2010). Gender and the development of handicraft production in rural Yucatán/Mexico.

**61.** Naz, Farhat; Saravanan V. Subramanian (2010). Water Management across Space and Time in India.

**62.** Evers, Hans-Dieter; Nordin, Ramli, Nienkemoer, Pamela (2010). Knowledge Cluster Formation in Peninsular Malaysia: The Emergence of an Epistemic Landscape.

**63.** Mehmood Ul Hassan; Hornidge, Anna-Katharina (2010). 'Follow the Innovation' – The second year of a joint experimentation and learning approach to transdisciplinary research in Uzbekistan.

**64.** Mollinga, Peter P. (2010). Boundary concepts for interdisciplinary analysis of irrigation water management in South Asia.

**65.** Noelle-Karimi, Christine (2006). Village Institutions in the Perception of National and International Actors in Afghanistan. (**Amu Darya Project Working Paper No. 1**)

**66.** Kuzmits, Bernd (2006). Cross-bordering Water Management in Central Asia. (**Amu Darya Project Working Paper No. 2**)

**67.** Schetter, Conrad; Glassner, Rainer; Karokhail, Masood (2006). Understanding Local Violence. Security Arrangements in Kandahar, Kunduz and Paktia. (**Amu Darya Project Working Paper No. 3**)

**68.** Shah, Usman (2007). Livelihoods in the Asqalan and Sufi-Qarayateem Canal Irrigation Systems in the Kunduz River Basin. (**Amu Darya Project Working Paper No. 4**)

**69.** ter Steege, Bernie (2007). Infrastructure and Water Distribution in the Asqalan and Sufi-Qarayateem Canal Irrigation Systems in the Kunduz River Basin. (**Amu Darya Project Working Paper No. 5**)

**70.** Mielke, Katja (2007). On The Concept of 'Village' in Northeastern Afghanistan. Explorations from Kunduz Province. (**Amu Darya Project Working Paper No. 6**)

**71.** Mielke, Katja; Glassner, Rainer; Schetter, Conrad; Yarash, Nasratullah (2007). Local Governance in Warsaj and Farkhar Districts. (**Amu Darya Project Working Paper No. 7**)

**72.** Meininghaus, Esther (2007). Legal Pluralism in Afghanistan. (**Amu Darya Project Working Paper No. 8**)

**73.** Yarash, Nasratullah; Smith, Paul; Mielke, Katja (2010). The fuel economy of mountain villages in Ishkamish and Burka (Northeast Afghanistan). Rural subsistence and urban marketing patterns. (**Amu Darya Project Working Paper No. 9**)

**74.** Oberkircher, Lisa (2011). 'Stay – We Will Serve You Plov!'. Puzzles and pitfalls of water research in rural Uzbekistan.

**75.** Shtaltovna, Anastasiya; Hornidge, Anna-Katharina; Mollinga, Peter P. (2011). The Reinvention of Agricultural Service Organisations in Uzbekistan – a Machine-Tractor Park in the Khorezm Region.

**76.** Stellmacher, Till; Grote, Ulrike (2011). Forest Coffee Certification in Ethiopia: Economic Boon or Ecological Bane?

**77.** Gatzweiler, Franz W.; Baumüller, Heike; Ladenburger, Christine; von Braun, Joachim (2011). Marginality. Addressing the roots causes of extreme poverty.
**78.** Mielke, Katja; Schetter, Conrad; Wilde, Andreas (2011). Dimensions of Social Order: Empirical Fact, Analytical Framework and Boundary Concept.
**79.** Yarash, Nasratullah; Mielke, Katja (2011). The Social Order of the Bazaar: Socio-economic embedding of Retail and Trade in Kunduz and Imam Sahib
**80.** Baumüller, Heike; Ladenburger, Christine; von Braun, Joachim (2011). Innovative business approaches for the reduction of extreme poverty and marginality?
**81.** Ziai, Aram (2011). Some reflections on the concept of 'development'.
**82.** Saravanan V.S., Mollinga, Peter P. (2011). The Environment and Human Health - An Agenda for Research.
**83.** Eguavoen, Irit; Tesfai, Weyni (2011). Rebuilding livelihoods after dam-induced relocation in Koga, Blue Nile basin, Ethiopia.
**84.** Eguavoen, I., Sisay Demeku Derib et al. (2011). Digging, damming or diverting? Small-scale irrigation in the Blue Nile basin, Ethiopia.
**85.** Genschick, Sven (2011). Pangasius at risk - Governance in farming and processing, and the role of different capital.
**86.** Quy-Hanh Nguyen, Hans-Dieter Evers (2011). Farmers as knowledge brokers: Analysing three cases from Vietnam's Mekong Delta.
**87.** Poos, Wolf Henrik (2011). The local governance of social security in rural Surkhondarya, Uzbekistan. Post-Soviet community, state and social order.
**88.** Graw, Valerie; Ladenburger, Christine (2012). Mapping Marginality Hotspots. Geographical Targeting for Poverty Reduction.
**89.** Gerke, Solvay; Evers, Hans-Dieter (2012). Looking East, looking West: Penang as a Knowledge Hub.
**90.** Turaeva, Rano (2012). Innovation policies in Uzbekistan: Path taken by ZEFa project on innovations in the sphere of agriculture.
**91.** Gleisberg-Gerber, Katrin (2012). Livelihoods and land management in the Ioba Province in south-western Burkina Faso.
**92.** Hiemenz, Ulrich (2012). The Politics of the Fight Against Food Price Volatility – Where do we stand and where are we heading?
**93.** Baumüller, Heike (2012). Facilitating agricultural technology adoption among the poor: The role of service delivery through mobile phones.
**94.** Akpabio, Emmanuel M.; Saravanan V.S. (2012). Water Supply and Sanitation Practices in Nigeria: Applying Local Ecological Knowledge to Understand Complexity.
**95.** Evers, Hans-Dieter; Nordin, Ramli (2012). The Symbolic Universe of Cyberjaya, Malaysia.
**96.** Akpabio, Emmanuel M. (2012). Water Supply and Sanitation Services Sector in Nigeria: The Policy Trend and Practice Constraints.
**97.** Boboyorov, Hafiz (2012). Masters and Networks of Knowledge Production and Transfer in the Cotton Sector of Southern Tajikistan.
**98.** Van Assche, Kristof; Hornidge, Anna-Katharina (2012). Knowledge in rural transitions - formal and informal underpinnings of land governance in Khorezm.
**99.** Eguavoen, Irit (2012). Blessing and destruction. Climate change and trajectories of blame in Northern Ghana.
**100.** Callo-Concha, Daniel; Gaiser, Thomas and Ewert, Frank (2012). Farming and cropping systems in the West African Sudanian Savanna. WASCAL research area: Northern Ghana, Southwest Burkina Faso and Northern Benin.
**101.** Sow, Papa (2012). Uncertainties and conflicting environmental adaptation strategies in the region of the Pink Lake, Senegal.

**102.** Tan, Siwei (2012). Reconsidering the Vietnamese development vision of “industrialisation and modernisation by 2020”.
**103.** Ziai, Aram (2012). Postcolonial perspectives on ‘development’.
**104.** Kelboro, Girma; Stellmacher, Till (2012). Contesting the National Park theorem? Governance and land use in Nech Sar National Park, Ethiopia.
**105.** Kotsila, Panagiota (2012). “Health is gold”: Institutional structures and the realities of health access in the Mekong Delta, Vietnam.
**106.** Mandler, Andreas (2013). Knowledge and Governance Arrangements in Agricultural Production: Negotiating Access to Arable Land in Zarafshan Valley, Tajikistan.
**107.** Tsegai, Daniel; McBain, Florence; Tischbein, Bernhard (2013). Water, sanitation and hygiene: the missing link with agriculture.
**108.** Pangaribowo, Evita Hanie; Gerber, Nicolas; Torero, Maximo (2013). Food and Nutrition Security Indicators: A Review.
**109.** von Braun, Joachim; Gerber, Nicolas; Mirzabaev, Alisher; Nkonya Ephraim (2013). The Economics of Land Degradation.
**110.** Stellmacher, Till (2013). Local forest governance in Ethiopia: Between legal pluralism and livelihood realities.
**111.** Evers, Hans-Dieter; Purwaningrum, Farah (2013). Japanese Automobile Conglomerates in Indonesia: Knowledge Transfer within an Industrial Cluster in the Jakarta Metropolitan Area.
**112.** Waibel, Gabi; Benedikter, Simon (2013). The formation water user groups in a nexus of central directives and local administration in the Mekong Delta, Vietnam.
**113.** Ayaribilla Akudugu, Jonas; Laube, Wolfram (2013). Implementing Local Economic Development in Ghana: Multiple Actors and Rationalities.
**114.** Malek, Mohammad Abdul; Hossain, Md. Amzad; Saha, Ratnajit; Gatzweiler, Franz W. (2013). Mapping marginality hotspots and agricultural potentials in Bangladesh.
**115.** Siriwardane, Rapti; Winands, Sarah (2013). Between hope and hype: Traditional knowledge(s) held by marginal communities.
**116.** Nguyen, Thi Phuong Loan (2013). The Legal Framework of Vietnam’s Water Sector: Update 2013.
**117.** Shtaltovna, Anastasiya (2013). Knowledge gaps and rural development in Tajikistan. Agricultural advisory services as a panacea?
**118.** Van Assche, Kristof; Hornidge, Anna-Katharina; Shtaltovna, Anastasiya; Boboyorov, Hafiz (2013). Epistemic cultures, knowledge cultures and the transition of agricultural expertise. Rural development in Tajikistan, Uzbekistan and Georgia.
**119.** Schädler, Manuel; Gatzweiler, Franz W. (2013). Institutional Environments for Enabling Agricultural Technology Innovations: The role of Land Rights in Ethiopia, Ghana, India and Bangladesh.
**120.** Eguavoen, Irit; Schulz, Karsten; de Wit, Sara; Weisser, Florian; Müller-Mahn, Detlef (2013). Political dimensions of climate change adaptation. Conceptual reflections and African examples.
**121.** Feuer, Hart Nadav; Hornidge, Anna-Katharina; Schetter, Conrad (2013). Rebuilding Knowledge. Opportunities and risks for higher education in post-conflict regions.
**122.** Dörendahl, Esther I. (2013). Boundary work and water resources. Towards improved management and research practice?
**123.** Baumüller, Heike (2013). Mobile Technology Trends and their Potential for Agricultural Development
**124.** Saravanan, V.S. (2013). “Blame it on the community, immunize the state and the international agencies.” An assessment of water supply and sanitation programs in India.
**125.** Ariff, Syamimi; Evers, Hans-Dieter; Ndah, Anthony Banyouko; Purwaningrum, Farah (2014). Governing Knowledge for Development: Knowledge Clusters in Brunei Darussalam and Malaysia.
**126.** Bao, Chao; Jia, Lili (2014). Residential fresh water demand in China. A panel data analysis.

**127.** Siriwardane, Rapti (2014). War, Migration and Modernity: The Micro-politics of the Hijab in Northeastern Sri Lanka.
**128.** Kirui, Oliver Kiptoo; Mirzabaev, Alisher (2014). Economics of Land Degradation in Eastern Africa.
**129.** Evers, Hans-Dieter (2014). Governing Maritime Space: The South China Sea as a Mediterranean Cultural Area.
**130.** Saravanan, V. S.; Mavalankar, D.; Kulkarni, S.; Nussbaum, S.; Weigelt, M. (2014). Metabolized-water breeding diseases in urban India: Socio-spatiality of water problems and health burden in Ahmedabad.
**131.** Zulfiqar, Ali; Mujeri, Mustafa K.; Badrun Nessa, Ahmed (2014). Extreme Poverty and Marginality in Bangladesh: Review of Extreme Poverty Focused Innovative Programmes.
**132.** Schwachula, Anna; Vila Seoane, Maximiliano; Hornidge, Anna-Katharina (2014). Science, technology and innovation in the context of development. An overview of concepts and corresponding policies recommended by international organizations.
**133.** Callo-Concha, Daniel (2014). Approaches to managing disturbance and change: Resilience, vulnerability and adaptability.
**134.** Mc Bain, Florence (2014). Health insurance and health environment: India's subsidized health insurance in a context of limited water and sanitation services.
**135.** Mirzabaev, Alisher; Guta, Dawit; Goedecke, Jann; Gaur, Varun; Börner, Jan; Virchow, Detlef; Denich, Manfred; von Braun, Joachim (2014). Bioenergy, Food Security and Poverty Reduction: Mitigating tradeoffs and promoting synergies along the Water-Energy-Food Security Nexus.
**136.** Iskandar, Deden Dinar; Gatzweiler, Franz (2014). An optimization model for technology adoption of marginalized smallholders: Theoretical support for matching technological and institutional innovations.
**137.** Bühler, Dorothee; Grote, Ulrike; Hartje, Rebecca; Ker, Bopha; Lam, Do Truong; Nguyen, Loc Duc; Nguyen, Trung Thanh; Tong, Kimsun (2015). Rural Livelihood Strategies in Cambodia: Evidence from a household survey in Stung Treng.
**138.** Amankwah, Kwadwo; Shtaltovna, Anastasiya; Kelboro, Girma; Hornidge, Anna-Katharina (2015). A Critical Review of the Follow-the-Innovation Approach: Stakeholder collaboration and agricultural innovation development.
**139.** Wiesmann, Doris; Biesalski, Hans Konrad; von Grebmer, Klaus; Bernstein, Jill (2015). Methodological review and revision of the Global Hunger Index.
**140.** Eguavoen, Irit; Wahren, Julia (2015). Climate change adaptation in Burkina Faso: aid dependency and obstacles to political participation. Adaptation au changement climatique au Burkina Faso: la dépendance à l'aide et les obstacles à la participation politique.
**141.** Youkhana, Eva. Postponed to 2016 (147).
**142.** Von Braun, Joachim; Kalkuhl, Matthias (2015). International Science and Policy Interaction for Improved Food and Nutrition Security: toward an International Panel on Food and Nutrition (IPFN).
**143.** Mohr, Anna; Beuchelt, Tina; Schneider, Rafaël; Virchow, Detlef (2015). A rights-based food security principle for biomass sustainability standards and certification systems.
**144.** Husmann, Christine; von Braun, Joachim; Badiane, Ousmane; Akinbamijo, Yemi; Fatunbi, Oluwole Abiodun; Virchow, Detlef (2015). Tapping Potentials of Innovation for Food Security and Sustainable Agricultural Growth: An Africa-Wide Perspective.
**145.** Laube, Wolfram (2015). Changing Aspirations, Cultural Models of Success, and Social Mobility in Northern Ghana.
**146.** Narayanan, Sudha; Gerber, Nicolas (2016). Social Safety Nets for Food and Nutritional Security in India.
**147.** Youkhana, Eva (2016). Migrants' religious spaces and the power of Christian Saints – the Latin American Virgin of Cisne in Spain.
**148.** Grote, Ulrike; Neubacher, Frank (2016). Rural Crime in Developing Countries: Theoretical Framework, Empirical Findings, Research Needs.

**149.** Sharma, Rasadhika; Nguyen, Thanh Tung; Grote, Ulrike; Nguyen, Trung Thanh. Changing Livelihoods in Rural Cambodia: Evidence from panel household data in Stung Treng.

**150.** Kavegue, Afi; Eguavoen, Irit (2016). The experience and impact of urban floods and pollution in Ebo Town, Greater Banjul Area, in The Gambia.

**151.** Mbaye, Linguère Mously; Zimmermann, Klaus F. (2016). Natural Disasters and Human Mobility.

**152.** Gulati, Ashok; Manchanda, Stuti; Kacker, Rakesh (2016). Harvesting Solar Power in India.

**153.** Laube, Wolfram; Awo, Martha; Derbile, Emmanuel (2017). Smallholder Integration into the Global Shea Nut Commodity Chain in Northern Ghana. Promoting poverty reduction or continuing exploitation?

**154.** Attemene, Pauline; Eguavoen, Irit (2017). Effects of sustainability communication on environments and rural livelihoods.

**155.** Von Braun, Joachim; Kofol, Chiara (2017). Expanding Youth Employment in the Arab Region and Africa.

**156.** Beuchelt, Tina 2017. Buying green and social from abroad: Are biomass-focused voluntary sustainability standards useful for European public procurement?

**157.** Bekchanov, Maksud (2017). Potentials of Waste and Wastewater Resources Recovery and Re-use (RRR) Options for Improving Water, Energy and Nutrition Security.

**158.** Leta, Gerba; Kelboro, Girma; Stellmacher Till; Hornidge, Anna-Katharina (2017). The agricultural extension system in Ethiopia: operational setup, challenges and opportunities.

**159.** Ganguly, Kavery; Gulati, Ashok; von Braun, Joachim (2017). Innovations spearheading the next transformations in India’s agriculture.

**160.** Gebreselassie, Samuel; Haile Mekbib G.; Kalkuhl, Matthias (2017). The Wheat Sector in Ethiopia: Current Status and Key Challenges for Future Value Chain Development.

**161.** Jemal, Omarsherif Mohammed, Callo-Concha, Daniel (2017). Potential of Agroforestry for Food and Nutrition Security of Small-scale Farming Households.

**162.** Berga, Helen; Ringler, Claudia; Bryan, Elizabeth; El Didi, Hagar; Elnasikh Sara (2017). Addressing Transboundary Cooperation in the Eastern Nile through the Water-Energy-Food Nexus. Insights from an E-survey and Key Informant Interviews.

**163.** Bekchanov, Maksud (2017). Enabling Environment for Waste and Wastewater Recycling and Reuse Options in South Asia.

http://www.zef.de/workingpapers.html

## ZEF Development Studies

edited by
Solvay Gerke and Hans-Dieter Evers

Center for Development Research (ZEF),
University of Bonn

Shahjahan H. Bhuiyan
*Benefits of Social Capital. Urban Solid Waste Management in Bangladesh*
Vol. 1, 2005, 288 p., 19.90 EUR, br. ISBN 3-8258-8382-5

Veronika Fuest
*Demand-oriented Community Water Supply in Ghana. Policies, Practices and Outcomes*
Vol. 2, 2006, 160 p., 19.90 EUR, br. ISBN 3-8258-9669-2

Anna-Katharina Hornidge
*Knowledge Society. Vision and Social Construction of Reality in Germany and Singapore*
Vol. 3, 2007, 200 p., 19.90 EUR, br. ISBN 978-3-8258-0701-6

Wolfram Laube
*Changing Natural Resource Regimes in Northern Ghana. Actors, Structures and Institutions*
Vol. 4, 2007, 392 p., 34.90 EUR, br. ISBN 978-3-8258-0641-5

Lirong Liu
*Wirtschaftliche Freiheit und Wachstum. Eine international vergleichende Studie*
Vol. 5, 2007, 200 p., 19.90 EUR, br. ISBN 978-3-8258-0701-6

Phuc Xuan To
*Forest Property in the Vietnamese Uplands. An Ethnography of Forest Relations in Three Dao Villages*
Vol. 6, 2007, 296 p., 29.90 EUR, br. ISBN 978-3-8258-0773-3

Caleb R.L. Wall, Peter P. Mollinga (Eds.)
*Fieldwork in Difficult Environments. Methodology as Boundary Work in Development Research*
Vol. 7, 2008, 192 p., 19.90 EUR, br. ISBN 978-3-8258-1383-3

Solvay Gerke, Hans-Dieter Evers, Anna-K. Hornidge (Eds.)
*The Straits of Malacca. Knowledge and Diversity*
Vol. 8, 2008, 240 p., 29.90 EUR, br. ISBN 978-3-8258-1383-3

Caleb Wall
*Argorods of Western Uzbekistan. Knowledge Control and Agriculture in Khorezm*
Vol. 9, 2008, 384 p., 29.90 EUR, br. ISBN 978-3-8258-1426-7

Irit Eguavoen
*The Political Ecology of Household Water in Northern Ghana*
Vol. 10, 2008, 328 p., 34.90 EUR, br. ISBN 978-3-8258-1613-1

Charlotte van der Schaaf
*Institutional Change and Irrigation Management in Burkina Faso. Flowing Structures and Concrete Struggles*
Vol. 11, 2009, 344 p., 34.90 EUR, br. ISBN 978-3-8258-1624-7

Nayeem Sultana
*The Bangladeshi Diaspora in Peninsular Malaysia. Organizational Structure, Survival Strategies and Networks*
Vol. 12, 2009, 368 p., 34.90 EUR, br. ISBN 978-3-8258-1629-2

Peter P. Mollinga, Anjali Bhat, Saravanan V.S. (Eds.)
*When Policy Meets Reality. Political Dynamics and the Practice of Integration in Water Resources Management Reform*
Vol. 13, 2010, 216 p., 29.90 EUR, br., ISBN 978-3-643-10672-8

Irit Eguavoen, Wolfram Laube (Eds.)
*Negotiating Local Governance. Natural Resources Management at the Interface of Communities and the State*
Vol. 14, 2010, 248 p., 29.90 EUR, br., ISBN 978-3-643-10673-5

William Tsuma
*Gold Mining in Ghana. Actors, Alliances and Power*
Vol. 15, 2010, 256 p., 29.90 EUR, br., ISBN 978-3-643-10811-1

Thim Ly
*Planning the Lower Mekong Basin: Social Intervention in the Se San River*
Vol. 16, 2010, 240 p., 29.90 EUR, br., ISBN 978-3-643-10834-0

Tatjana Bauer
*The Challenge of Knowledge Sharing - Practices of the Vietnamese Science Community in Ho Chi Minh City and the Mekong Delta*
Vol. 17, 2011, 304 p., 29.90 EUR, br., ISBN 978-3-643-90121-7

Pham Cong Huu
*Floods and Farmers - Politics, Economics and Environmental Impacts of Dyke Construction in the Mekong Delta / Vietnam*
Vol. 18, 2012, 200 p., 29.90 EUR, br., ISBN 978-3-643-90167-5

Judith Ehlert
*Beautiful Floods - Environmental Knowledge and Agrarian Change in the Mekong Delta, Vietnam*
Vol. 19, 2012, 256 S., 29,90 EUR, br, ISBN 978-3-643-90195-8

Nadine Reis
*Tracing and Making the State - Policy practices and domestic water supply in the Mekong Delta, Vietnam*
Vol. 20, 2012, 272 S., 29.90 EUR, br., ISBN 978-3-643-90196-5

Martha A. Awo
*Marketing and Market Queens - A study of tomato farmers in the Upper East region of Ghana*
Vol. 21, 2012, 192 S., 29.90 EUR, br., ISBN 978-3-643-90234-4

Asghar Tahmasebi
*Pastoral Vulnerability to Socio-political and Climate Stresses - The Shahsevan of North Iran*
Vol. 22, 2013, 192 S., 29.90 EUR, br., ISBN 978-3-643-90357-0

Anastasiya Shtaltovna
*Servicing Transformation - Agricultural Service Organisations and Agrarian Change in Post-Soviet Uzbekistan*
Vol. 23, 2013, 216 S., 29.90 EUR, br., ISBN 978-3-643-90358-7

Hafiz Boboyorov
*Collective Identities and Patronage Networks in Southern Tajikistan*
Vol. 24, 2013, 304 S., 34.90 EUR, br., ISBN 978-3-643-90382-2

Simon Benedikter
*The Vietnamese Hydrocracy and the Mekong Delta. Water Resources Development from State Socialism to Bureaucratic Capitalism*
Vol. 25, 2014, 330 S., 39.90 EUR, br., ISBN 978-3-643-90437-9

Sven Genschick
*Aqua-`culture´. Socio-cultural peculiarities, practical senses, and missing sustainability in Pangasius aquaculture in the Mekong Delta, Vietnam.*
Vol. 26, 2014, 262 S., 29.90 EUR, br., ISBN 978-3-643-90485-0

Farah Purwaningrum
*Knowledge Governance in an Industrial Cluster. The Collaboration between Academia-Industry-Government in Indonesia.*
Vol. 27, 2014, 296 S., 39.90 EUR, br., ISBN 978-3-643-90508-6

Panagiota Kotsila
*Socio-political and Cultural Determinants of Diarrheal Disease in the Mekong Delta. From Discourse to Incidence*
Vol. 28, 2014, 376 S., 39.90 EUR, br., ISBN 978-3-643-90562-8

Huynh Thi Phuong Linh
*State-Society Interaction in Vietnam. The Everyday Dialogue of Local Irrigation Management in the Mekong Delta*
Vol. 29, 2016, 304 S., 39.90 EUR, br., ISBN 978-3-643-90719-6

Siwei Tan
*Space and Environment in the Industrialising Mekong Delta. A socio-spatial analysis of wastewater management in Vietnam*
Vol. 30, 2016, 240 S., 29.90 EUR, br., ISBN 978-3-643-90746-2

zef

Center for
Development Research
University of Bonn

# Working Paper Series

Author: Maksud Bekchanov

Contacts: mbekchan@uni-bonn.de

Photo: Maksud Bekchanov

Published by:
Zentrum für Entwicklungsforschung (ZEF)
Center for Development Research
Genscherallee 3
D – 53113 Bonn
Germany

Phone: +49-228-73-1861
Fax: +49-228-73-1869
E-Mail: presse.zef@uni-bonn.de

www.zef.de