Mainstreaming Citywide Sanitation- Opportunities and Challenges for Excreta Management

‘Vermi-filtration for Faecal Waste Treatment’

Presented by

Dr. Sudipti Arora Gupta
Research Scientist
Dr. B. Lal Institute of Biotechnology,
Jaipur

Dr. B. Lal
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- Vermifiltration technology- Features & Mechanism
- Design Factors Influencing Vermifiltration Treatment Performance
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It is unfortunate to see.....but

Wespionage/Flickr

Wastewaters from more than 5.3 billion people (80% of the global population) have no form of treatment prior to discharge

BACKGROUND

- Poor sanitation management contributes proportionally to the increment in spreading of waterborne diseases.

- 90% of diarrhoeal diseases are caused by unsafe water supply and unhygienic sanitation (WHO, 2004)

- 1.8 Million die because of diarrhoeal diseases and about 90% are children under 5 years of age.

- **By improving sanitation alone, diarrhoeal diseases can be reduced to almost 35%.**

VERMIFILTRATION

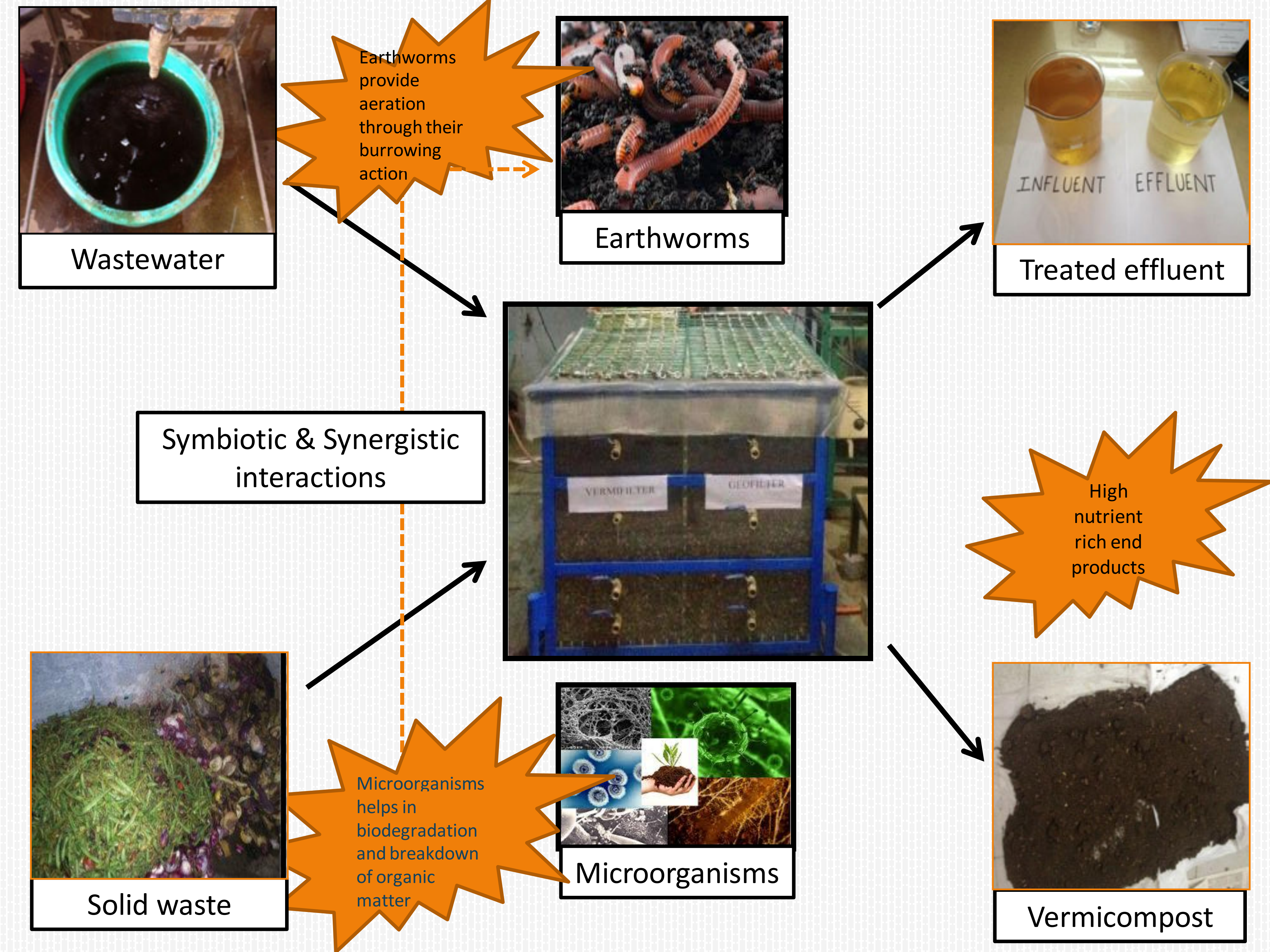
- Need to select economically affordable and efficient alternative technologies for wastewater treatment especially faecal waste treatment.

- *Vermifiltration – A Novel, Innovative, Sustainable technology based on the* synergistic and symbiotic Earthworms-Microorganisms interactions.

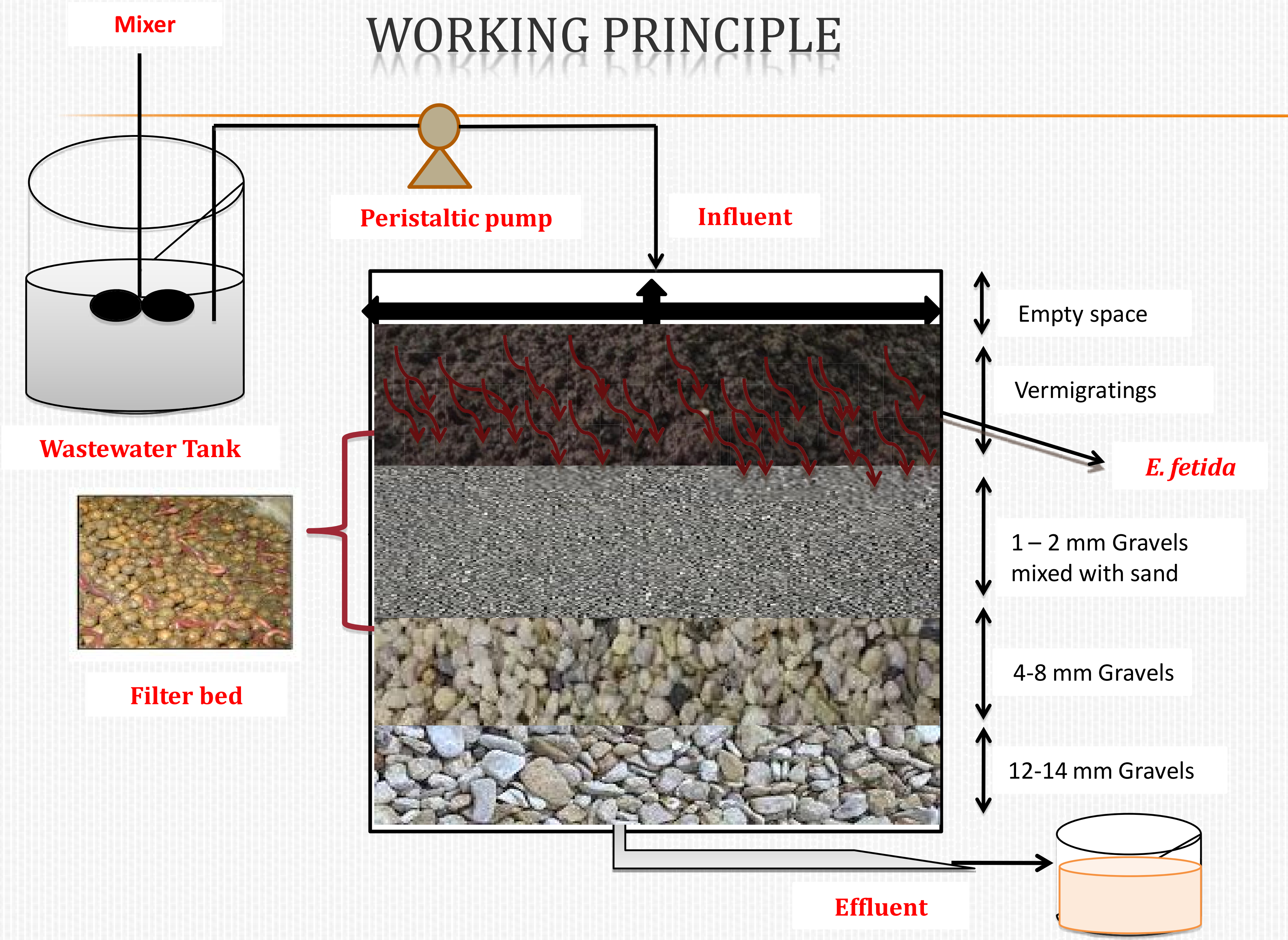
- Vermifiltration is a natural engineered system which has inoculated traditional vermicomposting system into a passive wastewater treatment process by using potential of earthworms.

VERMIFILTRATION

- First advocated by the Late Prof. Jose Toha in 1992 at the University of Chile.
- The central concept behind Vermifiltration is that microroganisms perform biochemical degradation of waste material, while earthworms regulate microbial biomass and activity by providing aeration through their burrowing activity, and directly/indirectly grazing on microorganisms.
- The effectiveness of vermifilters (VFs) for wastewater treatment has been demonstrated by a variety of wastewaters and sludge, such as domestic sewage, industry wastewater, urban run off, and livestock wastewater and at a range of scales in the recent years.
- VFs are efficient for removing organic matter, nutrients, pathogens, and has an additional benefit of low excess sludge production.


Wastewater
Earthworms provide aeration through their burrowing action
Earthworms
Treated effluent
INFLUENT
EFFLUENT
Symbiotic & Synergistic interactions
VERMIFILTER
GEOFILTER
High nutrient rich end products
Solid waste
Microorganisms helps in biodegradation and breakdown of organic matter
Microorganisms
Vermicompost

WORKING PRINCIPLE



FEATURES

- In vermifilters, microorganisms are responsible for the bio-chemical degradation of waste materials, whereas earthworms degrade and homogenize the material through muscular actions of their foregut and add mucus to the ingested material, thereby conditioning the filter media and improving its biological activity.

- The organic matter removal efficiency is attributed to the *enzymatic activity* of earthworms and microorganisms. Reduction of pathogens (3-4 log reduction) is attributed to the *antimicrobial activity and* due to the inhibitory effects of microroganisms present in VF.

- Earthworms can improve the filter media property and aeration by the burrowing activity so that the media stabilization and filtration system become effective.

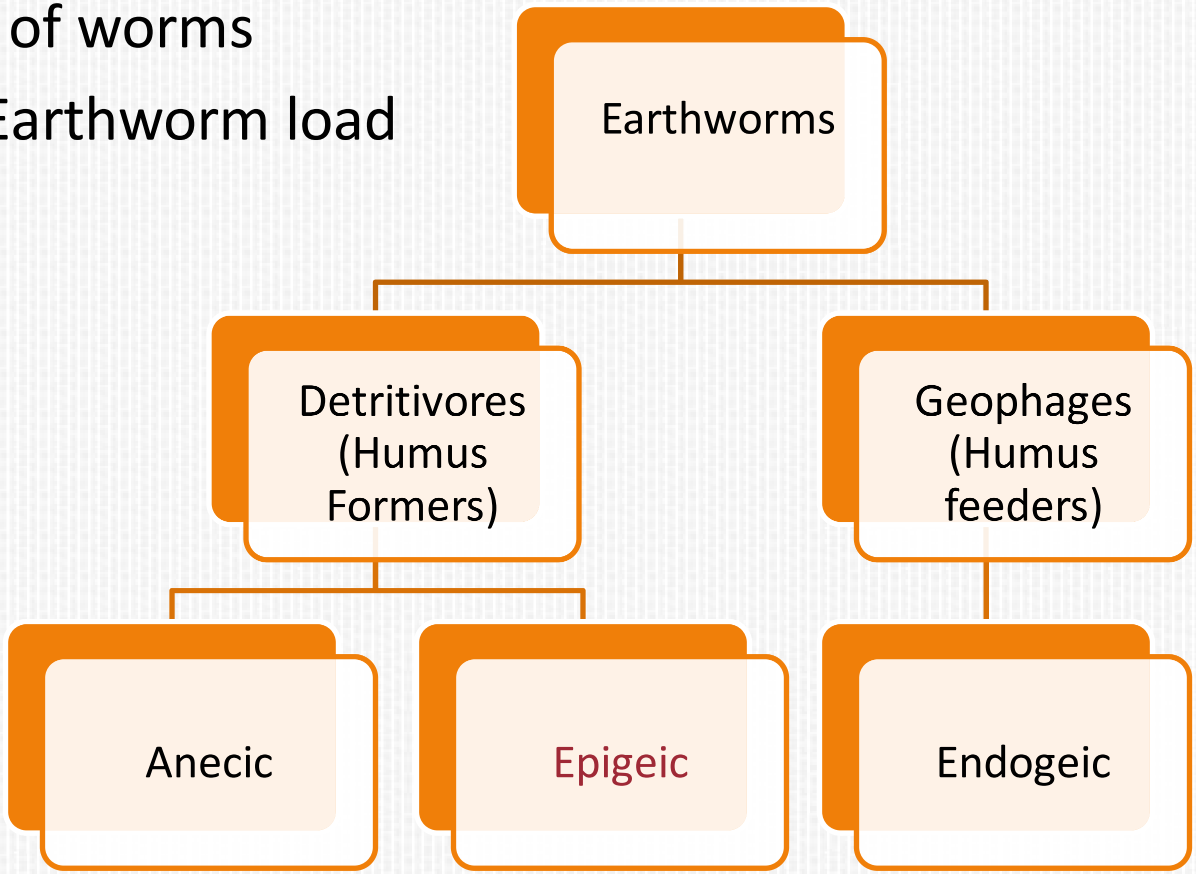
FEATURES

- Vermifiltration is odor-free technique, and the final water output can be potentially reused for irrigation in parks, gardens and farms, which will facilitate the reuse of reclaimed wastewater.
- VFs require less operational cost because of little energy requirement for pumping of wastewater and no experienced labor. Maintenance expense is also minimal since it did not involve any mechanical devices, except for pumps.
- VFs could simultaneously treat sewage and sludge components and transform the sludge into vermi-compost (a nutritive fertilizer of positive economic value) which could be used in agriculture and horticulture.

DESIGN FACTORS

Earthworm species and load

- Types of species
- Health and maturity of worms
- Population density/Earthworm load



DESIGN FACTORS

Filter media

- The filter media can provide a suitable growing medium for earthworms and microbes and also allow successful movement of sewage.

- The selection of filter media is determined by the hydraulic permeability and the adsorption capacity for pollutants.

- Filter media may also play the most important part in adsorption of various pollutants such as phosphorus.

- Filter media could change the external survival environment of earthworms, and the changes of the external environment plays an important part in the structure and function of the earthworm’s body wall which is closely relative with the activity and respiratory metabolism of earthworm.

- For this purpose, the filter media to be utilized for VF should be easily available and cost effective natural ingredients, such as river bed material, wood coal, glass balls, mud balls, slag-coal cinder ceramsite and quartz sand serves better.

DIFFERENT FILTER MEDIA

Gravels of size 6-8 mm and 10-12 mm

Coal

Glass balls

Mud balls

DESIGN FACTORS

Physico-chemical Factors

- pH (Hughes et al. 2007)
- Temperature (Arora & Kazmi, 2015)

DESIGN FACTORS

Operating and Design Features

- Hydraulic Loading Rate (HLR) is defined as the rate at which influent enters the VF.

$$HLR = \frac{V}{(A \times t)}$$

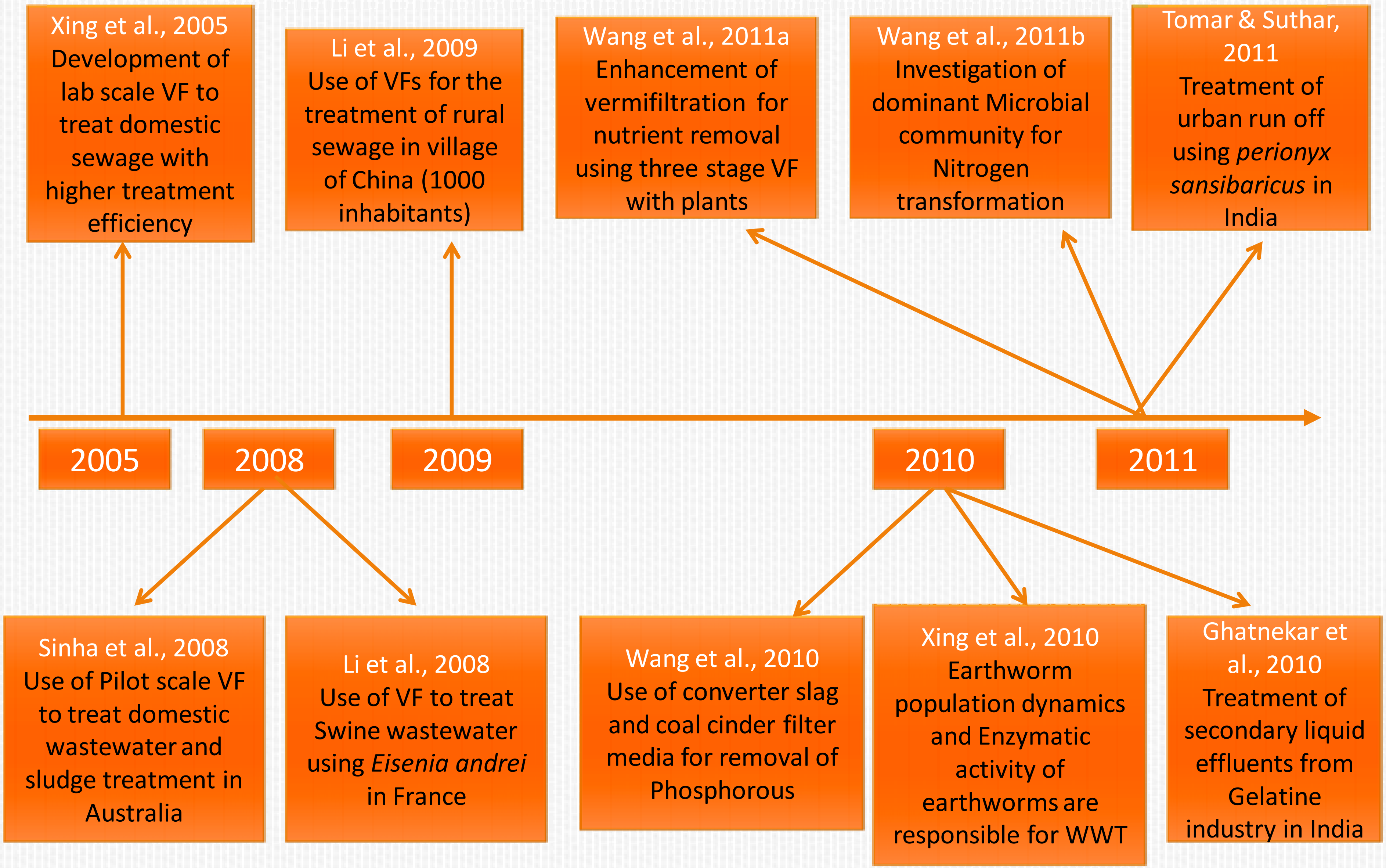
- Hydraulic Retention time (HRT) is the time taken by the wastewater to flow through the VF bed in which earthworms inhabit.

$$HRT = \frac{(p \times V_s)}{Q_{wastewater}}$$

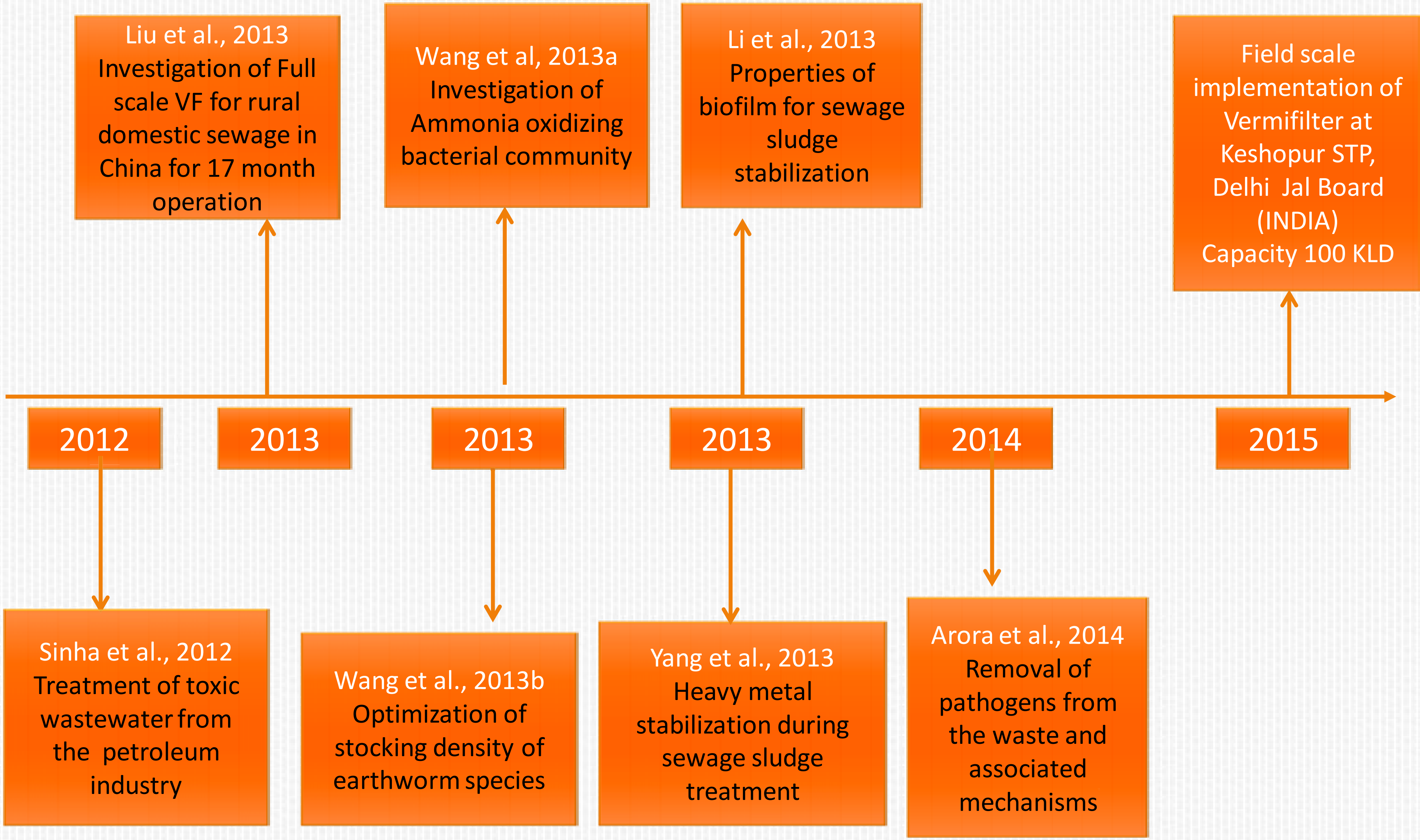
- Nutrient load: C: N Ratio
- Organic loading rate (OLR) is defined as the amount of BOD or COD applied to the VF per day per volume of filter media.
- *Organic Loading Rate (Kg/ m^3. day) = BOD (mg/L) Flow(m^3/day) 10^{-3} / Filter Volume (m^3)*

$$\text{Organic Loading Rate } (Kg/m^3 \cdot day) = \frac{BOD\ (mg/L) \quad Flow\ (m^3/day) \quad 10^{-3}}{Filter\ Volume\ (m^3)}$$

TIMELINE OF THE IMPORTANT RESEARCH IN THIS FIELD

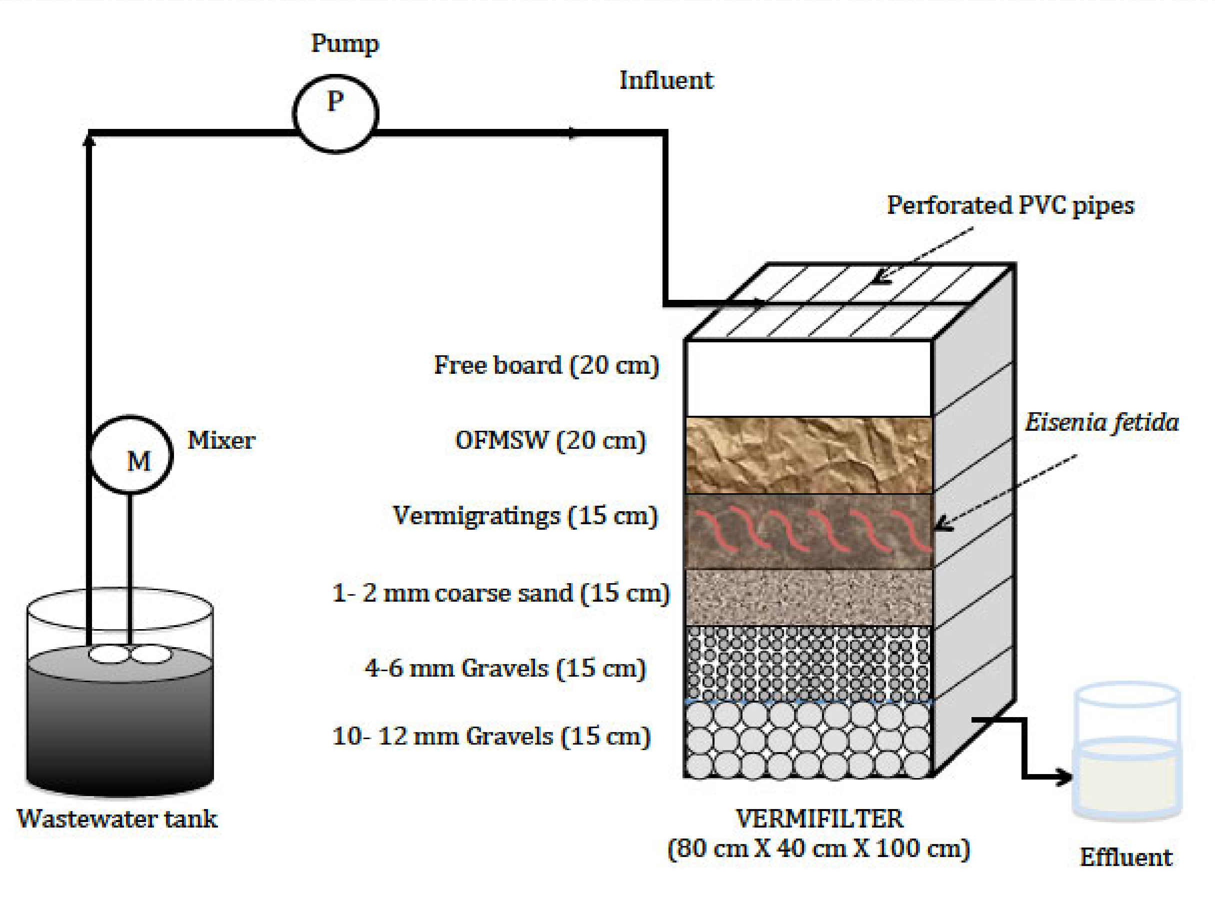


TIMELINE OF THE IMPORTANT RESEARCHES IN THE FIELD



CASE STUDIES

Pilot scale study at Indian Institute of Technology Roorkee (IITR) for the combined treatment of domestic wastewater and municipal solid waste



PILOT SCALE VERMIFILTER FOR COMBINED TREATMENT OF OFMSW AND WASTEWATER

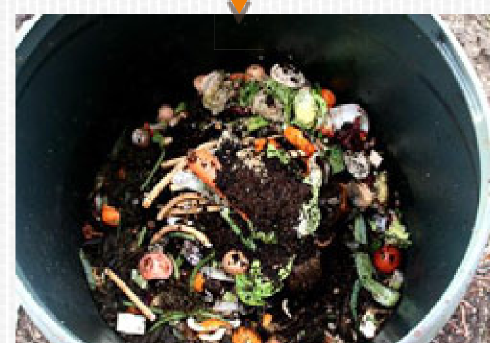
Dimensions : 0.80   0.40   0. 80 m^3
Duration: 3 months trial experiments
HLR: 1.0 $m^3/m^2/day$
Earthworm sp. *Eisenia fetida*,
Stocking density: 10, 000 worms/m^3
Filter media: River bed materials

Municipal solid waste collected

↓

Grinded, Shredded and mixed and kept for 7 days

↓



Processed OFMSW

PERFORMANCE EVALUATION OF VERMIREACTOR
Influent & Effluent Quality

Parameters	Influent	Final effluent	Removal (%)
pH	8.0 0.1	7.4 0.2	-
DO (mg/L)	0.8 0.4	5.1 0.6	-
BOD (mg/L)	244 25	26 19	89.3
COD (mg/L)	450 27	90 15	80.0
TSS (mg/L)	131 8	23 2	82.2
Ammonia (mg/L)	20.3 1.2	0.8 0.2	96.1
Nitrate (mg/L)	0.6 0.2	10 2.7	-
TC (MPN/100 mL)	6.63 0.60	2.72 1.60	98.89
FC (MPN/100 mL)	5.48 0.37	2.66 0.30	97.12
FS (MPN/100 mL)	5.45 0.66	2.80 ■ 0.50	99.29
E. coli (CFU/mL)	4.50 0.42	1.99 ■ 0.10	99.99
Salmonella (CFU/mL)	3.87 ▬ 0.94	1.67 ■ 0.92	96.81

Considerable pathogen removal

Significant BOD & COD removal

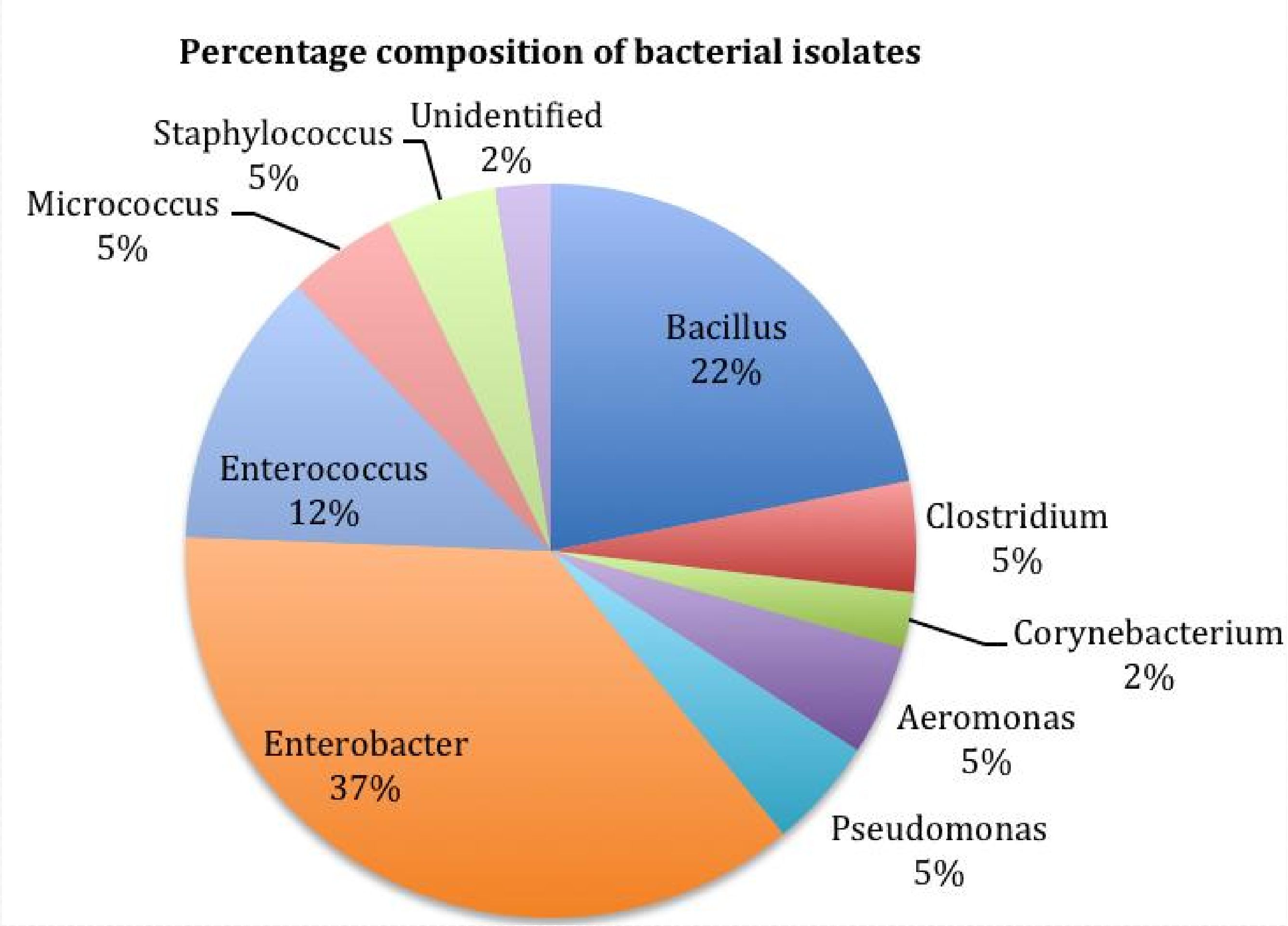
Initial & Final Solid Waste Characteristics

Parameters	0^{th} day	30^{th} day	60^{th} day	90^{th} day
pH	8.6 0.2	8.5 0.3	7.9 0.3	7.5 0.1
Ammonia- N (%)	0.4 0.2	0.3 0.2	0.2 0.2	0.1 ■ 0.1
Nitrate- N (%)	0.3 0.2	0.9 0.1	1.5 0.2	1.7 ■ 0.2
TOC (%)	58.3 0.2	48.4 0.9	39.6 0.8	32.0 1.1
TN (%)	0.97 0.1	1.0 0.2	1.5 0.3	1.9 0.1
C/N ratio	60.10	48.40	26.40	10.84
TP (%)	0.96 0.2	1.2 0.2	1.4 0.1	1.6 ■ 0.5
C/P ratio	60.73	40.33	28.28	20.00
TC (MPN/g)	6.68 0.5	4.86 0.3	3.72 0.2	2.60 0.2
FC (MPN/g)	4.73 0.6	4.23 0.2	3.32 0.2	2.50 0.3
FS (MPN/g)	3.56 0.4	2.98 0.5	2.2 0.6	1.90 0.2
Salmonella (CFU/g)	2.97 ▬ 0.2	2.25 ▬ 0.2	1.47 0.3	1.25 0.2
Escherichia coli CFU/g)	2.90 ■ [illegible]	[illegible]	1.50 ■ [illegible]	1.33 0.2

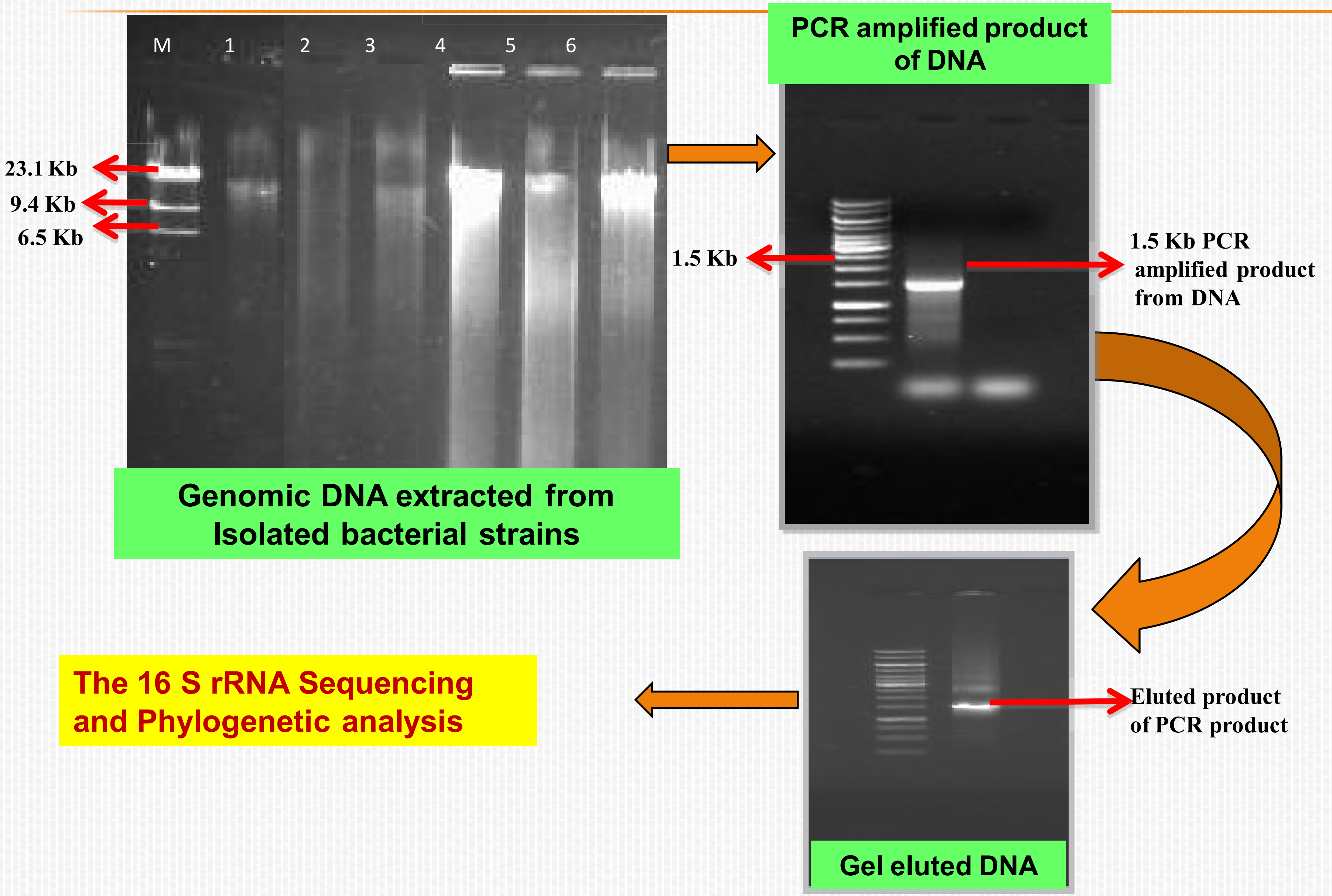
Mature Vermicompost but that may require further maturation

Leaching of nutrients N and P

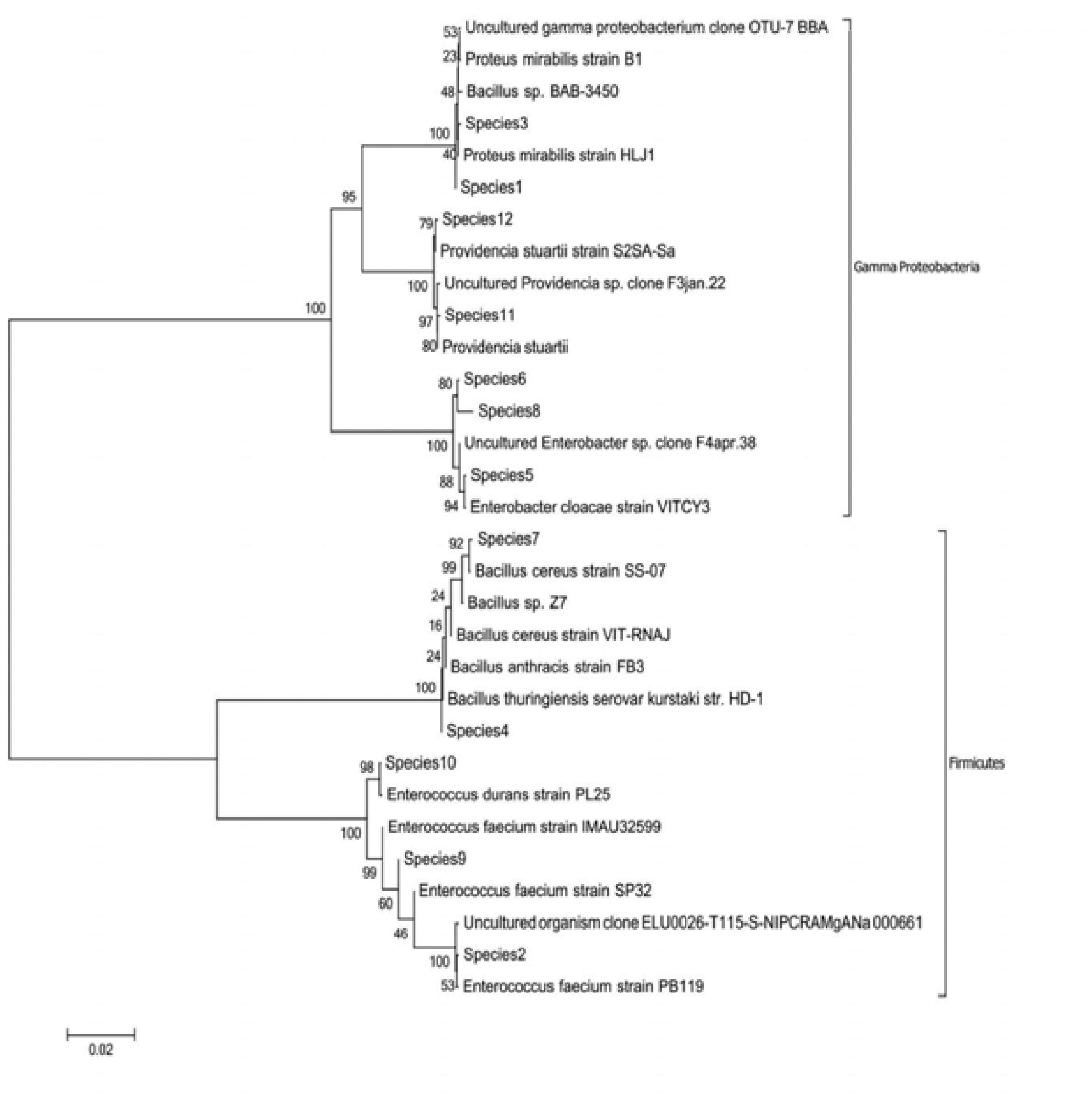
INVESTIGATION OF DOMINANT MICROBIAL COMMUNITY INSIDE A VF



MOLECULAR ANALYSIS



PHYLOGENETIC ANALYSIS

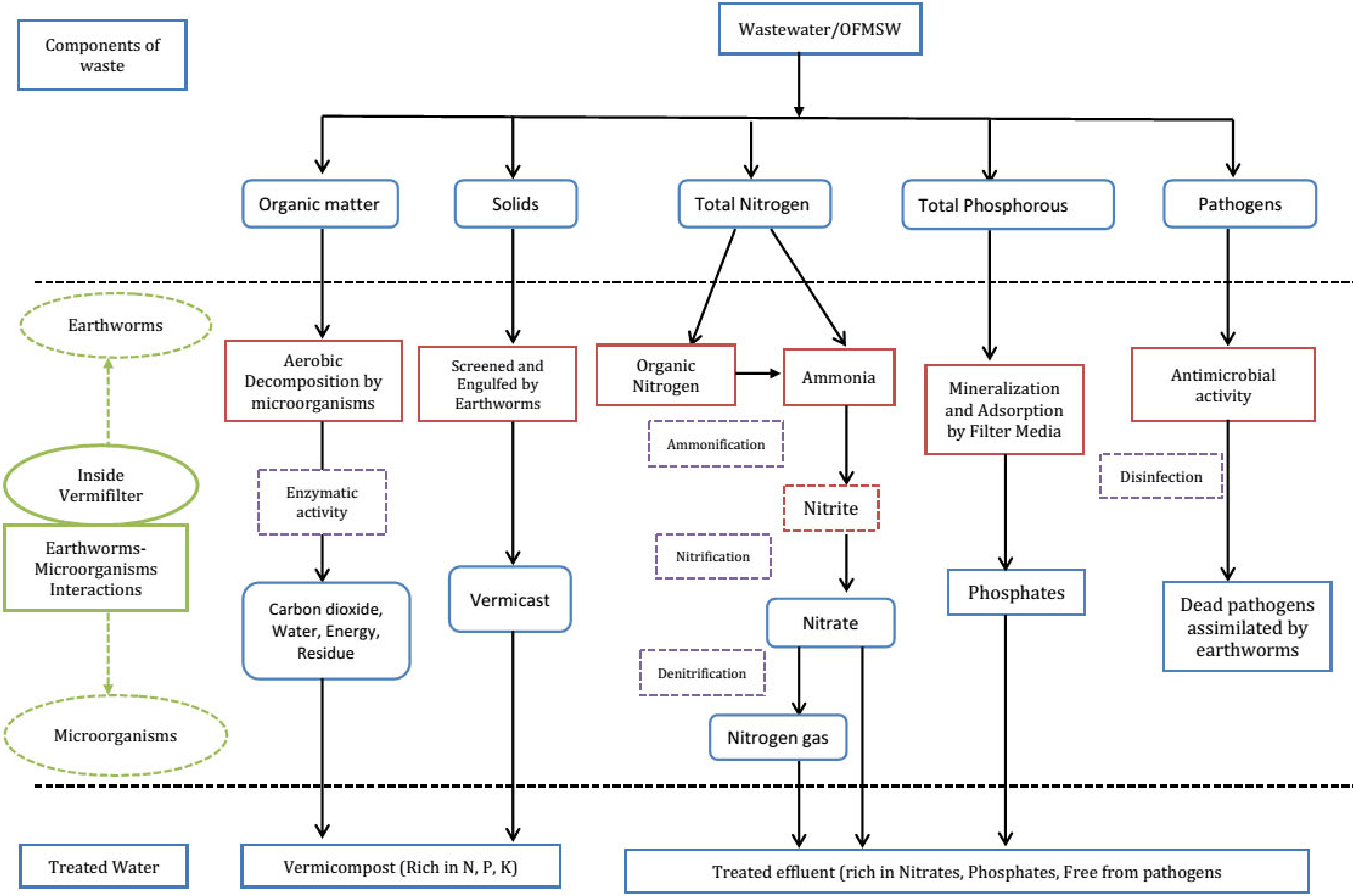


The 16 S rRNA analysis of the 12 active strains were clustered into 2 phylogenetic groups

- **Gamma-proteobacteria**
- **Firmicutes**

GEN BANK ACCESSION NO. FOR NOVEL SEQUENCES

S. No	Gen Bank Accession No.	Closely related Sequences (AN[a])	Hom[b] (%)	Family	Phylum
1	KM246409	*Bacillus licheniformis sp. BAB-3450 (KF917180.1)*	99	Bacillaceae	Firmicutes
2	KM246410	*Enterococcus faecium strain (JN792505.1)*	100	Enterococcaceae	Firmicutes
3	KM246411	*Proteus mirabilis strain HLJ1 (KF811051.1)*	99	Enterobacteriaceae	ϒ Proteobacteria
4	KM246412	*Bacillus thuringiensis strain LA40 (KJ534464.1)*	100	Bacillaceae	Firmicutes
5	KM246413	*Enterobacter sp. BSRA2(FJ868806.1)*	99	Enterobacteriaceae	ϒ Proteobacteria
6	KM246414	*Enterobacter cloacae strain BAB-2824 (KF535159.1)*	100	Enterobacteriaceae	ϒ Proteobacteria
7	KM246415	*Bacillus cereus SS 07 (EU624445.1)*	100	Bacillaceae	Firmicutes
8	KM246416	*Enterobacter cloacae subsp. dissolvens strain 189 (KF254602.1)*	100	Enterobacteriaceae	ϒ Proteobacteria
9	KM246417	*Enterococcus faecium strain SP32 (JX317638.1)*	100	Enterobacteriaceae	Firmicutes
10	KM246418	*Enterococcus durans PL25 (JN792514.1)*	99	Enterobacteriaceae	Firmicutes
11	KM246419	*Providencia stuartii strain (HG427202.1)*	100	Enterobacteriaceae	ϒ Proteobacteria
12	KM246420	*Uncultured Providencia sp. (JGQ416767.1)*	100	Enterobacteriaceae	ϒ Proteobacteria

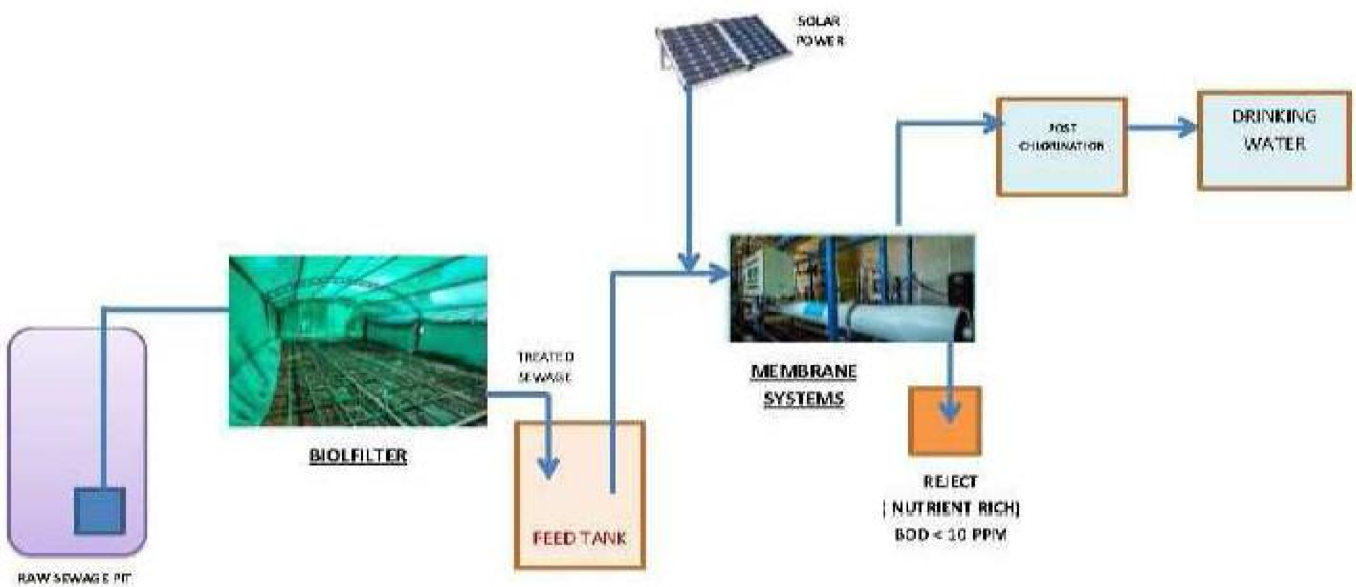


Components of waste
Wastewater/OFMSW
Organic matter
Solids
Total Nitrogen
Total Phosphorous
Pathogens
Earthworms
Inside Vermifilter
Earthworms-Microorganisms Interactions
Microorganisms
Aerobic Decomposition by microorganisms
Screened and Engulfed by Earthworms
Organic Nitrogen
Ammonia
Ammonification
Nitrite
Nitrification
Nitrate
Denitrification
Nitrogen gas
Mineralization and Adsorption by Filter Media
Phosphates
Antimicrobial activity
Disinfection
Dead pathogens assimilated by earthworms
Enzymatic activity
Carbon dioxide, Water, Energy, Residue
Vermicast
Treated Water
Vermicompost (Rich in N, P, K)
Treated effluent (rich in Nitrates, Phosphates, Free from pathogens

VERMIFILTER AT DELHI JAL BOARD, KESHOPUR STP AREA, NEW DELHI

SCHEMATIC DIAGRAM

RAW SEWAGE TO DRINKING WATER



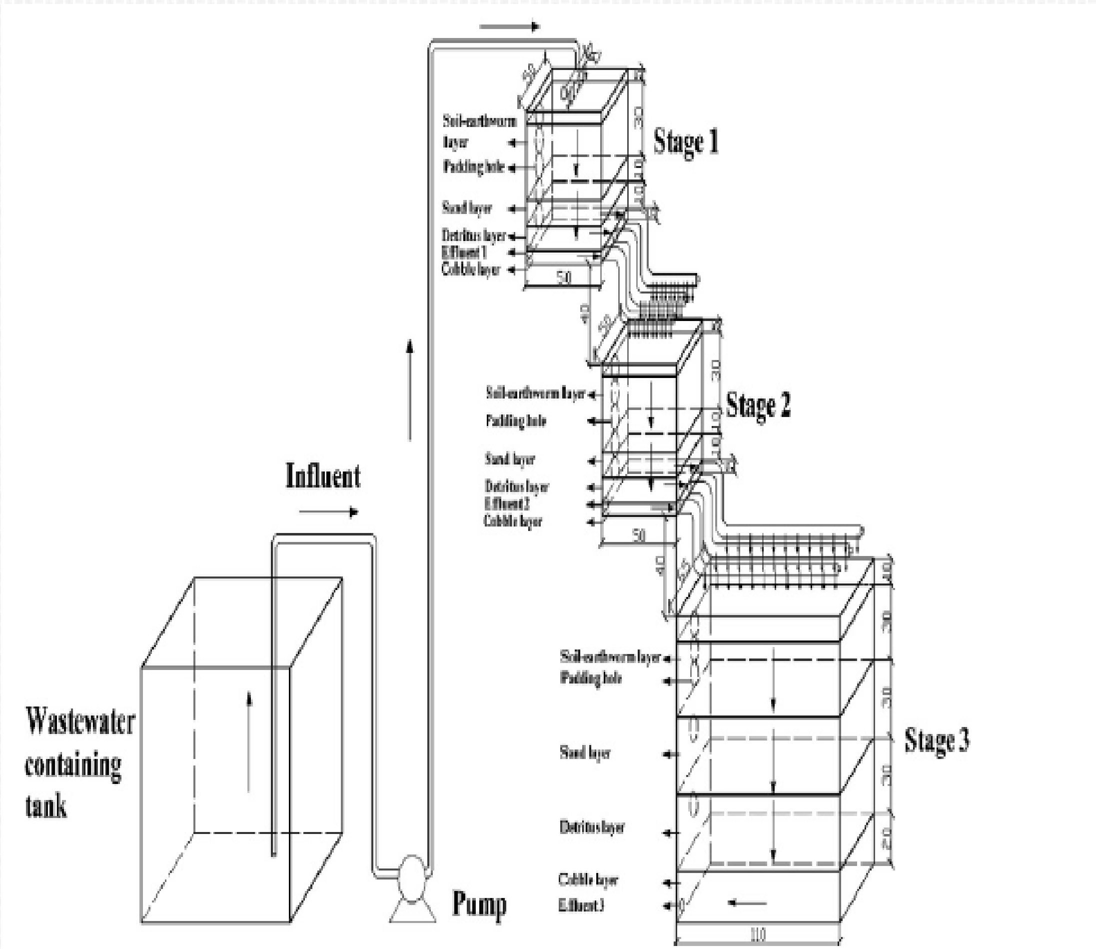
“राम बाण”

Water activist Shri Manoj Mishra visited the plant & quoted

This technology is “ Ram Baan”

(Perfect Solution) to return water to the river and keep the Yamuna pollution free

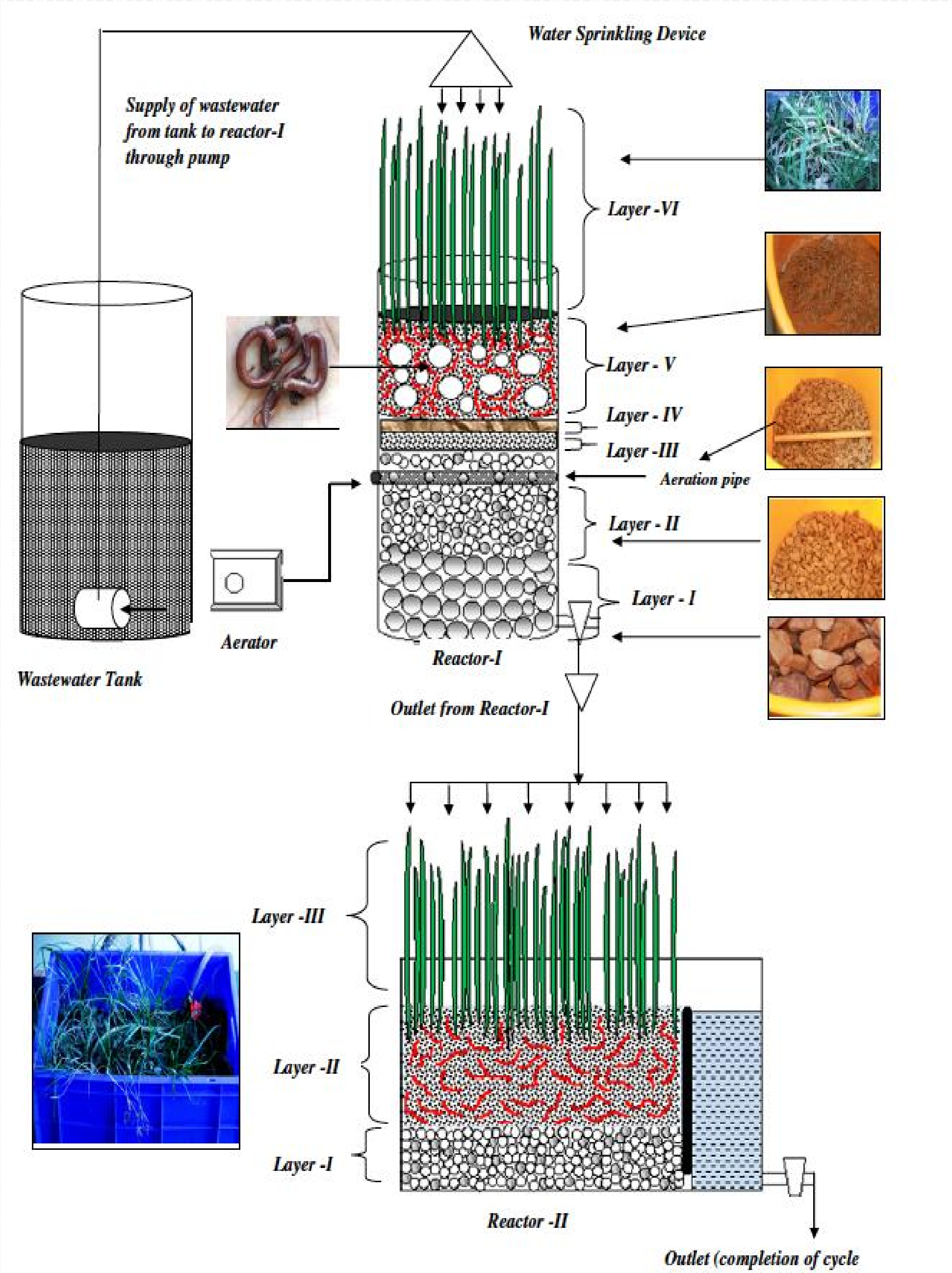
DESIGN ENHANCEMENT



- Wang et al., 2011 (China) designed a three stage VF to enhance the removal of nutrients from rural domestic wastewater.

- Three stage VF had higher COD, Ammonia and phosphorous removal efficiencies.

- It might be benefit from the advancement of oxygen demand concentration in the effluents by designing three section.



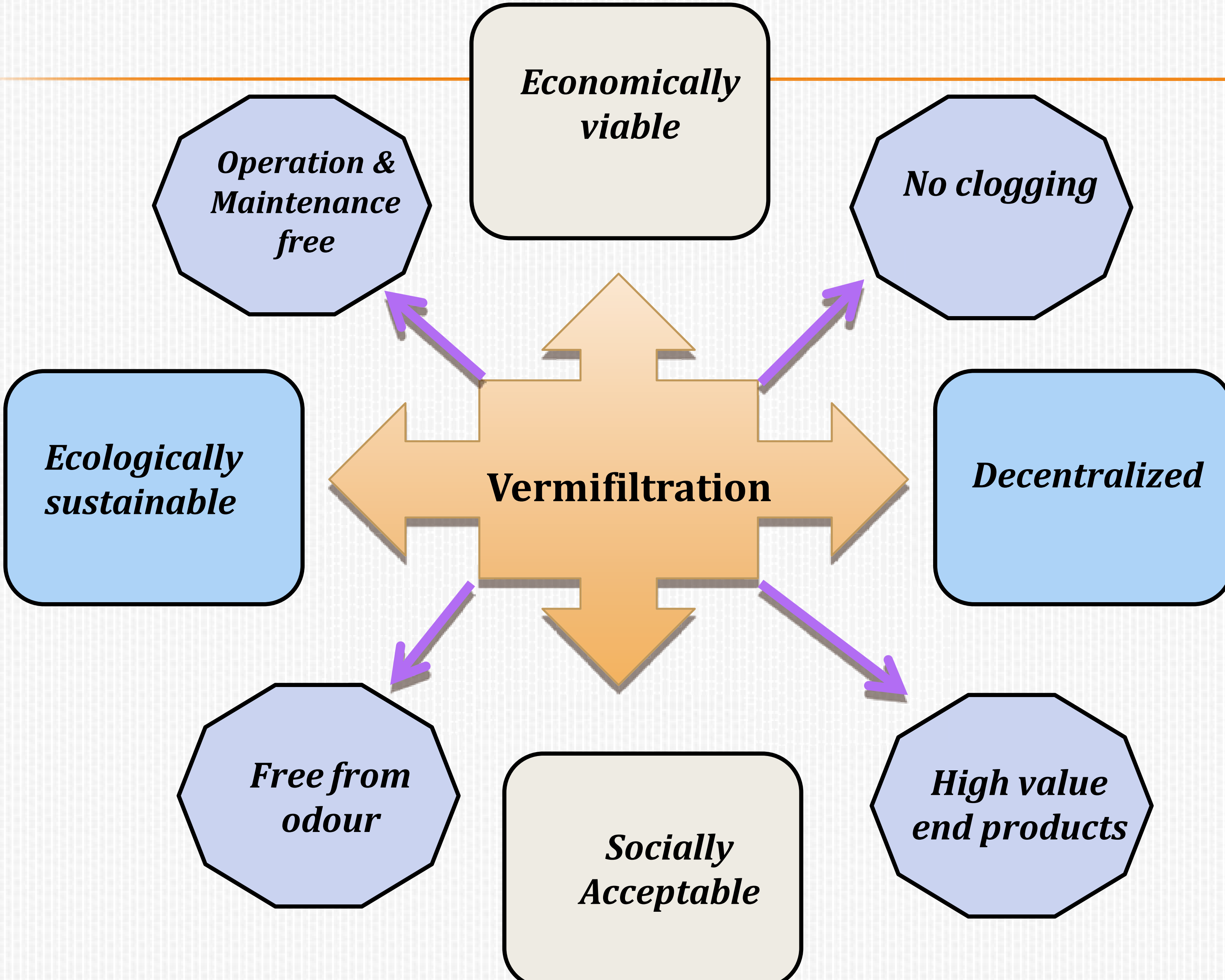
Tomar & Suthar, 2011 (Dehradun, India) integrated 2 technologies together.

Combination of VF with constructed wetlands to treat urban run off wastewater and the system came out to be even more efficient than traditional biofiltration system in terms of contaminants removal.

CONCLUSIONS

- Vermifiltration technology encompasses ALL forms of TREATMENT (Primary- removal of silt, grit, etc., Secondary- removal of organic matter and Tertiary- removal of pathogens/disinfection) INTO ONE SINGLE UNIT.
- The applicability of the technology is more in rural areas of developing regions.
- Cost –effective treatment technology, does not require external aeration, -80% decrease in operational cost because VF does not need aerating oxygen pumps and heavy maintenance.
- Wastes gets converted into useful products: Treated water for non potable use and vermicompost for agricultural applications.
- Does not produce odor, no problem of clogging.
- No problem of excess sludge production

Vermifiltration technology by earthworms is a self-promoted, self-regulated, self improved, self-driven, self-powered and self-enhanced, very low energy and less chemical requiring zero-waste technology, easy to construct, operate and maintain & is comparable to and better than all other 'bio-conversion', bio-treatment' and 'bio-degradation' technologies !!


Vermifiltration
Economically viable
Operation & Maintenance free
No clogging
Ecologically sustainable
Decentralized
Free from odour
Socially Acceptable
High value end products

LIMITATIONS OF THE TECHNOLOGY

- The technology is vitally dependent on suitability and functionality of earthworm species in suitable environmental conditions (temperature, extreme pH, moisture content, tolerance of high intensity of contamination, cold climate, etc.).

- Earthworm isolation from the filter bed by hand sorting is a tedious task.

- The research and actual application in VFs have been going on, future studies urgently need new technologies and methods applied in VFs for the enhancement of wastewater treatment performance.

- These technologies and methods may include: combination of various filter media, integration of VFs with traditional sewage treatment technologies, designing multi-stage VF, addition of various plants, etc.

Thank you for your Kind Attention !

For more details contact
Dr. Sudipti Arora Gupta
Mob: +91-9829675677
Email: sudiptiarora@gmail.com

CONTD…

Author , Year	Findings	Country
Taylor et al., 2003	Treatment of domestic wastewater and solid waste using small scale vermicompost filters factors and factors affecting the treatment process	Australia
Xing et al., 2005	Treatment of sewage using vermifiltration bed made up of granular materials and earthworm species	China
Sinha et al., 2007	Significant organic matter and suspended solids removal from organic rich dairy wastewater	Australia
Sinha et al., 2008	Vermifiltration of sewage and sludge together, from the oxley treatment plant, Removal efficiency 98% BOD, 45% COD, 98% Turbidity removal, pH buffering ability, significant removal of heavy metals and toxic compounds	Australia
Li et al., 2008	Effective for treating wastewater from swine facility, reduces ammonia and green house gas emissions	China
Li et al., 2009a	Pilot scale vermifilter for long term operation in a village inhabiting 1000 people, optimization of HLR, OLR, and seasonal temperature	China
Li et al., 2009b	PCR- DGGE revealed the presence of diverse microbial community in three different vermifiltration column with different densities of earthworms	China
Liu et al., 2009	74.5% BOD, 51.9 % COD, 91.9 % TSS, 69.3 % Ammonia removal efficiency during co treatment of municipal wastewater & sludge	China
Yang et al. 2009	Batch column experiments to test the suitability of filter media, converter slag and coal cinder	China

CONTD…

Author , Year	Findings	Country
Wang et al., 2010	Evaluation of the effects of earthworms and filter media (ceramic pellets) height on vermifiltration	China
Xing et al., 2010a	Relationship between earthworm population dynamics, enzymatic activity and treatment efficiency in a vermifilter	China
Ghatnekar et al., 2010	Application of three tier vermiculture technology to treat gelatin industry wastewater, synergistic interaction of earthworms, enzymes and microbes	India
Dhadse et al., 2010	Capacity to treat pharmaceutical wastewater at different HLRs and OLRs	India
Zhao et al., 2010	In depth study of Earthworm- microorganisms interactions for sewage sludge stabilization	China
Xing et al., 2010b	Significant BOD, COD, SS, Ammonia removal efficiency, sludge stabilization, cost savings upto 48.72%	China
Wang et al., 2011a	Enhancement of wastewater treatment using multi stage tower VF with plant *Penstemon campanulatus*	China
Wang et al., 2011b	Microbial earthworm ecofilter for Nitrogen removal	China
Kharwade and Khedikar, 2011	Comparison of filter with and without worms, significant contaminants removal efficiency with worms	India
Tomar and Suthar, 2011	Integration of vermifilter with constructed wetland technology	India

CONTD…

Author , Year	Findings	Country
Robin et al., 2011	Eartworms reduce emissions of ammonia, nitrous oxide and methane, carbon and nitrogen abatement	France
Xing et al., 2011	Comparison of ceramsite and quartz sand as filter media for sewage sludge reduction	China
Yin et al., 2011	Effect of filter bed temperature on municipal wastewater treatment efficiency	China
Li et al., 2012	Treatment effects of multi layer vermifilter, 85 % BOD, 75% COD, 91.7% SS, 73 % ammonia, 69 % phosphorous removal efficiency	China
Sinha et al., 2012	Effective for treating toxic petroleum wastewater, 99.9 % reduction in volatile hydrocarbons from petroleum	Australia
Zhao et al., 2012	Vermifilter inoculated with earthworms *E. fetida* and plants with varying C: N ratio	China
Suthar et al., 2012	Potential to convert milk processing sludge into vermicompost (with high nutrients)	India
Liu et al., 2012	Comparison of VF and biofilter for sludge reduction capability along with investigation of microbial community diversity, Specific groups of bacteria present in vermifilter, and not in control.	China
Singh and Kaur, 2012	Chemical sludge from soft drink industry can be converted to good quality manure in short span (88-110 days)	India
Liu et al., 2013	Use of gene library technology for investigation of microbial community diversity	China

CONTD…

Author , Year	Findings	Country
Negi and Suthar, 2013	Vermistabilaiztion of paper mill sludge resulting into stable, nutrient rich end prodcts	India
Li et al., 2013	Fluorescence EEM spectra of HAL fractions indicating the stability and maturity of VF biofilm after sludge stabilization	China
Yang et al., 2013a	VF biofilm dominated by unclassified *Bacillus sp., c- proteobacteria, b-proteobacteria* and *Actinobacteria*	China
Yang et al., 2013b	Effect of earthworms on heavy metal stabilization of liquid state sludge	China
Wang et al., 2013a	Investigated the ability of microorganisms in different layers to remove nitrogen, investigating of AOB (Ammonia oxidizing bacteria) community	China
Wang et al, 2013b	Effect of earthworm loads on COD, Ammonia, N, P removal and on bacterial community structure and diversity of substrates	China
Xing et al., 2014	Liquid state sludge stabilization using fatty acid profiling	China