Training Program on Sustainable Natural and Advance Technologies and Business Partnerships for Water & Wastewater Treatment, Monitoring and Safe Water Reuse in India

Wastewater Fertigated Short Rotation Coppice (wfSRC)

Prepared by: ttz Bremerhaven

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Introduction to the authors

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Learning objectives

At the end of this session, participants will be able to:

- Gain a comprehensive understanding of the wfSRC system, including its components, processes, and functionality
- Learn the design criteria, parameters, and additional requirements specific to the wfSRC system
- Understand the selection criteria for the materials, equipment and technologies suitable for the wfSRC system
- Learn how to effectively integrate the different components of the wfSRC system
- Gain insight into the operational parameters, monitoring and maintenance specific to the wfSRC system
- Learn how to evaluate the performance of the system, including sampling, analysis, and compliance requirements
- Understand the steps involved in commissioning and starting up the wastewater treatment system

Agenda of the session

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Time	Content
5 min	Introduction to the session
25 min	Introduction to the technology (background overview, principles, performance expected, appropriateness)
60 min	Design of the technology (key considerations, basic calculations, key formulas, etc.)
15 min	Break
15 min	Operation and maintenance
15 min	Construction and implementation
30 min	Example: the PAVITR pilot
12 min	Homework: exercise to design/implement the technology for a case study
13 min	Final remarks

Introduction to the wfSRC system

Nature-Based system that efficiently combines wastewater treatment and reuse with biomass production, enabling sustainable nutrient recycling.

Wastewater treatment through microbial decomposition, respiration, filtration, plant uptake, nitrification/denitrification, adsorption among other processes.

Fast-growing tree species are planted and harvested after relatively short periods depending on the plant species used, climate, nutrient availability, among other factors.

Source: https://www.pavitr.net/ & Biopros, 2008, 20th November 2022

wfSRC System with Bamboo

Biomass from fast growing tree species cultivated in wfSRC systems have the potential to substantially contribute to provide sustainable sanitation services and reducing greenhouse gas emissions.

Materials, heat, power and biofuels produced from biomass are CO_2-neutral.

Wastewater Treatment in wfSRC

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In wfSRC systems raw or pre-treated wastewater is applied directly on the surface or in the upper soil layer with different irrigation systems

Treatment process takes place in the upper layer and in the root zone

Nutrients are mostly taken up by the plants or accumulated and transformed in the soil

Microorganisms in the soil and the biofilms attached to the roots, degrade organic matter

Most implemented Plant Species in wfSRC

Bamboo

Poplar

Willow

Eucalyptus

Advantages of wfSRC System

- Efficient Wastewater Treatment Technology: 86-96% Removal Efficiency
- Low CAPEX and OPEX Costs
- Reduction in Costs (fertilizer, water) and Production
- Enhance Biomass Yield
- Reliable Source of Renewable Energy and Materials
- Continuous Water Supply
- Reduction of Emissions
- Ecosystem Services

Design of the wfSRC system

wfSRC Design Criteria

Site Selection

Soil Requirements	Water & nutrient requirements	Climate
Access	Location	Legislation

wfSRC Design Criteria

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Soil Requirements

Medium to heavy clay loams with good aeration and moisture retention are ideal for wfSRC cultivation

WfSRC tree species grow on a wide range of agricultural soil types and productivity will be determined by site fertility, local climate and availability of water and light

For the treatment performance, very light sandy soils with low water holding capacity can have problem with water availability and therefore may be avoided

Sites with high ground water levels (less than 2m) are not suitable in order to avoid anoxic conditions and pollution

wfSRC Design Criteria

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Water & nutrient requirements

wfSRC's water demand is usually higher than for other conventional crops. Therefore, constant water availability (e.g. from wastewater sources and/or water bodies) should be ensured

Some SRC species such as willow are well-known to tolerate anoxic conditions due to water-in-excess, but the water demand of SRC varies depending on the species used

Local tree nurseries should be consulted about the suitability of the plant material under the specific site conditions

Enough soil moisture is crucial to ensure the success of the plantation. Timing of initial planting and water supply must be well-planned, as it can lead to serious losses during very dry periods.

wfSRC Design Criteria

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Climate

A vast range of climatic conditions can be appropriate for the establishment of wfSRC systems

Locations with longer periods of frost and low temperatures should be avoided in order to operate the system all over the year

wfSRC Design Criteria

Access

wfSRC plantations should have good access to wastewater sources and infrastructure (roads and laboratories) for the equipment required and the biomass harvested

Access via pipes to wastewater is strongly recommended to control costs and ensure constant water and nutrient supply.

wfSRC Design Criteria

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Location

Planting wfSRC in agricultural fields close to forest stands gives a feeling of a natural continuation of the landscape and should be preferred

Planting different clones with different habitus increases visual diversity and prevents proliferation of potential pests. Broad openings between fields provide opportunities for the recreation in the area (e.g. walking).

General factors determining the site selection of a wfSRC system are also distance to biomass costumers (harvest), accessibility for planting, harvesting and management, power lines crossing the field and availability of suitable machinery and staff.

wfSRC Design Criteria

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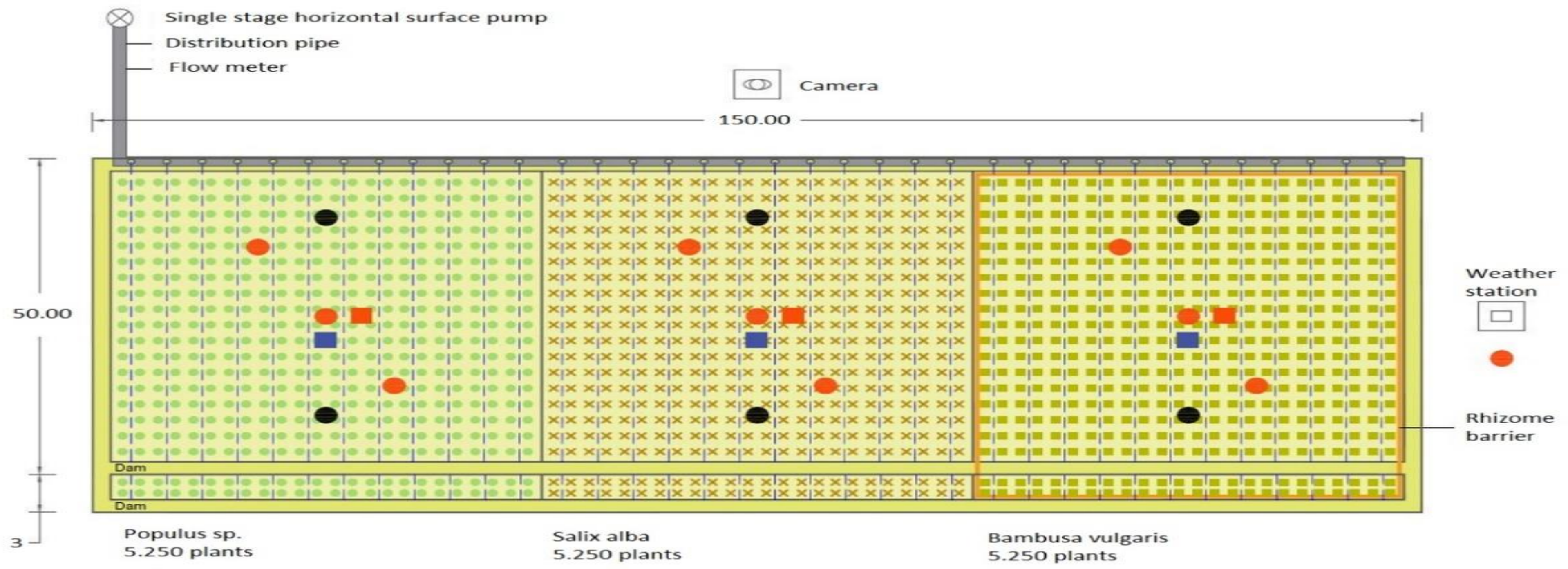
Legislation

By combining wastewater treatment and biomass production diverse legal requirements (changes in land use, permission to treat wastewater) needs to be considered for the establishment of new wfSRC systems

Legislation may also have an impact on the selection of approved varieties and clones as sometimes this is prescribed

Distance to neighbors is usually regulated and requests e.g. a 2 m empty space to the neighboring land.

Layout of the wfSRC



SRP Layout (PAVITR, 2019)

- Typical coppice plantations use very high densities: 5,000 to 20,000 cuttings per hectare are planted.
- Planting in single or double rows is recommended to allow easier operations by mechanical management for planting, fertilization and harvesting,

Layout Considerations

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Size

Surface areas range from:

- Small systems of 1m2,
- Small set-ups with up to 30m^2,
- Medium systems of 150-200m^2
- Large scale systems of up to hundreds of hectares

The largest application has been found in Huolinguole City, China (880 ha).

Shape

In general, longer and rectangular fields are easier to manage planting, harvesting and fencing against mammals.

An important point in relation with the loading of wastewater (and the design of the wastewater distribution system) is a shape which enables an equal distribution of wastewater.

Monitoring

Control stations and monitoring sensors must be installed to ensure the proper working of the system and in accordance with technical parameters.

- Sensors measure soil moisture, pH, salinity and soil temperature
- Water traps and vacuum-controlled water samplers
- Weather station, and an online camera

Design Data

Hydraulics

Soil Characteristics

Field Capacity

Selection of Plants Species

Hydraulics

Furrows Irrigation System Aligarh

To ensure a robust, effective low-cost irrigation and even water distribution, a furrow irrigation system is recommended with the following characteristics:

- **Slope** in the range of 0.05 to 0.5% in the direction of where the water is fed
- **Soil bank** to retain excess water to avoid water losses and potential health risks to the adjacent plots
- **Furrows** are sloping channels cut into the soil surface to direct wastewater streams.

Soil Characteristics

Soil Profile Characterization

To determine the soil characteristics, soil analysis are recommended:

- **Nitrogen (N)**
- **Phosphorus (P2O5)**
- **Potassium (K2O)**
- **Total CaCO3**
- **Humus content**
- **Organic matter**
- **Total Sulphur (S)**
- **Trace elements**
- **Other physical characteristics** (soil type, field capacity, permeability, hydraulic conductivity, density, pH).

It is relevant to have information regarding the presence of aquifer below the plot (depth, water quality and any other relevant information).

Field Capacity

Texture Class		Wilting Point WP %Vol			Residual wat. θ_r (%Vol)			Field Capacity FC %Vol		
		Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Light textured soils	Sand	4.50	6.36	8.50	4.50	7.26	13.71	11.80	13.71	15.92
	Loamy Sand	4.85	7.32	10.90	4.85	8.07	15.58	13.20	15.58	18.10
	Sandy Loam	3.87	8.90	13.20	3.87	8.96	20.82	17.00	20.82	24.00
Medium textured soils	Loam	6.09	11.09	15.60	6.09	12.25	26.61	22.90	26.61	30.10
	Silt	3.40	7.92	9.50	3.40	11.57	30.64	30.10	30.64	31.20
	Silty Laom	6.45	11.36	19.69	6.45	13.74	30.76	23.40	30.76	40.19
	Sandy Clay Loam	6.33	14.20	17.50	6.33	12.46	26.76	25.30	26.76	28.50
Heavy textured soils	Clay Loam	7.92	16.13	20.00	7.92	15.44	32.99	30.50	32.99	34.94
	Silty Clay Loam	8.90	18.13	21.80	8.90	17.75	38.40	38.40	38.40	38.40
	Sandy Clay	10.00	20.36	29.40	10.00	16.85	32.83	27.40	32.83	38.80
	Silty Clay	7.00	22.01	32.60	7.00	17.60	42.34	37.80	42.34	47.80
	Clay	6.80	24.13	35.90	6.80	18.10	44.47	37.30	44.47	50.40

Texture Class		Saturation Wat. Cont. θ_S %Vol			Bulk Density BD g/cm^3			Hydraulic conductivity K Cond. cm/min		
		Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Light textured soils	Sand	34.5	37.6	43.0	1.62	1.68	1.73	0.047000	0.214198	0.495000
	Loamy Sand	35.1	38.7	41.5	1.55	1.65	1.72	0.019667	0.105774	0.243194
	Sandy Loam	38.1	41.3	45.6	1.44	1.54	1.64	0.009500	0.047453	0.073680
Medium textured soils	Loam	39.9	44.3	48.9	1.35	1.44	1.56	0.005833	0.027508	0.047000
	Silt	40.5	42.9	48.9	1.55	1.57	1.58	0.004167	0.045821	0.057833
	Silty Laom	38.2	45.3	50.7	1.30	1.42	1.64	0.007500	0.034221	0.060667
	Sandy Clay Loam	38.4	45.0	48.3	1.37	1.39	1.41	0.002183	0.005001	0.009160
Heavy textured soils	Clay Loam	41.0	47.9	50.8	1.30	1.33	1.35	0.004000	0.004371	0.005681
	Silty Clay Loam	43.0	50.3	52.2	1.27	1.27	1.27	0.001167	0.004483	0.007715
	Sandy Clay	38.0	46.5	51.8	1.28	1.33	1.38	0.001500	0.002922	0.007882
	Silty Clay	36.0	50.0	54.7	1.20	1.24	1.28	0.000330	0.004334	0.006674
	Clay	38.0	50.3	55.2	1.19	1.24	1.29	0.001667	0.004213	0.010243

This Table is a part of the unpublished PhD Thesis of Dr. Mohammad Elnesr, Data in the table are collected from Keller and Karmeli (1975), Saxton et al. (1986), and van Genuchten et al (1991)

Keller, J., and D. Karmeli, 1975. *Trickle irrigation design*, Rain Bird Sprink. Manif. Corp. 133 pp.

Saxton, K. E., W.J. Rawls, J.S. Romberger, and R. I. Papendick et al. , 1986. *Estimating generalized soil-water characteristics from texture.* URL:http://www.bsyse.wsu.edu/saxton. Soil Sci. Soc. Amer. J. 50(4):1031-1036

van Genuchten M. Th., F. J. Leij, and S. R. Yates, 1991. *The RETC code for quantifying the hydraulic functions of unsaturated soils*, U.S. Salinity Lab., U.S. Dept. of Agric., Agric. Res. Service, Riverside, California. 93pp

Soil Physical Properties according to Dr. Mohammad Elnesr

Field capacity is the amount of soil moisture or water content held in the soil after excess after has drained away and the rate of downward movement has decreased.

This factor needs to determine before suppling wastewater in order to avoid uncontrolled leaching of wastewater to groundwater bodies.

The range of a suitable field capacity for wfSRC is rather large but also depends on other factors such as the use of heavy machinery.

Selection of Plant Species

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Different factors play a decisive role in the selection of the most suitable plant species

Potential crop yield (from the economic point of view)

Perennial SRCs are woody species such as alder, ash, southern beech, birch, eucalyptus, poplar, willow, paulownia, paper mulberry, robinia, Australian Blackwood, sycamore, and others are suitable species for wfSRC systems.

In Europe, the main species used are poplar and willow as these trees are suitable plants for a high treatment efficiency and high biomass productivity

Let’s have a break

We will be back in 15 min

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Construction and system establishment of the wfSRC System

System Establishment

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System Establishment

Field Preparation

Harrowing

The soil must be harrowed for breaking up compaction in the subsoil, to prepare the seedbed for planting the seedlings. A minimum plough depth of 20-25 cm is required.

Ground Levelling

Precise levelling of the planting ground is essential to guarantee a homogeneous distribution of the wastewater. Ground levelling can be executed using a laser levelling system The leveling guarantee adequate slope degree to ensure distribution of irrigation waters in the entire plot.

Field Preparation Activities WfSRC

Source: AMU University, 2019

System Establishment

Field Preparation

Irrigation System Installation

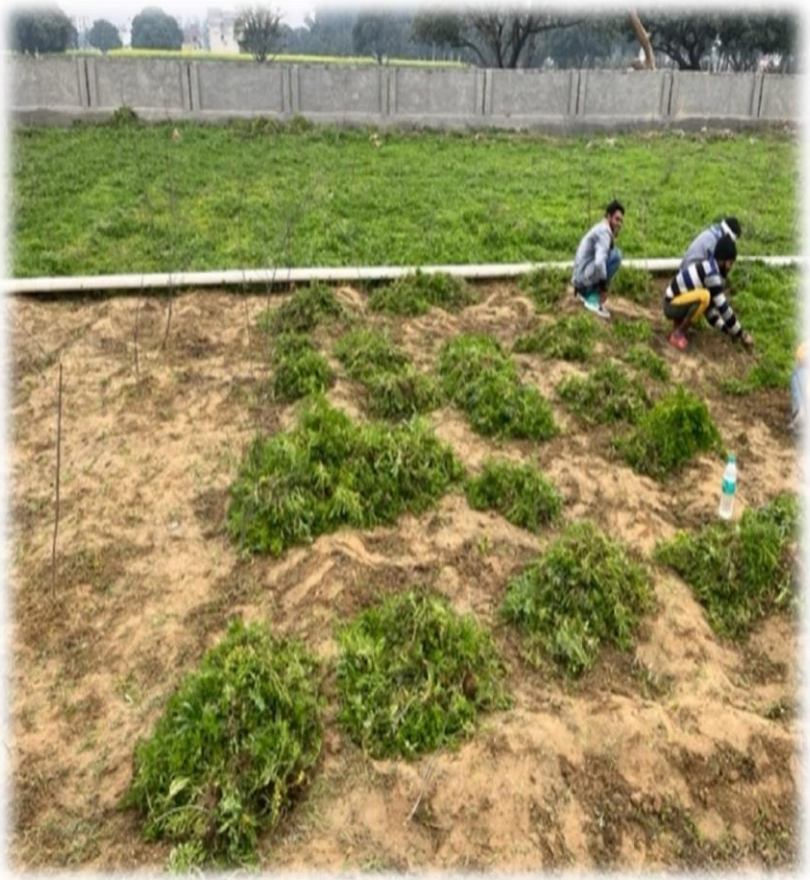
Soil Bank Construction

The soil bank is required to hold back the wastewater but also the rainwater and avoid the potential pollution of adjacent plots. Usually have a height of 30 cm and are constructed surrounding each area.

Irrigation System Installation

The irrigation system installation comprises the construction of the furrows and the installation of the pipeline and pump

Crop Establishment


Crop Establishment

Planting strategies of SRC plants can be adapted depending on the species chosen, available planting equipment, labor costs, harvest planning etc.

A boundary zone of around 2-3 m should be left on the other boarders of the wfSRC plantation.

Planting is usually done in spring when weather conditions allow soil preparation

The planting can be done automatic using planting machines or manually (Depending on the case)

It is important to keep the rows parallel to each other and to keep the distances between the plants within the rows equal to each other in order to avoid inter-competition.

Start-Up Period

Initial Start-Up Period of a wfSRC

- Corresponds to the first 6 months after planting.
- In this period, the water irrigation load is provided using treated water
- Once steady state conditions are achieved, wastewater is pumped from the equalization tank to the SRC area.
- In this period the plantation should be monitored to keep it free from competing vegetation and emerging weeds and other calamities.

Materials and Equipment

Plants

Bambusa vulgaris seedlings

The yield of each specie strongly depends on many factors, including soil conditions, climate region, nutrient availability, plant growth, coppicing, among others

Materials and Equipment

Wastewater Collection System

The collection system is composed by pipelines, equalization tanks and pumps.

The sewage is pre-treated by means of a screen and a grit removal chamber, stored in an equalization tank and then pumped directly via pipelines and distributed into the wfSRC system

Wastewater Collection System

Materials and Equipment

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<u>Water transport system (Pumps and Pipes)</u>

Wastewater Transport System

A standardized submerged pump (5-7 kW) feed the wastewater from the tank into the pipeline network

Standard PVC water pipes, elbows and valves of different diameters form a standard irrigation system and are implemented in each sector.

Materials and Equipment

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Monitoring equipment

The monitoring equipment in a wfSRC system is necessary to control and ensure the correct operation of the system and the compliance of the national regulations.

Monitoring Equipment wfSRC System

Materials and Equipment

Protection Barriers

The construction and/or installation of physical protection barriers is usually not recommended due to the high costs. However, extensive damage due to rabbits, hares, roe deer, mice and other rodents has been reported in newly established wfSRC plantations. Standard fencing would be sufficient to stop grazing animals to enter the plot

Fence Surrounded the Planting Area

Operation and maintenance

Operation and Maintenance Activities

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- Wastewater Irrigation
- Weed Control
- Harvesting

Operation Activities

Irrigation and Fertilization with Wastewater

- Irrigation should be performed daily during the selected period, but should be reduced or stopped when heavy rainfall occurs in order to avoid extensive nutrient leaching or washing out of the wastewater.
- Irrigation should be shifted throughout the day to different parts of the field for short periods of time.
- An irrigation of each sector on a rotary principle seems to be beneficial for water treatment and biomass production

Wastewater irrigation in wfSRC System

Operation Activities

Biomass Harvesting

According to the produced, the harvesting techniques can differ depending on:

- crop cultivation model and density
- Species
- Climate
- Final utilization of the biomass

In order to promote the development of multiple shoots it is recommended to cut each stem after the first winter, but in other cases specificities and procedures are well defined.

Manual Biomass Harvesting Activities

Maintenance and Management of the wfSRC plantation

Daily maintenance tasks

- **Water supply:** The pumping system must be verified to guarantee water supply. Once is completed and the supply ensured. The flow can be adapted by opening and closing of valves an equal distribution of wastewater over the complete area. In addition, refilling of the storage tank must be checked.
- **Flowmeter:** Correct functioning of the device must be verified and flow recorded daily.
- **Mechanical damages:** Components of the water distribution system must be inspected to verify and anticipate possible damages and malfunctions of the system.

Maintenance and Management of the wfSRC plantation

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Weekly maintenance tasks

- **Pipeline system:** Inspection of the complete system in order to ensure that there are no leakages or possible disruptions.
- **Water distribution system**: Inspection of correct functioning of all the components.
- **Plant health**: via visual inspection and measurements to determine the presence of termites, other harmful insects and pests among other abnormalities.
- **Weather station, crop view camera and Sentek sensors:** review the weather station, crop
- **Camera and sensors data:** Review to detect possible drawbacks on time.

Maintenance and Management of the wfSRC plantation

Monthly maintenance tasks

- **Status of the fence**: visual inspection of the fence and infrastructure.
- **Status of the dams:** visual inspection of the conditions and structure of the dams.
- **Status of water pump**: emptying the wastewater tank and inspecting and cleaning the submerged pump.
- **Flow meter**: check on the flow speed and correct functioning of the flow meter.
- **Water distribution system**: inspection of the system including pipes, valves, elbows, among others.
- **Water samples** : samples should be taken and analyzed from water collectors under the root zone in each to check nutrient content (especially nitrate) to avoid ground water contamination.
- **Inspection of the furrows**: visual inspection of the conditions and structure of the furrows and verification that the slope is allowing an even wastewater distribution.
- **Weed control** (if required): weed should be removed, especially in the first year to avoid

Maintenance and Management of the wfSRC plantation

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Biannual maintenance tasks

- **Plant control**: Plantation should be monitored to keep it free from competing vegetation, emerging weeds and other calamities.
- **Cleaning of the water distribution system**: flashing pipes and perform deep cleaning in the additional components.
- **Inspection of weather station, crop view camera and sensor system**: check battery status and SIM-cards in order to ensure continuous data transfer.
- **Soil, wastewater & biomass samples:** samples should be taken and analyzed to check the nutrients status and to avoid accumulation of pollutants.
- **Biodiversity checkup:** visual check of additional species which are habituating the system.

Control and follow-up

Monitoring Task	Method	Values	Frequency
Amount of applied wastewater	US Flow Measurement	m^3	Continuous measuring
Quality of incoming wastewater	Samples	BOD5 COD, N, P, K	Monthly
Quality of soil	Samples	Field capacity, Organic content, N,P,K	1x before planting, 1x per year
Weather conditions – precipitation, wind and temperature	Data from installed weather station	C°, mm/m^2, m/s	Continuous measuring
Distribution of wastewater and rain water	Installed Soil moisture sensors (SENTEK)	Penetration level in cm,	Continuous measuring
Exit of nutrients (groundwater)	Samples taken from percolation water	N, P, K, BOD, COD,	Monthly
Biomass growth	Direct measurements And optical data (installed camera)	Weight of fresh &dry biomass, thickness and number of shoots	Monthly
Quality of Biomass	Samples	Ash content, chlorophyll	1 per year
Evapotranspiration	Measurements		1per year
Plant Survival Rate (Bamboos, Poplars, Willows and Reference Garden)	Measurements	Number of plants	1 per week

wfSRC Costs

Construction and installation costs (CapEx)

wfSRC wastewater treatment unit	Units	€ unit	subtotal (€)
wastewater pump, single stage horizontal surface pump 5-7 kw	1	500	500
pressure reducer before the main pipe	1	50	50
piping and water distribution system	1	1.000	1.000
Melaleuca alternifolia Cheel	2.500	0,2	500
Salix tetraspermo	5.000	0,1	500
Bambusa vulgaris	5.000	0,1	500
Valves, check valves, armatures etc.	10	50	500
Flow meters	1	125	125
Sum A			3675
Sensor and data system			
Weather station UMTS (+SIM card),	1	1500	1.500
Data logger	1	250	250
Camera system	1	450	450
Soil moisture, pH, salinity sensors (ENVIRONSCAN, SENTEK)	9	850	7650
Leachate passive water traps	27	8	216
Pressured water traps	9		500
Hand Measurement equipment (N) Horiba	1	3500	3.500
Sum B			14.066
Total Sum A+B			17.741

Operation and maintenance costs (OpEx)

Wastewater treatment unit	Units	€ unit	€
Research staff & local operator	400	€/month	4.800 €
Chemical reagents for lab analysis of water, soil and plant material (N, P, K, TOC)	100	€/month	1.200 €
Analysis of plant material (number of shoots, weight (fresh & dry), ash content, chlorophyll, transpiration rates)	50	€/month	1.800 €
Online monitoring and data transfer	5	€/month	180 €
TOTAL			8.160 €

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Example:
The PAVITR pilot project

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Cooperation between EU and India aiming to tackle water challenges and ensure the provision of safe water reuse in India through the development of cost effective and sustainable technologies.

Technical, financial and environmental aspects of the most representative technologies are assessed within the framework of the project.

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European Commission

Horizon 2020
European Union funding
for Research & Innovation

Case Study Description

A field trial is carried out in North India at the research station of the Aligarh Muslim University (Aligarh).

Field Trial Location- AMU

The system has been designed to receive and mechanically pre-treated (screened) municipal wastewater from the AMU University facilities with a max. capacity of 2273 PE and a wastewater volume of 250 m3/day.

Design Criteria

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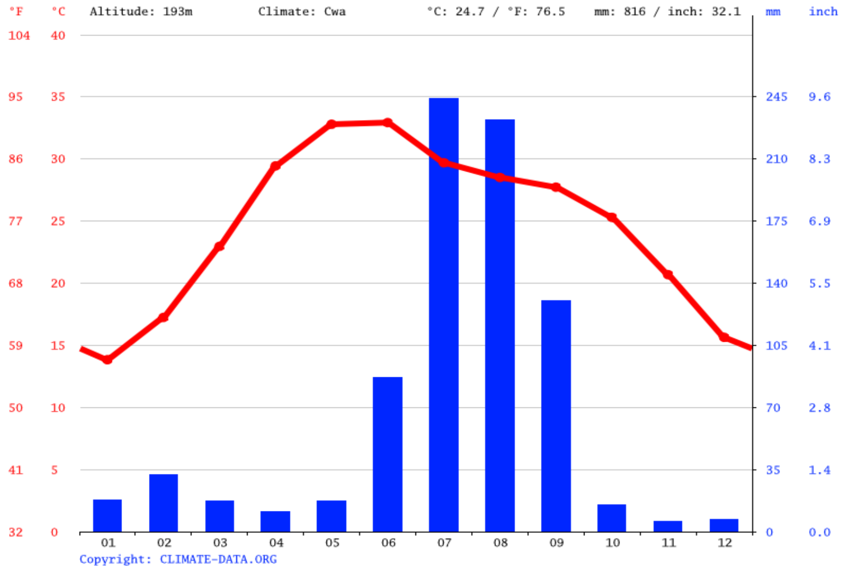
Climate

- Aligarh's climate is classified as a monsoon influenced humid subtropical climate.
- In summer, average temperatures lies between 28-38°C,
- In winter, the temperatures vary between 7-11°C in average.
- Between 900 and 1100 mm of precipitation falls annually in Aligarh, mostly during the monsoon season, which starts in June and continues until early October (Climate Data, 2021).



Climate graph Aligarh (Climate Data , 2021)

Design Criteria

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Hydraulics & Field Capacity

- Hydraulic loading of 250 m^3 /d,
- Reported water consumption rate of 125 LPCD in Aligarh
- Estimated wastewater return co-efficiency: 0.8

As a result, the specific land requirement for the pilot plant was calculated as 6,864 m^2/2,500 PE= 2.75 m^2/PE.

Design Criteria

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Soil Characteristics

The soil composition of the area varies from sands, loams and silts to heavy clay that are all ill drained and sometimes charged with salts.

Soil Profile Case Study

Design Criteria

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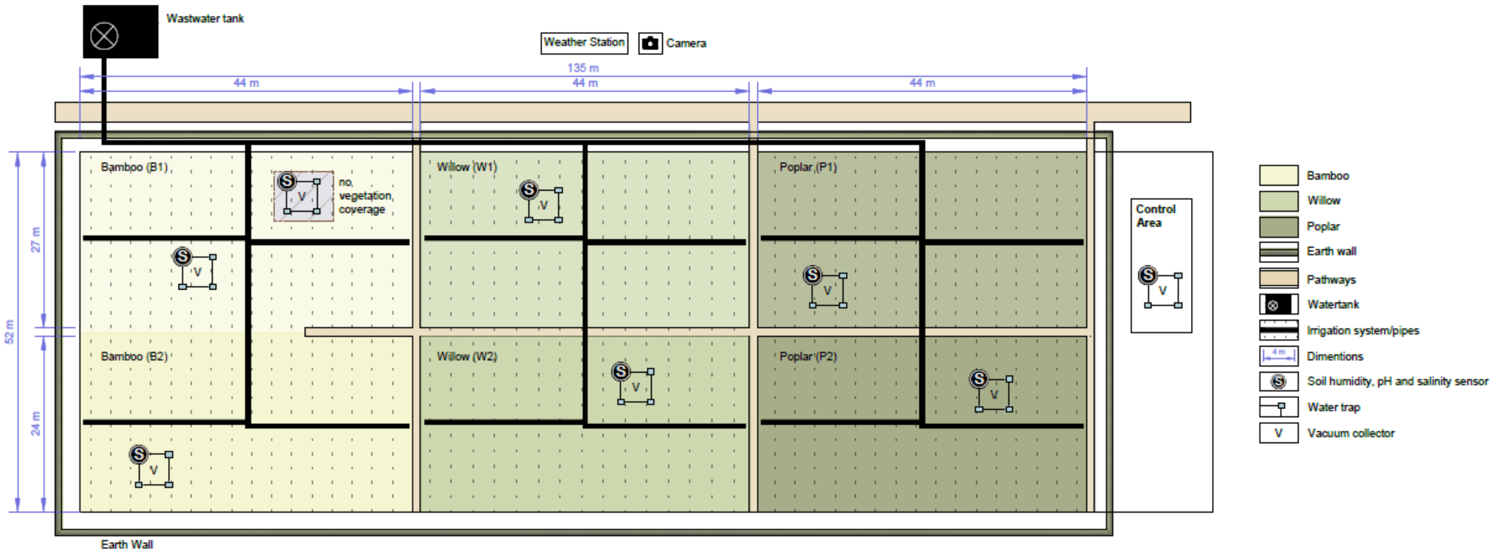
Selection of Plants Species

In PAVITR, three plant species have been selected:

- Poplar (Populus tremula)
- Willow (Salix alba, Salix purpurea)
- Bamboo (Dendrocalamus strictus, Bambusa vulgaris, Bambusa bambos).

Different local available bamboo varieties have been selected due to very promising data on biomass production and given economic potential for the produced biomass. All plants are local varieties and have been purchased in regional tree nurseries.

Layout of the wfSRC System



The wfSRC system is taking place on a 0.75-hectare plantation, divided in three individual sectors of 2.500 m2 in which each species of willows, poplars and bamboos are planted in each sector.

Poplar sector

- one-year old trees of poplar (*Populus tremula*) planted in January 2022
- Density of 10,000 plants/ha
- 1 m row spacing, 1 m plants spacing on row

Willow sector

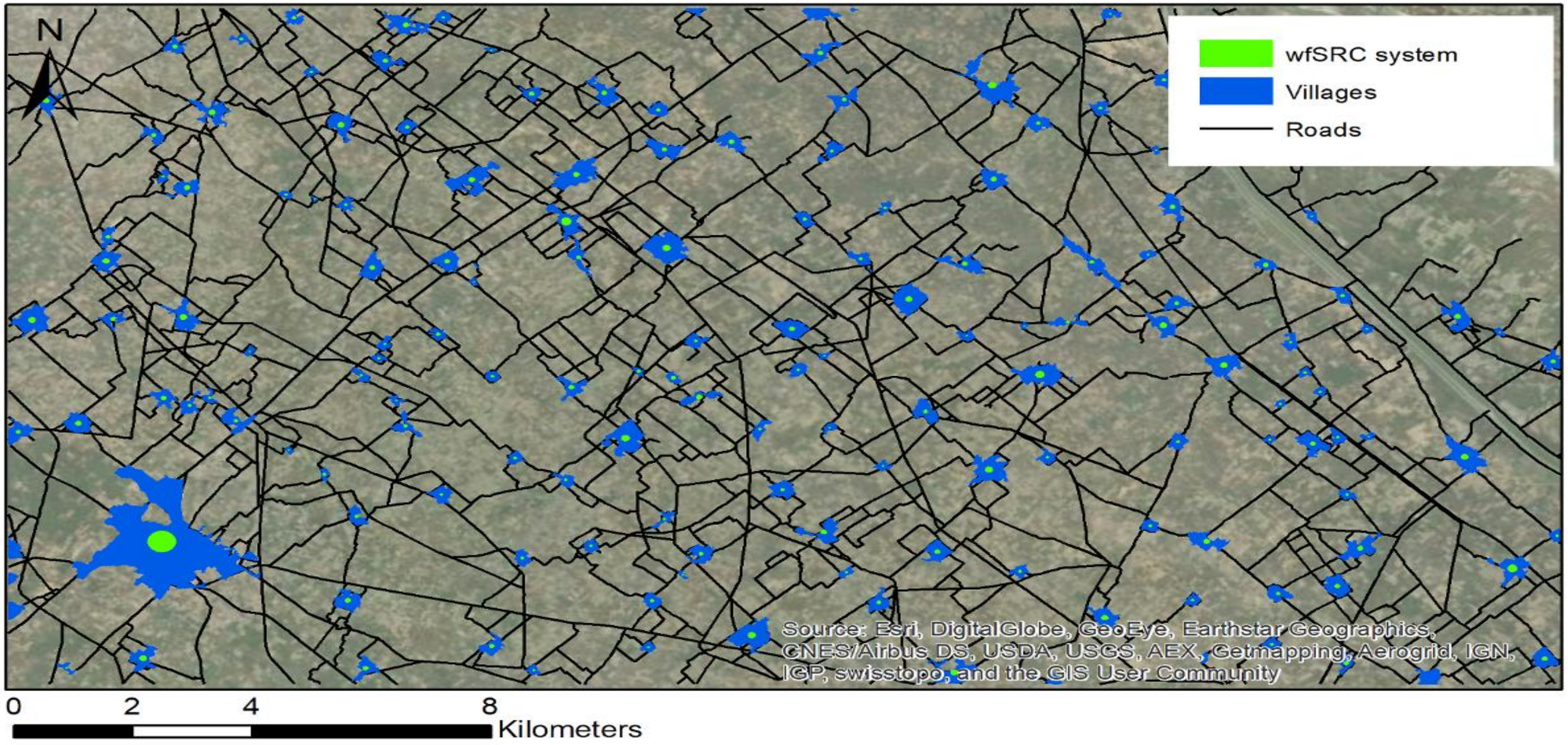
- two one-year old willow species (*Salix alba, Salix purpurea*) were planted in August 2021
- Density of 10,000 plants/ha
- 1 m row spacing, 1 m plants spacing on row)

Bamboo section

- Planted in August 2021 with three different bamboo species (*Dendrocalamus strictus, Bambusa vulgaris, Bambusa bambos*)
- Density of 20,000 plants/ha
- 0.5 m row spacing, 0,5 m plants spacing on row

Homework

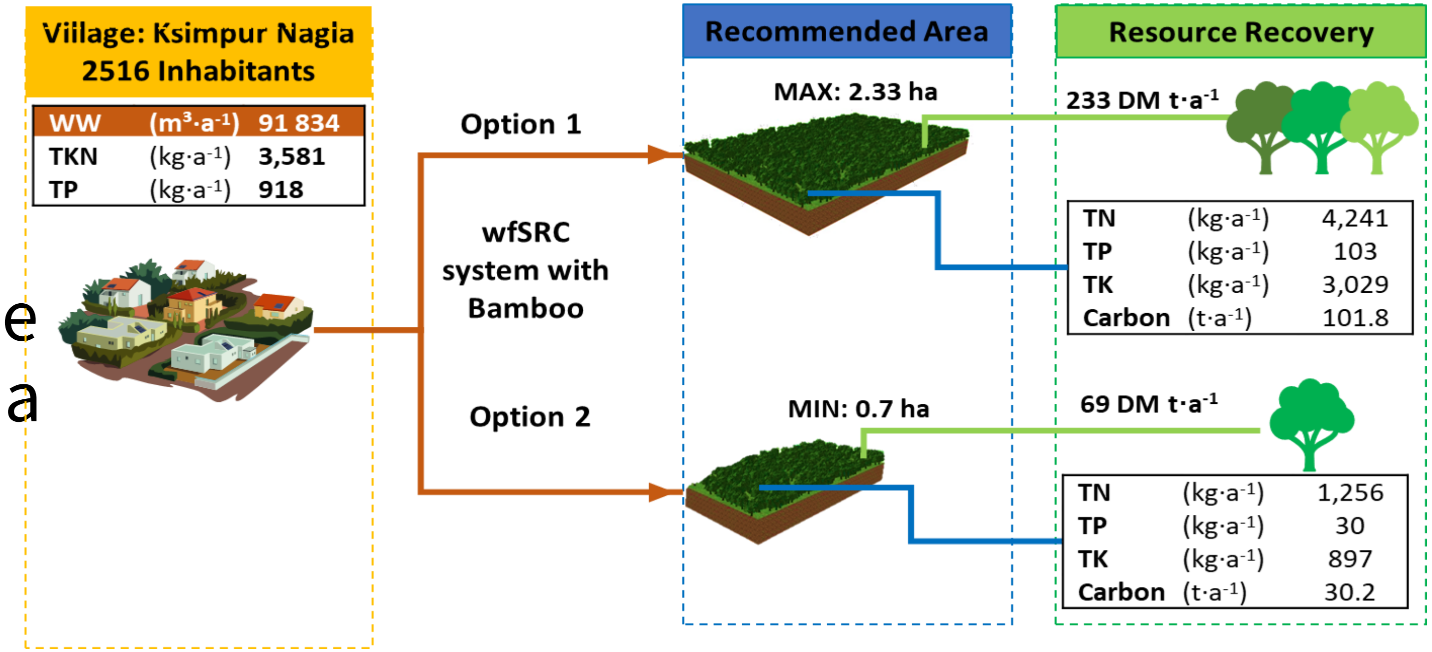
Introduction to the case study



Key data for calculations

Village: Ksimpur Nagia

- 2516 inhabitants
- 75 % of the people are connected to a collection pond



Your homework is

1. Calculate the minimum and maximum size of a bamboo wfSRC system using the available water from the pond.
2. How much biomass can be produced in both scenarios?
3. What would be a realistic income from the bamboo biomass per hectare and year?
3. Which local stakeholder should be involved from the beginning?
4. Which conflicts do you expect and why? Which trouble shooting strategies do you have?

References

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