The Wastewater Reuse Practice in Botswana – a Challenge for the Development of the Water Sector

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Abstract

The paper presents different aspects of the wastewater reuse practice in terms of formulation and choice of strategies and approaches, and the development and implementation of projects. Also, it presents international experience in the field, common drawbacks in Botswana and lessons to be learned. As an example, the results of a study of an existing institutional wastewater reuse plant (at BOTEC) are presented and critically assessed. Results from this specific study, as well as other information from literature sources, are analyzed. The need to implement a systematic approach to the development of such projects, where the treatment and the reuse options are viewed and developed as two mutually interrelated entities, and the need of a sound preliminary survey, together with the need for public awareness and involvement, are emphasized. Recommendations are made in order to implement a cost-effective and sustainable wastewater reuse practice.

Keywords: municipal wastewater, wastewater reuse, project management

1. INTRODUCTION

Water reuse is widely used practice of beneficial use of partially treated wastewater and it could be applied to different types of industrial and municipal wastewater. Considering the scarcity of fresh water resources worldwide, water reuse in different forms is an important aspect of any effective and sustainable water resources management practice, but it is of greatest importance for arid regions and countries as Botswana. Different forms of municipal water reuse include the application of treated (reclaimed) wastewater for irrigation purposes, recharge of aquifers, washing/ moisturizing of inert materials and others. Water reuse for irrigation purposes is strongly recommended, because of the nutrients content in treated wastewater, which enhances plants growth. If wastewater were not reused, but need to be discharged in natural water bodies, it would necessitate an additional stage of treatment to remove nutrients in order to prevent eutrophication of water resources.

Internationally, the vast majority of water reuse cases apply to centralized wastewater systems, where water is collected from the whole population center and is treated in large treatment facilities, correspondingly the treated wastewater generated comprises a bulk volume and its beneficial reuse requires complex design and operation structures, and in the case of irrigation – large irrigation and storage areas. A relatively new development in the wastewater reuse practice is the introduction of decentralized wastewater collection and treatment systems, which allow localized treatment and reuse, applicable to individual households, blocks of flats, institutional organizations, farm houses, recreational complexes, etc. In such cases, the collection, treatment and reuse of municipal wastewater water is a relatively non-expensive and easy to operate and maintain practice, where treated water could be used for irrigation of gardens and small-scale agricultural activities, washing of courts, etc. A possible modification of these systems is the introduction of separate collection, treatment and reuse of black and gray water, possibly in conjunction with storm runoff, in order to reduce treatment costs. *Black* water is the wastewater generated by the use of toilets, while *gray* water is the wastewater generated from washing and cooking activities.

The objective of this paper is to discuss different aspects of wastewater reuse in terms of general strategies and approaches, as well as, the development and implementation of such type of projects in the practice. In addition, the paper aims to present international experience in the field, common drawbacks in Botswana and lessons to be learned. As an example to illustrate some problems in this direction, the results of a case study of an existing institutional wastewater reuse plant are presented.

2. SYSTEMS ANALYSES AND RELIABILITY

The application of wastewater reuse practice requires a systematic approach to the solution of the problem. The first aspect to be considered is the analysis of the wastewater system as a whole, its interaction with the water supply and distribution system, as well as its dependence upon the natural water resources at a catchment, national or regional level. It should be emphasized that the quantity and quality of wastewater to be reused depend entirely on the water quantity supplied to the community and future projections for population increase. An optimal wastewater reuse technology in terms of cost-effectiveness and social/environmental issues would consider the available sources of water to be used for different types of beneficial use and the environment. In arid countries, such as Botswana, different types of wastewater reuse options could be applied and their applications are usually competitive or less costly compared to classic wastewater treatment options, which envisage discharge of the treated effluent into natural water bodies. This is due to the fact that the transport of fresh water at large distances and the high water quality requirements, when the treated wastewater is discharged into an ephemeral river, make classic water and wastewater systems much more expensive, compared to wastewater reuse options, which could reduce considerably the need of fresh water supply at a lower level of wastewater treatment. Therefore, an analysis of the available fresh water resources, in terms of quantity and quality, and their capacity to provide for beneficial uses of water and to receive wastewater effluents, as well as for a safe and ecologically acceptable aquatic environment, is the first step in the system analyses process. As result of this step wastewater reuse strategies could be formulated.

Another aspect of the system analysis process relates to the wastewater system itself. Centralized wastewater systems provide a bulk amount of treated water, where the level of treatment will depend on the type of beneficial reuse. In most cases, wastewater treatment plants form an integrated part of the wastewater system and are functional during the analysis process. Therefore, the design of wastewater reuse systems should consider the existing capacity of the plant in terms of quantities and qualities and its ability to provide effluents for a designated beneficial reuse. The system analysis in this direction would consider different reuse options, the need of upgrading or altering the existent sewerage and treatment facilities, as well as appropriate design parameters. It should be emphasized that in cases when water demand management strategies are implemented, which encourage reduction of the domestic water use, it would reflect in a smaller volumes of wastewater available for reuse and a higher concentration of contaminants, requiring in some cases specific treatment approaches. In addition, if within the limit of a sewered urban development on-site wastewater reuse activities are encouraged, such as gray water reuse or other techniques, this would reflect on a serious reduction in the wastewater flow with corresponding problems for the sewer system in terms of flow transportation, resulting in reduced flow velocities, sediments depositions, clogging, poor ventilation and a general malfunction of the sewer system. Such cases have been reported in Windhoek and the municipal authorities have considered them in their regulations [1]. Thus, the lack of a sound wastewater reuse strategy could jeopardize the benefits of this practice. The analysis of the wastewater system as whole and the specific conditions would allow the local authorities to elaborate an urban development strategy and provide for a sound regulatory basis in this direction. The application of decentralized systems would be a viable and highly recommendable solution, in the case of sewer systems, which have reached their capacity. Future upgrading should consider in what direction to develop the system, whether increasing the capacity of the centralized system, with consideration for the expansion of the reuse option as well, or providing for a decentralized systems with a closed loop cycle in terms of wastewater disposal and reuse.

The third aspect with respect to a systematic analysis would be the link between the wastewater treatment facility and its effluent reuse facility. In many cases of reuse of municipal effluent for irrigation purposes this link is grossly neglected. The wastewater treatment plant is usually under the management of the local authorities, while the irrigation system is managed by different entities. In some cases problems might arise from errors during the design stage, where wrong design parameters have been used, or provision for protection structures of the irrigated fields have not been done. In other cases, problems might arise from ineffective management practices or neglect. In any case of wastewater reuse it should be well understood that the output of the treatment plant is the input of the reuse option and during the design and the operation of the system, the reuse option should be able to absorb any fluctuations in the quantity or quality of the plant effluent without public health or environmental risks. In the practice of wastewater reuse, however, there are numerous cases when such an approach has not been applied. Several cases of wastewater and sludge reuse for irrigation purposes, which have become sources of diffuse pollution of surface and ground water resources or the soil structure, have been reported [2]. Considering the above-mentioned, one very important aspect of the practice of wastewater reuse is the provision of reliable output of the wastewater treatment plant, in terms of quantity and quality of the effluents. It is necessary to bear in mind this aspect during the design and the operation of the wastewater reuse system and to provide a sound monitoring strategy in order to control the effluents quantity and quality regularly, as well as the possible impacts on the reuse system after long periods of time.

Finally, the systematic approach to the wastewater reuse practice and the analysis of the data available for each specific case would allow to formulate clear objectives in respect to a wastewater reuse policy in the locality and to provide a sound regulatory basis for its implementation.

3. THE PRELIMINARY STAGE

Civil engineering projects in general require a well-designed preliminary stage of investigation in order to avoid major errors and to provide technical solutions at an optimal cost. With respect to wastewater reuse projects this requirement is even more important considering the possible public health end environmental hazards. The preliminary stage of wastewater reuse projects should fulfill the following tasks:

- Data collection and analysis with respect to:
  - Wastewater quantity and quality with corresponding seasonal and diurnal variations;
  - The status of natural (surface and ground) water quality and variations, including hydrologic information;
  - The geological site conditions with corresponding properties, including soil characteristics in cases of wastewater reuse for irrigation purposes;
  - Geographical data in the form of maps or GIS;
  - Development trends and population projections;
  - Local, national, regional and international regulatory instruments and design criteria;
  - Available tools for the design and assessment of different wastewater reuse options and interactions with the built and natural environment.

- Choice of suitable design criteria and benchmarks of the project.
- Development of several alternatives of wastewater reuse, suitable for the locality, in order to achieve the formulated objectives;
- A first approximation of the cost of the different alternatives and assessment of the advantages and disadvantages of each one of them, in terms of technical, social economic and environmental aspects;
- Risk assessment and analysis of the different alternatives;
- Cost assessment and economic analysis.

4. THE CASE STUDY

4.1 The study area

An investigation with respect to an existing and functioning institutional wastewater treatment plant was performed, aiming at the evaluation of its performance and design criteria applied. The study was performed during the period March to September 2004 at the Botswana Technology Center (BOTEC) wastewater treatment plant, which has the objective to treat the wastewater from this institution and to reuse it for irrigation of the loans and gardens surrounding the building. It should be emphasized that this case study has the purpose to critically evaluate a specific case and to draw conclusions and recommendations with respect to the application of this practice in general. It should be emphasized that the specific results of this study might not apply to other cases, but should serve as an example for a critical assessment of other cases of wastewater reuse.

A schematic representation of the treatment plant is shown on Fig. 1. The treatment scheme includes a septic tank (ST), serving as a sedimentation basin, followed by a planted rock filter (PRF), followed by a nitrification column (NC - a biofilter with corrugated plastic blocks for biofilm formation), followed by a free surface flow wetland. The outflow from the wetland (when available) would be used for irrigation of the loans and the gardens. During the period of study, no outflow from the wetland was recorded.

The survey shows that during the investigation the staff at BOTEC was 107 persons, but not the full staff establishment should be considered as generating wastewater, as some are often on business trips or on leave. Also, the institution has a small restaurant at its premises, which contributes to the total wastewater quantity, but during the study it was marginally functioning and its contribution could be neglected.

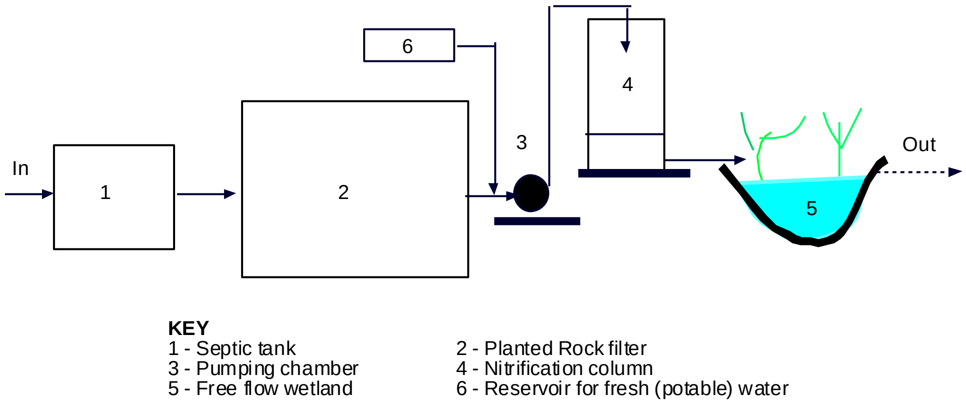

Figure 1. A schematic representation of the BOTEC wastewater treatment plant

4.1 Methodology

Samples have been collected on three sampling occasions for locations SP1 and SP2, representing the inlet and the outlet to the nitrification column. Other sampling locations were not identified, as during the period of study no wastewater flow to the nitrification column and the wetland was directed, but the wetland was maintained by limited amounts of potable water and portion of it has dried. Composite samples have been taken for a period of 2 hours at 30 min. intervals from both sampling locations. Field measurements and laboratory tests were performed with respect to BOD, total suspended solids (TSS), total solids (TS), conductivity, pH, temperature, fecal coliforms (FC), total coliforms (TC), sodium (Na), potassium (K) and total phosphorous (TP) according the Standard Methods [3]. TP has been determined by the Vanadomolybdophosphoric acid colorimetric method after nitric acid-sulfuric acid digestion, ammonia was determined by selective electrodes method and the FCs were determined by the membrane filtration method, and BOD as BOD_5. Temperature measurements were determined on the field for each fraction of the composite samples and averaged. The sampling procedure was executed after full cleaning of the septic tank and following a period between one and three months after it started functioning normally. During the fill up of the septic tank, records of the water level were taken daily at two hours interval from 8 a.m. to 5 p.m. Results were used to calculate the actual wastewater quantities generated during this period, based on 15 working days data.

Statistical data analysis of the data sets for the determination of mean values and standard deviations has been done based on EXCEL standard statistical tools, at 95% confidence interval.

4.2 Results

The actual wastewater quantity generated obtained during the period of study was 4.6 m^3/d with a standard deviation of 0.451, determined as a volume generated during working hours. The variation of the water level during the night was very low to negligible, pointing out that after working hours and during weekends or public holidays no wastewater was generated, which is consistent with the observations on the site. Also, it is an indication that there were no substantial leakages from faulty taps or toilets in the institution. Based on the average daily volume it could be calculated that the actual wastewater generated during this study was 43 l/person.day, which is released from 8 a.m. to 5 a.m. This figure represents a half of the figure anticipated during the design process of 90 l/person.day [4]. Considering the fact that for the institutional water demand no use of water is made for bathing and cooking, together with a reduced number of toilet use, as well as the general attitude to save water, the figure obtained during this study is realistic and shows that the design figure has been grossly overestimated.

The diurnal flow variation was calculated based on averaging flow volumes over the two hours intervals. Mean values over the period of observation are shown in Fig. 2. It shows that peak flow rates are observed around lunchtime. The average daily flow rate was 0.45 m^3/h, with an average maximum flow rate of 0.72 m^3/h, indicating to a maximum hourly peak factor of 1.6. The maximum peak flow rate observed during the period of study was 0.83 m^3/h (10h – 12h). The high flow rates observed during the periods 10h – 12h and 12h – 14h were consistent during the period of measurements.

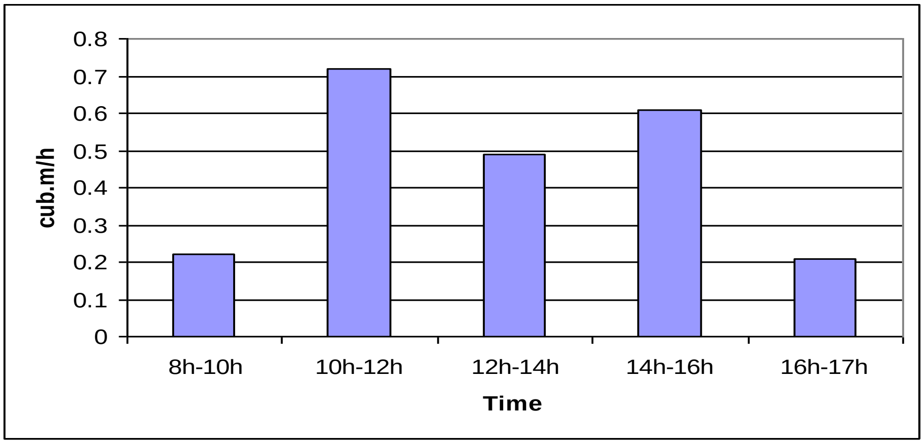

Figure 2. Diurnal variation of flow rates at BOTEC wastewater treatment plant

Due to the time limitations of the study and the lack of a discharge measurement device it is difficult to estimate seasonal flow rate variations, but it is advisable to perform such exercise after each cleaning procedure of the septic tank in order to obtain information regarding the wastewater quantities for control and optimization of the treatment process.

Results with respect to the qualitative aspect, describing the plant performance during the study period, are presented in Table 1. During the investigation, the plant was not under normal operation conditions, as the wetland was almost dry and was cleaned from excess vegetation. Only the septic tank and the planted rock filter were functional. The results show that the PRF was achieving a substantial reduction in BOD and TSS, with treatment efficiencies of 79% and 57% respectively. A partial reduction has been shown with respect to ammonia, TP and FC with treatment efficiencies of 44%, 16% and 11% respectively. The variation of pH values from 6.3 (slightly acidic conditions, typical for ST effluents) to 7.12, show that the conditions in the PRF are aerobic, enhancing partial degradation of the ammonia and an increase in the pH value. Conductivity values are relatively high, typical for ST effluents and could not be expected to change throughout the system. The expected high salts concentration is supported by the relatively high Na concentrations. K is an essential parameter, enhancing plant growth, and would be a positive factor if the treated effluent were reused for irrigation.

During the design process, the initial water quality characteristics of the raw water were assumed based on literature data [4]. A comparison with this data was done, considering the expected removal efficiencies during the process of sedimentation and a COD/BOD ratio of 1.6 [5, 6].

Table 1 Water quality characteristics at BOTEC wastewater treatment plant

Parameter	SP1		SP2	
	Mean value	Standard deviation	Mean value	Standard deviation
PH	6.30	0.173	7.12	0.254
Temperature (ºC)	21.10	3.554	20.37	3.362
Conductivity (µS/cm)	1415	16.503	1373	14.107
TS (mg/l)	412.50	5.333	209.33	3.204
TSS (mg/l)	76.47	3.595	33.43	2.212
BOD (mg/l)	150.67	3.055	31.00	3.606
Ammonia (mg/l)	24.13	12.914	13.60	11.247
TP (mg/l)	13.73	1.295	11.52	0.877
Na (mg/l)	36.00	7.565	37.24	6.736
K (mg/l)	60.79	9.112	44.24	9.618
FC (number/100ml)	18166	5392.897	16166	4536.886
TC (number/100ml)	11233	2482.606	10133	1724.336

Also, it is important to consider the fact that the septic conditions result in the release of soluble elements as TP and ammonia from the sediments decomposition, and correspondingly, the effluents from the ST could have increased concentrations with respect to TP, ammonia and conductivity. As result of this comparison, it was found that the actual characteristics are comparable with the assumed design data with respect to TSS, TP, and FC. The assumed COD value of 1495 mg/l looks high, compared to the actual measurements. The anticipated ammonia value of 97 mg/l is way above the actual measured values. It could be expected that the actual water quality characteristics at SP1, with respect to ammonia, TP and conductivity, could be increased after the accumulation of a larger volume of sediments in the tank, but not at the extent of the assumed values.

4.3 Discussion

The choice of technology of a wastewater treatment plant depends primarily on the quality of the raw water to be treated and the desired qualitative characteristics of the effluent, based on the consequent fate of their disposal or reuse. Regulatory instruments and guidelines usually describe the effluent characteristics for different cases of disposal or reuse. Additional factors during the process of selection of an appropriate technology are the flow rates to be treated, specific requirements with respect to climatic conditions, availability of land, materials and manpower, and the level of complexity and cost of the operational and maintenance (OM) procedures. An optimum choice of a wastewater treatment technology would achieve the quality objective requirements at a minimum cost, e. g. in many cases the quality objectives could be achieved by different treatment technologies, but the optimum one would require minimum capital and OM cost for its implementation. In the case study of BOTEC the effluent quality objectives selected during the design stage [4.] were based on water quality regulations for irrigation water and are as follows: COD < 75 mg/l, TSS < 25 mg/l, ammonia < 10 mg/l and FC < 1000/10ml. The objective with respect to ammonia is questionable, given the fact that many international guidelines [6, 7, 8, 9] do not specify this parameter, as it is a nitrogen compound and is commonly used in manufactured fertilizers. The reason for limiting ammonia concentrations in effluents is related to its toxicity to aquatic life. The consideration of this objective parameter during the design stage resulted in the choice of technology (shown in Figure 1), which incorporates the nitrification column, followed by the wetland. During the actual functioning of the plant, the column has never worked properly, as there is not a visible indication of biofilm formation in the filter bed, therefore it is an element of the treatment technology, which could be omitted, resulting in reduced capital and OM cost. This example shows the importance of a correct choice of water quality objectives during the design stage of wastewater reuse systems.

The large discrepancies between the anticipated design characteristics of the influent and the actual ones show that the plant under consideration is grossly over designed, which would result in a higher capital and operational cost of the system. Thus the importance of accurate preliminary investigation is evident, if the practice of wastewater reuse could be considered as a cost-effective alternative of the normal practice of landscape irrigation with potable water.

Another important aspect to be considered in this specific case is the lack of a systematic approach to the problem. The design procedure gives emphasis on the wastewater treatment plant and nothing has been done with respect to the irrigation site. The experience during the process of exploitation, as well the analysis of the data during this study shows that the treated effluent quantity is not enough to sustain even the wetland, which requires addition of potable water for its normal functioning. The systematic analysis of the plant shows that the wetland serves as a polishing treatment step and as the disposal site of the treated effluent, considering the high evaporation and evapotranspiration rates in Botswana. Effective outflow from the wetland could be expected only during periods of intensive and frequent rains but in such cases water for irrigation will not be necessary. A proper design approach to a wastewater reuse system would require the consideration and the design of both – the wastewater treatment facility and the effluent reuse facility. If the latter would be an irrigation site, consideration should be given to the quantity and quality of the effluent to be reused, the size of the irrigation field, which could be sustained by the generated effluent, as well as, to the need for storage facilities or other alternatives to dispose the effluent, when irrigation is not necessary. In addition, the type of vegetation to be irrigated and the type of irrigation facilities, and an irrigation schedule should be included during the design process. The choice of subsurface irrigation techniques could reduce considerably the cost of the wastewater treatment plant, because the effluent quality objectives in this case are not stringent.

Wastewater reuse could be applied at different levels – at the level of a municipal wastewater treatment plant (centralized systems), at the level of institutions or separate urban developments (decentralized systems) or at household level (on-site sanitation). Nevertheless the scale of application, one essential requirement is the proper operation and maintenance of the wastewater treatment facility as the primary provider of the effluents to the reuse system [10, 11]. The need for a high reliability of the wastewater treatment process has already been emphasized, but in many practical cases, as well as in the case of BOTEC, these facilities lack regular cleaning and maintenance practice.

5. THE NEED FOR CAPACITY BUILDING

The proper design, operation and maintenance of wastewater reuse systems, together with the need for system analysis, would require the involvement of professionals, with corresponding expertise and specialization. It could not be expected that a general background specialist could be able to assess correctly the specific conditions and fulfill the task, especially in the case of large projects. It is not the aim of this paper to give specific recommendations in this direction as the different cases would need different approaches and measures, but to mention that during the design stage of any wastewater reuse project, a clear indication should be given to the operational and maintenance procedures, including water quality monitoring requirements and staff establishment, with corresponding level of expertise. With respect to existing facilities, a regular revision of the existing practice is essential, together with the need for training of the personnel involved. The development of a management program, indicating the objectives, different types of activities, including training of the personnel involved, timeframes for execution, and financial backup could contribute in this direction. The role of academic institutions and training centers is evident, as they should provide for competent and committed professionals in the field.

6. THE PUBLIC AWARNESS AND INVOLVEMENT

Public awareness and involvement form an essential part of the efforts to implement successfully a wastewater reuse project, especially for large projects. The development of a public awareness program (PAP) as part of the activities of the organization, which would execute the project, is a very important step, in order to streamline the efforts of all stakeholders, prepare a sound plan of the activities to be undertaken, and to provide for the resources and financial backup. In a PAP we could differentiate two main streams:

- Continuous and regular public information and education programs;
- Specific public awareness campaigns related to a defined event or specific objective.

The most important step in designing a PAP is to identify the term "public". There are different levels of involvement of different sectors of the public, based on technical expertise, job duties, levels of concern and willingness to invest time and effort. Therefore, different types of public education and involvement will be required to reach the different sectors or groups. A broad classification could include:

- Stakeholders - this group involves the parties directly concerned with the activities of the project (legitimate stakeholders) and other interested parties, such as communities, environmental groups and non-governmental organizations, related to the PAP objectives.
- Press and media
- General public

Considering the public health and environmental risks, associated with the implementation of wastewater reuse projects, public involvement would provide for a wide basis of understanding and support for the project and differentiation of responsibilities. A proper public education and involvement program could help to minimize the risks associated with wastewater reuse, especially in the cases when a centralized plant offers wastewater for reuse by the public. In such cases, clear instructions with respect to the specific types of beneficial reuse must be given.

6. CONCLUSIONS

Wastewater reuse should be viewed as a viable option to augment the available water resources in Botswana, considering the scarce fresh water resources. However, its practical implementation would require a new approach to the existing practice of design and operation of wastewater treatment and reuse options, as well as a the development of a general strategy with respect to the future development of wastewater systems in the larger urban population centers. Based on the specifics for each locality, such strategy should emphasize the future development of wastewater systems as centralized, decentralized or mixed pattern systems, thus providing the basis for the development of specific wastewater and storm water management programs by the local authorities. Such a strategy could be developed by local authorities or at national level and should be considered during the process of assessment, allocation and development of the available water resources. With respect to smaller population centers and institutions in remote areas the wastewater reuse applications should be strongly encouraged, preferably by application of simple, cost effective and robust treatment technologies, which do not require high level of expertise for their maintenance, followed by beneficial reuse techniques, such as irrigation of landscape features and gardens, tree plantations, pastures, and small scale agriculture of crops, which are not consumed raw.

The effective application of the wastewater reuse practice require a sound regulatory basis, stating clearly the different levels of the effluent quality objectives, based on preferred reuse options, and other requirements, which would protect the public health and the environment.

In all cases of wastewater reuse applications, the following recommendations could be done:

- A sound preliminary data collection and investigation process, together with the evaluation of different treatment and reuse alternatives, should form the basis of any wastewater reuse project.
- A systematic analysis and development of both the reuse and the treatment option should be applied since the initial stage of the project development;
- The tendering process for wastewater reuse projects should include the above-mentioned requirements, and preferably should provide the regulatory documents to the parties, which would design and operate the wastewater treatment and reuse system.
- Public involvement and awareness programs should form an essential part of wastewater reuse projects.

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