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Eco-Sustainable Approach in Rural Housing: Handling Village Wastewater through Natural Treatment Systems

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ABSTRACT

This study assess the long-term sustainability for operation and maintenance (O&M) of constructed wetland based sewage treatment system. The study focused on the integrated assessment of an engineered constructed wetland followed by fish pond of 0.5 million liters per day capacity in the Pipar Mazra Village, District Ludhiana, the State of Punjab, northern India. Major areas during the assessment included health, environmental, societal and institutional views aspects as well as the quality of treated effluent subjected for reuse. The treatment facility met the Indian regulatory standards (downstream reuse and discharge into the legally permitted water bodies) in terms of physical-chemical parameters. The total coliform and faecal coliform removal was up to 2 - 3 log units, nevertheless it was not capable to come across the bacterial count requirement (<1000 per 100 mL to minimise human health risk in aquaculture practices). The wastewater treatment facility was able to generate enough profits which utilised for routine O&M. Annual revenue collected by the Gram Panchayat from the lease of the facility as well as selling of treated wastewater was $1,029 and $294 – $441, respectively. The additional benefit from the facility to the farmers included the saving of fertilizers and cheaper source of treated wastewater available for irrigation. Recycling of treated sewages for irrigation is also returned nutrients to the surrounding farms around the facility. The system has saved significant quantities of chemical fertilizer (0.766 – 1.132 Ton of nitrogen, 0.383 – 0.456 Ton of phosphorous and 2.372 – 3.650 Ton of potassium per year) and the overall benefit for farmers during cultivation of one acre of crop was calculated to be approximately $74 per year.

Keywords: Constructed wetland; Natural treatment systems; Water conservation; Wastewater treatment.

1. INTRODUCTION

India is a nation of villages where almost 70 percent of the country's population lives in rural areas. It has been estimated that about 500,000 rural and tribal communities (<5,000 population each), having a cumulative population of approximately 600 million, are still aspiring for having sewage treatment plants (STPs) in their respective communities (Kumar and Asolekar, 2016). This huge population is generating large volume of wastewater that are continued to discharge into natural watercourses, including rivers, lakes and ponds that leading to its pollution (Kumar *et al.* 2015a; Kumar *et al.* 2015b). This resulted in contamination of the major rivers and streams across across India and posing a severe threat to the human and ecosystems health (CPCB, 2009). In addition, excessive withdrawal of groundwater for agricultural and other utilities has posed a problem of rapid decrease in groundwater table which seems to be a major impediment in the path of development of any rural community as mostly livelihood depends on agriculture (Kumar *et al.* 2015c). Therefore, to maintain the pace of development in rural communities, it is the urgent need to make the society "zero water deficits". This can be achieved only when an appropriate water management and conservation strategy being adopted through development of zero liquid discharge (ZLD) facilities to fulfill the aim of self sustenance.

During the past four decades, Government of India (GoI) has made concerted efforts to treat sewages and sullages from communities all over the country. In this endeavour, GoI has implemented more than one hundred natural treatment system including constructed wetlands for wastewaters management in small communities (rural and peri-urban) across the Nation (Goyal, 2014; Kumar and Asolekar, 2016). Interestingly, in the recent past, communities have accepted constructed wetland based STPs due to its several merits and are capable of giving adequate treatment to wastewaters for irrigation of farms and agro-forests (CPCP, 2009; Starkl *et al.* 2013; Starkl *et al.* 2014).

Moreover, In India, an appropriate climate conditions and availability of land have attracted the policy makers to choose constructed wetland as a suitable technological option for cost-effective management of wastewaters in rural and peri-urban areas. However, the studies published in the Indian context related with integrated assessment of the prevailing treatment facilities – especially about the overall treatment performance, reuse potential of treated wastewater, associated health risks, institutional and operational aspects, and economic aspects, are missing. Hence, the work was undertaken to fulfill this gap of this esteemed research area. This paper presents the results from the recently environment friendly conducted integrated assessment of the constructed wetland based STPs facility in village Pipar Majra, district Ludhiana, the State of Punjab, Northern India. This facility was created under “National Rural Employment Guarantee (NREGA) Act 2005”, which utilized some of the desirable features like use of eco-centric technology, least O&M costs, production of a better quality of treated sewage and creation of a pond within the village which provides irrigation water and flood protection for the surrounding community. The learning from the integrated assessment was utilized to develop a Constructed Wetland facility in Ibrahimpur Revenue Village, district Haridwar, the state of Uttarakhand, northern India, by retrofitting and up-gradation an existing pond. Also, the principles of local integrated water resource management (IWRM) are being implemented in developing a village water conservation plan, which includes natural wastewater treatment systems aimed at catalyzing the rural development.

2. STUDY SITE

There are several locations across India, where constructed wetlands are in practice for wastewater management for rural and peri-urban areas. During this study, constructed wetlands based STP in Village Pipar Majra, district Ludhiana, the state of Punjab was selected for in-depth evaluation in the context of managing rural wastewater. Prior to establishment of this facility, untreated wastewater continued to deposit in natural shallow areas around the rural community and has created several problems including, increased mosquitoes population and associated vectors, foul smell, increased risk of groundwater contamination, etc. To handle these issues, in year 2006, Ropar Municipal Corporation has taken indicative in establishment of constructed wetland based STP of 0.50 MLD capacity, aimed to improve sanitation in the village community (Pipar Majra), with financial assistance from the Water and Sewerage Board, Ludhiana as well as from the National Rural Employment Guarantee (NREGA) Act 2005. The STP was designed to receive domestic wastewater from the village community mostly via gutters and open channels.

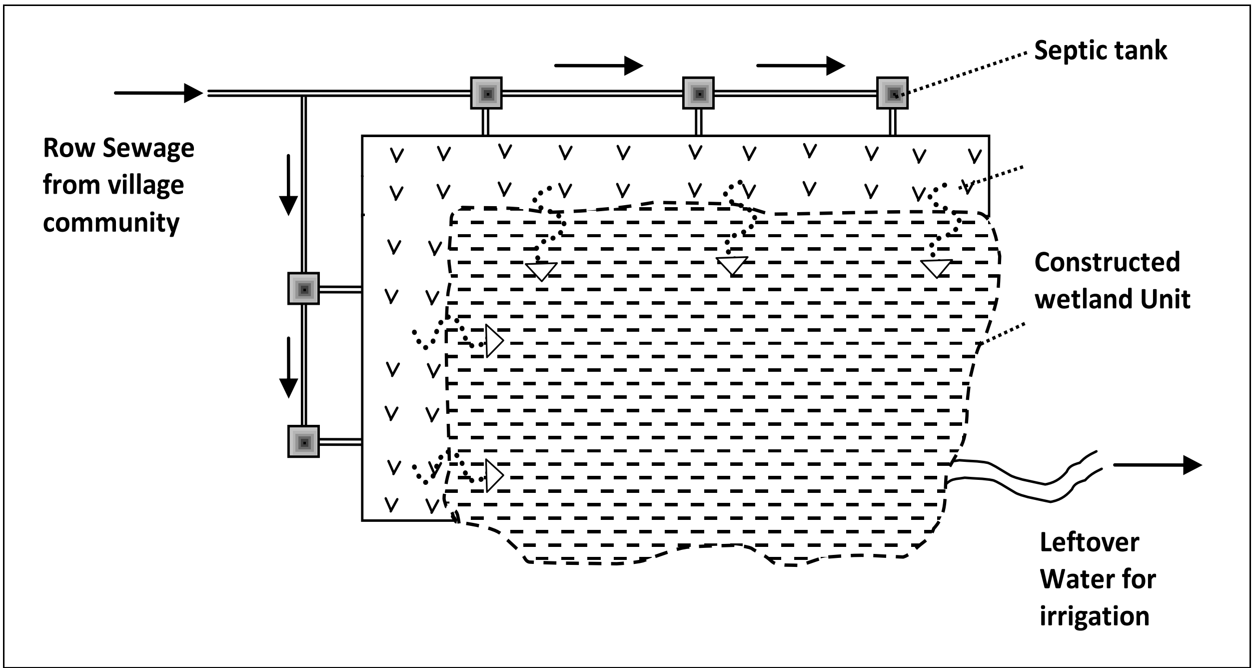

Fig. 1: Treatment scheme adopted at constructed wetland based STP of 0.5 MLD capacity in village Pipar Majra a rural community in the District Ropar, State of Punjab in northern India.

(a) Outflow of septic tank connected to the constructed wetland having *Typha latifolia* (*i.e.* common cattail).

(b) Collected treated sewage from constructed wetland into the fish pond.

Fig. 2: Photographs from decentralized sewage treatment facility of 0.5 MLD capacity in Pipar Majra, a rural community in the district Ropar, the state of Punjab, northern India

The primary treatment is comprised of a grit chamber, bar-screen, and septic tanks. Bar-screen prevents the floating solids from getting into the septic tank which are being routinely cleaned by manual operations. Pre-treated wastewater enters into the septic tank for further treatmemt. The constructed wetland bed is filled with locally available river sand. The bed is planted with locally abundant Typha latifolia plants (Common Cattail). The primary treated effluent from the septic tank further undergoes for secondary treatment through constructed wetland. Further, treated effluent from the wetland unit is discharged into the adjacent fish pond which is being utilised for pisciculture. The process applied for treatment of sewage is pictured in Fig. 1 and Fig. 2.

3. RESEARCH METHODOLOGY

During the integrated assessment of environment friendly natural treatment system for management of wastewater, data were collected related with technical, physical, geographical and social aspects by interviewing operating staff as easily as by utilizing the literature, log records, and progress reports. Interviews with villagers and farmers were also directed to assess the adequacy of treated effluent, any adverse health impacts detected during handling of effluent for irrigation as well as the related monetary value-benefits in comparison with using bore-well water for irrigation. Effluent samples from facility were collected to assess the adequacy treatment. The treatment performance of the facility was assessed for one year by analysing the raw and treated wastewater for three seasons (winter, summer and rainy).

During the sample collection, composite samples were prepared from the inlet and outlet points of the facility. Composite samples were made after taking hourly samples for eight hours (from 9:00am to 5:00pm) to assess the average performance of the facility (Kumar *et al.* 2014). During preparation composit sample, hourly collected samples were right away stored in the icebox and at the end all samples were mixed in a bigger sterilized container and transported to a local lab for detailed analysis.

The wastewater samples were analyzed for conventional physical-chemical and biological parameters. All the collected samples were analyzed within three hours, according to standard methods for examination of water and wastewater (APHA 2005). The parameters including pH, dissolved oxygen were measured during on-site by probe based HACH instrument (model HQ40d). The rest of the physical-chemical parameters including BOD, COD, TSS, total phosphorus and total nitrogen were done as standard five day BOD test, closed reflux titrimetric method, gravimetric methods, stannous chloride method and Kjeldahl method, respectively. The biological parameters including total coliform and fecal coliform were analyzed according to the most probable number (MPN) method followed by the confirmatory tests. All kinds of sample parameters were analyzed in triplicate and average values were reported.

4. RESULTS & DISCUSSION

Integrated assessment of facility carried out for the aspects related with health, environmental, social, institutional, as well as quality of treated effluent subjected for reuse in irrigation in the adjoining fields. The three seasonal performance of constructed wetland based STP of 0.5 MLD capacity in Pipar Majra is given in Table 1.

The constructed wetland facility is being successfully managed for wastewater treatment as well as for revenue generation through fish production, which is being utilized by the Gram Panchayat (village council) to cover the various costs associated with operation and maintenance (O&M). Treatment facility achieved the treated wastewater quality standards in all three seasons prescribed by CPCB New Delhi for discharge of treated effluent into the natural water body or reuse in irrigation (CPCB 2009). During the rainy season, STP received more wastewater than their design capacity that led to increase in the suspended particulate matter in the fish pond – which some time resulted in the killing of fishes. Such kind of associated problems is being overcome by applying lime dose of 5 to 10 kg per event which triggers precipitation of suspended particulate matter which also resulted in simultaneous reduction of biochemical oxygen demand.

Performance of the treatment facility: The performance of the system happens to be satisfactory in terms of conventional pollutant removal as prescribed by CPCB, New Delhi. As stated earlier, samples were analysed partly on the site and partly in the laboratory. The comparative mass removal rates of BOD5, COD and TKN were found higher in summer (average temperature 25°C to 35 °C) when compared with winter and rainy seasons (average temperature 10°C to 30°C). However, the mass removal rates of total phosphorus were found higher in the winter season – which can be attributed to the higher settling of suspended particulates which may slowly relese in near future. Higher percentage removal of organics (BOD and COD) reported in summer was mainly due to enhanced activity of bacterial degradation of biodegradable pollutants in response to increased metabolic activity at optimum temperature in summers. The annual typical range of pollutant removal, namely BOD5, COD and TKN was found between 92 – 96.2% , 75.5 – 85.7% and 62.2 – 74%, respectively.

Table 1: Seasonal performance of constructed wetland based STP of 0.5 MLD capacity in Pipar Majra, a rural community in the district Ropar, state of Punjab.

Parameter	Winter Season				Summer Season				Rainy Season			
	Influent	Effluent	% Removal	Mass Removal Rate (Kg/Day)	Influent	Effluent	% Removal	Mass Removal Rate (Kg/Day)	Influent	Effluent	% Removal	Mass Removal Rate (Kg/Day)
BOD_5 (mg/L)	240	19	92	110.5	260	8	96.2	126	180	12	93.3	84
COD (mg/L)	490	120	75.5	185	455	65	85.7	195	402	66	83.6	168
*p*H	7.3	8.2	--	--	7.3	8.1	--	--	7.2	8.2	--	--
TP (mg/L)	9.3	2.5	73.1	3.4	8.1	2.2	72.8	2.95	7.1	2.1	70.4	2.5
TKN (mg/L)	14.5	6.5	62.2	4	16.2	4.2	74	6	12.6	4.66	63	3.97
DO (mg/L)	0.80	3.1	--	--	0.4	2.6	--	--	0.66	3.2	--	--
TSS (mg/L)	268	45	83.2	111.5	282	66	76.59	108	212	59	72.16	76.5
TCC/100 mL	$2.2x10^6$	$2.3x10^3$	99.895 2.981 log	--	2.3×10^6	10^3	99.956 3.361 log	--	$8.9x10^6$	$2.3 x 10^3$	99.974 2.587 log	--
FCC/100 mL	1.4×10^5	$1.2x10^2$	99.914 3.066 log	--	7.1×10^5	$0.8x10^3$	99.887 2.948 log	--	1.4×10^5	$1.9 x 10^2$	99.864 2.867 log	--

BOD_5 = five day Biochemical Oxygen Demand; COD = Chemical Oxygen Demand; TP = Total Phosphorus; TKN = Total Kjeldahl Nitrogen; DO = Dissolved Oxygen; TSS = Total Suspended Solids; TCC = Total Coliform Count; FCC = Fecal Coliform Count.

In case of total coliform and fecal coliform, slightly higher removals were found in winter as compared with summer which occurred mainly due to combined action of higer precipitation of suspended particulate matter (sweep action) and higher dissolved oxygen (natural degradation), in winters when compared with summers. The total coliform removals during winter, summer and rainy reason were 99.895%, 99.956% and 99.974%, respectively. Fecal coliform removals during winter, summer and rainy reason were 99.914%, 99.887% and 99.864%, respectively. Clearly, the constructed wetland in village Piper Mazra was giving satisfactory performance with respect to the regulatory parameters and therefore found to be suitable for decentralize wastewater treatment and irrigation application in the vicinity.

Reuse of treated wastewater and associated Health risks: The excess treated effluent from fish pond is being reused in irrigation. In treated wastewater irrigated fields, the most popular crops include sugarcane, wheat, rice, millet, maize, barley, jute, cotton, and oil seeds etc. Farmers have realized gain of utilising the treated wastewater as it gives the added benefit of saving on fertilizer purchase up to some extent, hence it is well accepted by the farmers. The crop requirement of chemical fertilizers reduced due to the presence of nutrients (nitrogen and phosphorous) in the treated effluent.

During harvesting of fish from pond, the workers were directly exposed to wastewater. Hence, there could be some occupational health risk to the workers. However, these types of issues can be easily resolved if proper operational practices are followed and adequate safety measures are taken and therefore, should not be considered as system associated problems. According to Martin Strauss, described in RIRDC (2003) and reported by Kumar *et al.* (2015a), the actual public health risk occurring through the use of waste in aquaculture, which may be divided into three main categories; *i.e*., those affecting consumers of the aquatic products grown in wastewater (consumer risk), those affecting the operators of the aquaculture system who might become exposed to treated and/or diluted wastewaters (operators' risk), and those who handle and process the products such as fish (workers' risk).

In all three seasonal performance data of the treatment facility, 2 to 3 log removals of total coliform and fecal coliform bacteria were observed, but still there was a high count of pathogen indicators in the range of 10^2 to 10^3 per 100 mL of wastewater which may cause the health hazard. According to Buras (1987) and also reported by Kumar and Asolekar (2016), that there is little likelihood of enteric organisms, including pathogens, invading edible fish tissues if the fecal coliform count is <1000 per 100 mL. Further, at lower microbial levels in the pond water, the fishes and other aquatic macro-organisms usually accumulate a high concentration of micro-organism in the digestive tract and in the intra-peritoneal fluid (Hejkal *et al.* 1983). Also, the human fecal material is generally considered to be of greater risk to human health as it is more likely to contain human enteric pathogens (Scott *et al.* 2003). Hence, detection enteric micro-organisms (bacteria, viruses, helminths and protozoa) in treated wastewater indicates a public health risk that exists with reuse of secondary treated wastewater. The micro-organism present in treated wastewater may survive in the environment for days, weeks and months in the soil and on crops that come in contact with wastewater.

Furthermore, the presence of fecal bacteria in treated wastewater used for irrigation or discharge into water bodies without any disinfection may cause the severe problems including groundwater and surface water contamination (Kumar *et al.* 2015a). The crop irrigated with wastewater containing high number of fecal bacteria may also pose the problem of food contamination if the grown vegetables (e.g. tomato, carrot, cabbage, beans, cucumber etc.) is eaten uncooked (Kumar *et al.* 2015b).

Operational and Institutional aspects: The trained person appointed for the O&M of treatment facility was selected from the local village community based on prior experience. The operator was well-trained and their main tasks were to clean the bar screen, observe the appropriate flow-pattern of wastewater in the treatment units including septic tanks, constructed wetland and fish pond as well as any nuisance in the fish pond due to excess runoff during rainy season. To operate the facility, only one person has been appointed on a full-time basis (sweeper cum watchman). The rest of the workers required for harvesting of fish were hired as on the need-basis as per the event. Hence, the manpower required for O&M of STP was approximately six times lesser when compared with conventional wastewater treatment systems. All the salaries and wages of the manpower deployed were being recovered from the revenue generated from aquaculture activities. During treatment, it has been observed that the fish count gradually increased towards outlet side of pond which gives the direct indication that fish pond also plays a role in improving the quality of treated effluent.

Economic aspects: Presently, the Gram panchayat have leased the treatment plant for one year to a private contractor for aquaculture practice. In the current lease year, the contractor has paid INR 30,000 ($1,029) to the Gram panchayat. The annual fish production rate of the facility was estimated about 600 to 800 kg, which give raise the profit of INR42,000 – 56,000 ($617 – $823) by selling the fish in the local market at the rate of INR 70 ($1.029) per kg of fish. Additionally, the Gram Panchyat is getting revenue of INR 20,000 – 30,000 ($294 – $441) per year by selling treated wastewater to the farmers. In addition to recycling the treated sewages for irrigation, the nutrients are also being returned to the surrounding farms of the village. As cited by Arienzo *et al.* (2009) and reported by Pettygrove *et al.* (1985) and Emongor *et al.* (2004), the typical potassium concentration in treated sewage range between 13 – 20 mg/L. It would be interesting to note that this practice has saved significant amounts of chemical fertilizer (0.766 – 1.132 Ton of nitrogen, 0.383 – 0.456 Ton of phosphorous and 2.372 – 3.650 Ton of potassium per year). Hence, all expenses incurred during wastewater collection and treatment was easily recovered.

It was found that the farmers using the treated wastewater were also able to save some fertilizers (up to 50 kg of urea and 50 kg of di-ammonium phosphate during cultivation of one acre of crop during one year of the cycle) – which gives the benefit of around INR 1,000 ($15). Furthermore, the cost saving due to utilization of wastewater instead of borewell water gives the benefits of around INR 4,000 ($59) for irrigation of one acre of ground for one year (about 8 - 10 flood irrigations). Hence, farmers get two-way benefits in using of wastewater. These two primary reasons were attractive to farmers and they were enthusiastic to irrigate their fields with treated wastewater only, if available.

Social aspects: The pisciculture activity plays two significant functions; first, helps in recycling of nutrients from wastewater and reduce eutrophication and second, supply of fish at the affordable rate to the community. The availability of fishes at affordable price may help in improving the nutritional balance in the vicinity by providing high-protein food. Also, The treatment facility was utilizing the waste from the gram Panchayat and producing treated effluent for irrigation, while at the same time increasing income and employment.

The treatment facility has created employment for the nearby community as well as providing low-cost fish (INR 70 per kg or ≈ $1.029 per kg) for poor communities. More than 10 persons are involved during harvesting of fish as well as selling it in the local market. As discussed earlier, the treated effluent having ample amount of nutrients (nitrogen, phosphorus and potassium) for the benefits of cultivated crops. The overall benefit for farmers by using the treated effluent for cultivation of one acre of crop was estimated to be about INR 5000 ($70 to $75) per year. Thus, in the long run, such profits may be helpful in improving the socioeconomic condition of the farmers. An added benefit observed from the treatment facility was the better quality of treated wastewater as compared to conventional treatment process. The rate of fish survival and its production during wastewater treatment is a direct index of the quality of treated effluent. Further, high organic loadings into ponds subjected to fish kills. When the facility is being operated and managed efficiently, the resulted superior quality of treated wastewater leads to tangible social benefits.

5. CONCLUSION

The integrated low-cost environment friendlywastewater management systems through constructed wetland followed by reuse of treated wastewater in irrigation is effectively preventing the eutrophication of recipient water resources and reduced the water demand for the agriculture sector. The multiple benefits may arise from the natural treatment system based on constructed wetland for wastewater treatment if appropriately manage. It may be attractive and one of its kind for wastewater treatment and resource recovery. The wastewater treatment facility takes the wastewater from the village community and returns high-protein food in the form of fish and treated wastewater for irrigation while at the same time create employment and preserve the environment. The overall performance of the wetland facility was found to be in compliance to the guidelines prescribed by CPCB, New Delhi for disposal of treated effluent into the natural water bodies. The facility was able to remove physical-chemical pollutants up to a satisfactory level but could not achieve the bacterial count of <1000 per 100mL which is desirable for cultivation of fish to minimize health risk. However, reuse of secondary treated effluent from treatment technology without any post-treatment may pose health hazards if community takes this wastewater in practice for production of vegetable which eaten in raw. Also, higher bacterial count in the treated wastewater may cause severe health risk during the consumption fishes if proper precautions could not be taken during food preparation (cooking). It is anticipated that a properly operated facility could be an attractive, cost-effective, environment-friendly and socially acceptable wastewater treatment and resource recovery technology for thousands of villages, towns and urban centers across India.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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REFERENCES

APHA, Standard methods for the examination of water and wastewater. 21st, eds., *American Public Health Association, Washington, D.C.*(2005).

Central Pollution Control Board, Status of water supply, wastewater generation and treatment in Class-I Cities and Class-II Towns of India, 01-93(2009).

Goyal, V. C. Best Management Practice Fact Sheet on Constructed Wetlands, Compiled by WP-1 Group of "Saph Pani" Project, *National Institute of Hydrology, Roorkee(Ed.)* (2014).

Hejkal, T. W., Gerba, C. P., Henderson, S. and Freeze, M., Bacteriological, Virological and Chemical evaluation of a wastewater-aquaculture system, *Wat. Res.*, 17(12), 1749-1755(1983). https://doi.org/10.1016/0043-1354(83)90196-3

Kumar, D., Asolekar, S. R., Sharma, S. K., Constructed wetlands and other natural treatment systems for treatment of sewages and effluents: India status report, Natural water treatment systems for safe and sustainable water supply in the Indian context: Saph Pani, edited by Thomas Wintgens, Anders Nattorp, Lakshmanan Elango, Shyam R. Asolekar, chapter 8: pages 127-148; IWA Publishing, UK., ISBN: 9781780407104 (2015a).

Kumar, D., Asolekar, S. R., Significance of natural treatment systems to enhance reuse of treated effluent: A critical assessment, *Ecol. Eng.*, 94, 225-237(2016). https://doi.org/10.1016/j.ecoleng.2016.05.067

Kumar, D., Asolekar, S. R., Sharma, S. K., Significance of incorporating constructed wetlands to enhance reuse of treated sewages in India, Natural water treatment systems for safe and sustainable water supply in the Indian context: *Saph Pani*, edited by Thomas Wintgens, Anders Nattorp, Lakshmanan Elango, Shyam R. Asolekar, 161-176; IWA Publishing, UK., ISBN: 9781780407104(2015b).

Kumar, D., Chaturvedi, M. K. M., Sharma, S. K. and Asolekar, S. R., Sewage-fed aquaculture: a sustainable approach for wastewater treatment and reuse, *Environ. Monit. Assess.,* 187(10), 656(2015c). https://doi.org/10.1007/s10661-015-4883-x

Martin S. Kumar and Michael Sierp, Rural Industries Research and Development Corporation, Integrated wastewater treatment and aquaculture production a report for the rural industries research and development corporation, RIRDC Publication No 03/026(2003).

Starkl, M., Amerasinghe, P., Essl, L., Jampani, M., Kumar, D and Asolekar, S. R., Potential of natural treatment technologies for wastewater management in India, *J. Water Sanit. Hyg. Dev.*, 3(4), 500-511(2013). https://doi.org/10.2166/washdev.2013.016

Starkl, M., Brunner, N., Amerasinghe, P., Mahesh, J., Kumar, D., Asolekar, S. R., Sonkamble, S., Ahmed, S., Wajihuddin, Md., Pratyusha, A. and Sarah, S., Stakeholder views, financing and policy implications for reuse of wastewater for irrigation: a case from Hyderabad, India, Water, 7(1), 300-328(2014). https://doi.org/10.3390/w7010300

Van den Heever, D. J. and Frey, B. J., Microbiological quality of the catfish (*Clarias gariepinus*) kept in treated wastewater and natural dam water, *Water SA*, 20 (2), 113-118(1994).