# DEVELOPMENT OF A POND BASED STORMWATER TREATMENT SCHEME FOR RURAL AREAS

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## ABSTRACT

Due to increasing population and the improved water supply systems the quantity of greywater generated from the village ponds has increased to a large extent. This has in turn degraded the quality of the receiving water body. Excessive generation of greywater and absence of any village level wastewater treatment mechanism has severely affected the quality of the water in village ponds. So a research has been undertaken to suggest a low cost mechanism for treatment of storm water and grey water found in rural ponds or water bodies. The research conducted includes the study of ten rural catchments in the radius of around sixty kilometres in Doaba region of Punjab. Ponds were used as the disposal points for the greywater generated in the villages. It is worth mentioning that limited quantity of greywater was generated in the villages and hence the self-cleansing capacity of the pond was sufficient to treat the wastewater being disposed of in it. Talking of last few decades the quantity of greywater generated from the village ponds has increased many folds due to increase in population and modern sanitation facilities. Although the self-sufficiency of village ponds in treating the influent remains same, therefore posing a problem in treatment.

This thesis presents the outcomes of the research carried out to establish the volume as well as peak rate of runoff in rural catchments. These runoff parameters derived from the study conducted is used in designing various treatment units that are required for treatment of greywater/stormwater.

The focus of study is to establish the low-cost based natural treatment systems for rural ponds so that treated water can be reused for irrigation facilities or can be recharged into the ground. The data which was collected for all the selected catchments include rainfall data, land use auto-cad maps including village and pond areas. The boundaries of the catchment areas were obtained through Google earth pro software. To cover all catchment areas rainfall data from five rainfall stations were collected. Rainfall volume was calculated using the US SCS-CN method with collected daily rainfall data of 15 years (1998-2013) for the selected five rainfall events in all the catchments. The effective rainfall event was 80th percentile in all the catchments except one. It was noted that the rainfall volume during extreme rainfall events was much more than that during 90th percentile rainfall events. The treatment scheme is designed for 90 percentile rainfall volume of stormwater in the form of spreadsheets on MS-excel which contains design of constructed wetland, facultative pond, roughing filter, storage area and slow sand filter. The areas for all these components are calculated. According to these designs their top view and L-section view maps are created using Auto-cad.

The treatment scheme is suitable for rural areas where requirement for easy availability of land can be full-filled. This is a low-cost pond treatment scheme which contains natural treatment units like wetland, facultative ponds and filters. System is designed to remove BOD, COD, total suspended solids, pathogens and nutrients so that either the wastewater can be used for irrigation or can be recharged to the groundwater.

# CHAPTER 1

# INTRODUCTION

Water is a rare and valuable natural resource to be managed, developed, planned and conserved as such, and on united and environmentally sound origin, keeping in mind the socio-economic characteristics of a country. Increasing population is resulting in an increased demand for fresh water. In specific for rural areas, source sustainability of drinking water supply with increasing demand is one of the major worries. The inadequate water availability and increasing demand has encouraged the need for water conservation and in particular the village ponds.

## 1.1 General

Any depression in the ground which collects and recollects an enough amount of precipitation can be considered as pond. It can catch and preserve rainwater leading to enhanced filtration and ground-water recharge, to be used for both drinkable and non-potable usages by humans and cattle. In some areas with small rainfall they can also be dry for few months in each year. Such depressions can be formed by different kinds of ecological, geological events or can be even manmade.

Historically in India, lakes and ponds have always played a significant part in supplying drinking water, irrigation, ecology and domestic use. Different approaches of water conservation were established to suit meteorological and geographical conditions of the area in several parts. Water resources in the form of capturing precipitation is done by surface storage bodies like ponds, irrigation tanks that has an important role in ground water recharge.

Disposal of wastewater in village ponds can cause serious public health issues. Stationary wastewater smells bad and also acts place for mosquitoes resulting in spread of serious diseases. Reuse and disposal of wastewater helps in fighting diseases as well as water shortage.

India gets an average rainfall of 4000 billion cubic meters per annum. Rainfall is extremely unequally distributed with respect to time and space, over the country. Village ponds serve significant environmental, social and economic purposes, source of drinking water, supporting bio-diversity and providing livings, recharging ground water acting as sponges to control flooding. These water bodies, whether natural or man-made, fresh water or salty play a dynamic role in sustaining environmental sustainability.

With the improvement of drinking water supply, the wastewater generation is increasing fast. Such wastewater constantly getting collected in ponds and if not treated and disposed properly, it will adversely affect the quality of groundwater as well as local environment and public health.

## 1.2 Greywater

Grey water actually is wastewater but does not contain wastewater from toilets. It is generated from houses and office building. The greywater comes from kitchens, washing machines, baths, showers, sinks etc. The greywater is different from toilet wastewater (Blackwater) because it contains less nitrogen, fewer amount of pathogens as compared to blackwater.

Greywater is different from blackwater because it can be used again after its proper treatment for different kind of purposes like irrigation, heat reclamation and toilet flushing. The major benefit of greywater use is that it reduces the need of fresh water and amount of wastewater entering sewers. So it is preferred to distinct it from blackwater to lessen the amount of water that gets contaminated. The most actual and nontoxic way to avoid negative environmental influence form the by-products of digestive systems is to keep greywater and blackwater separate.

Greywater and blackwater must be recovered and treated on-site by using natural treatment or pond based treatment systems before they come to be mixed and abandoned by non-organics. The treatment and recycle process of greywater is easy and faster than blackwater and can be done onsite. The treatment of greywater can be done by filtering, sedimentation, anaerobic &anaerobic digestion techniques.

### 1.2.1 Sources of contamination of greywater

- **Biological –** microorganisms
- **Chemical –** dissolved salts and chemicals such as sodium, nitrogen, phosphorous, oils, fats, milk, soap, detergents etc.
- **Physical –** soil, food, lint.

| Source | Percent | Category |
|---|---|---|
| Toilet | 40 | Blackwater |
| Kitchen Waste | 10 | Greywater |
| Misc. | 5 | |
| Laundry | 15 | |
| Bath/Shower | 30 | |

### 1.2.2 Greywater characteristics against combined wastewater

- Lower in BOD concentration, 140 to 160 mg/L.
- Lower in suspended solids, 50 to 150 mg/L.
- Lower in phosphorous concentration, 0.4 to 2.0 mg/L.
- Lower in nitrogen concentration, 5 to 10 mg/L.
- Higher in salt content.
- More alkaline in nature.

## 1.3 Current techniques for Greywater Treatment

#### 1.3.1 Facultative ponds

Facultative ponds are those in which an arrangement of anaerobic, aerobic, stabilization, maturation and facultative (able to grow in either the presence or absence of oxygen) bacteria stabilise wastes. These facultative ponds for greywater treatment are suitable for rural area because of availability of land. The polluted storm water can also be treated using these ponds. The treated water can be used for different purposes like irrigation.

**1.3.2 Waste Stabilization Ponds: -**This method is also known as lagoons which is a natural method for wastewater treatment. This process of wastewater treatment needs a significant amount of space. Therefore it is not suitable for urban areas. It can treat industrial wastewater, municipal effluent or contaminated stormwater. After treatment, the effluent could be returned to the environment as irrigation water and fertilizer.

### 1.3.3 Aerobic ponds

In aerobic treatment ponds, aerobic microorganisms decompose the organic matter into water, carbon-dioxide and cell biomass using dissolved oxygen. Naturally aerated ponds depend on oxygen produced during photosynthesis and dispersion of oxygen into surface layers from the air. Micro-organism growth is a fast process so a large amount of the organic matter is converted into cell biomass.

### 1.3.4 Anaerobic ponds

Anaerobic bacteria does not need free oxygen to stay alive. The conditions in anaerobic pond allow such bacteria to continue decomposing the remaining organic compounds into fertilizer which produces carbon dioxide and methane. The activity of anaerobic bacteria is concentrated in the layer immediately above the sludge.

### 1.3.5 Constructed Wetlands

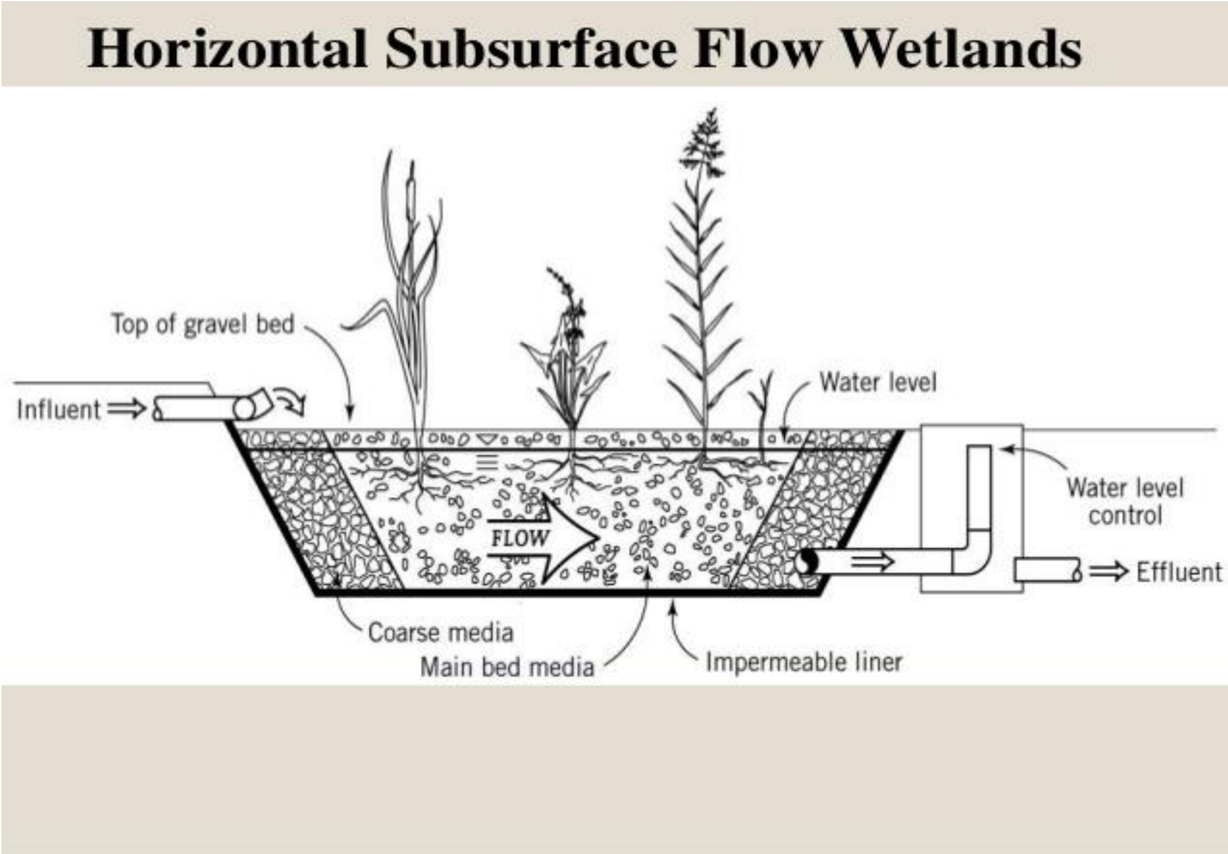
Constructed wetlands are man-made systems built to remove various types of pollutants present in greywater. They are constructed to recreate the function and structure of natural wetlands. They have a rich microbial community to effect the biochemical transformation of pollutants and they are self-sustaining and biologically productive. These wetlands act as a natural treatment system for removal of organic matter, suspended solids and also heavy metals. As a primary treatment constructed wetlands can also be used after septic tanks. The main advantage of constructed wetland is that it is a self-sustaining technique which can be used over other conventional systems which are actually costlier.

### 1.3.5.1 Types of construct wetland

**Vertical flow Constructed Wetland:** Vertical flow wetlands are designed for treatment of Blackwater and greywater operated in aerobic conditions. The water flows vertically down to the bottom and then collected into a drainage pipe. These type of wetlands are highly recommend for removal of total dissolved solids, pathogens and BOD.

**Surface flow Construct Wetland: -**These systems are used for municipal wastewater treatment. It make use of influent waters that flow across a channel that supports different kinds of vegetation of vegetation. Bed depth is about 0.4 m. The water is visible at a shallow depth directly above the surface of the substrate materials. Substrates are native soils and clay or impervious geotechnical materials that prevent seepage. Inlet devices are connected to maximise sheet flow of wastewater through the wetland, to the outflow channel.

**Horizontal Sub-surface Flow Construct Wetland:-**In Sub-surface Flow system, water flows from one end to the other end through permeable substrates which is made of mixture of gravel and soil. Media size for gravel substrate ranged from 5 to 230 mm with 13 to 76 mm. The depth of media is about 0.6 m deep and the bottom is a clay layer to prevent seepage. To minimise the water that flows overland, bottom of the bed made sloped. Due to gravity action wastewater flows horizontally under the gravel surface through the roots of the vegetation. For collection of waste water the outlets at the base of media are used.




**1.3.6 Oxidation Pond**

This type of pond is designed to receive flows that have passed through primary settling tanks or stabilization pond. Biological treatment and a few reduction in the number of fecal-coliform are provided by these ponds. Their designed specifications are same as the stabilization pond.

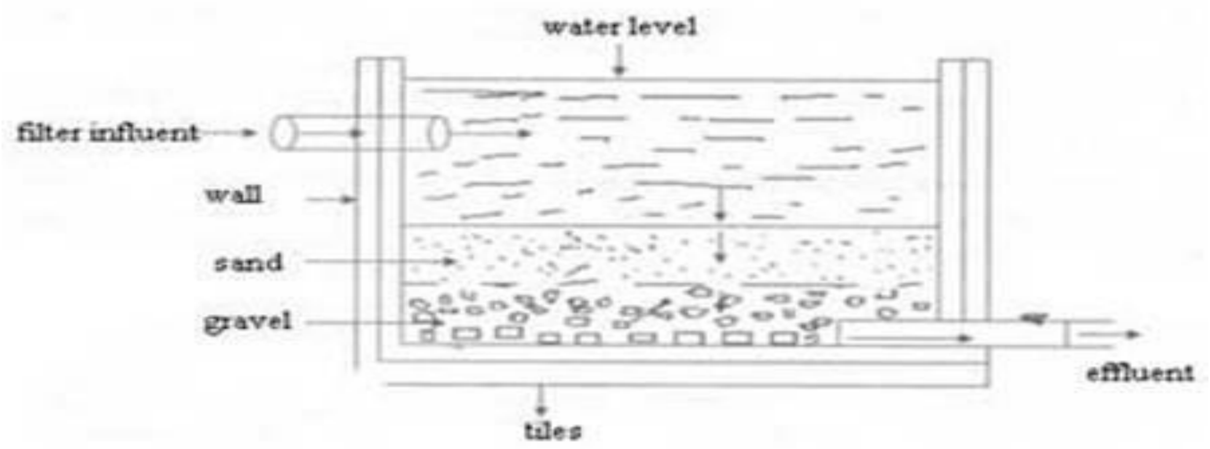
**1.3.7 Sand filters**

They are used mostly in water purification for treatment of raw water. They can be rectangular or cylindrical in cross section. By the flow rate desired by the filters, width and length can be determined, which has a loading rate of 0.1 to 0.2 metres per hour. They are mostly 1 to 2 metres deep.

**1.3.7.1 Types of sand filters**

**Rapid Sand Filter**: Rapid sand filters are designed for domestic or municipal wastewater treatment. These filters are also known as rapid gravity filters. These filters can handle much flow rate than sand filters. But they cannot operate for small societies due to their high cost, greater maintenance and production of large vol. of sludge.

**Slow Sand Filter:** Slow sand filters are used for treatment of raw water and wastewater. These are low cost based filters, require small maintenance so can be operated for rural purposes. Their treatment frequency is much better than rapid sand filters. They occupy less area foe their installation.




### 1.3.8 Roughing Filters

Roughing filters are used to pre-treatment of turbid wastewater, because it separates fine solid particles over extended periods, without addition of any chemicals. These filters can be operated as both up-flow and down-flow filters. Sometimes, when greywater/stormwater remains still in ponds in presence of sunlight, algae starts to grow and water becomes turbid. Roughing filters are provided there for treatment of that turbid water. Mostly, the filter contains different size of gravel as filter media in different layers from which water have to pass.

#### 1.3.8.1 Types of roughing filters

**Vertical flow Roughing Filter:** The filter media is filled with coarse, medium and fine gravel in three separated compartments. The water to be treated passes through these compartments one by one. The flow can be in both upward and downward directions. Their operations can be done at 0.3 – 1.0 m/h filtration rate.

**Horizontal flow Roughing Filter:** The main advantage of horizontal roughing filter is its simple design and unrestrained length of filter, to handle turbidity between 500 to 1000 NTU. These filters can be operate between ranges 0.3 – 1.5 m/h filtration rate.

## 1.4 Stormwater runoff as a source of pollution

Water which originates during rainfall or other activities like snow/hail melting etc. penetrates into the soil, the part of this water which doesn't penetrate acts as runoff and leads its way to the nearby water sources like ponds, lakes etc. This runoff which joins nearby streams is called storm water. This water is also a source of pollutant as it picks up substances like pesticides, oils and soaps etc. on its way and flows into low lying areas.

## 1.5 Objectives of the study

The objectives of this study are:

- To determine the runoff volumes from selected catchments.
- To study the different low-cost treatment options suitable for rural areas.
- To develop a pond based system for treatment of greywater and stormwater in villages.

## 1.6 Organization of Thesis:

The thesis has been organized in seven different chapters dealing with different aspects of study as follows:

**Chapter 1 – Introduction -** This chapter describes about ponds, background on ponds, greywater, effects of greywater on ecosystem, various types of pond based treatment systems and the objective of this work.

**Chapter 2 – Literature Review**

This chapter gives details about the earlier works carried out by various researchers related to the present work. It is presented under different headings for ease in understanding.

**Chapter 3 – Problem formulation**

This chapter presents the problem defined and significance of the research work.

**Chapter 4 - Methodology**

This chapter presents the methodology of the research used to achieve the objectives is explained thoroughly. Background data for rainfall, survey maps, and types of soil are collected and used in various hydrological models in order to achieve the objectives

**Chapter 4 - Results and Discussion**

This chapter presents results of the research work in different sections. The results are presented with tables and figures and are discussed within each section of result.

**Chapter 5 - Conclusion**

This chapter gives the details about findings of the research work and scope for future studies.

# Chapter 2

# LITERATURE REVIEW

## 2.1 GENERAL

This chapter deals with the review of the published literature on pond based natural wastewater treatment systems like wetlands, stabilisation ponds, sand filters and specifically the applicability of this technology in the treatment scheme of wastewaters. The most important investigations have been summarized and the salient facts, which seem to emerge from the reported investigations have been discussed.

## 2.2 CONSTRUCT WETLAND (CWs)

**Shubiao Wu et al (2014**) studied that CWs plays an important role on removal mechanisms which is mainly depends on wetland design and operations. Different techniques can be adopted like earthworm integration, reciprocation, recirculation, flow-direction recirculation, aeration etc. Different designs of CWs can be adopted like towery hybrid CWs, circular flow corridor CWS, baffled subsurface CWs which provides new thoughts in improvement of intensified CWs mostly for removal of organic matter and nitrogen.

**Wurochekke A. et al (2014)** evaluated performance efficiency and greywater loading characteristics of constructed wetland for treatment of domestic greywater. The conducted study shows the high removal performance of 45.01% turbidity, 54.70% suspended solids, 81.42% BOD, 84.57% COD and 39.83% AN.

**O. Phewnil et al (2014)** carried out a study on performance of vertical flow constructed-wetland by choosing different aquatic plant species for treatment of wastewater. The study concluded that removal efficiency depends upon significance of choosing plant species.

**Gude V. G. et al (2013)** reviewed technologies to treat waste-water by using natural processes and passive components. The study was mainly focused on wetland systems and their applications in pollutant removal, waste-water treatment and nutrient. The study had showed the effect of wetland design, storm water treatment and vegetation effect on removal efficiency.

**Mulling B. T. M et al (2013)** studied the change occurred in biological & physical characteristics of suspended particles throughout residence in the full scale surface flow constructed wetland. This study concluded that the nature and type of suspended particles has been changed by CWs and it also reduced the input of anthropogenic particles into receiving surface waters.

**L. Amado et al (2011)** worked on a LECA-based horizontal subsurface flow constructed wetland which calculated the effect of storm-water infiltration on removal of organics, solids, nitrogen and phosphorous. It was observed that the treatment capacity of horizontal subsurface flow systems can be improved by using a bed material with high specific surface area provided the organic and surface loading rates are controlled well.

**Jan Vymazal (2010)** represented the study on different types of CWs which can be classified as hydrology type, vegetation type & flow direction which further could be combined into different hybrid CW systems to attain improved treatment performance.

**Renee Lorion et al. (2001)** studied that using CWs contaminants from waste water can be removed effectively. Apart from municipal waste-water, CWs can also be used for other waste waters like agricultural, landfill leachate, industrial, storm water.

**Tony H F Wong et al (1999)** compared ponds with CWs. In this paper they have discussed their performance and various issues related with CWs and their significance and requirements. The study had showed the effect of wetland design, storm water treatment and vegetation effect on removal efficiency.

**Fernando J.T.Q.** represented the stabilization ponds all over the world by showing their parameters and characteristics. The study showed the effective treatment by improving the wastewater quality by 95% by removing pathogens and this method is also a low cost based system, requires less maintenance. In Brazil and Egypt this method works efficiently for removal for eggs and parasite from wastewater.

## 2.3 ROUGHING FILTER

**Mohammad Khazaei et al (2014)** evaluated the performance efficiency of horizontal roughing filter for removal of total suspended solids, phosphorous and organic matter. It was concluded that at a constant filtration rate of 0.5m3/$m^2$/h1 provide better efficiency. Increasing the filtration rate may reduce performance efficiency.

**Gulhane M. L. and Yadav P.G. (2014)** investigated that high removal rates of TSS, BOD and COD can be achieved by using multi-media filter technology with attached growth processes for domestic wastewater and to improve the outlet quality materials like porous aerocon and burnt bricks media may be more efficient.

**Affam A. C. et al (2013)** investigated that for better removal of turbidity, BOD and COD vertical roughing filter with limestone media could be used for treatment of wastewater and leachate, but filtration rate could be reduce removal efficiency.

**Patil V.B. et al (2012)** concluded that horizontal-flow roughing filter can be considered as a pre-treatment process for removal of contaminants like BOD, COD, suspended solids and turbidity. Roughing filters exhibit the ability of both filtration and sedimentation and thus system may be of low cost.

**OnyekaNkwonta (2010)** performed a comparison between vertical roughing filter and horizontal roughing filter which shows their advantages and disadvantages also. According to this study, horizontal roughing filter was found to be much better for pre-treatment process of wastewater to remove total suspended particles and other parameters compared to vertical roughing filter due to its simple layout and unlimited filter length.

**Nkwonta O. and Ochieng G. (2009)** investigated some modifications in filter media using coconut fibre, burnt bricks and charcoal for roughing filters which can be used for pre-treatment process in rural areas without using any input energy, manpower, chemical and can be operated at low cost.

**Nkwonta O. and Ochieng G. (2009)** investigated that roughing filter for wastewater treatment for mine water using charcoal as filter media is much efficient compared to gravel as filter media because of its permeability and highly specific surface area.

**Dastanaie A.J. et al (2007)** evaluated performance efficiency of horizontal-flow roughing filter for treatment of drinking water. The study showed successful results in removal of total suspended solids and turbidity. The study also showed that this filtration technique is also efficient, using surface water as influent.

**A H Mahvi et al (2004)** represented a modified system of filtration which is named as direct horizontal roughing filter with different size of filter media while operating at condition of coagulant dose (2mg Fe/L) and at fixed filtration rate. This system could handle input effluent with turbidity of 200-400 NTU.

**AH Mahvi et al (2001)** conducted a study to evaluate performance efficiency of both vertical roughing filter and horizontal roughing filter to remove parasite egg removal and turbidity from fresh water. It was concluded that horizontal roughing filter has a better removal efficiency for treatment of water as compared with vertical roughing filter.

## 2.4 SAND FILTER

**B. A. AMA et al (2015)** attempted a new design of low cost sand filter for treatment of wastewater which was made of polyvinyl chloride pipe (PVC). It had three different sections in "U" shape. It was concluded that performance efficiency increased with decrease in medium grain size. On the other hand, it decreased with increase in hydraulic load.

**Anggraini and Silva (2014)** evaluated a study on performance of slow sand filter using two different filter media size at two different level of supernatant layer called constant level and decreasing level. It was observed that coarse grain size sand as filter media performs same to remove turbidity as fine grain size sand. However, filtration rate of fine grain size can be controlled easily.

**Almoayied assayed et al (2014)**represented a study on performance efficiency of a modified version of slow sand filter called drawer compacted sand filter for grey water treatment which was able to  remove BOD, COD, total suspended solids and E-coli. It was concluded that it gives overall 90% removal efficiency even if there was some changes made in hydraulic load along with organic load.

**NassarA. M. andHajjaj K. (2013)** evaluated a study on performance efficiency of sand filter at different depths for storm-water and industry wastewater and also generated a relationship between the effective depth and removal of fecal-coliforms and suspended particles.

**K. Vijayaraghvan et al (2013)** established a study on different types of sand filters containing activated-carbon, sargassum and zeolite. The assembly based Sargassum-loaded sand filter shows better removal of dissolved and microalgae pollutants from a eutrophic pond. It was determined that this system was successful in removal of heavy metal ions, microalgae and reduction of pH, turbidity within limits of EPA.

**Paul J. Hunter et al (2012)** investigated the effect of microbial colonization on therejuvenation and working of slow sand filters using culture-independent profiling. It was concluded that the structure of microbial inoculum from a previous filter could not be keep up through a cycle of culture, re-culture and storage.

**Banejad H. et al (2012)** conducted a study on removal of excessive amount of iron from water resources using rapid-sand filter. It was resulted that for rapid-sand filters could be used for influent have low concentrations of iron while for influent with high concentration of iron, a series of rapid-sand filters should be used. The study also concluded that there is increase in head loss if discharge increased. These results can be used for further design of rapid-sand filters.

**Ochieng G. et al (2004)** introduced a comparison study between multistage filtration (A combination of Slow Sand Filter) and a conventional treatment system (Horizontal Roughing Filter) in removal of physical, chemical and bio-logical parameters from drinking water. It was found that multistage filtration treatment technique is better than roughing filtration because it gives removal efficiencies form E. coli and total coliforms over 99% and 98%, but due to possibility of water-borne diseases, chlorination process must require as final process in multistage filtration.

**SJ. Haig et al (2011)** reviewed a study on slow sand filtration technique for treatment of water to control microbiological contaminants. The study concludes that slow-sand filters can work more efficiently if conventional microbiological tools are used along it.

**Ann M. Gottinger et al** studied the performance efficiency of slow sand filter to treat Canadian rural water. It was concluded that due to cold weather circumstances there was some problems occur like maintaining and performance of slow sand filter.

**Ben R. Urbonas and P.E.** evaluated the performance efficiency using sand filter for treatment of urban storm-water run-off. It was found that for removal of total suspended solids, sand filter could be used.

## 2.5 FACULTATIVE POND

**Ricardo Gomes Passos et al (2014)** designed a 3D computational fluid dynamics model of a facultative pond to improve performance efficiency which shows its hydrodynamic conditions. It concluded that the half the flow at surface layer was blew from outlet to inlet due to action of wind and existence of dead zones, short circuits could be verify using this model.

**Haydeh Hayati et al (2013)** evaluated the performance efficiency of waste stabilization ponds for wastewater treatment of Birjand city. The samples were taken from influent of facultative pond, anaerobic pond and maturation pond. It was concluded that treated water could not be used for agriculture because the results does not satisfy the standards of EPA in terms of turbidity, BOD and COD.

**Almasi A. et al (2013)** evaluated a comparison study between primary facultative pond and secondary facultative pond by determining the ratio of effluent algal BOD concentration to influent BOD concentration. The study concludes that temperature play an important role in facultative pond. Microbial metabolism and algal photosynthesis increase due to rise in temperature and vice versa. The study showed that effluent could be used for irrigation purpose because of presence of algae in it.

**Mohammed ali I. Al-Hashmi et al(2013)** did their research to check and study the suitability of waste stabilization ponds for treating wastewater in rural areas by using three different hybrid systems like sand filters, facultative & aerobic ponds and also aeration process in series which shows better result by decreasing COD, total suspended solid and BOD.

**Rashed Al-Sa`Ed et al (2011)** has studied the six months study on two different treatment systems for their performance efficiency in waste stabilization ponds. It was observed that a pilot-scale algae-rock filter pond system was more efficient in removal of BOD, COD, fecal-coliforms, total suspended solids, metals and organic matter as compared with algae-based pond system.

**Oliveira R. De et al (2011)** represented a baffled primary facultative pond for treating domestic wastewater with inlets and outlets set at different levels. It was concluded that installing longitudinal baffles, outlets and inlets had some small impact on performance but also made unnecessary addition in cost.

**Giraldo E. et al (2002)** developed a model in facultative pond for digestion of organic matter by using aerobic and anaerobic processes. The model analysed the amount of removal outflow of total solids by 343.8 mg/L and total BOD by 55 mg/L. It also concluded that effluent concentration does not effected by aerobic degradation and suggests further improvements to facultative ponds.

**Fernando J. Trevino Quiroga** evaluated a study on waste stabilization ponds for treatment of waste water. These ponds can be operated at low cost working as natural treatment method and can be used for removal of pathogens, suspended solids, BOD and COD.

**Laginestra M. and Robbery van-Oorschot** studied the applications, issues, requirements, maintenance of ponds and also suggested some design improvements and other operational aspects based on actual pond system.

## 2.6 ARTIFICAL RECHARGE

**S. Kaliraj et al (2015)** evaluated a study to investigate the locations and zone mapping for artificial recharge using GIS and remote sensing techniques. The study also concluded the site for recharge where augmentation of groundwater resources needed.

**Ambe Emmanuel Cheo et al (2015**) calculated the groundwater recharge rates using GROWA model which depends on run-off properties of that place. It was estimated that groundwater recharge occur only at river beds but most of run-off gets evaporated due to hot weather.

**Hossein Hashemi et al (2013)** investigated in their study that floodwater spreading system is an effective technique to recharge storm-water into groundwater resources in dry areas. The study also concluded that floodwater spreading system is a low cost based recharge system and could be used well in rainy seasons.

**HassenOuelhazi et al (2013)** assessed a four year study of artificial recharge technique in Korba aquifer because of increasing salinity in groundwater. By using artificial wells, it was resulted that some progress had been made during these years in reducing the salinity in groundwater. It also helped in augmentation of groundwater resources.

**Kostas Voudouris (2011)** modified a filtration system, which had used along with artificial recharge system. It has provided better performance efficiency in removal of grease, fat and oil. It was investigated that artificial recharge of treated wastewater is the one of the finest technique to increasing the reserves of groundwater.

**Patel P. et al (2011**) established study to artificially recharge rain water into ground by using recharge wells and also represented co-relations between recharge capacity, depth and permeability of wells for development of their designing parameters. The observed results shows rise in water level in that area, reduces salinity of water and improvement in groundwater quality, which are reasonably good.

**Takashi Asano, Joseph A. Cotruvo (2004)** reviewed a study to recharge groundwater with domestic municipal wastewater prudently while taking care of health and technical issues arisen during this procedure. It was discussed that special orientations should be planned while recharging groundwater and its management.

**Kaledhonkar M.J. et al (2003)** evaluated a study to artificially recharge the depleting groundwater by installing two recharge wells during two rainy seasons. It was estimated that individually both wells performed average recharge rate of 10.5 l/s.

**Peter H. Riad et al** conducted their study on design and management of ponds to recharge the wastewater coming from treatment plants. Due to infiltration rate of soil and largely available area, treated wastewater has recharged directly into the desert soil which faced the problem of evaporation due to hot climate.

# CHAPTER 3

# PROBLEM FORMULATION

For many years the village ponds have been used for fulfilling daily water uses like washing, irrigation, animal usage etc. by village people. Ponds have also been used as the disposal points for the greywater generated in the villages. Due to the limited quantity of greywater generated in the villages, the self-cleansing capacity of the pond was sufficient to treat the wastewater being disposed of in it. But in past few years due to increasing population and the improved water supply systems the quantity of greywater generated from the village ponds has increased to a large extent. This has in turn degraded the quality of the receiving water body. Excessive generation of greywater and absence of any village level wastewater treatment mechanism has severely affected the quality of the water in village ponds.

The objective of village ponds is generally to allow human effluents to be disposed of without danger to human health or unacceptable damage to the natural environment. But due to increase in population and increase in greywater generation, ponds being small with time and are easily disrupted by human activity. The quantity of greywater also enlarged and it becomes problem in rainy season. Because of its degraded quality it cannot be used for any purpose like washing and animals etc. Due to presence of bacteria and fecal-coliform in wastewater, it is unfit for irrigation also.

In the past, various treatment systems have been employed to treat greywater in some villages of Punjab, but these systems proved to be un-successful because of improper design, high running costs, poor maintenance, frequent electricity break downs and lack of technical man power. Some pond based low cost treatment schemes have also been tried but the quality of the final effluent does not meet the disposal standards and these schemes also required a large chunk of land.

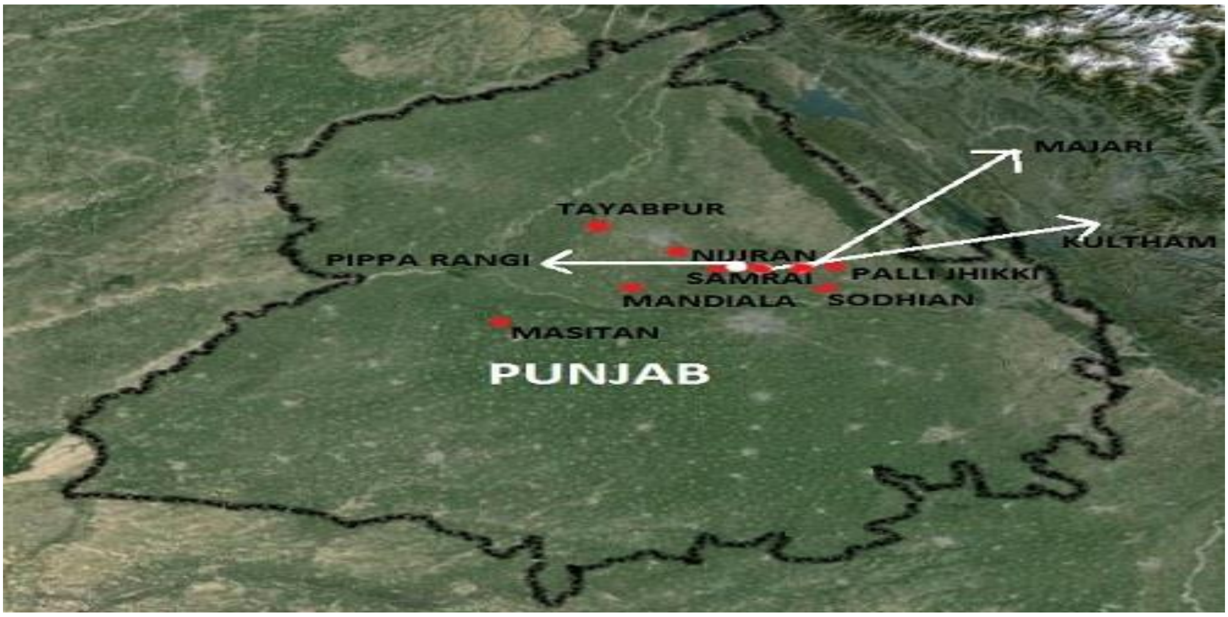
So, in the present study, an attempt has been made to design a low cost pond based wastewater treatment system which can be used to treat greywater after collection in pond. Natural treatment systems like wetlands, stabilisation ponds, sand filters etc. will be designed as a part of the proposed system. System will be designed to remove BOD, COD, total suspended solids, pathogens, bacteria and fecal-coliforms so that either the wastewater can be used for useable purposes like irrigation or can be recharged to the groundwater.

# CHAPTETR 4

# METHODS AND METHODOLOGY

## 4.1 Study Area

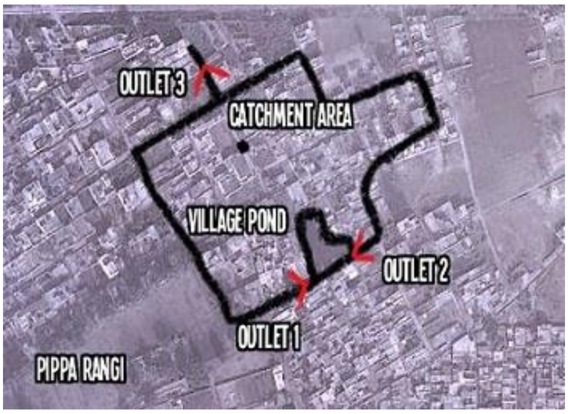
Ten rural watersheds were identified in the radius of around sixty kilometres in Doaba region of Punjab state for the present study. The ten catchments represent a wide range of population sizes, catchment areas of the pond and land uses. The selected watersheds were covered by five rainfall stations of Indian Meteorological Department (IMD), namely, Nawanshahar, Kapurthala, Phagwara, Nakodar and Jalandhar. Kultham (Nawanshahar) is a multiple outlet village, but the studied catchment area of the village pond is small. Majari village (Nawanshahar) is located along the state highway and having small area serving as catchment for the studied pond. Pippa Rangi (Phagwara) is again a small sized catchment village located at the outskirts of an urban centre and having multiple outlets for the figure flow. Samrai (Jalandhar) is a large village having at least four identified outlets for village catchment area. PalliJhikki (Nawanshahar) is a small sized village having high concentration of paved streets and one pond in the catchment area. Sodhian (Nawanshahar) is a mid-sized village with only one pond for collection of almost whole of the figure generated in the catchment. Mandiala (Nakodar) is a large catchment village having one pond to collect the figure generated. Masitan (Kapurthala) is a mid-sized catchment served by only one pond. Tayabpur (Kapurthala) is a small catchment village with one pond serving as an outlet for whole of the catchment figure. Nijjran (Jalandhar) is an affluent large village with multiple outlets. Fig. 4.1 shows location of the study area.

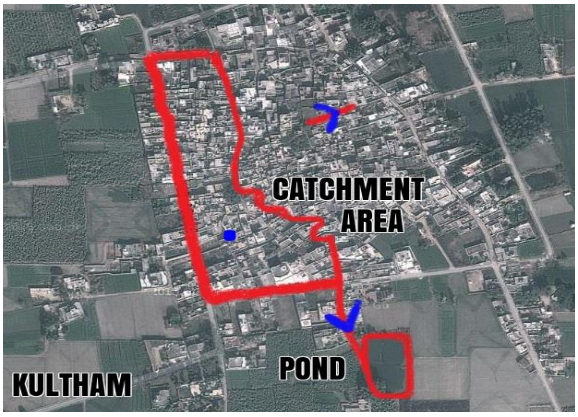


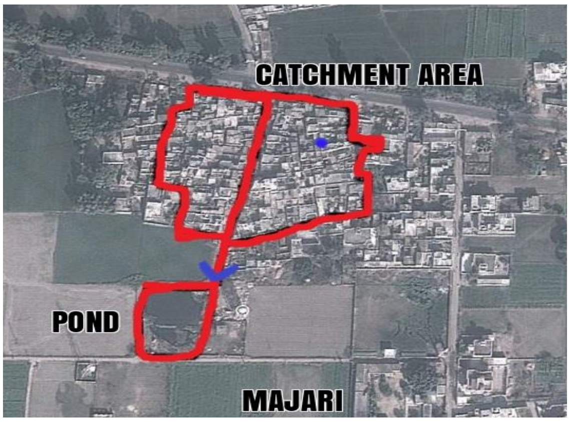

## 4.2 Background information collected for the selected catchments

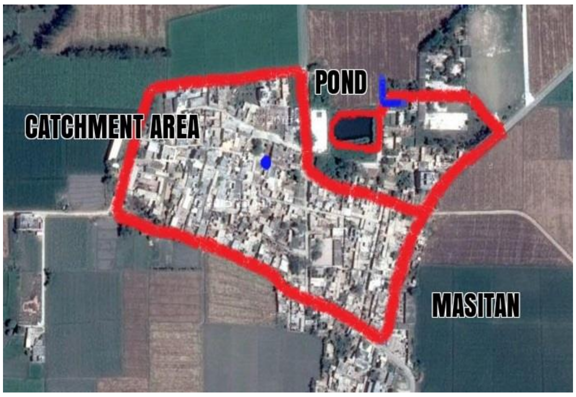
### 4.2.1 Sub-watershed characteristics

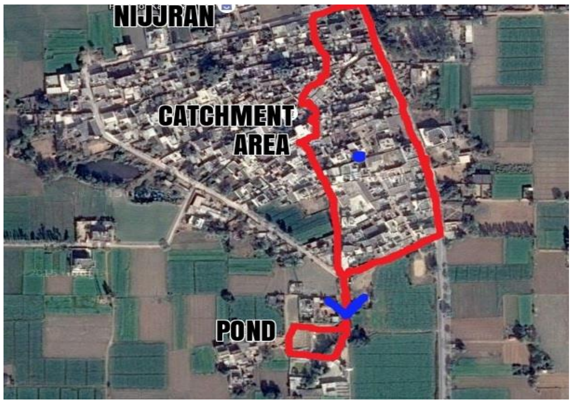
- <u>Maps of the selected villages</u> – The maps collected were in the AutoCAD format. The maps so collected contained information about the elevations of different areas along with information of different land uses.
- <u>Boundaries of catchment area</u> – The boundaries of the catchments as marked through Google earth are as shown in Fig. 5.1(a) – 5.1(j). Catchment area (in $m^2$) of all the ten selected villages was calculated. It can be seen that the village Samrai was having largest catchment area (approx. 115000 $m^2$) and the village Tayabpur was having least catchment area (approx. 2500 $m^2$).The catchment areas of these villages are demarked and shown below in figures:

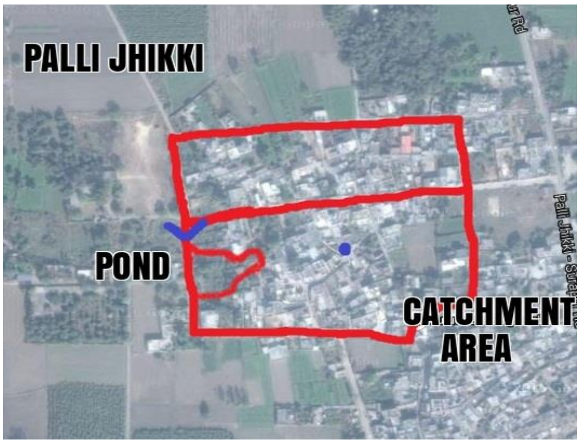



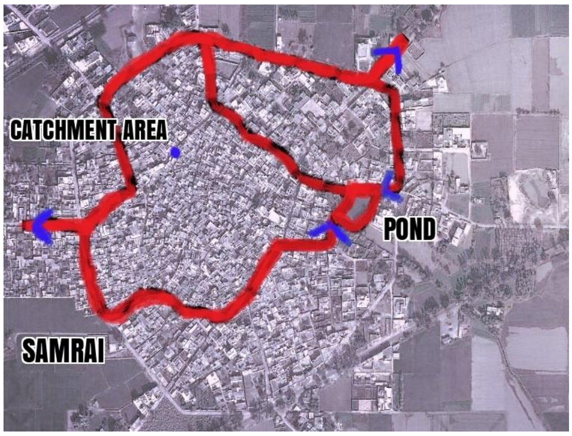

CATCHMENT
AREA
POND
KULTHAM

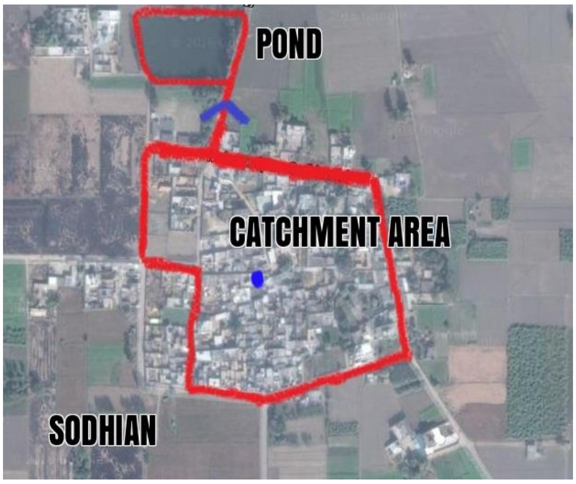

CATCHMENT AREA
POND
MAJARI


POND
CATCHMENT AREA
MASITAN


NIJJRAN
CATCHMENT
AREA
POND


PALLI JHIKKI
POND
CATCHMENT
AREA


CATCHMENT AREA
POND
SAMRAI


POND
CATCHMENT AREA
SODHIAN

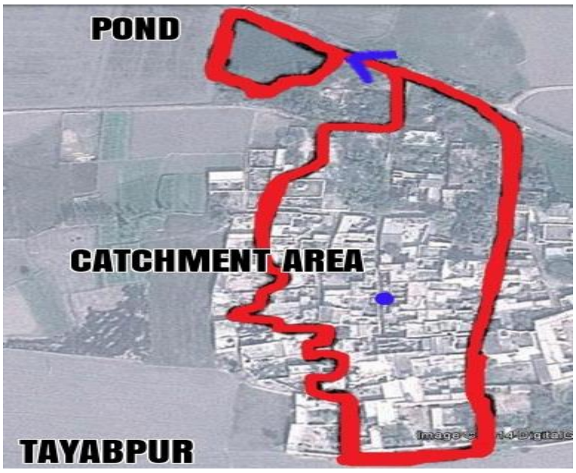

POND
CATCHMENT AREA
TAYABPUR

**Table - 4.1: Details of village area, pond area and 90 percentile volume of stormwater.**

| SUB-WATERSHED | VILLAGE AREA in $m^2$ | POND AREA in $m^2$ |
|---|---|---|
| Sodhian | 67720.4 | 5060.85 |
| Kultham | 31354.5 | 714.04 |
| Majari | 38277.2 | 1252.01 |
| Pallijhikki | 43578.4 | 3893.82 |
| Tayabpur | 25176.7 | 2811.97 |
| Masitan | 69137.12 | 2846.07 |
| Mandiala | 77056.6 | 3248.84 |
| Pippa Rangi | 40107.28 | 815.01 |
| Nijjran | 45081.13 | 1807.77 |
| Samrai | 114765.5 | 3324.50 |

## 4.3 Design Calculations

### 4.3.1 Collecting Characteristics

- Maps of the selected villages -- Detailed maps of the respective villages were procured from the Water Supply and Sanitation Department, Govt. of Punjab. These maps provided the information regarding the various land uses of the villages and the channel slopes.
- Boundaries of catchment area -- The boundaries of the catchment area in the respective villages were demarcated using Google Earth pro.
- Land cover area -- The Land area was determined using AUTOCAD maps and hence could be used in the selected hydrologic model for various calculations.
- Soil type -- In general, the higher the rate of infiltration, the lower the quantity of storm water runoff. Thus, information regarding the type of soil was needed to be collected.

**4.3.2 Collecting Rainfall Data**

- Rainfall data was obtained from India Meteorological Department for the 10 years (2003-2013). The data so obtained was the daily rainfall (mm) of the five rainfall stations of doaba region of Punjab, namely, Kapurthala, Nawanshehar, Nakodar, Jalandhar, Phagwara
- 90 percentile rainfall event were determined from the collected rainfall data.

## 4.4 Calculating Runoff Volume

After collecting the background information of the selected villages, the selected hydrologic model was employed for the calculation of volume of the runoff for ten selected villages of Punjab. Following steps were taken to calculate runoff volume using US SCS-CN Method:

**4.4.1 Selection of curve number**

The value of curve number depends on the land uses, type of soil and antecedent moisture condition.

1. Firstly, area of different land uses was calculated for the selected rural catchments.
2. Corresponding curve number values ($CN_{II}$) of different land uses were taken based upon the type of soil of selected area. (Table – A1 for curve number values based upon different land uses and soil type is given in appendix A) .
3. Weighted curve number ($CN_{II}$) was then calculated using the following formula:

$$CN = CN_1*A_1 + CN_2*A_2+\ldots\ldots.. CN_n*A_n/ A_1+ A_2+\ldots.. A_n \qquad \text{-------- (4.1)}$$

   Antecedent moisture conditions (AMC) were calculated for the selected rainfall events i.e. 60$^{th}$, 70$^{th}$, 80$^{th}$, 90$^{th}$ and three extreme rainfall events. It is calculated based upon the previous 5 days rainfall as given in the rainfall data collected from the Indian meteorological department (Table for the daily rainfall data is given in appendix B). In the present study, we have chosen $AMC_{II}$(wet conditions).

4. $CN_{II}$ value as calculated in step 2 was converted to $CN_I$ and $CN_{III}$ based upon the antecedent moisture conditions i.e. using following equations:

For $AMC_I$, $CN_I = CN_{II} / (2.281+0.01281* CN_{II})$ -------- (4.2)

For $AMC_{III}$, $CN_{III} = CN_{II} / (0.427+0.00573* CN_{II})$ -------- (4.3)

### 4.4.2 Runoff volume calculations

1. Using the corresponding values of curve number, potential storage (S) was calculated using the following relation:

$$S = \frac{25400}{CN} - 254 \qquad \text{-------- (4.4)}$$

2. Runoff depth was then calculated using the following relation:

$$Q = (P - 0.3S)^2 / (P + 0.7S) \qquad \text{-------- (4.5)}$$

Where Q is the runoff depth, P is the precipitation and S is the potential storage

3. Runoff volume was then calculated using the following equation:

$$V = Q*A \qquad \text{-------- (4.6)}$$

Where V is the runoff volume ($m^3$), Q is the runoff depth (mm) and A is the total area ($m^2$) of the catchment.

### 4.4.3 Formula Used

- **Settling velocity of particle**

$$Vs = \frac{\{9.81(\rho p - \rho) dp^2\}}{18 * \mu}$$

Where

$Vs$ = Settling velocity of particle (m/sec)

$\rho_p$ = Density of particle (kg/m³)

$\rho_w$ = Density of water (kg/m³)

$\mu$ = Dynamic viscosity at 20° C (kg*m/sec)

$dp$ = Size of particle to be removed (mm)

- **Surface BOD loading**

$$\lambda s = (350\,(1.107 - 0.002) * T)^{T-25}$$

Where

T = minimum avg. temperature

$\lambda s$ = Surface BOD loading (kg/hc/day)

- **Area of Facultative Pond**

$$A = \frac{\{10 * Li * Q\}}{\lambda s}$$

Where

A = area of facultative pond ($m^2$)

Li= Influent BOD (mg/L)

Q = Stormwater flow ($m^3$/day)

$\lambda s$ = Surface BOD loading (kg/hc/day)

- **Depth of facultative pond**

$$d = \frac{V}{Ap}$$

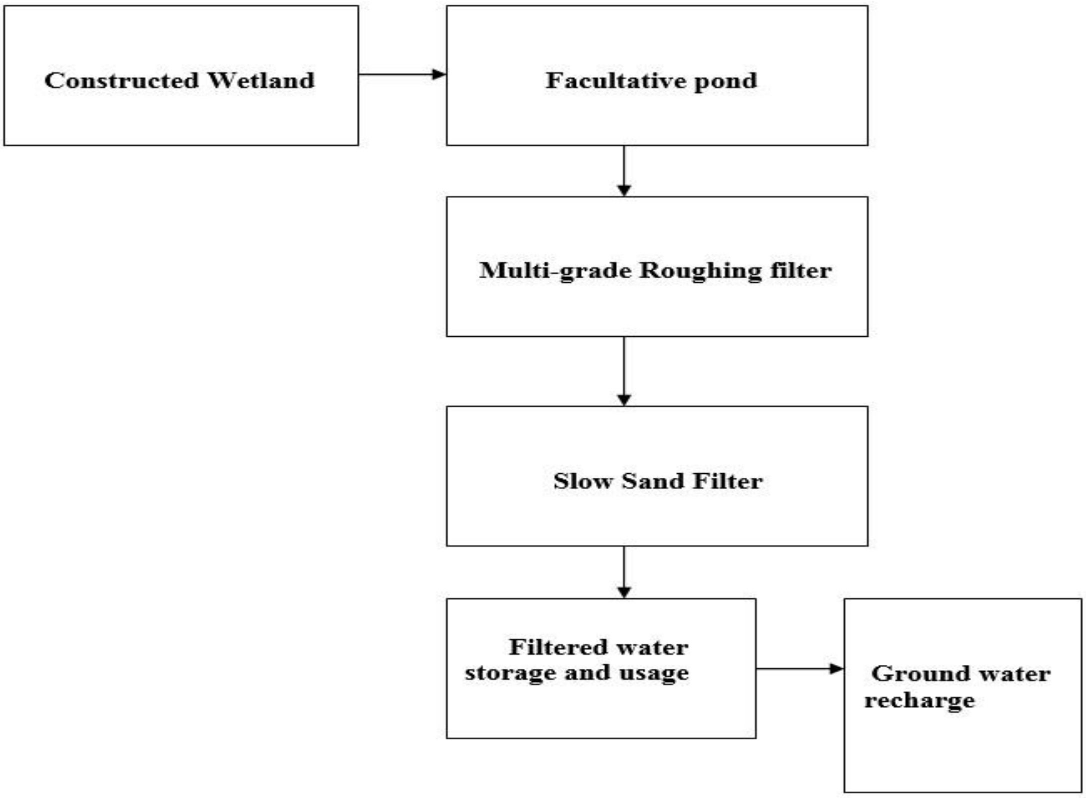
V = volume of stormwater flow ($m^3$/hour)

$A_p$ = area provided ($m^{2)}$

## 4.5 Overall Treatment System: An Overview

This treatment system is based on concept of low-cost which is designed for treatment of greywater contains several components which are designed in a series. The treatment involves removal of total suspended particles, pathogens and BOD in different stages. The flow is kept steep. The effluent treatment system will consist of the following units:

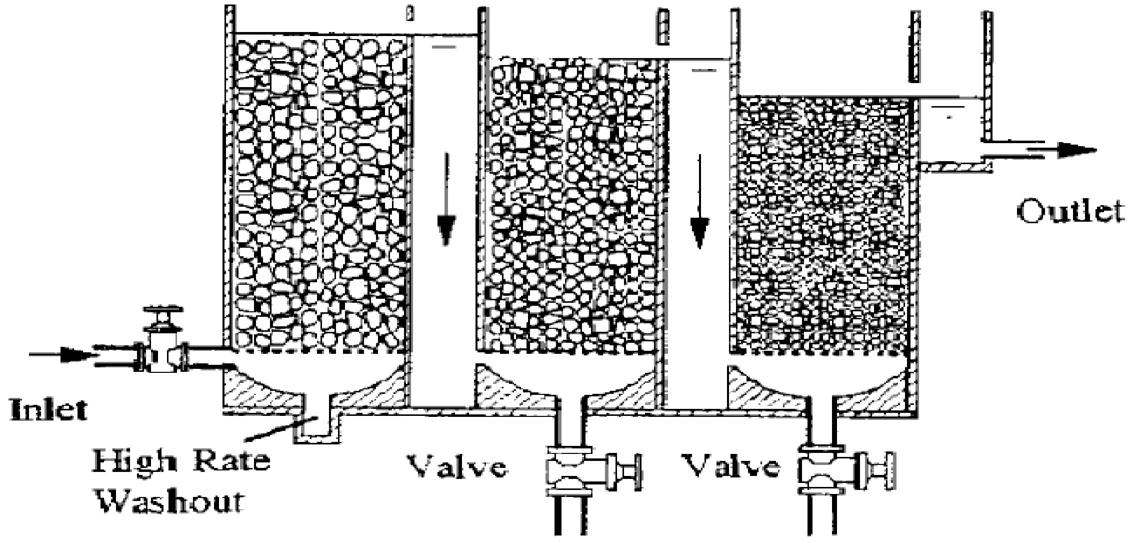
A general systematic flow diagram of treatment system shown below in fig 4.2.




**4.5.1 Constructed Wetland:** The wetland is designed for removal of particle size 0.15 mm. The detention time is assumed to be 15 min. Maximum possibility of flow is taken by calculating the peak runoff volume of $90^{th}$ percentile rainfall including the grey water flow from the houses. The required depth of wetland is calculated according to its designed surface area and 20 % of the $90^{th}$ percentile runoff volume being taken as peak hourly flow generated from the watershed. A horizontal surface-flow type construct wetland will be provided for this treatment system. It is gravel and sand filled basin which is planted with wetland vegetation. The sheet flow conditions will be created through the wetland. The wetland is further divided into 2 or 3 wetland cells to increase its removal efficiency. The depth of bed is assumed as 0.3 m, retention time is 6 min and 15% area of total pond will be covered by wetland. The purpose of providing surface-flow wetland is the removal and retention of suspended solids from greywater and stormwater.

**4.5.2 Facultative Pond:** By passing through the wetland the stormwater enters into facultative pond. The maximum area is occupied by facultative pond where digestion of organic matter occurs. The available area for facultative pond is determined by deducting the areas required for all other components from the total area of pond. The facultative pond is designed in such a way that if the flow will be equal or more than 90 % volume then it goes to further units of treatment otherwise it will be stored in its designed permanent storage. The greywater from wetland enters into facultative pond. This pond is used for high removal of BOD and COD from greywater under both aerobic and anaerobic digestion.

**4.5.3 Multi-grade roughing filter:–** Roughing filter is commonly used for pre-treatment of turbid water. When flow corresponding to $90^{th}$ percentile rainfall volume enters the facultative pond then the water will start passing through from roughing filter. The vertical flow type roughing filter is adopted here. The different sizes of filter media are provided in it. The bed area, length and width of filter is calculated by assuming the values of flow rate and filtration rate. The depth of roughing filter is kept at 1 m. Roughing filtration is a pre-treatment process in which wastewater passes through different layers of gravel where suspended matter is trapped. In this study an up-flow vertical roughing filter is taken. The filtration rate is kept ≤ 2 m/hr. This process of roughing filtration should be done before sand filtration to minimise clogging effect and to get better performance efficiency. The main advantage of roughing filter is that it occupy less area, maintenance is simple and no chemicals are needed. A multi-grade roughing filter is shown below in fig 4.3.




**4.5.4 Slow-sand Filter:** After passing all these stages of treatment the water will be collected in a storage tank which occupies the left area of village pond. This treated water will be free from impurities such as pathogens and can be used for different purposes like irrigation etc. This is the last stage of treatment system where water further will pass through sand filter. The slow-sand filter is used for this purpose because of its low maintenance cost and having high efficiency in removal of coliform bacteria. By assuming filtration rate and flow rate the area, length and width of sand filter is calculated. The depth of sand filter is kept 1 m. In slow-sand filtration process greywater is allowed to slowly pass through the sand bed for treatment. During the passage of greywater and stormwater through slow sand filter, pathogens and other bacteria are removed. Vertical slow-sand filter is presumed for this study. The filtration rate is kept $\leq$ 0.5 m/hr. it occupy less space for its construction.

**4.5.5 Recharge –** After passing through slow sand filter treated water will remain in storage area and can be recharged into the ground but it should be free from impurities before recharging. This treated water will be free from BOD, total suspended solids and pathogens. A recharge well is provided at inner periphery of slow sand filter. If treated water have not any usage for irrigation, this will recharged into ground through recharge well.

# CHAPTER 5

# RESULT AND DISCUSSION

The low cost based treatment plant is designed for ten villages according to their areas, size of the pond and rainfall data. The objective of village ponds is generally to allow human effluents to be disposed of without any adverse effect to human health or unacceptable damage to the natural environment. System is designed using suitable treatment units for removal of BOD, COD, total suspended solids, bacteria, pathogens and fecal-coliform.

## 5.1 Proposed Stormwater Treatment System

The inlet of greywater is through constructed wetland which can be planted with *typha* and *hyacinth.* Any species that will grow well can be chosen. The wetland is designed for removal of suspended particles of size 0.15 mm having specific gravity 1.05. The treatment system is designed for 90 % of storm water and greywater. Around 40% removal of BOD will occur at wetland. As the greywater/stormwater comes at outlet of wetland the suspended matter concentration will be reduced to 100 mg/l. The detention time in wetland is assumed as 15 minutes according to designed settling velocity using Stoke's law. The area for facultative pond is calculated according to stormwater flow, influent BOD and designed surface BOD loading. The removal of organic matter occurs in facultative pond and it will also acts as sedimentation tank. The greywater/stormwater will remain in it until the holding capacity of pond exceeds the 90 percentile rainfall runoff volume capacity of the pond. The water in facultative pond may become turbid because of algae formation in facultative pond. For removal of turbidity the greywater/stormwater will then pass through roughing filter. The treated water will be collected in storage area where it could be used for different purposes like irrigation, animal bath etc. During the rainfall events, if the volume of water exceeds the 90 percentile runoff volume in storage area, then the treated water can be used for recharging of underground aquifer. But, before recharging, water should be free from pathogens which may be present in the stored water. Therefore, slow sand filter is provided for removal of pathogens at the periphery of the recharge well.

## 5.2 Results for calculations of Runoff volume

After collection of background information, the runoff volume calculations were done for the selected catchments by US-SCS CN method. Using the corresponding value of curve number, runoff volume calculations that were done using formula 4.2 – 4.3. The results of these calculations are discussed in the following table

**Table-5.1: Runoff volume from rural catchments**

| **Rainfall (mm) at Nawanshahar rainfall station** | **Rural catchments runoff volume ($m^3$) (approx.)** | | | |
|---|---|---|---|---|
| | **Kultham** | **Majari** | **Sodhian** | **Palli jhikki** |
| **22 (80th percentile)** | 20.45 | 1.89 | 14.46 | 1.31 |
| **36 (90th Percentile)** | 175.51 | 115.80 | 270.21 | 124.94 |
| **120.4** | 2181.13 | 2297.63 | 4330.69 | 2585.40 |
| **124** | 2281.63 | 2413.71 | 4541.17 | 2716.94 |
| **203** | 4580.52 | 5118.15 | 9405.72 | 5786.74 |
| **Rainfall (mm) at Kapurthala rainfall station** | **Rural catchments runoff Volume ($m^3$) (approx.)** | | **Rainfall (mm) at Nakodar rainfall station** | **Rural catchments runoff volume ($m^3$) (approx.)** |
| | **Tayabpur** | **Masitan** | | **Mandiala** |
| **28 (80th percentile)** | 26.45 | 83.80 | **24 (80th percentile)** | 2.61 |
| **52 (90th percentile)** | 264.64 | 763.24 | **40 (90th percentile)** | 258.93 |
| **102** | 1173.53 | 3296.19 | **107** | 3463.63 |

| | | | | |
|---|---|---|---|---|
| **135** | 1874.97 | 5237.38 | **136** | 5282.95 |
| **137** | 1918.99 | 5359.02 | **237** | 12269.28 |
| **Rainfall (mm) at Jalandhar rainfall station** | **Rural catchments runoff volume ($m^3$) (approx.)** | | **Rainfall (mm) at Phagwara Rainfall station** | **Rural catchments runoff volume ($m^3$) (approx.)** |
| | **Samrai** | **Pippa Rangi** | | **Nijjran** |
| **30 (80th percentile)** | 267.25 | 57.04 | **25 (80th percentile)** | 21.54 |
| **60 (90th percentile)** | 2097.04 | 618.30 | **40 (90th percentile)** | 229.33 |
| **125** | 8071.87 | 2608.09 | **67** | 919.97 |
| **126** | 8172.86 | 2642.35 | **75** | 1170.16 |
| **203** | 16289.54 | 5421.56 | **113** | 2511.46 |

## 5.3 Design of Treatment Scheme Units

The design calculations for various treatment units have been using MS-excel spreadsheets which are shown here:

**Design of Constructed Wetland**

| | | | | |
|---|---|---|---|---|
| **Size of particle** to be removed | 0.00015 | m | | |
| Assume **Detentoin time** | 15 | min | | |
| Peak runoff **Volume** at 90th percentile rainfall (From Table) | 115.8 | $m^3$ | | |
| Density of Water | 1000 | $kg/m^3$ | | |
| Density of particle | 1050 | $kg/m^3$ | | |
| Dynamic viscosty of \ water | | | | |
| At 20 °C | (1.002-1.003)/1000 | | 0.001003 | kg.m/s |
| At 25 °C | 0.80/1000 | | 0.00089 | kg.m/s |
| **Settling Velocity** of particle, v | 0.0006 | m/s | | |
| **20%** of peak runoff **volume** taken as one hour peak flow | 23.16 | $m^3/hr$ | 0.006 | $m^3/s$ |
| | 11.58 | | | |
| Required surface **area of wetland**,As | 10.52 | $m^2$ | | |
| Wetland **Depth** | 0.55 | m | | |

**Figure 5.1**

**Figure 5.2**

## Design of Facultative Pond

| | |
|---|---|
| Stormwater flow, $m^3/d$ | 763.24 |
| Influent BOD, mg/l | 53.3 |
| Mean minimum temperature of wettest month, °C | 25 |
| Design surface BOD loading, kg/ha/d | 350 |
| Area of facultative pond, $m^2$ | 1162.31 |
| Area Provided | 1842.47 |
| Free Board, m | 1 |
| Total Depth of Pond, m | 4.57 |
| Actual BOD Loading, kg/ha/d | 220.79 |
| Actual Depth in m | 0.41 |
| Permanent Storage Depth, m | 3.16 |

| Village | 90th percentile Stormwater volume | Mean influent BOD Wetland inlet | F.P inlet | Pond Area | Area Provided | Avg. Depth Of Pond |
|---|---|---|---|---|---|---|
| | $m^3/d$ | mg/L | mg/L | $m^2$ | $m^2$ | m |
| Tayabpur | 264.64 | 102 | 66.3 | 2811.97 | 2140.966 | 4.57 |
| Sodhian | 270.21 | 96 | 62.4 | 5060.85 | 3937.81 | 5.48 |
| Majari | 115.8 | 102 | 66.3 | 1252.00 | 954.08 | 4.57 |
| Palli Jhiki | 124.94 | 63 | 40.95 | 3893.82 | 3063.786 | 5.18 |
| Mandiala | 258.93 | 108 | 70.2 | 3248.84 | 2492.822 | 5.48 |
| Kultham | 175.51 | 100 | 65 | 714.04 | 499.222 | 4.57 |
| Pippa Rangi | 618.3 | 94 | 61.1 | 815.01 | 398.308 | 3.96 |
| Nijjran | 229.33 | 53 | 34.45 | 1807.77 | 1352.116 | 5.18 |
| Samrai | 2097.04 | 115 | 74.75 | 3324.50 | 1799.13 | 4.27 |
| Masitaan | 763.24 | 82 | 53.3 | 2846.07 | 1842.466 | 4.57 |

**Figure 5.3**

## Design of Roughing Filter

| | | |
|---|---|---|
| **Flow Rate** (Peak Runoff ) | 4.83 | $m^3/h$ |
| **Filtration Rate** can be (**0.3 - 1.0**) m/h | 1 | m/h |
| Filter Bed **Area** | 4.83 | $m^2$ |
| Width | 1.27 | m |
| Length | 3.80 | m |
| **Depth** of filter bed (assumed) | 1 | m |

**Figure 5.4**

| Design of Slow Sand Filter | | |
|---|---|---|
| Flow Rate | 4.83 | $m^3/h$ |
| Filtration Rate (0.1 - 0.2)m/h | 0.15 | m/h |
| **Area** Per Filter Bed | 32.17 | $m^2$ |
| Width | 3.27 | m |
| Length | 9.82 | m |
| **Depth** of filter bed (assumed) | 1 | m |

## 5.4 Area of Treatment System Units

The total area of pond is further distributed for several designed components .i.e. constructed wetland, facultative pond, storage area, roughing and sand filter. The maximum area is occupied by facultative pond where digestion of organic matter occurs. The available area for facultative pond is determined by deducting the areas required for all other components from the total area of pond. According to surface BOD loading, the area for facultative pond is calculated which is the minimum required area. However, if the village pond has sufficient area then the provided area is kept more than the calculated area so as to reduce the surface BOD loading. Except, Samrai and Pippa Rangi villages, area of facultative pond in all other villages have been provided according to this scheme. In Samrai, due to large amounts of runoff generation, additional area is required for the facultative pond, whereas, Pippa Rangi village has a small pond which necessitates more area requirement for facultative pond. Therefore, to handle this designed surface BOD loading more area should be acquired for implementation of this treatment scheme in these two villages. The calculated areas are shown in table

**Table 5.2: Area Distribution of all Villages**

| Area Distribution ($m^2$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Village** | **Total area** | **Wetland** | **Roughing Filter** | **Sand Filter** | **Storage Area** | **Facultative Pond Area** | | |
| | | | | | | **Available** | **Designed** | **Provided** |
| Tayabpur | 2811.97 | 24.05 | 11.03 | 73.53 | 562.39 | 2140.97 | 501.30 | 2140.97 |
| Sodhian | 5060.85 | 24.55 | 11.26 | 75.06 | 1012.17 | 3937.81 | 481.75 | 3937.81 |
| Majari | 1252.00 | 10.52 | 4.83 | 32.17 | 250.40 | 954.08 | 219.36 | 954.08 |
| Palli Jhiki | 3893.82 | 11.35 | 5.21 | 34.71 | 778.76 | 3063.79 | 146.18 | 3063.79 |
| Mandiala | 3248.84 | 23.53 | 10.79 | 71.93 | 649.77 | 2492.82 | 519.34 | 2492.82 |
| Kultham | 714.04 | 15.95 | 7.31 | 48.75 | 142.81 | 499.22 | 325.95 | 499.22 |
| Pippa Rangi | 815.01 | 56.19 | 25.76 | 171.75 | 163.00 | 398.31 | 1079.38 | 1079.38 |
| Nijjran | 1807.77 | 20.84 | 9.56 | 63.70 | 361.55 | 1352.12 | 225.73 | 1352.12 |
| Samrai | 3324.50 | 190.58 | 87.38 | 582.51 | 664.90 | 1799.13 | 4478.68 | 4478.68 |
| Masitaan | 2846.07 | 190.58 | 31.8 | 212.01 | 569.21 | 1842.47 | 1162.31 | 1842.47 |

## 5.5 Removal Efficiencies

### 5.5.1 BOD

The average and maximum influent BOD characteristics at the inlet of pond is tested for all villages. The designed surface BOD loading is calculated is 350 kg/hc/day for minimum average temperature of wettest month. At the outlet of wetland 35% of BOD will be removed and 65% BOD will be enter into the facultative pond. Using BOD removal equation (    ) the removal rate of BOD is calculated and hence BOD at outlet sof facultative pond. At the outlet of facultative pond BOD will be remain 10 to 15 mg/L. The removal efficiency for mean and maximum influent BOD is observed 73e to 97 percent which is shown below in the table for all the villages.

- Equation for $BOD_5$ removal

$$\textit{Removal rate of BOD} = (0.725 * \lambda_s) + 10.75$$

$\lambda_s$ = Surface BOD loading (kg/ha/day)

**Table 5.3: Removal Efficiency for Average $BOD_5$**

| For Average $BOD_5$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Village** | **Mean influent $BOD_5$(mg/l)** | | **Surface BOD Loading (Kg/ha/day)** | | **Removal Rate of BOD** | | **$BOD_5$ at outlet of F.P mg/L** | **Removal Efficiency** |
| | **CW inlet** | **F.P inlet** | **Designed** | **Actual** | **Kg/ha/day** | **Mg/L** | | |
| Tayabpur | 102 | 66.3 | 350 | 81.95 | 70.17 | 56.76 | 9.54 | 85.62 |
| Sodhian | 96 | 62.4 | 350 | 42.82 | 41.79 | 60.91 | 1.49 | 97.61 |
| Majari | 102 | 66.3 | 350 | 80.47 | 69.09 | 56.92 | 9.38 | 85.86 |
| Palli Jhiki | 63 | 40.95 | 350 | 16.70 | 22.86 | 56.05 | 1.49 | 97.61 |
| Mandiala | 108 | 70.2 | 350 | 72.92 | 63.61 | 61.24 | 8.96 | 87.24 |
| Kultham | 100 | 65 | 350 | 228.52 | 176.43 | 50.18 | 14.82 | 77.20 |
| Pippa Rangi | 94 | 61.1 | 350 | 350.00 | 264.50 | 46.17 | 14.93 | 75.57 |
| Nijjran | 53 | 34.45 | 350 | 58.43 | 53.11 | 31.31 | 3.14 | 90.90 |
| Samrai | 115 | 74.75 | 350 | 350.00 | 264.50 | 56.49 | 18.26 | 75.57 |
| Masitaan | 82 | 53.3 | 350 | 220.79 | 170.83 | 41.24 | 12.06 | 77.37 |

**Table 5.4: Removal Efficiency for Maximum $BOD_5$**

| For Maximum $BOD_5$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Village | Mean influent BOD5 | | Surface BOD Loading | | Removal Rate of BOD | | BOD5 at outlet of F.P | Removal Efficiency |
| | CW inlet | F.P inlet | Designed | Actual | | | | |
| | mg/L | mg/L | Kg/hc/day | Kg/hc/day | Kg/hc /day | mg/L | mg/L | % |
| Tayabpur | 143 | 92.95 | 350 | 114.89 | 94.05 | 76.09 | 16.86 | 81.86 |
| Sodhian | 190 | 123.5 | 350 | 84.74 | 72.19 | 105.2 | 18.30 | 85.19 |
| Majari | 140 | 91 | 350 | 110.45 | 90.83 | 74.83 | 16.17 | 82.23 |
| Palli Jhiki | 102 | 66.3 | 350 | 27.04 | 30.35 | 74.43 | 18.30 | 85.19 |
| Mandiala | 238 | 154.7 | 350 | 160.69 | 127.2 | 122.5 | 32.19 | 79.19 |
| Kultham | 170 | 110.5 | 350 | 388.48 | 292.4 | 83.17 | 27.33 | 75.27 |
| Pippa Rangi | 159 | 103.35 | 350 | 592.02 | 439.9 | 76.81 | 26.54 | 74.32 |
| Nijjran | 98 | 63.7 | 350 | 108.04 | 89.08 | 52.52 | 11.18 | 82.45 |
| Samrai | 276 | 179.4 | 350 | 840.00 | 619.7 | 132.3 | 47.04 | 73.78 |
| Masitaan | 110 | 71.5 | 350 | 296.19 | 225.4 | 54.43 | 17.07 | 76.13 |

### 5.5.2 Bacterial Removal

The removal rate of fecal coliforms is calculated using Marais' equation ( ). The results obtained from this equation shows 97 to 99 percent removal efficiency in facultative pond for all villages.

- Marais' Equation for Bacteria removal

$$\mathbf{N_e = N_i / (1 + k_{B(T)}\,\Theta)}$$

$N_e$ = no. of E coli per 100 ml of pond effluent

$N_i$ = no. of E coli per 100 ml of pond influent

$k_{B(T)}$ = first order rate constant for E coli removal

$\Theta$ = mean hydraulic retention time in the pond

T = design temperature, C

**Table 5.5: Removal Efficiency for Bacteria**

| Bacteria Removal Rate | | | | | | |
|---|---|---|---|---|---|---|
| **Village** | **Avg. Fecal Coliform in influent** | **$k_{B(T)}$** | **HRT,days** | **Depth (actual + permanent)** | **Fecal Coliform in effluent** | **Removal Efficiency** |
| Tayabpur | 37500 | 6.205 | 29.18 | 3.57 | 206.01 | 99.45 |
| Sodhian | 21200 | 6.205 | 66.50 | 4.48 | 51.26 | 99.76 |
| Majari | 48300 | 6.205 | 29.72 | 3.57 | 260.53 | 99.46 |
| Palli Jhiki | 31000 | 6.205 | 105.74 | 4.18 | 47.18 | 99.85 |
| Mandiala | 55200 | 6.205 | 43.66 | 4.48 | 203.04 | 99.63 |
| Kultham | 35400 | 6.205 | 10.19 | 3.57 | 551.15 | 98.44 |
| Pippa Rangi | 29900 | 6.205 | 5.18 | 2.96 | 751.56 | 96.98 |
| Nijjran | 45700 | 6.205 | 24.83 | 4.18 | 294.75 | 99.36 |
| Samrai | 43660 | 6.205 | 7.00 | 3.27 | 982.29 | 97.75 |
| Masitaan | 51800 | 6.205 | 8.64 | 3.57 | 948.16 | 98.17 |

### 5.5.3 Ammoniacal Nitrogen Removal

The removal rate for ammoniacal nitrogen in facultative pond is calculated by using Pano and Middlebrooks equation ( ). The results obtained are shown below in the table in terms of removal efficiency

- Pano and Middlebrooks equation:

$$\mathbf{Cc = Ci/ [1 + 8.65 \times 10^{-3}(A/Q) \exp(1.727(pH - 6.6))}$$

Where

Cc = the in-pond column-sample ammonia concentration, mg N/L

**Table 5.6: Removal Efficiency for Ammonical Nitrogen**

| Ammoniacal Nitrogen Removal | | | | | | |
|---|---|---|---|---|---|---|
| **Village** | **Avg. inlet ammoniacal Nitrogen mg/L** | **Area Provided $m^2$** | **Flow rate $m^3/d$** | **Average pH** | **Effluent ammoniacal Nitrogen mg/L** | **Removal Efficiency** |
| Tayabpur | 5.90 | 2140.97 | 264.64 | 7.74 | 3.93 | 33.39 |
| Sodhian | 8.23 | 3937.81 | 270.21 | 7.88 | 3.83 | 53.48 |
| Majari | 6.00 | 954.08 | 115.8 | 7.77 | 3.90 | 34.96 |
| Palli Jhiki | 6.78 | 3063.79 | 124.94 | 7.73 | 2.72 | 59.89 |
| Mandiala | 8.95 | 2492.82 | 258.93 | 7.83 | 5.27 | 41.06 |
| Kultham | 9.54 | 499.22 | 175.51 | 7.69 | 8.21 | 13.91 |
| Pippa Rangi | 6.65 | 1079.38 | 618.3 | 7.66 | 6.08 | 8.61 |
| Nijjran | 7.80 | 1352.12 | 229.33 | 7.82 | 5.50 | 29.55 |
| Samrai | 8.65 | 4478.68 | 2097.04 | 7.52 | 7.93 | 8.30 |
| Masitaan | 10.54 | 1842.47 | 763.24 | 7.76 | 9.13 | 13.41 |

## 5.6 Maps

The plan and L-section views of the treatment scheme for selected villages are shown in the figure nos.

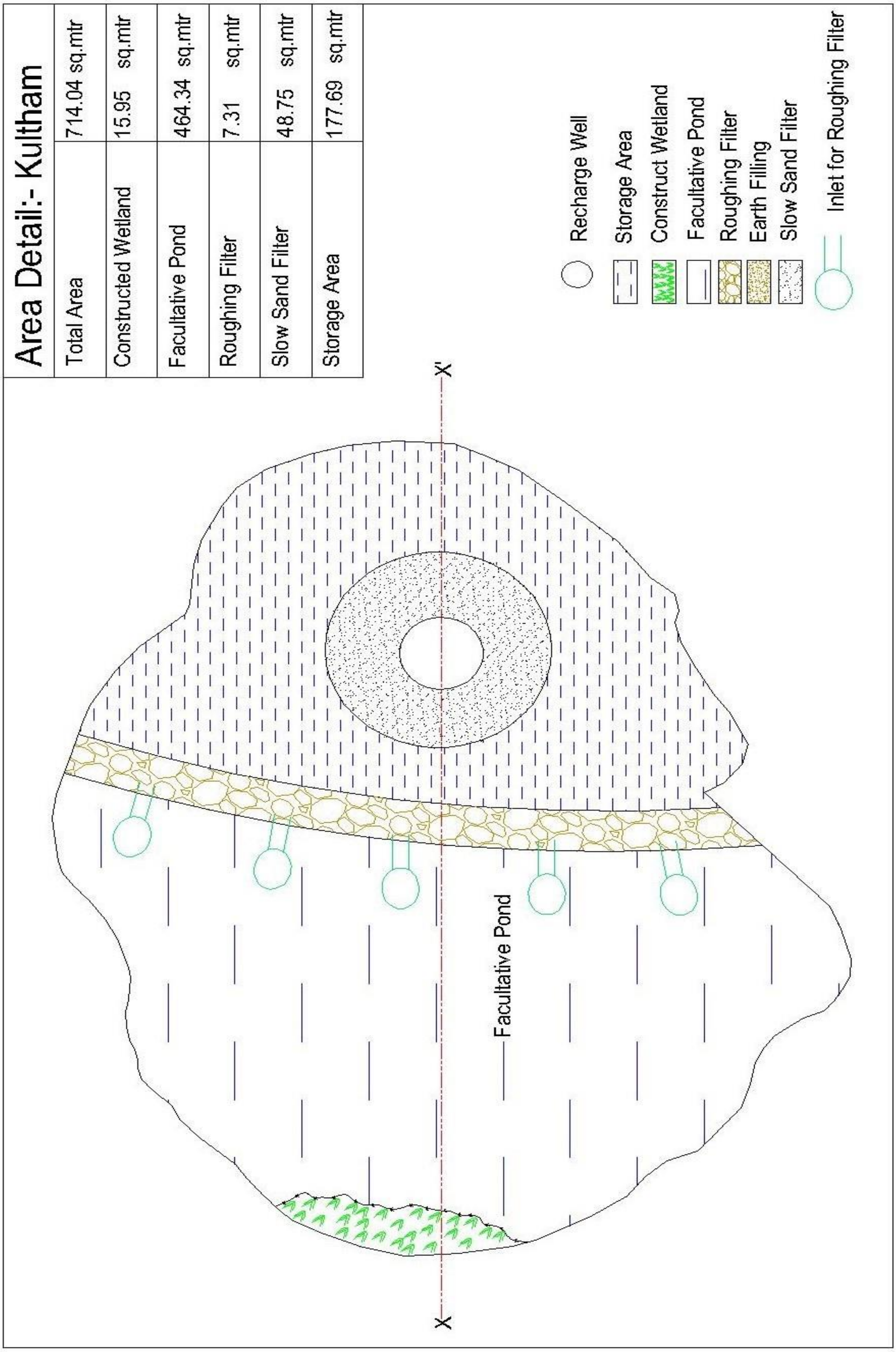

Area Detail:- Kultham
Total Area 714.04 sq.mtr
Constructed Wetland 15.95 sq.mtr
Facultative Pond 464.34 sq.mtr
Roughing Filter 7.31 sq.mtr
Slow Sand Filter 48.75 sq.mtr
Storage Area 177.69 sq.mtr
Recharge Well
Storage Area
Construct Wetland
Facultative Pond
Roughing Filter
Earth Filling
Slow Sand Filter
Inlet for Roughing Filter
X'
Facultative Pond
X

**Figure 5.5**

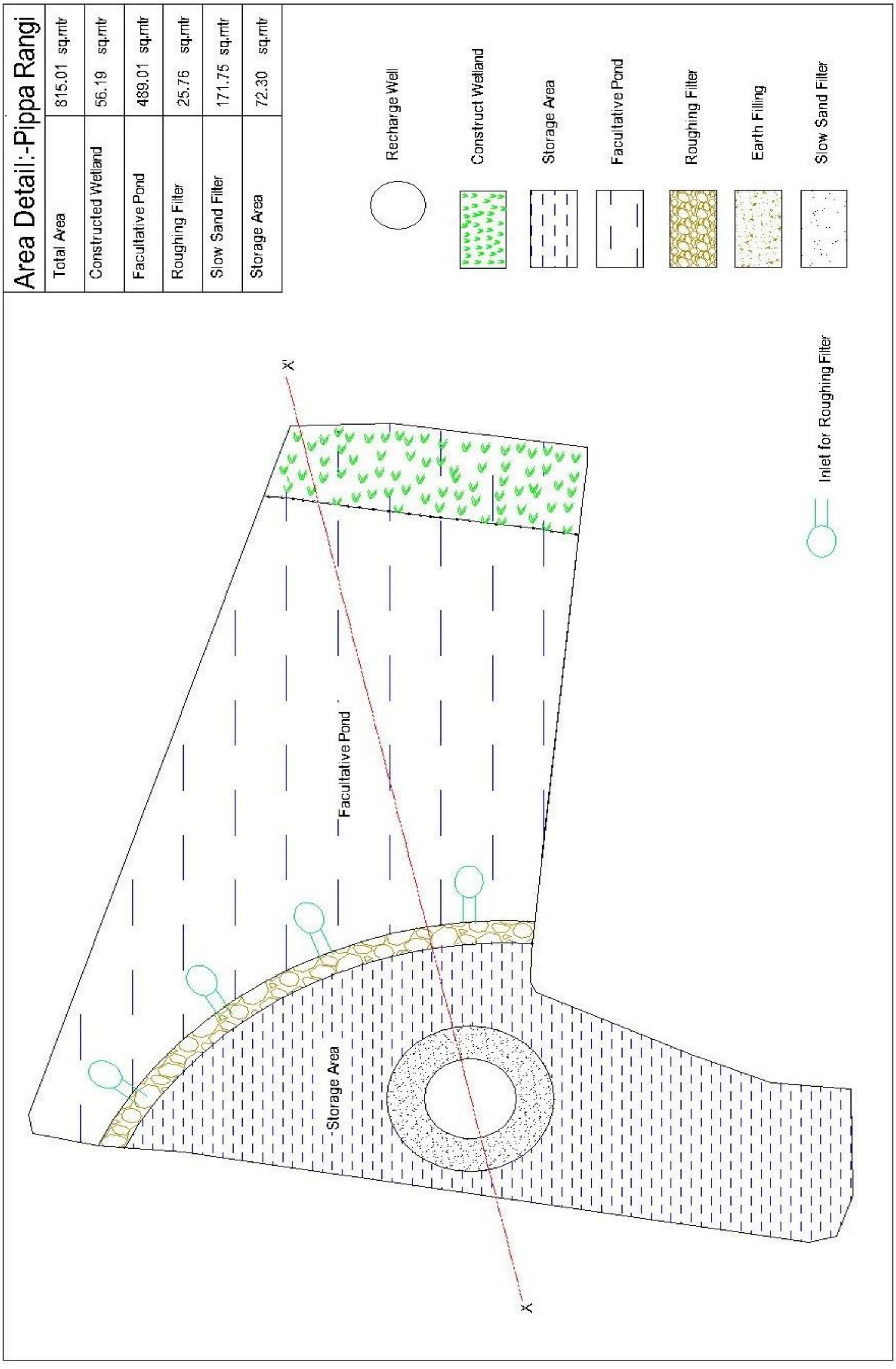

Area Detail:-Pippa Rangi
Total Area 815.01 sq.mtr
Constructed Wetland 56.19 sq.mtr
Facultative Pond 489.01 sq.mtr
Roughing Filter 25.76 sq.mtr
Slow Sand Filter 171.75 sq.mtr
Storage Area 72.30 sq.mtr
Recharge Well
Construct Wetland
Storage Area
Facultative Pond
Roughing Filter
Earth Filling
Slow Sand Filter
Inlet for Roughing Filter
Facultative Pond
Storage Area
X'
X

**Figure 5.6**

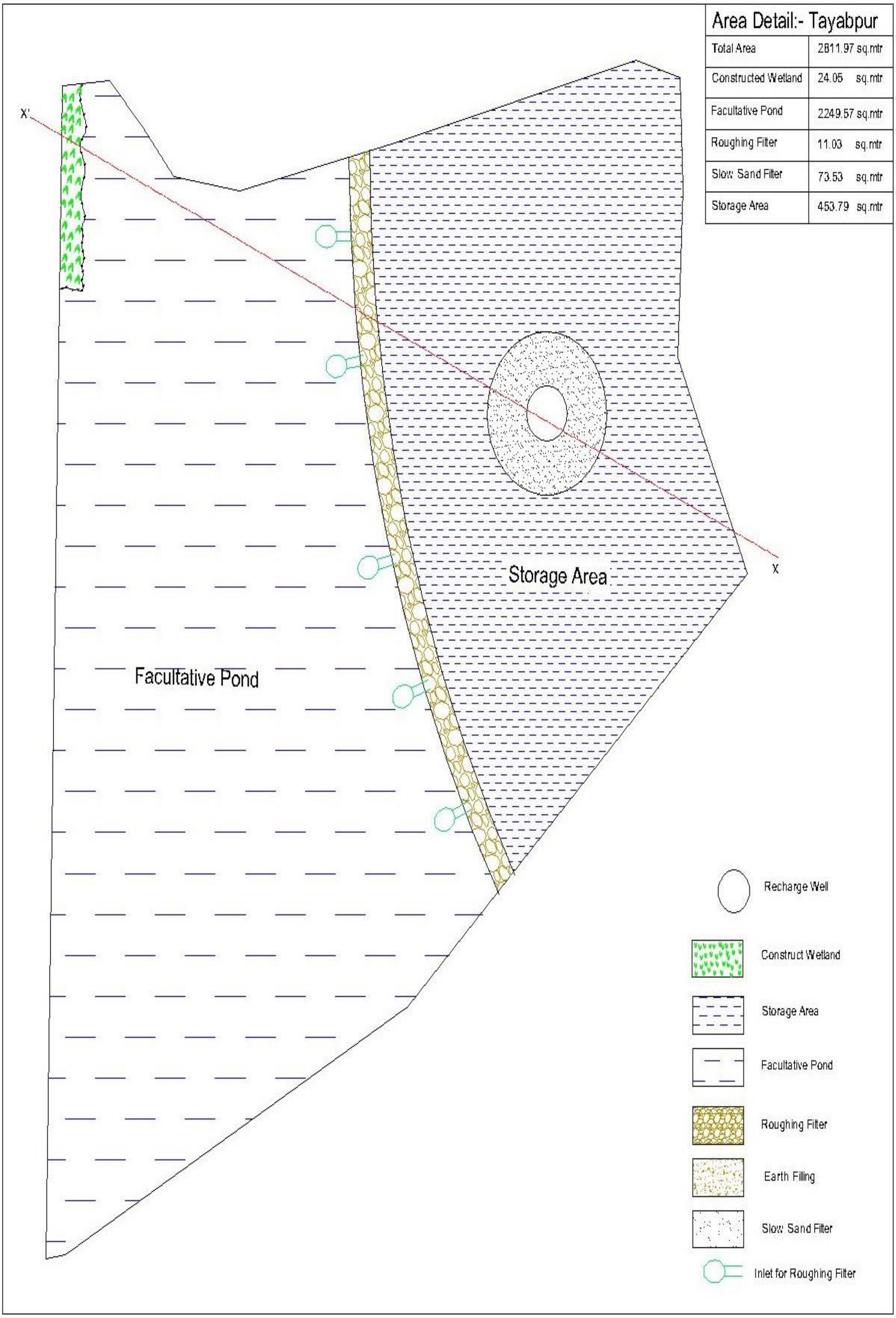

Area Detail:- Tayabpur
Total Area 2811.97 sq.mtr
Constructed Wetland 24.05 sq.mtr
Facultative Pond 2249.57 sq.mtr
Roughing Filter 11.03 sq.mtr
Slow Sand Filter 73.53 sq.mtr
Storage Area 453.79 sq.mtr
X'
X
Storage Area
Facultative Pond
Recharge Well
Construct Wetland
Storage Area
Facultative Pond
Roughing Filter
Earth Filling
Slow Sand Filter
Inlet for Roughing Filter

**Figure 5.7**

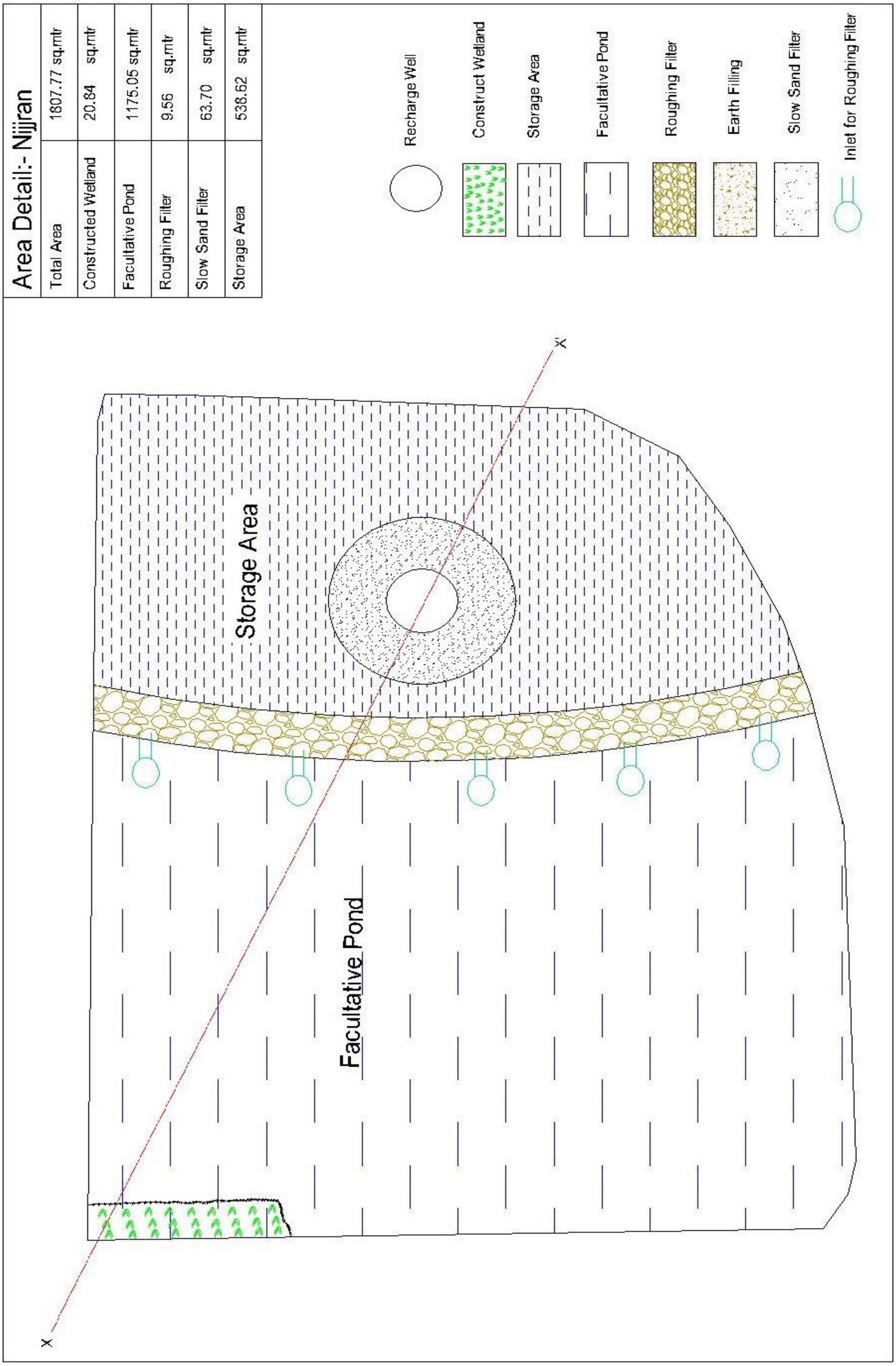
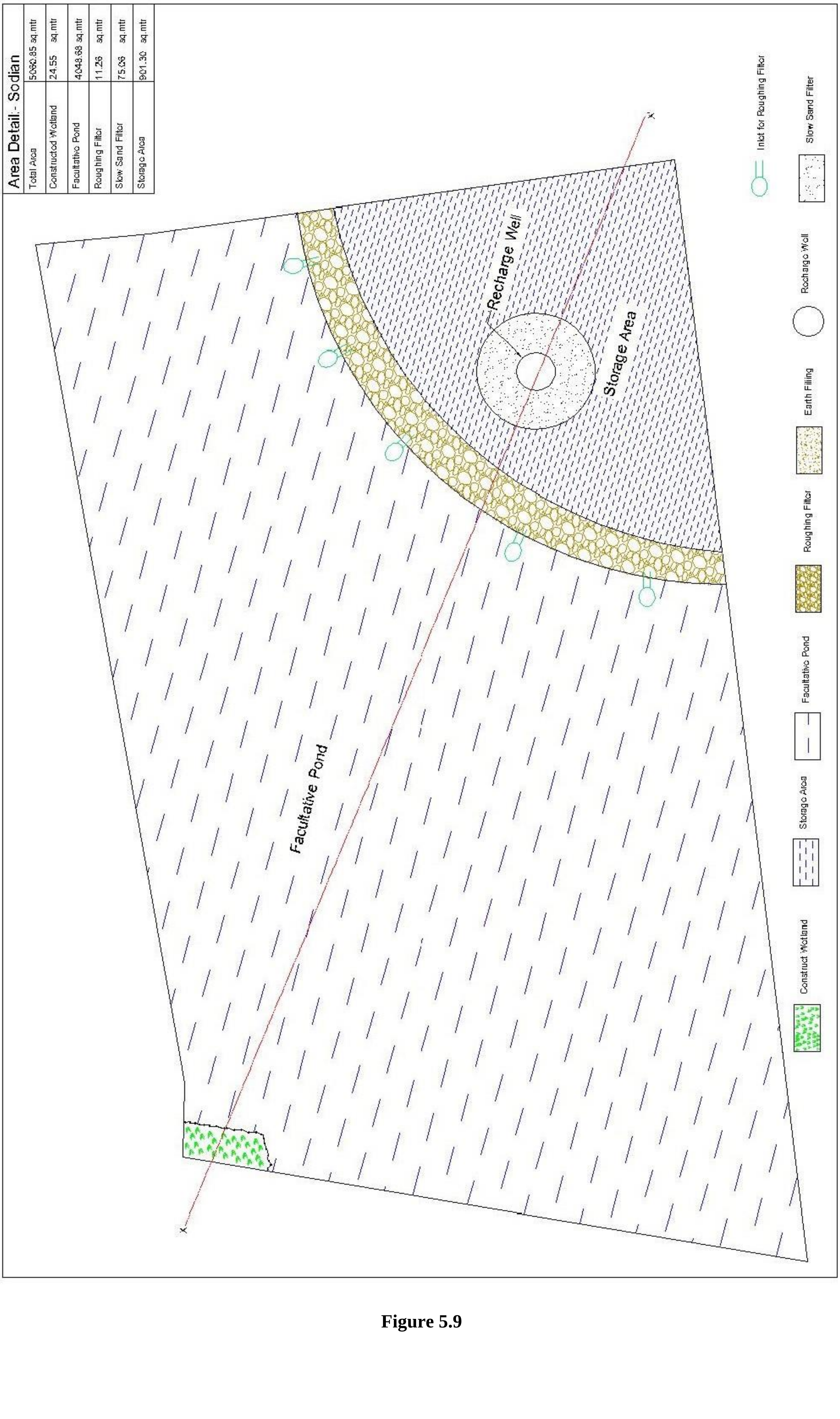
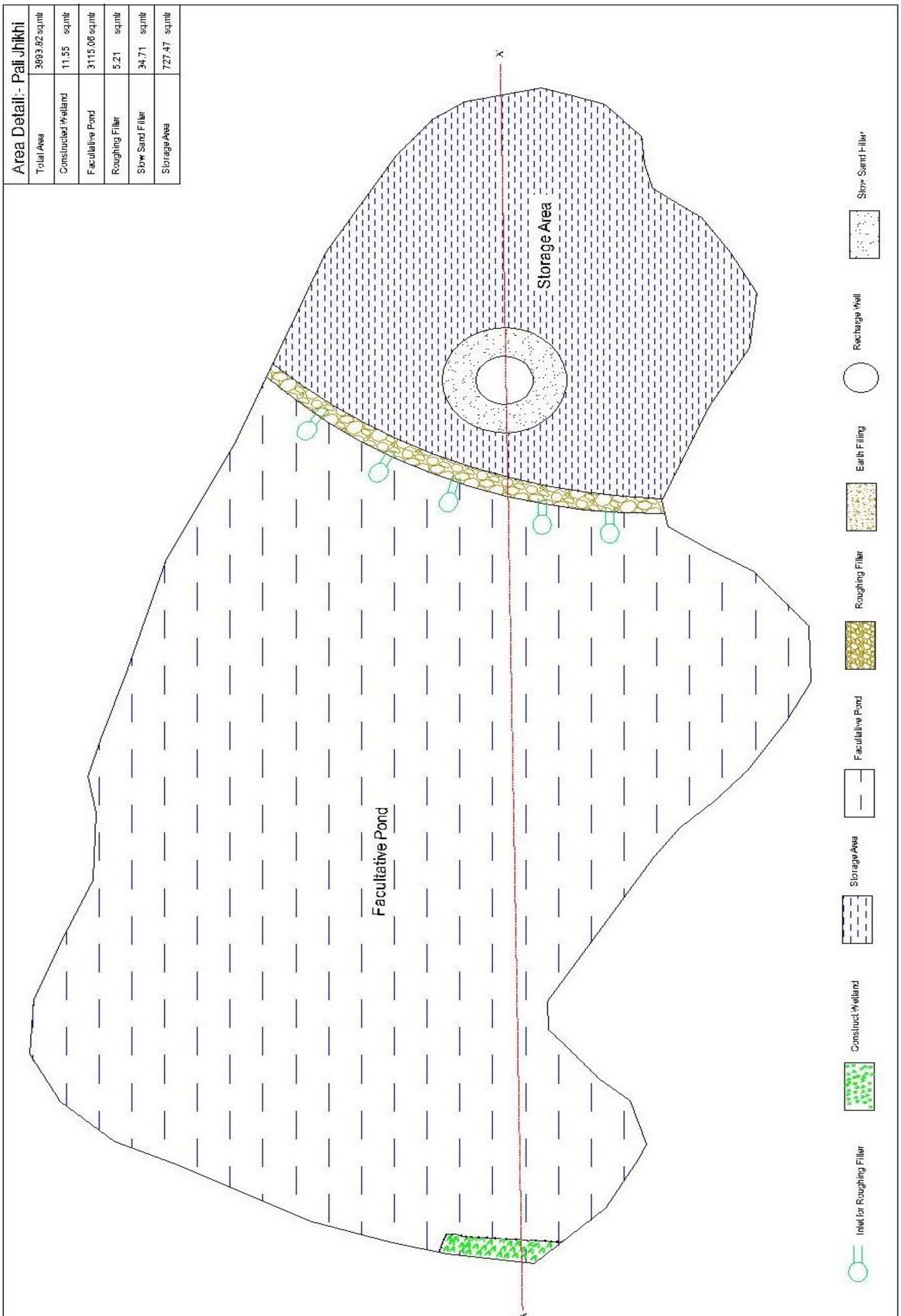

Area Detail:- Nijjran
Total Area 1807.77 sq.mtr
Constructed Wetland 20.84 sq.mtr
Facultative Pond 1175.05 sq.mtr
Roughing Filter 9.56 sq.mtr
Slow Sand Filter 63.70 sq.mtr
Storage Area 538.62 sq.mtr
Recharge Well
Construct Wetland
Storage Area
Facultative Pond
Roughing Filter
Earth Filling
Slow Sand Filter
Inlet for Roughing Filter
Storage Area
Facultative Pond
X
X'

**Figure 5.8**



Area Detail:- Sodian
Total Area 5060.85 sq.mtr
Constructed Wetland 24.55 sq.mtr
Facultative Pond 4048.68 sq.mtr
Roughing Filter 11.26 sq.mtr
Slow Sand Filter 75.06 sq.mtr
Storage Area 901.30 sq.mtr
Recharge Well
Storage Area
Facultative Pond
Inlet for Roughing Filter
Slow Sand Filter
Recharge Well
Earth Filling
Roughing Filter
Facultative Pond
Storage Area
Construct Wetland


**Figure 5.9**



Area Detail:- Pali Jhikhi
Total Area 3893.82 sq.mtr
Constructed Wetland 11.55 sq.mtr
Facultative Pond 3115.08 sq.mtr
Roughing Filter 5.21 sq.mtr
Slow Sand Filter 34.71 sq.mtr
Storage Area 727.47 sq.mtr
Storage Area
Facultative Pond
X'
X
Inlet for Roughing Filter
Construct Wetland
Storage Area
Facultative Pond
Roughing Filter
Earth Filling
Recharge Well
Slow Sand Filter


**Figure 5.10**

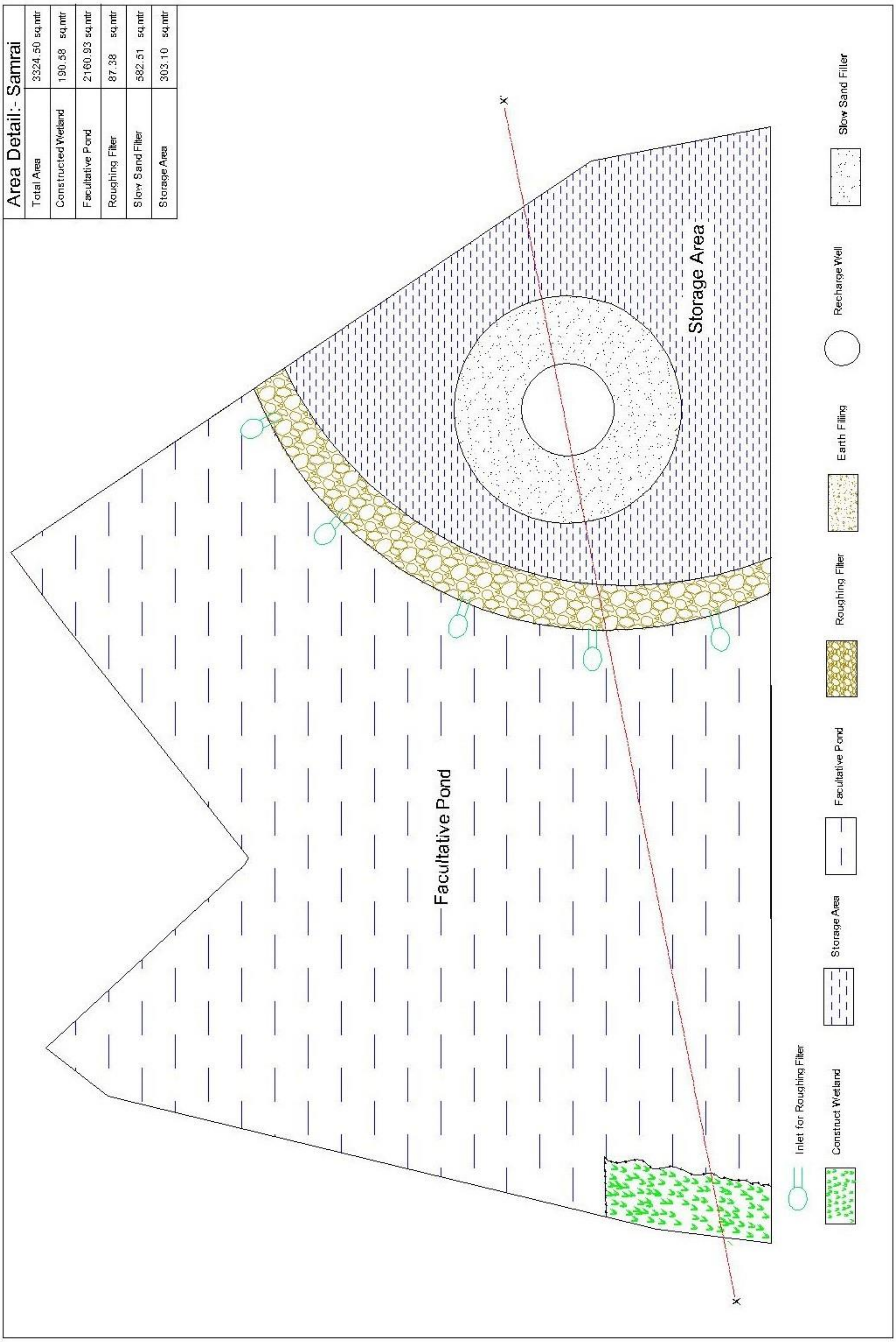

Area Detail:- Samrai
Total Area 3324.50 sq.mtr
Constructed Wetland 190.58 sq.mtr
Facultative Pond 2160.93 sq.mtr
Roughing Filter 87.38 sq.mtr
Slow Sand Filter 582.51 sq.mtr
Storage Area 303.10 sq.mtr
Storage Area
Facultative Pond
X
X'
Inlet for Roughing Filter
Construct Wetland
Storage Area
Facultative Pond
Roughing Filter
Earth Filling
Recharge Well
Slow Sand Filter

**Figure 5.11**

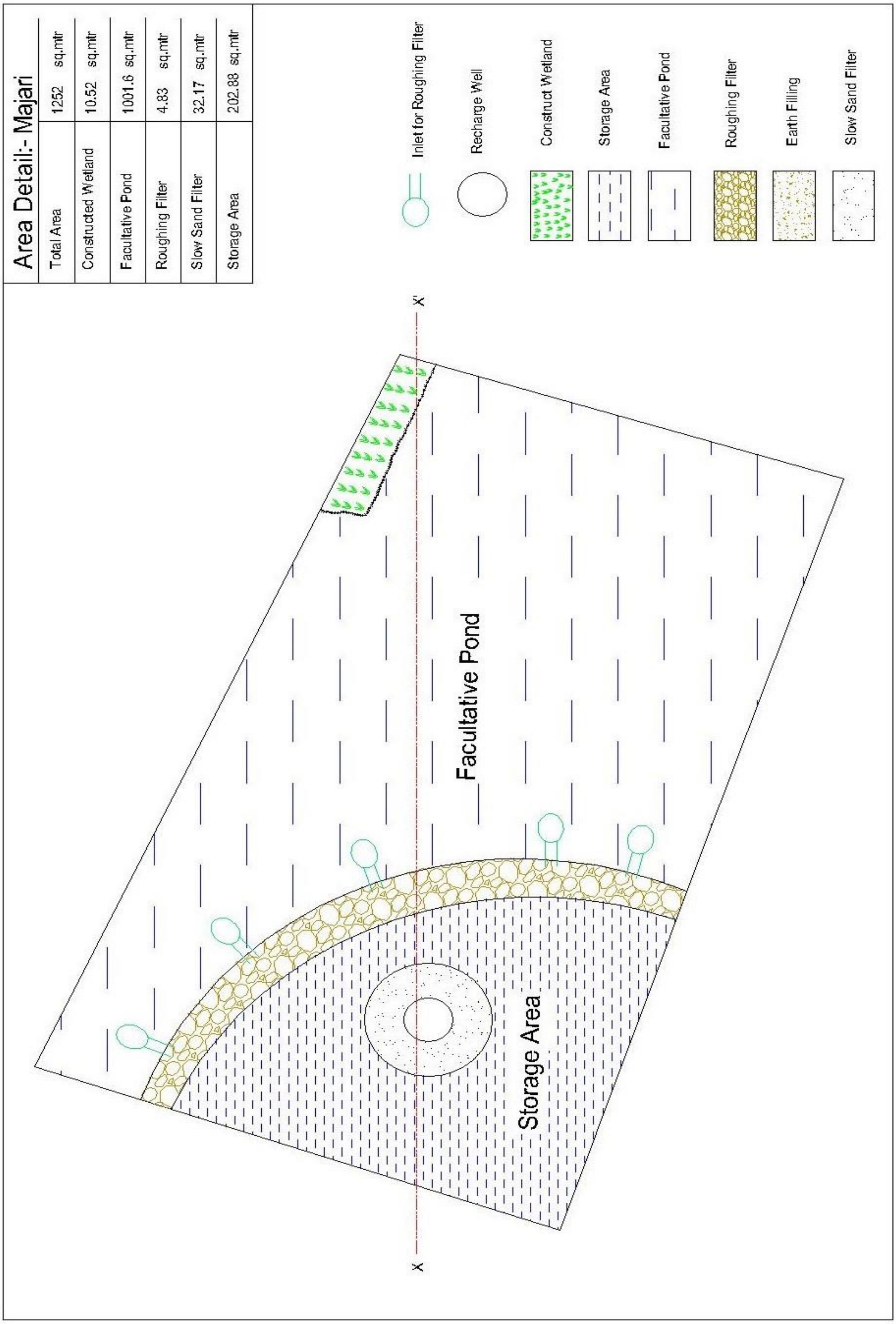

Area Detail:- Majari
Total Area 1252 sq.mtr
Constructed Wetland 10.52 sq.mtr
Facultative Pond 1001.6 sq.mtr
Roughing Filter 4.83 sq.mtr
Slow Sand Filter 32.17 sq.mtr
Storage Area 202.88 sq.mtr
Inlet for Roughing Filter
Recharge Well
Construct Wetland
Storage Area
Facultative Pond
Roughing Filter
Earth Filling
Slow Sand Filter
X'
Facultative Pond
Storage Area
X

**Figure 5.12**

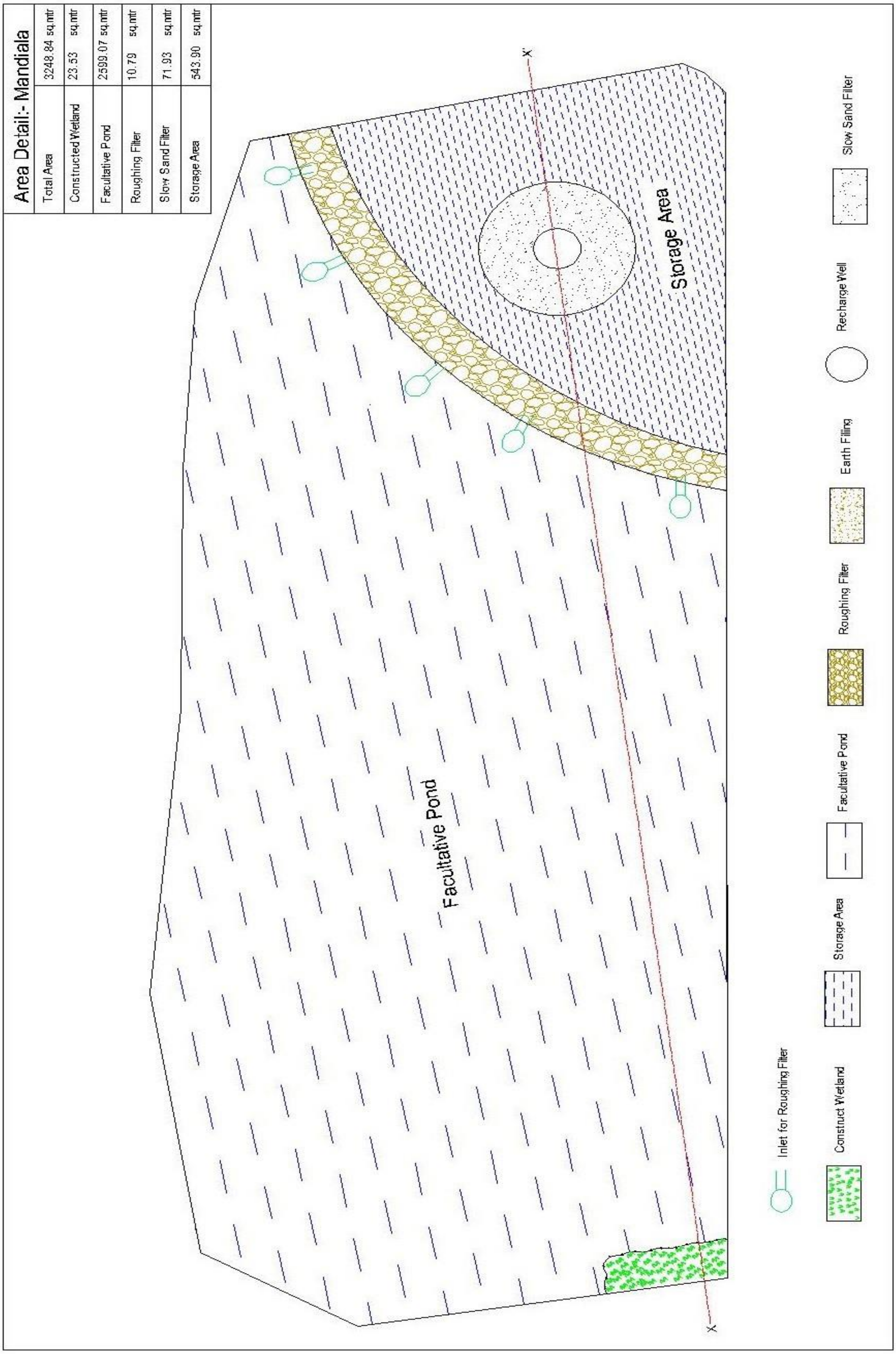

Area Detail:- Mandiala
Total Area 3248.84 sq.mtr
Constructed Wetland 23.53 sq.mtr
Facultative Pond 2599.07 sq.mtr
Roughing Filter 10.79 sq.mtr
Slow Sand Filter 71.93 sq.mtr
Storage Area 543.90 sq.mtr
X'
X
Storage Area
Facultative Pond
Inlet for Roughing Filter
Construct Wetland
Storage Area
Facultative Pond
Roughing Filter
Earth Filling
Recharge Well
Slow Sand Filter

**Figure 5.13**

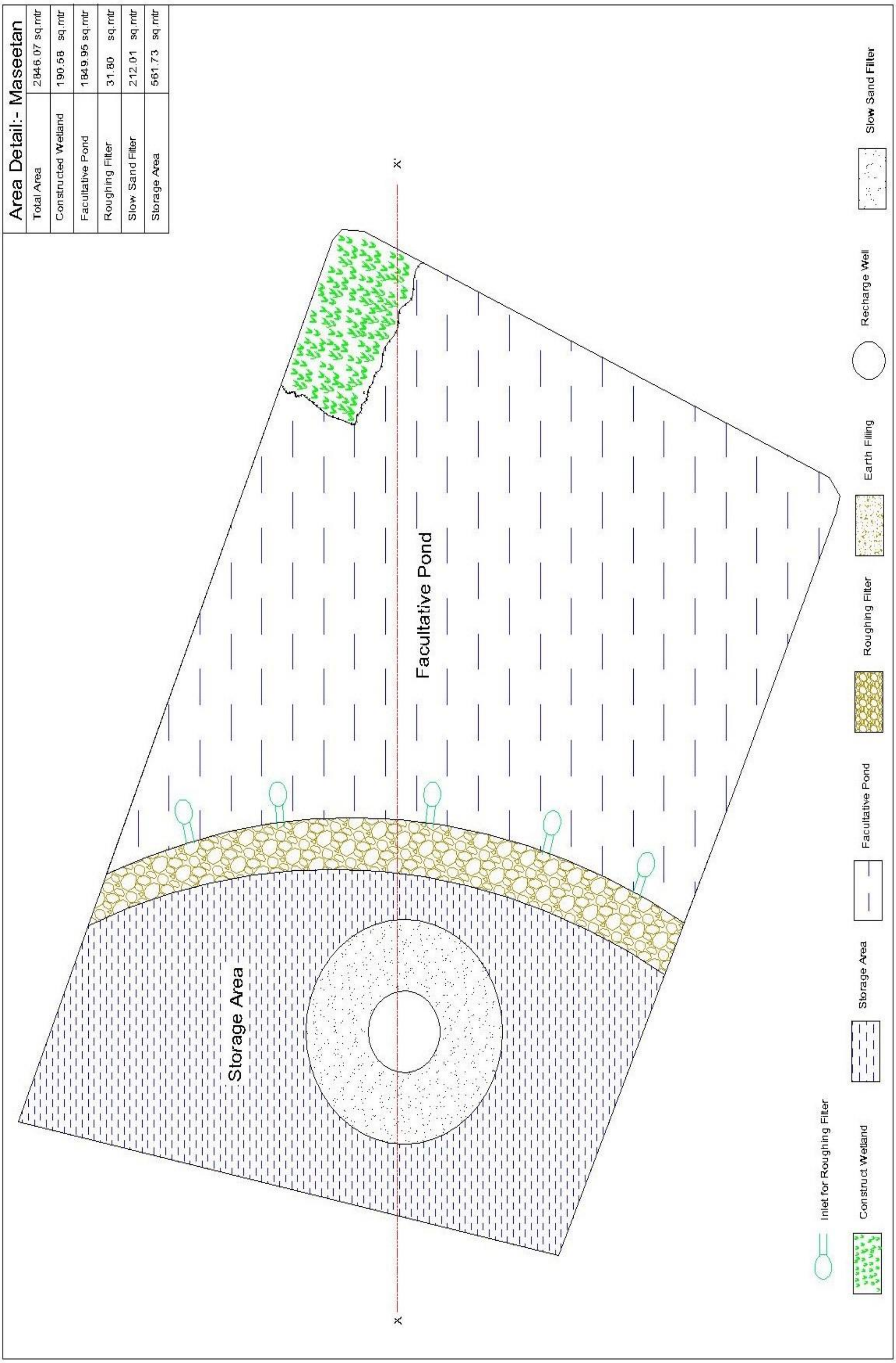
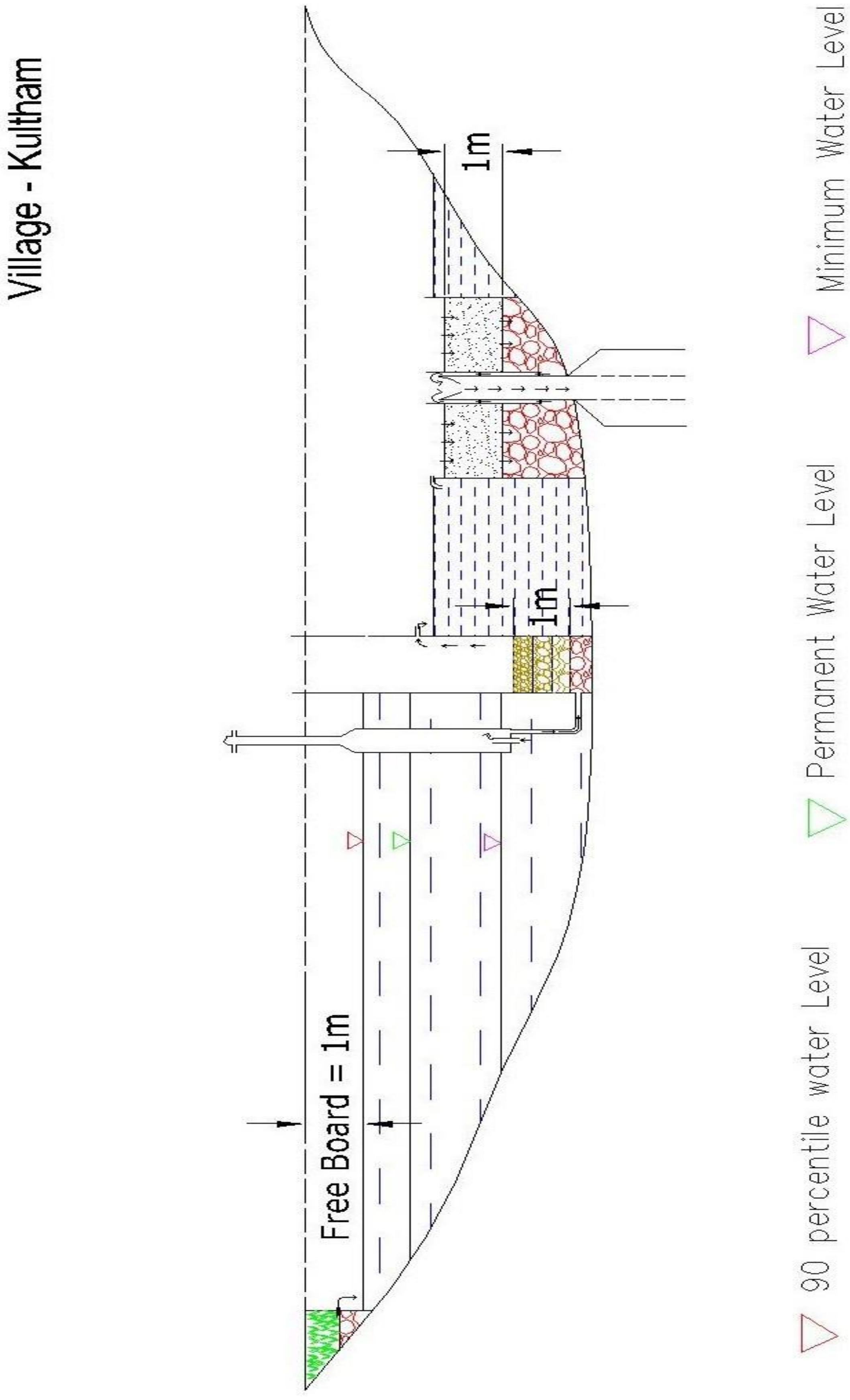

Area Detail:- Maseetan
Total Area 2846.07 sq.mtr
Constructed Wetland 190.58 sq.mtr
Facultative Pond 1849.95 sq.mtr
Roughing Filter 31.80 sq.mtr
Slow Sand Filter 212.01 sq.mtr
Storage Area 561.73 sq.mtr
X'
Facultative Pond
Storage Area
X
Inlet for Roughing Filter
Construct Wetland
Storage Area
Facultative Pond
Roughing Filter
Earth Filling
Recharge Well
Slow Sand Filter

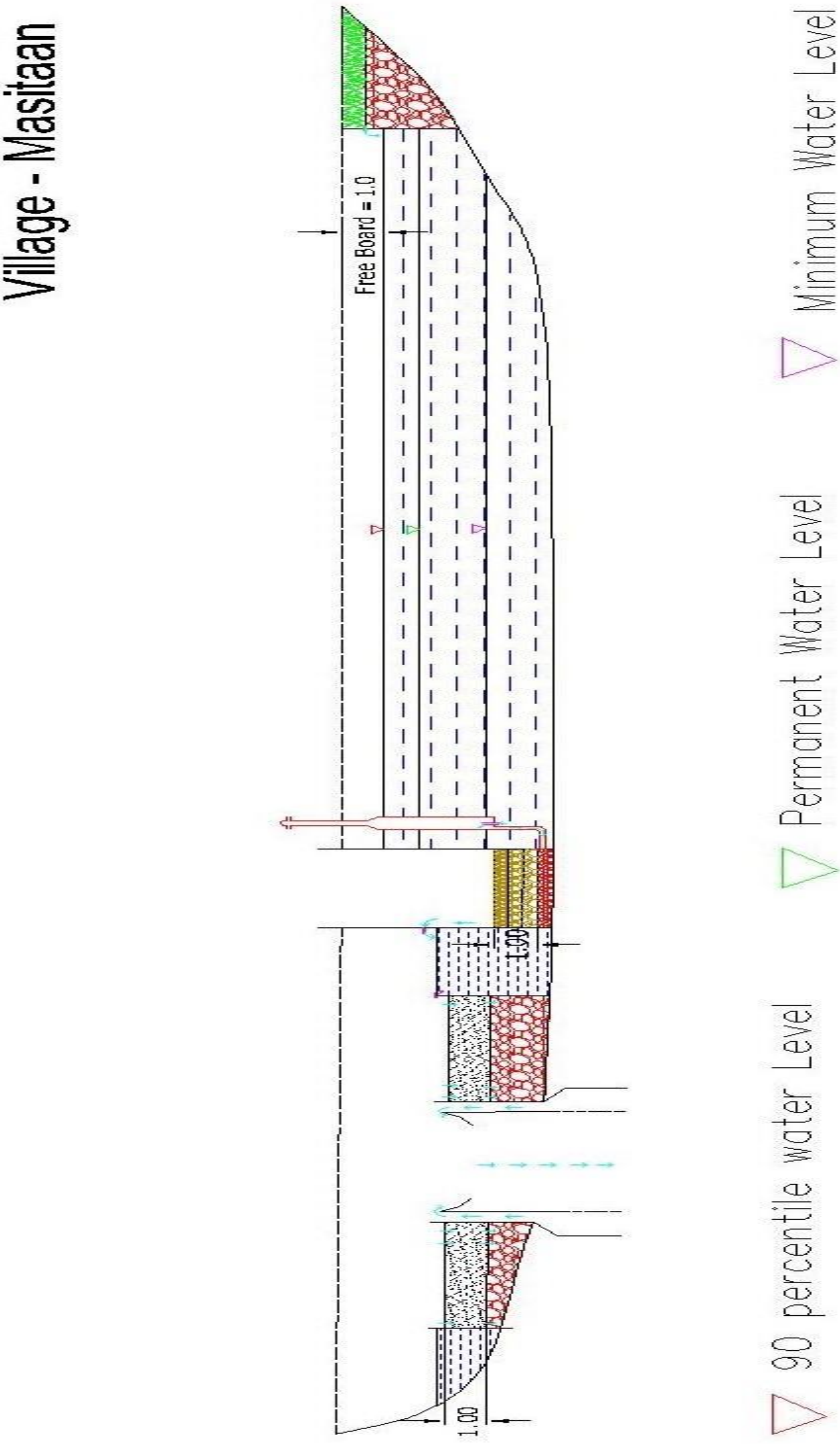
**Figure 5.14**

**Figure 5.15**



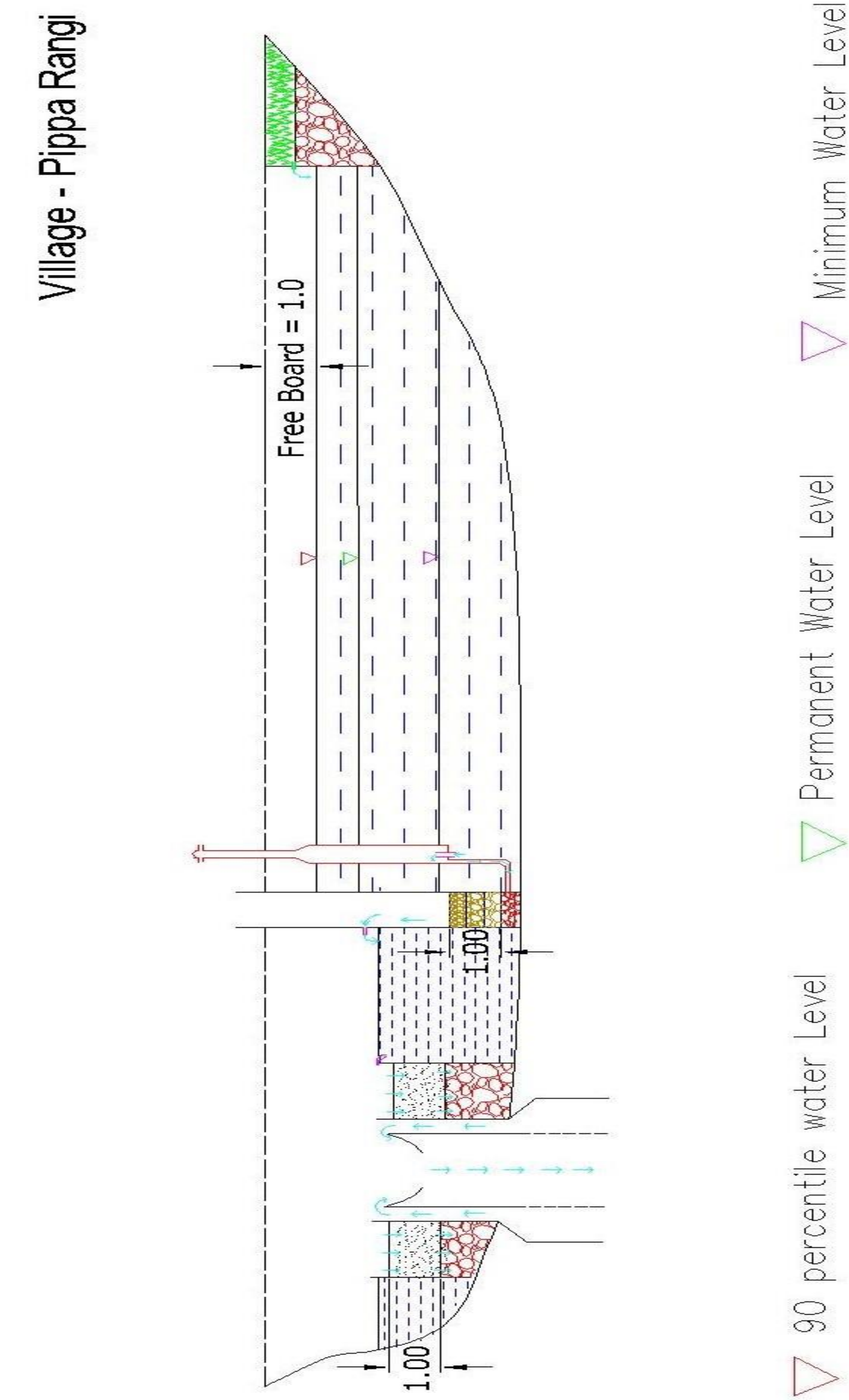
Village - Kultham
1m
1m
Free Board = 1m
90 percentile water Level
Permanent Water Level
Minimum Water Level

**Figure 5.16**



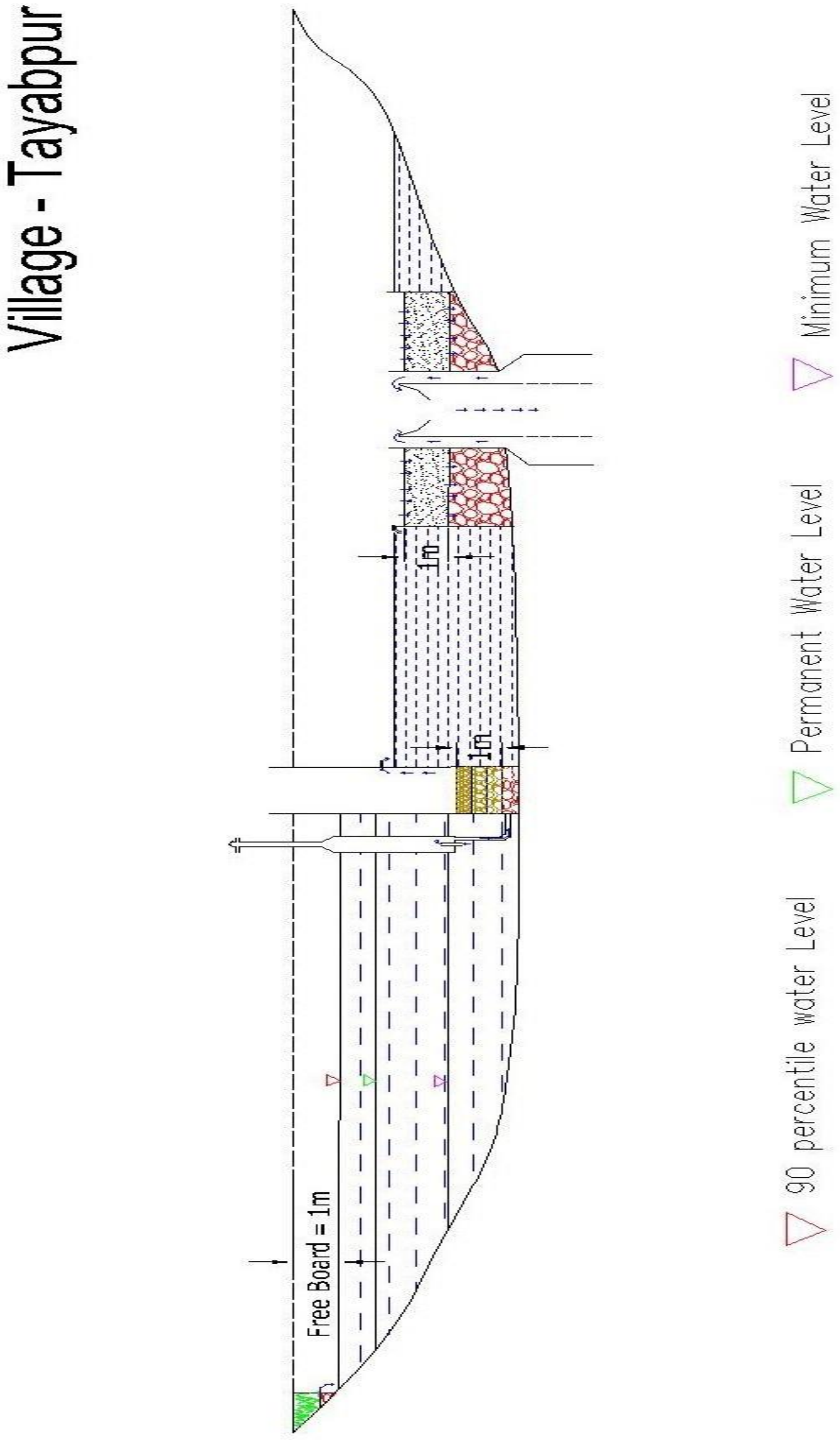
Village - Masitaan
Free Board = 1.0
1.00
1.00
90 percentile water Level
Permanent Water Level
Minimum Water Level

**Figure 5.17**



Village - Pippa Rangi
Free Board = 1.0
1.00
1.00
90 percentile water Level
Permanent Water Level
Minimum Water Level

**Figure 5.18**



Village - Tayabpur
Free Board = 1m
1m
1m
90 percentile water Level
Permanent Water Level
Minimum Water Level

# CHAPTER 6

# CONCLUSIONS

In this study, a village level integrated stormwater and greywater treatment system has been conceptualized. All the design parameters required for this system have been discussed in detail. Following conclusions were drawn from this study:

- This study shows that this designed system is a low-cost treatment system which is economical for ponds in rural areas.
- The pond based village treatment systems are so designed that these systems will operate without any human intervention except during the prescheduled maintenance.
- Requirement of associated machinery like pumping systems, etc. is negligible or not required at all.
- In this designed system wetland can remove up to 40% of organic load and total suspended solids at outlet will be less than 100 mg/l.
- Facultative pond can hold and sufficiently treat the greywater of the villages during dry period.
- Facultative ponds are designed in such a way that during wet period they are able to store the stormwater volume up to 90 percentile rainfall and subsequent treatment of stormwater will also takes place.
- BOD will be remain up to 10 to 15 mg/L at the outlet of the facultative pond which can be further reduced in roughing filter and slow sand filter.
- Roughing filters can efficiently remove the turbidity of facultative ponds effluent which can further be stored and used for purposes like irrigation, animal bathing etc.
- Further the treated water can be used for recharging after passing through slow sand filter.

- The treated water will meet the standards for irrigation and recharging in terms of organic loading, total suspended solids, nutrients and fecal-coliforms removal.

## Future Scope

In continuation with this work, a protocol for the design of recharging system can be developed. As the study was limited to one region of Punjab state, more diverse areas can be included in the extension of this work. If funds are available in sufficient amounts, this system can be implemented in any of the selected villages.

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