Integrated Water Resource Management Studies in Rural Human Settlements

A THESIS
SUBMITTED IN FULFILLMENT OF THE
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DOCTOR OF PHILOSOPHY
in
Environmental Science and Engineering

By

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CERTIFICATE

I hereby certify that the work being presented in the thesis entitled **'Integrated Water Resource Management Studies in Rural Human Settlements'** submitted to the School of Energy and Environment, Thapar University, Patiala for award of the degree of **Doctor of Philosophy**, is an authentic record of my own research work carried out under the guidance and supervision of Dr. Akepati Sivarami Reddy.

The matter presented in this thesis has not been submitted, in part or full, for the award of any other degree/diploma at this or any other university/institute. All the ideas and references have been duly acknowledged.

Date: 26-04-2016

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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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This thesis is dedicated to my parents.

For their love, endless support and encouragement

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Abstract

Rural human settlements (villages) of India suffer from severe water supply and sanitation problems. Village ponds, which used to perform an important role in the water supply and wastewater management of the villages by naturally treating the wastewater and stormwater and making it available for human use, are now heavily polluted due to higher strength and increased wastewater and stormwater inflows. Aim of this study was to develop an integrated water resources management (IWRM) system for 10 villages, from three districts of Doaba region in the state of Punjab, India. Focus of the study was to develop a generic IWRM with the objective of addressing the water supply and sanitation issues of the rural human settlements. Development of such a system required the demarcation of pond catchments and determination of wastewater and stormwater quantities and characteristics.

Quantification and characterization of wastewater flows revealed that both strength and volume (per capita day) of wastewater generated was much higher than the expected. Water use in cattle-sheds and discharge of cattle-shed wastewater, and having dwelling level parallel water supply source were apparently responsible for this. Wastewater quantification results were used in the design of the village pond system, a vital component of rural integrated water resources management (IWRM) system. Stormwater runoff quantification was done for 90 percentile rainfall events, and peak runoff flow rates were determined for the rainfall events with 2- years return period. Regression modeling of the characterization results of wet weather flows against the rainfall event size and the antecedent dry days was used to predict the wet weather flow characteristics corresponding to different rainfall event sizes and antecedent dry days. Predicted wet weather flows and their characteristics were used in the design of the village pond system.

The village pond system, comparable to a sustainable wastewater treatment plant was capable of treating the wet weather and dry weather flows of the pond catchments and making them fit for reuse as reclaimed water.

Outcome of this research work can provide a system framework for the application of IWRM approach for water supply and sanitation sector of rural human settlements. Rehabilitation of village ponds (within the existing village ponds) is at the centre stage of this approach.

Research Publications

Publications in peer reviewed journals:

- *Characterization and Prediction of Stormwater Runoff Quality in Sub-Tropical Rural Catchments,* Cheema, P. P. S., Reddy, A. S. and Kaur S. (2017), *Water Resources,* 44 (2), 331-341.
- Paper titled *Multivariate Analysis of Wastewater Quality of Different Human Settlements in Punjab (India),* Cheema, P. P. S., Reddy, A. S., Garg, L. and Kaur, D. accepted in *Environmental Engineering and Management Journal.*

Publications in conference proceedings:

- *Development of Intensity-Duration-Frequency Curves for Rural Watersheds of Punjab* Bhatia, S., Cheema, P.P.S., and Reddy, A.S. Proc. of National conference on 'Geotechnical Engineering and Sustainable Infrastructure Development' held at Guru Nanak Dev Engineering College, Ludhiana from 11^{th} -12^{th} Oct., 2014.
- *Characterisation and Quantification of Pond Water in Micro Watershed of Village Kultham in Nawanshahar, Punjab,* Garg, L., Cheema, P.P.S., and Reddy, A.S. Proc. of National conference on 'Geotechnical and Geo-Environmental Aspects of Wastes and their utilization in Infrastructure Projects' held at Guru Nanak Dev Engineering College, Ludhiana from 15^{th} -16^{th} Feb., 2013.

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- Paper titled *Conceptualizing a Sustainable Water Management System for Rural Human Settlements,* Reddy, A. S., Cheema P. P. S., and Singh A. accepted in 7^{th} International Congress of Energy and Environment Engineering and Management to be held from 17^{th} -19^{th} July, 2017 at Canary Islands, Spain.

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Abbreviations

ADD	Antecedent dry days
AMC-II	Antecedent moisture condition –II
APHA	American Public Health Association
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
Bgl	Below ground level
BMPs	Best management practices
BOD	Biochemical oxygen demand
Cd	Cadmium
CDA	Contributing drainage area
CGWB	Central Ground Water Board
CN	Curve Number
COD	Chemical oxygen demand
CPHEEO	Central Public Health and Environmental Engineering Organization
Cu	Copper
CV	Coefficient of variation
FC	Fecal coliform
Fe	Iron
FWS	Free water surface
GIS	Geographic information system
GPS	Global positioning system
GWP	Global Water Partnership
GWT	Ground water table

HRF	Horizontal roughing filter
HRT	Hydraulic retention time
HSSF-CW	Horizontal subsurface flow constructed wetland
IDF	Intensity-Duration-Frequency
IMD	India Meteorological Department
IWRM	Integrated water resources management
LCLU	Land cover land use
MSW	Municipal solid waste
NATMO	National Atlas and Thematic Mapping Organization
Ni	Nickel
NO_3-N	Nitrate- Nitrogen
NRCS	National Resource Conservation Service
Pb	Lead
QA	Quality assurance
QC	Quality control
SAR	Sodium adsorption ratio
SCS	Soil conservation Service
SSF	Slow sand filter
SWMM	Stormwater management model
t_c	Time of concentration
TDoT	Texas Department of Transportation
TDS	Total dissolved solids
TKN	Total kjeldahl nitrogen

TN	Total nitrogen
TP	Total phosphorous
TSS	Total suspended solids
UDT	Urine diverting toilets
USEPA	United States Environmental Protection Agency
US-SCS-CN	Unite States Soil Conservation Service Curve Number
VRF	Vertical roughing filter
WATSAN	Water supply and sanitation
WSP	Waste stabilization ponds
WSTR	Wastewater storage and treatment reservoir
Zn	Zinc

Chapter-1
Introduction

1.1 Background

Traditionally, most of the villages, at least in the Punjab region, have village ponds as an important source of water for rural human settlements. Wastewater and stormwater generated in the rural human settlements (villages) mostly flow through road side open drains into these village ponds. The wastewater in the village ponds is treated naturally over time and become available for rural human settlements as an important source of water. Further, the village pond water is lost over time through evapo-transpiration and percolation and ground water recharging.

Presently, village ponds are heavily polluted from the high organic content, solids, nutrients, and pathogens received through the wastewater and stormwater of villages draining into it. The village ponds are heavily infested with weeds, rodents, flies and mosquitoes. So, village ponds are no-more fit for use as a source of water.

Rural human settlements (villages) of India suffer from severe water supply and sanitation problems. Water demands of the villages are now met from the government sponsored water supply schemes of tube wells, submersible pumps and exploitative use of the rapidly depleting and scarce ground water resources. Tube wells, hand pumps and submersible pumps are also used at individual dwelling level for the supply of water.

Open defecation; discharge of black water and cattle manure (dung and urine) into the village drains; disappearance and/or non-existence of proper drainage system; undersized and/or clogged drains have been the serious sanitation problems encountered in the villages of Punjab. While, population pressures and developmental compulsions are leading to encroachments of, and even extinction of village ponds, increasing impervious areas and enhanced drainage connectivity are increasing the stormwater and the wastewater flows to the village ponds. Flooding and overflowing of the village ponds leads to contamination of cropland and spread of the pollution in rural human settlements (villages). Village ponds, instead of being sources of water for the villages, are now posing serious environmental and health risks.

Studies by Shivashankara et al. (2004) and Toor et al. (2011) have revealed that renovation of village ponds have positive effects on the environment, the rural economy and the groundwater regime. Further, if sufficiently treated, the village pond water can be used for irrigation purposes.

This work for Ph.D. is an effort towards the development of a sustainable water resources management system for selected 10 villages (human settlements) from three districts (Jalandhar, Kapurthala and Nawanshahar) of Doaba region in the state of Punjab, India. Focus of the study was to consider the village ponds at the center of the sustainable rural water resources management system. The study has taken into consideration the various problems, issues and concerns related to the rural water supply and sanitation. Efforts have also been made to ensure that the developed integrated water resource management system is technologically and economically feasible, water conserving, and socially acceptable.

1.2 Objectives and scope of the work

Objectives of the work for Ph.D. are explicitly stated as following:

- To analyze the village pond catchments for understanding the water supply and sanitation situation, and the status of village ponds.
- To develop integrated water resource management plan for rural human settlements.
- To work on the systems and techniques integral to the rural integrated water resource management.

The above objectives of the study have been achieved through working on the following work elements:

1. Survey of the rural human settlements (villages) and demarcation of the pond catchments.
2. Analysis of village ponds and characterization of their catchments.
3. Quantification and characterization of wastewater of the villages.
4. Quantification and characterization of stormwater of the villages.
5. Development of village level integrated water resources management (IWRM) system.
6. Conceptualization of a village pond system.
7. Design of the village pond system.

This study was conducted in ten villages from the Doaba region of Punjab. The selected villages were having population between 500 to 3000 and fall under the jurisdiction of three districts (Jalandhar, Kapurthala and Nawanshahar) of Punjab. All the selected villages fall within the same agro-climatic zone and covered by 5 rain gauge stations of the state (Jalandhar, Kapurthala, Nawanshahar, Nakodar and Phagwara). Within these villages the thesis work was limited to ten village ponds (one pond per village) and to their demarcated catchments.

Most of the thesis work was carried out between May 2009 and February 2014. This work considered the 15 years (1998 to 2013) daily rainfall data. A multitude of secondary data sources, including the survey sheets developed by the Department of Water Supply and Sanitation, Government of Punjab were used in this study. Quantification and characterization of the residential wastewater was done on the basis of the wastewater being received by the village ponds at their inlets. Instead of the characterization of stormwaters, characterization of the wet weather flows from the village pond catchments was carried out. While village pond systems were designed for all the ten villages, the grey water – stormwater drainage system was designed for only one village (Samrai village).

1.3 Outline of the thesis

This thesis includes five chapters, including an introduction chapter and a conclusions chapter, five appendices and bibliography and references.

Chapter 1 is introduction. It includes a brief description of background for the proposed research, objectives and scope of the research and outlines of this thesis contents.

Chapter 2 is a literature review chapter. It includes a comprehensive and up-to-date review of the published research in the areas relevant to this research work. It provides a critical review of past research relevant to the current research work. The aspects covered in the literature review include Rural water supply and sanitation, Ecological sanitation (Eco-San), Integrated Water Resources Management in the rural water supply and sanitation context, Characterization and quantification of rural residential wastewater and stormwater, Village ponds, Wastewater treatment technologies, and groundwater recharge. Gaps in research were also identified in this chapter.

Approach followed and methodology is presented in Chapter 3. The approach and methods are described work-element wise in this chapter.

Chapter 4 includes the results and discussion. Characteristics of the village ponds and their catchments, water supply and sanitation situation, quantification and characterization of residential wastewater and stormwater, IWRM and village pond systems, design details of grey water-storm water drainage system, and design details of the village pond systems are presented in this chapter.

Chapter 5 is conclusions chapter. Conclusions drawn from this research and scope for future research are presented here. Short-coming of the research and contributions to the current knowledge are also presented in this chapter.

All the references cited in the thesis are listed, and the following appendices are included at the end:

1. Appendix A-Data collection form for physical survey of the rural settlements
2. Appendix B-Wastewater flow characterization results of rural settlements
3. Appendix C-Development of IDF curves
4. Appendix D-Wet weather flow characterization results of rural settlements
5. Appendix E-Box plots of rainfall data from rain gauge stations

Chapter-2
Review of Literature

For the work proposed in the present study, the relevant literature review was carried out from the various sources like research publications from peer reviewed journals, technical reports, working papers of the projects sponsored by various national and international government and non-governmental agencies, papers published in the proceedings of international conferences and technical manuals published by national and international agencies, like, Central Public Health and Environmental Engineering Organization (CPHEEO), Central Ground Water Board (CGWB), United States Environmental Protection Agency (USEPA), Global Water Partnership (GWP), Natural Resources Conservation Service (NRCS), Texas Department of Transportation (TDoT) etc. Web based sources were also reviewed to carry out the literature survey.

Review of literature was carried out on the following aspects of rural water management:

- Rural water supply, sanitation and ecological sanitation (eco-san)
- Village ponds
- Integrated water resources management (IWRM) at local level
- Wastewater and stormwater quantification and characterization
- Wastewater and stormwater management in rural areas
- Groundwater recharge systems

2.1 Rural water supply, sanitation and ecological sanitation (eco-san)

2.1.1 Rural water supply and sanitation

Household water supply and sanitation conditions in the villages continue to be inadequate, in spite of the longstanding efforts at the government and community's level. Adequate sanitation and water supply are development priorities, yet the ambition of international policy on drinking water and sanitation is not there. Globally, eight out of ten people suffer from of unimproved sanitation facilities, and six out of seven people defecate in the open in rural areas (Bartram and Cairncross, 2010). At world level, under millennium development goals (MDG), the access to improved water supply and sanitation facilities from 1990 to 2015 in rural areas has increased from 62 to 84% and 35 to 51%, respectively. In Indian context, the increase in the access to improved water supply and sanitation facilities in rural areas during this period was 64 to 93% and 6 to 28%, respectively (WHO, 2015). Open defecation in rural areas of India has decreased from 91 to 61% from 1990 to 2015 (WHO, 2015). The transition from open defecation to the use of an improvised latrine is a step forward, but is unlikely to offer health benefits unless it provides an adequate barrier between the users and their excreta and is well maintained (Bartram and Cairncross, 2010).

Churchill et al. (1987) found that, even ignoring the effect on health, the value of time saved from water collection alone was sufficient to justify the investments in rural water supply in most of the scenarios. A WHO report suggested that the time lost in collecting water and seeking somewhere to defecate could be valued at US$63 billion annually (Hutton et al., 2007). Keshavarzi et al. (2006) reported that water consumption pattern was negatively related with the education level of household head in rural areas of Fars province of Iran. (Kulinkina et al., 2016) assessed the temporal and spatial variations in consumption of water from standpipes of four public water systems in Ghana. Temporal accessibility showed negative correlation with rainfall indicating that rainwater was preferred over standpipes when available. Consumer demand in the studied areas was appeared to be influenced more by water quantity, accessibility and perceived water quality instead of microbiological water quality or price. Authors suggested that consumption from existing public water supplies should be analyzed in combination with qualitative approaches for more efficient planning of community based water supplies.

Health problems, especially in rural areas are often related with sanitation conditions of the surroundings. Any form of sanitation system in developing countries should have the main objective of controlling pathogenic materials which can be achieved by employing the on-site treatment options, like, waste stabilisation ponds, constructed wetlands etc. Apart from acting as a barrier to the spread of pathogenic organisms, the on-site sanitation options has an added advantage of dispersing rather than concentrating the wastes, an important consideration if the sanitation facilities are not well maintained (DFID, 1998). Fung et al. (2013) demonstrated that water sanitation and hygiene interventions such as improved latrines, piped water supply, and point-of-use chlorination could avert 57,949–78,567 cholera cases in Haiti in two decades. Sanitary risk of locating the drinking water source (hand pump) close to household toilets and accumulation of animal excreta near the drinking water source is the major risk in a rural setting. Gopal et al. (2009) examined the water and sanitation facilities of a village in southern India using geographic information system (GIS) tools. Analysis using direct observations supplemented by GIS maps revealed that poor planning, inadequate engineering design and lack of policing of the water distribution system was causing contamination of drinking water from sewage at multiple sites.

Mara and Alabaster (2008) proposed that water supply and sanitation provision in villages should be to groups of households, not to individual households. Groups of households would form water and sanitation cooperatives. They recommended the provisions of standpipe and yard-tap cooperatives served by the community managed sanitation blocks and on-site sanitation systems for a group of households. Akosa et al. (1995) measured single efficiency score for 10 water supply and sanitation projects in Ghana and showed that, out of 10 projects, the hand-dug wells and the pit latrines were most efficient in rural areas whereas in large cities, capital and management intensive water supply and sanitation projects gave equal efficiency. Communal water supply and wastewater systems would be the suitable method for providing water for rural households and wastewater treatment for the wastewater generated from rural communities (Danielson and Dawood, 2001). Goel and Sharma (2014) developed a low-cost model for the clean water supply and sanitation system for the rural poor people using hybrid renewable energy system.

Sustainability of rural water supply and sanitation systems are important to achieve the desired results for designed life of the system. Nolasco and Migone (2007) showed that the success of rural water supply and sanitation systems were dependent on hygiene habits in the household, community management system, reliability of water resources, proper selection and implementation of technical solutions, and user satisfaction level.

Poor technology choice is the most common reason for failure of the water supply and sanitation projects in rural areas. For increased success, stakeholders should be sensitized about the sustainability criteria associated with the water supply and sanitation projects (Barnes et al., 2014). Montgomery and Elimelech (2007) identified three components .i.e. community demand, local financing and cost recovery and dynamic operation and maintenance which are essential for the sustainability of any water supply and sanitation system.

Integration of water supply, sanitation and watershed development has also been proposed by the researchers as a possible solution to the drinking water and sanitation problems. Kakade et al. (2003) conducted a study on seven different agro climatic rural watersheds in India highlighting the effects of watershed development models on drinking water and sanitation systems. It was suggested that sustainable water management should be an integral part of any watershed/catchment development plan.

2.1.2 Ecological sanitation (eco-san)

Ecological sanitation (eco-san) is based on three fundamental principles (Winblad, 2004):

- preventing pollution rather than controlling it after polluting
- sanitising the urine and the faeces
- using the resultant safe products in agriculture

In rural areas, eco-san is targeted to strengthen the sanitation sector by grouping the rural agriculture and rural development. Rural eco-san programs are much more focused around the household, and thus within a rural community, households have the choice to select different eco-san systems for themselves as per their preferences.

Eco-san is a sustainable, closed-loop system that closes the loop between sanitation and agriculture. Closing of the local nutrient and water cycles is the underlying aim of eco-san so that to contribute towards a sustainable development. Human excreta are considered as a resource which is normally processed on-site and treated off-site under eco-san. Nutrients present in the excreta are then recycled by using in agriculture. In eco-san systems treatment of human excreta is based on the cycles of nature (Langergraber and Muellegger, 2005; UNICEF, 2011). Eco-sanitation systems are now adopted in several countries in which separation of black water from grey water is an essential aspect. Separated black water with low dilution can be converted into safe manure that will replace synthetic products from the fields and also prevent the spread out of pathogens and other pollutants to natural water bodies. Separate collection and management of grey water and black water is the salient feature of any eco-san system (Otterpohl, 2002; Chen et al., 2010; Anand and Apul, 2014). Wendland and Oldenburg (2003) studied the source separation of black water, grey water and stormwater in a densely populated rural area in Germany. For the treatment of grey water and stormwater, swales and constructed wetlands were used, whereas, black water together with organic waste was treated anaerobically thus producing biogas. It was observed that the operating costs of the eco-san system were much lesser than the conventional sanitation systems. The flushing system in eco-san system required only about 0.7 liters water per flush which reduced the daily mean water consumption from 129 liters to 77 liters per person.

Anand and Apul (2014) categorized the different types of composting toilets into self containing type, waterless or with water, and single or multiple chambers. Authors identified the important factors affecting the composting process as temperature (40-65°C), moisture content (50-60%), C:N ratio (25-25%) and pH (5.5-8.0). Public perception, regulations, and lack of knowledge and experience in composting toilet design were described as the main barriers in the widespread use of composting toilets. Benetto et al. (2009) performed the comparative life cycle assessment of an eco-san system and a conventional system. It was observed that contribution to ecosystem quality damage can be reduced by 60% by eco-san system. Eco-san appeared to be the potential alternative to small scale wastewater treatment, whereas at higher scales conventional systems were found to be better performing than eco-san systems.

Meinzinger et al. (2009) studied the urine-separating facilities in Ethiopia and showed that the system was accepted by the users. Urine-separating facilities provided two advantages to the users .i.e. savings of water in toilet flushing and reduced cost of wastewater treatment in septic tank. The separated urine was used as fertilizer which resulted in the improved crop growth. Heinonen-Tanski et al. (2010) reviewed that by installing urine-separating toilets, the volume of wastewater generated from the households could be reduced and urine could be used as a fertilizer for the growth of vegetables and cereals. There might be some uncertainty over the yields of urine fed crops and mineral fertilized crops but urine fed crops always produced higher yields than non-fertilized crops.

Human attitude and perceptions and cultural preferences about eco-sanitation has proved to be a major barrier in the universal acceptance of eco-san systems. Nawab et al. (2006) underscored the importance of cultural preferences in the planning and design of eco-sanitation systems. Their study in a village of Pakistan indicated that given the alternative between the eco-san and conventional systems, the communities would prefer the conventional system consisting of flush toilets. Eco-san systems, however, are cheaper and environmentally sustainable than conventional systems, but the human perception of associating the prestige with the flush toilets creates hindrance in the universal acceptability of eco-san systems. Mariwah and Drangert (2011) conducted a study among an agricultural community in Ghana to understand the perception of people towards the use of human excreta as manure. It was observed that people were not willing to use the sanitized human excreta as manure in their own farms and were not willing to consume excreta fertilized crops. Authors recommended that a consensus build-up exercise was required in the communities for the successful implementation and operation of eco-san systems. Lamichhane and Babcock (2013) conducted an online survey to determine the public acceptance of urine diverting toilets (UDT) in Hawaii. Results of the survey indicated that 60% of the respondents were willing to pay more for UDT and with a public awareness program most of the people would accept UDT. Full potential of eco-san can only be realized by developing the cost effective eco-san technologies, improvement in infrastructure, raising awareness and breaking down the cultural barriers (Haq and Cambridge, 2012).

2.2 Village ponds

Village ponds traditionally played the role of a harvesting structure by collecting and storing the stormwater and grey water from the pond catchment, which was then used by the inhabitants after being naturally treated in the pond. Presently, untreated wastewater, polluted stormwater runoff from dumps and cattle sheds is being discharged into the ponds. The ponds have become the source of disease vector, posing serious health hazard and creating poor living environment. Besides being an important source of water, ponds maintain ecological balance as a natural drainage, contribute towards groundwater recharge and are home to local flora and fauna (Singh and Singh, 2007). Panda et al. (2006) reported that upgradation of community water sources (like ponds and wells) have led to improvements in the quality of water and also reduced the time spent in fetching water. Ponds being community assets required a community-based long term approach for their development especially when short-term efforts did not yield desired results. Seenivasan and Kumar (2004) worked on the development of traditional pond structures called ‘Oorani’ in the villages of Tamilnadu, India. Reviving the traditional pond water collection and storage systems resulted in the availability of water for livestock and irrigation purposes and restored village-based water management systems by collaborating with the local people. Kakade et al. (2003) proposed a model for interlinking of ponds feeding one another in the drought prone area of Karnataka, India. One pond was dug for every two hectares of land and excess water was fed to another pond through a trench. Flow of excess water under gravity was facilitated by locating the ponds along contour lines. Successful implementation and running of this model resulted in the groundwater table increase by 3.8 meters in the area.

Wastewater generated from pond catchments and open defecation along the ponds, especially, in the rural areas of low and middle income countries are the major pollution sources that contribute pathogens to the pond water. Knappett et al. (2011) analyzed forty three ponds in Bangladesh and established the correlation between the population, latrine density and quality and concentrations of pathogens and fecal bacteria in pond water. Bacteroidales measurements showed that humans were the major source of fecal contamination in 79% of the ponds. Fecal indicator bacteria were highest (up to 10^6 MPN/100mL) in the ponds that directly received latrine effluent. Concentrations of fecal indicator bacteria were found to be correlated with population within a distance of 30–70 m and with total latrines within 50–70 m. Authors observed that unsanitary latrines (visible effluent or open pits) within the pond catchment were also significantly correlated to fecal bacteria concentrations. Unsanitary latrines were the major contributor of fecal contamination in pond water and to a lesser extent, sanitary latrines and cattle also increased the fecal bacterial contamination in the pond water.

Chawla et al. (2001) determined the quality of the pond water in rural areas of Ludhiana, India. Authors found that pond water was suitable for irrigation as it was rich in nutrients and was also found to be suitable for pisciculture. It was found that renovation of village ponds was required in some of the surveyed villages which would positively affect the environment, the rural economy and the declining groundwater table.

Availability of the resources and capacity of the people to sustain the system play an important role in deciding and selecting the appropriate technologies and options available for restoration of the village ponds. Ansal et al. (2010) proposed that duckweed based bio-remediation of the village ponds followed by aquaculture is an ecologically and economically feasible approach for the development of ponds. In this approach nutrient rich pond water can be used for the production of high quality fish protein alongwith the purification of pond water. Pond water can be used for aquaculture thus generating employment and boosting the rural economy. Rejuvenation of village ponds through waste stabilization ponds (WSP) have been attempted in Punjab. Per capita cost of treatment through WSP (excluding sewerage system cost) was about Rs. 400 ($ 5.8) which was quite reasonable as the village ponds and low lying areas were used for the construction of WSP. However, periodical maintenance checks like removal of floating scum and duckweed from the surface of pond and removal of screenings and grit would be essential for the operation of ponds at maximum efficiency (MDWS, 2012).

Arya and Yadav (2006) evaluated the benefits of a project on ‘rainwater management in a micro-watershed’ implemented in a village in Himachal Pradesh state, India. Authors concluded that diverting the runoff from agricultural fields to rejuvenated village pond had improved the availability of water for irrigation purposes thereby increasing the net agriculture income of the inhabitants by three times in six years of implementation of the project.

2.3 Integrated water resources management (IWRM) at local level

According to Global Water Partnership (2000), “IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems”. Land has profound effect on the water quality, therefore land management has been included by some organizations in the classification of IWRM (Davis, 2007). IWRM adopts a holistic approach and is strongly associated with sustainable development goals. Here, framework of IWRM is limited to water resources management .i.e. water quantity and quality and related work in the water management has been reported. IWRM adopts coordinated management of water demand and its supply which necessitates the integration under two different categories .i.e. natural system and human system (Global Water Partnership, 2000). Integration should be both within and between these categories. Human aspect of water usage and wastewater generation .i.e. integration between water and wastewater management has been discussed here for achieving the goals of water resources management.

Moriarty et al. (2004) presented that the application of IWRM is important in water supply and sanitation (WATSAN) sector. Where water is scarce or increasing competition among various water users (.i.e. WATSAN, agriculture, industry etc.) create a situation of conflict among water users, IWRM offers an integrated approach for managing the multiple uses of water without creating a situation of conflict. Moreover, IWRM can provide a framework to consider and manage the impacts of inadequate sanitation and wastewater management on other water users .i.e. agriculture, industry etc.

IWRM principles include all sources of water in planning while addressing the water quantity, quality and ecosystem needs. Incorporation of principles of equity, efficiency and public participation in water planning are important to achieve the objectives of IWRM (USACE, 2010).

Bouwer (2000) argued that the goal of any integrated water management should be the public health, sustainability and environmental protection. Municipal wastewater can be an important water resource for irrigation but its use must be regulated to prevent undesirable health effects and contamination of groundwater. Groundwater withdrawals in excess of groundwater recharge has resulted in the aquifer depletion and compromised its long-term sustainability as source of water. Foster and Ait-Kadi (2012) stated that to promote groundwater resource sustainability, application of IWRM to the groundwater resources is required. In the light of large scale abstractions and low recharge of aquifers, groundwater management plans have been developed. According to Garduno et al. (2006), groundwater management and protection should be addressed within the spatial framework of groundwater, instead of the conventional way of defining groundwater management in the framework of river basins.

Butterworth et al. (2010) presented a more realistic approach for the implementation of IWRM. This approach is focused on the local levels instead of basin or national level. Termed as 'light' approach for IWRM application, this concept takes into account the local realities and accepts that partial integration may sometimes fulfill the objectives of IWRM plan. Local water planning should be given due importance in the rural areas to make the villages self dependent in water needs. Continuous interaction between IWRM planners and local people should take place for the success of water management programs (National Water Mission, 2010). Ako et al. (2010) evaluated the implementation of IWRM in Cameroon and concluded that participation of local people, extending the scope of IWRM to include Integrated Natural Resource Management (INRM) and considering water as economic and a social good would enhance the functional performance of IWRM. Dungumaro and Madulu (2003) described that a successful water resources management is dependent on the expertise and knowledge of the local communities who are the key stakeholders in water conservation.

It is important to implement IWRM at local levels to find a solution to the water related problems which directly affect the communities. Practical implementation of the theoretically agreed upon procedures of IWRM is required to ensure sustainable water resources management at the local level (Biswas, 2008).

2.4 Wastewater and stormwater quantification and characterization

2.4.1 Wastewater quantification and characterization

Wastewater quantification and characterization forms the backbone of any exercise directed towards the management of wastewater. Quantities and characteristics of wastewater vary in rural and urban areas and depend on the amount of water usage and on the habits of the people. Wastewater can be distributed into two components .i.e. black water and grey water.

Reymond et al. (2014) estimated black water flow from the villages in Egypt where villages have on-site sanitation system as well as sewer network to collect and convey the wastewater to some disposal point. The amount of black water was estimated based on the excreta volume ($a_{excreta}$), the quantity of water for cleaning ($q_{anal\ clean}$) and the amount of water for flushing (q_{flush})

$q_{bw} = a_{excreta} + q_{analclean} + q_{flush}$

The amount of grey water from the bathrooms was estimated to be around 30% of the total grey water flow (Henze, 1997; MetCalf & Eddy, 2003; Morel and Diener, 2006). Almeida et al. (1999) estimated individual household hydrographs and pollutographs, based on household appliance use surveys and found that in terms of volumes, water closets and kitchen sinks contributed most towards wastewater production.

Butler et al. (1995) developed the pollutographs for BOD, ortho-phosphate, ammonia and nitrate to determine the contribution of water closets (WC) and washing machines in domestic wastewater flows. The WC was a major contributor to all four pollutants and in particular to ammonia. The washing machine was found to be a significant contributor to ortho-phosphate and nitrates and the wash-basin to ortho-phosphate.

2.4.2 Stormwater quantification and characterization

Quantification of stormwater is required for sizing of the stormwater treatment schemes. Generation of runoff is dependent on rainfall characteristics such as intensity, duration and frequency of occurrence as well as on watershed characteristics such as soil type, watershed area and land cover type. Time of concentration also plays a significant role in estimation of runoff. Stormwater management requires the determination of following types of stormwater flows:

- Peak stormwater runoff flow rate
- Volume of stormwater runoff from a rainfall event
- Time varying flow (hydrograph method)

Various hydrologic analysis methods can be used for the quantification of stormwater runoff during a rainfall event. Each method demands data in the form of catchment and rainfall parameters Designers may use conceptual or empirical methods to determine the peak stormwater flow rates (Hydraulic Design Manual, 2011)

Rational, modified rational methods and hydrograph methods have been the most commonly used conceptual methods for peak runoff rate determination. Rational method is recommended for estimating peak flows for small and highly-impervious drainage areas (Iowa Stormwater Management Manual, 2009). Peak discharges in small drainage areas having no significant flood storage of up to 200 acres can be estimated using rational method. Use of rational and modified rational method requires the computation of time of concentration (t_c) which is the time required for the whole catchment area to contribute to runoff at the point of interest. Time of concentration determines the appropriate rainfall intensity for use in rational method equation (Hydraulic Design Manual, 2011). Two commonly used methods for computation of 't_c' are National Resource Conservation Service (NRCS) velocity method and Kerby-Kirpich method.

NRCS method is applicable for small catchments (Hydraulic Design Manual, 2011) where majority of flow is overland flow. This method assumes that overland time of concentration is the sum of travel times along flow segments of sheet flow, shallow concentrated flow, and open channel flow (NRCS, 2008). Kerby-Kirpich method computes the time of concentration by considering overland flow as well as channel flow and is applicable to the catchments ranging from 0.25 square miles to150 square miles (Hydraulic Design Manual, 2011).

Rational and modified rational method use runoff coefficient (C) for determining the amount of rainfall that will appear as runoff. The runoff coefficient represents the integrated effects of infiltration, evaporation, retention, flow routing, and interception; all of which affect the time distribution and peak rate of runoff (Iowa Stormwater Management Manual, 2009). More impervious surfaces tend to have more runoff coefficients. A summary of the values of runoff coefficients developed by different research works in India for different soil conditions are given in Table 2.1.

Chena et al. (2007) used rational method for estimating the maximum discharge of a landslide-induced debris flow. Peak debris velocity ranged from 2.4 to 4.7 m/s and the peak debris discharge was between 6.7 and 35.7 m^3/s. An increase in the peak flow at the upper portion was observed and then peak flow decreased gradually at the lower portion. This proved that the erosion occurred in upper channel while the lower channel experienced deposition. Rational method was also used by Akan (2002) for estimating the size of infiltration basins and trenches to control stormwater runoff. Runoff rate were computed by using rational method and runoff hydrograph method was assumed to be trapezoidal in shape.

Table 2.1: Values of Runoff Coefficient (C) for different soil conditions in India

Type of vegetation	Slope range (%)	Runoff coefficient (C)		
		Sandy loam	Loam/Loam clay soil	Stiff clay soil
Woodland and Forests	0-5	0.1	0.3	0.4
	5-10	0.25	0.35	0.5
	10-30	0.3	0.5	0.6
Grass land	0-5	0.1	0.3	0.4
	5-10	0.16	0.36	0.55
	10-30	0.22	0.42	0.6
Agricultural land	0-5	0.3	0.5	0.6
	5-10	0.4	0.6	0.7
	10-30	0.52	0.72	0.82

Source: CGWB (2007)

United States Soil Conservation Service Curve Number (US-SCS-CN) method, now known as NRCS method (NRCS, 2000) has widespread application in the determination of stormwater volumes. US-SCS-CN method can be used for stormwater volume determination in small catchments (Iowa Stormwater Management Manual, 2009). Surface imperviousness in this method is represented by curve number (CN). It ranges between 0 to 100, where 0 represents full retention and 100 represents zero retention (impervious surface). Curve number is influenced by hydrologic soil group (A, B, C and D) of the catchment, land use pattern, treatment and antecedent moisture condition (NRCS, 1986).

Mishra and Singh (2013) have advocated the use of CN method for Indian conditions on the basis of the similarity in the soil types observed for the Indian sub-continent. Prakasa Rao et al. (2011) used runoff curve number method to estimate the stormwater runoff from Krishna river basin in India. Flood estimation using NRCS method was estimated at 989.74 million cubic meters during rainfall of 11 days. Mishra and Singh (2004) introduced a more versatile model based on the modified SCS-CN method. The newly introduced model was applied to the Hemavati watershed in India and was observed to yield satisfactory results in both calibration and validation. The model satisfactorily estimated monthly and annual runoff volumes.

Pradhan et al. (2010) modified existing SCS-CN hydrological model by using Hybrid Classifier and soil map given by National Atlas and Thematic Mapping Organization (NATMO) as input to soil conservation system (SCS) model for rainfall runoff estimation in order to study land cover type. Original model that considers parameters like slope, catchment size, vegetation and drainage length was not used in this study. Millhollon et al. (2009) used NRCS runoff curve number method to determine the runoff from the catchment in its natural, forested state and in its current state of cultivated crop land and pasture.

Apart from these methods, many other models have also been used by researchers for quantification of stormwater runoff.

Lowe et al. (2003) used EPA's BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) software to create a HSPF watershed model in lower Westchester County, New York. Flow data of 20 years was used to successfully calibrate and verify the model. Land use, river reach and topographic data supplied with BASINS were compared to local data and some discrepancies were found with the reach data.

Ghnanapala (2006) assessed the possible impact of urbanization upon the magnitude of flood peaks using the Basic Model HEC-l in two urban catchments in Colombo, Sri Lanka. Land cover of the watersheds showed that in the urbanized areas the pervious extent was approximately 62% while in the less urbanized areas the previous extent was about 76%. Average curve numbers for the urbanized areas were found to be 95 and 70 for impervious and pervious areas, respectively.

Satisfactory peak discharge matching was produced by HEC rainfall-runoff model for both catchments and hence could be used for drainage environment improvement projects in urban areas.

Depending on the land use, human activities and materials used in the catchment area, stormwater pollutant loads vary significantly. Stormwater exhibits very different quality characteristics from domestic wastewater. Stormwater is recognized as the important source of inorganic materials, whereas domestic wastewater mainly comprises of organic loads and nutrients (Gasperi et al., 2010; Hvitved-Jacobsen et al., 2010). Generation of solids, nutrients, organic matter, and heavy metals from the catchment surface is mainly influenced by the anthropogenic and transportation activities (Huang et al., 2010; Mahbub et al., 2011; Gunawardana et al., 2012; Kayhanian et al., 2012; Chow et al., 2013).

In urban areas, a number of attempts have been undertaken to establish the relationship between land-use types and runoff pollution characteristics. Various catchment land use included residential, commercial, industrial, highway, bridge, street etc. (Sansalone et al., 2005; Kim et al., 2007; Kayhanian et al., 2007; Davis and Birch, 2010; Lee et al., 2011). Some studies have also highlighted the stormwater runoff from rural highways as a significant contributor to water quality degradation (Legret et al., 1999; Gan et al., 2008). Mallin et al. (2009) in their work concluded that impervious nature of rural human settlements results in the generation of considerable quantities of stormwater runoff during large rainfall events that can be laden with high quantities of pollutants.

There is paucity of the stormwater characterization literature in the rural areas, therefore review of literature was carried out from the studies done in small areas or urban areas. Huang et al. (2007) analyzed water quality parameters, such as, pH, turbidity, TSS, COD, TN, Zn, Pb, and Cu in the surface runoff from a 0.14 km^2 catchment in China. TN and COD were observed to be the major pollutants with mean concentrations of 8.5 mg/L and 201.4 mg/L, respectively. These concentrations were four times higher than the Class V surface water quality standards developed by SEPA, China. Brodie and Porter (2006) conducted their study in small catchments of 50 to 450 m^2 area comprising of both impervious and pervious areas. Event mean concentrations of non-coarse particles (size less than 500 μm) were determined by taking flow-weighted samples. Authors found that stormwater from impervious surfaces like bituminous roads contained highest non-coarse particle load for small to moderate rainfall events (< 20 mm). From pervious surfaces no runoff was generated for these storm events. Stormwater pollutants occurrence depend on the location and characteristics of the catchment area. There is a varying level of understanding among the researchers about the occurrence of these pollutants. However, for some parameters like total suspended solids, organic material, nutrients and heavy metals, considerable amount of data is available (Göbel et al., 2007; Kayhanian et al., 2003; Ingvertsen et al., 2011)

Concentration and loads of pollutants in the stormwater vary significantly with the characteristics of rainfall events and the duration between two rainfall events .i.e. antecedent dry period. Therefore, attempts have been made to develop the relationships between rainfall event parameters and stormwater runoff characteristics by using regression, stochastic and deterministic simulations (Irish et al., 1998; Kayhanian et al., 2007).

Regression analysis was used by many researchers to predict and characterize rainfall event characteristics and stormwater quality characteristics, and to show the relationship between these two variables (Han et al., 2006; Ha and Stenstrom, 2008; Maniquiz et al., 2010; Chow et al., 2013; Arora and Reddy, 2014). Hamilton and Luffman (2009) employed regression modeling for the prediction of the concentration of E.Coli by using precipitation, discharge, and turbidity as predictors and achieved relative success (R^2 = 0.565). Sufficient number of storms is an essential requirement in the development of a reliable regression model and to overcome the over-fitting problem (Madarang and Kang, 2014).

2.5 Wastewater and stormwater management in rural areas

2.5.1 Wastewater management

Wastewater management in rural areas has always been a low priority area in developing countries due to the associated low economic efficiency (Yoon, 2007). Studies have been done on the application of conventional as well as natural wastewater treatment systems in the rural settings. Liang et al. (2010) investigated the performance of a drop aeration bio-film process in the removal of TSS, COD, NH_4^+-N , TN, and TP from the rural wastewaters in China. The removal efficiencies of TSS, COD and NH_4^+-N were 90%, 80%, and 90%, respectively. However, removal rate of TP was not satisfactory. In rural areas, intensive treatment technologies can be combined with semi-intensive systems to get the desired treatment efficiencies. Sabbah et al. (2004) proposed that the effluent of UASB can be fed into constructed wetland system in a rural setting to sufficiently reduce the organic matter and suspended solids load from the wastewater originating from rural areas of Palestine. Elmitwalli et al. (2003) combined UASB with septic tank for decentralized wastewater treatment in rural areas of Egypt. They also proposed a separate accumulation system for cow dung. UASB-septic tank system was able to remove 65% COD from the incoming wastewater and produced 14 litres methane per person per day. The treated wastewater found to be low in total suspended solids and fit to be used for irrigation purpose.

Application of natural treatment systems employing natural processes are always preferred for predominantly rural areas because of two major reasons .i.e. availability of land and scarcity of resources like electricity and trained manpower. Constructed wetlands and waste stabilisation ponds have been widely used and improvised for wastewater treatment in rural as well as semi-urban areas (Giraldo and Garzón, 2002; Al-Saed et al., 2010; Gude et al., 2013; Klemenčič and Bulc, 2015; Almasi et al., 2015).

Constructed wetlands are considered as complex systems in which pollutants are separated and transformed by a multitude of mechanisms like physical, chemical and biological. External factors and characteristics of the wetlands normally dictate the principal mechanisms and their order of reaction. The external factors of the concern are quantity and quality of wastewater and system hydrological cycle (EPA, 2000). Dong et al. (2012) carried out the evaluation of wastewater treatment systems in rural areas in eastern China and concluded that for sparsely populated villages having sufficient lands, constructed wetlands were more reliable and suitable than activated sludge and stabilization ponds. Constructed wetlands are considered to be a better option for wastewater treatment in the small residential areas where sewers have not yet been provided (Verhoeven and Meuleman, 1999)

Wurochekke et al. (2014) measured the effectiveness of the constructed wetland system for grey water treatment provided at a village in Malaysia. It was found that wetland system removed 82% BOD_5^{20}, 85% COD, 55% TSS and 45% Turbidity from the influent grey water. Construed wetlands can be categorized on the basis of the flow type, vegetation type and hydrology and for attaining improved treatment efficiency can be combined into hybrid wetlands (Vymazal, 2010). Wang et al. (2012) conducted a comparison analysis of subsurface constructed wetlands and surface flow wetlands. It was observed that subsurface flow wetlands efficiently removed organic loads and in COD removal, horizontal flow wetlands were more efficient than vertical flow wetlands. Free water surface (FWS) wetlands can efficiently remove organic loads through microbial degradation, suspended solids by filtration through vegetation and nitrogen through nitrification followed by de-nitrification (Kadlec and Wallace, 2008). Table 2.2 gives the basic sizing criteria of free water surface wetland for BOD_5^{20}, TSS and TKN removal.

Table 2.2: Sizing criteria of FWS wetland

Parameter	Effluent quality	Loading rate
BOD_5	30 mg/L	6 g/m^2.d
	25 mg/L	3 g/m^2.d
	20 mg/L	4.5 g/m^2.d
TSS	30 mg/L	7 g/m^2.d
	30 mg/L	5 g/m^2.d
	25 mg/L	3.5 g/m^2.d
	20 mg/L	3 g/m^2.d
TKN	10 mg/L	1.5 g/m^2.d

Source: (Wallace and Knight, 2006) and EPA, (2000)

Due to the removal of organic material in anoxic/anaerobic conditions in horizontal flow subsurface wetlands (Vymazal and Kröpfelová, 2008), these wetlands have found application in the treatment of high strength industrial wastewaters (Mantovi et al., 2003; Revitt et al., 2004; Drizo et al., 2006; Calheiros et al., 2007; Serrano et al., 2011; Yadav et al., 2012).

In stormwater runoff treatment, constructed wetlands are considered as one of the Best Management Practices (BMPs). Alongwith the pollutant removal, mitigation of peak rates and reduction of runoff volume also takes place in constructed wetlands. Surface flow wetlands are commonly employed for the treatment of stormwater runoff but subsurface wetlands may also be used (Pennsylvania Stormwater Best Management Practices Manual, 2006). Subsurface wetlands result in more efficiency in removal of suspended solids load and organic content of stormwaters. But, subsurface wetlands are associated with low treatment capacities, hence, limiting their use for low stormwater flows. On the basis of nutrients reduction, two levels of constructed wetland design are given. In level 1 design, TP and TN event mean concentration is to be reduced by 50 and 25%, respectively, whereas in level 2 design the targeted removal of these two nutrients is 75 and 55%, respectively (Virginia DEQ Stormwater Design Specification, 2011). Table 2.3 gives the stormwater wetland design criteria for maximizing nutrient reduction. Choi et al. (2015) studied the urban stormwater runoff treatment in a hybrid constructed wetland comprising of a settling tank, FWS wetland, and horizontal sub surface flow wetland. It was found that hybrid wetland was able to reduce the concentrations of TSS, COD, TN, TP, Zn, and Fe by almost 68-95%.

Table 2.3: Constructed wetland design criteria on the basis of nutrient reduction

Level 1 Design	**Level 2 Design**
Mean wetland depth is more than 1 foot	Mean wetland depth is less than 1 foot
The surface area of the wetland is less than 3% of the contributing drainage area (CDA).	The surface area of the wetland is more than 3% of the CDA.
Length/Width ratio or Flow path = 2:1 or more	Length/Width ratio or Flow path = 3:1 or more
Length of shortest flow path/overall length = 0.5 or more 3	Length of shortest flow path/overall length = 0.8 or more 4
Emergent wetland design	Mixed wetland design
Single cell (with a forebay)	Multiple cells or a multi-cell pond/wetland combination

Source: Virginia DEQ Stormwater Design Specification, (2011)

Removal efficiency of the wetlands is dependent on the plant species. (Yu et al., 2012) measured nutrients removal efficiency of seven plant species in constructed wetland systems in China. Plant’s biomass production and nutrient content in wastewater was taken as criteria to measure nutrient removal efficiency. It was observed that at different HRTs, except Iris pseudacorus all other six species produced more biomass above ground. Phewnil et al. (2014) conducted a study to select the most appropriate plant species from three selected plants .i.e. Typha angustifolia, Cyperus corymbosus, and Canna indica for a vertical flow wetland in Thailand. On the basis of the wastewater treatment efficiency achieved by growing the selected plant species in the constructed wetlands, Typha was observed to achieve highest efficiency and thus the most preferred species for wastewater treatment.

Since long, waste stabilization ponds (WSP) have been used as wastewater treatment option for the municipal wastewaters. Due to the low initial cost and maintenance, high efficiency and high sustainability of WSPs, these are considered to be the most appropriate for developing countries (Waste Stabilization Ponds, 2004). Usually, anaerobic ponds and facultative ponds are employed for organic matter removal whereas maturation ponds are used for pathogen removal. Maturation ponds are needed when treated wastewater is to meet the criteria for unrestricted irrigation of crops. Study conducted in Iran (Naddafi et al., 2005) revealed that growth in crops irrigated by treated WSP effluent were 60% more than the crops irrigated by water. Nutrients present in the treated effluent were equal to the application of 25 tonne manure on land. (Mara and Pearson, 1998) concluded that it was possible to achieve up to 60% BOD_5^{20} removal at 20°C and 70% BOD_5^{20} removal at 25°C in anaerobic stabilization ponds. Anaerobic degradation of the settled solids was found to be at peak with minimum sludge accumulation.

Kotsovinos et al. (2004) studied the waste stabilization pond systems in Greece and concluded that if designed and maintained properly, WSPs could be a feasible solution for the small and rural communities. Even in the case of no maintenance, these systems were found to be operating moderately. Studies have been conducted on the hybrid systems using WSP with some low cost treatment option like sand filter, rock filter or wastewater storage for removal of algal cells and pathogens from WSP effluent. (Mara and Pearson, 1999) proposed a hybrid system of waste stabilization pond and wastewater storage and treatment reservoir (WSTR). The wastewater after treatment in an anaerobic pond and facultative pond system would collect in WSTR during non-irrigation period. The water from WSTR was found to be microbiologically and used for un-restricted irrigation. Al-Saed et al. (2010) conducted the study on a hybrid system of algae pond and rock filter and compared its wastewater treatment efficiency with algae ponds. Results revealed that hybrid system was more efficient in the removal of TSS, COD and fecal coliforms (84%, 84% and 4 log) than the conventional algae based pond (81%, 81% and 3 log). Ammonium and phosphorus removal rates in hybrid system were 68.8 and 50.0%, respectively, whereas, algae pond resulted in 57.9 and 41.5% ammonium and phosphorus removal, respectively. Al-Hashimi and Hussain (2013) used a hybrid system consisting of a facultative pond, aerobic pond and a sand filter for the wastewater treatment in a rural area of Iraq. The addition of sand filter resulted in the increased removal of TSS, BOD_5^{20} and COD from the aerobic pond effluent.

Mburu et al. (2013) compared a WSP and a pilot scale horizontal subsurface flow constructed wetland (HSSF-CW) on the basis of performance, land requirement and initial and operating costs in Kenya. WSP showed better removal efficiencies for TP and ammonium, while the removal of organic matter and suspended solids was found to be similar in both the systems. WSP however required three times more area than HSSF-CW to treat the equivalent amounts of wastewater. De Oliveira et al. (2011) studied the effect of baffling on the treatment efficiency of four 2.3 m deep primary facultative ponds in Brazil. They concluded that longitudinal baffling of the ponds did not increase the efficiency of the process significantly but increased the cost of the system. However, TSS and chlorophyll-a exhibited lower concentrations for all combination of baffles.

Effluent from waste stabilization ponds needs polishing for the removal of algal cells and to improve the microbiological quality for irrigation use. Khazaei et al. (2015) performed the treatment of aerated lagoon effluent in a horizontal roughing filter (HRF). Filter was run at three filtration rates .i.e. 0.5, 1 and 1.5 m/h. Removal efficiencies of TKN, TP, COD, and TSS at the lowest filtration rate were observed as 50, 54, 63, and 68%, respectively. Removal efficiencies decreased with increase in the filtration rates. Researchers reported that HRF was able to retain nitrogen, phosphorous, and COD at the rate of 24.3, 10.1, and 435.4 $g/m^3/d$, respectively. Hamdan and Mara (2014) conducted a study using blast furnace slag as filter material in aerated rock filter for the removal of nutrients from the effluent of primary facultative pond effluent in Bradford, UK. Results indicated that the aerated rock filter system was able to lower down the ammonium-N and phosphorus concentrations below the permissible limits. Vertical flow filter removed the ammonium-N in higher proportion than horizontal flow filter (<1 mg/L). Comparison between the performance of horizontal and vertical roughing filter (VRF) has been attempted by some researchers. According to Nkwonta (2010), HRF due its simple layout and unlimited length gives much better performance than VRF in TSS removal during the pre-treatment of wastewater. Mahvi and NuriJ (2001) conducted their study on highly turbid raw water in Iran and found that HRF was more efficient than VRF in removing parasite eggs and turbidity.

Design of roughing filters requires the information on turbidity levels, suspended solids concentration and fecal coliform load in the incoming wastewater. Information on peak concentration period and solid settling characteristics should also be taken into account

(Wegelin, 1996). Lee and Jayalath (1998) performed pilot scale, as well as field scale studies on the two horizontal roughing filters for pre-treatment of raw water. Results indicated that at pilot scale, significant reduction in algae (80-87%) had taken place alongwith the removal of turbidity and colour (50-60%). From field experiments, it was concluded that length of the filter did not considerably affect the removal efficiencies of algae, colour and turbidity.

Often wastewater requires a low pathogen levels and high organic matter removal if these are meant to be used for irrigation purpose or groundwater recharge. In rural areas or semi-urban areas, sand filters have found extensive usage for this purpose. Depth of the sand filter, type of sand and distribution of sand, quality of influent water, desired effluent quality, filtration rate and dosing system are the factors which govern the treatment efficiency of the filters (Anderson et al., 1985; AWWA, 2002; Torrens et al., 2009). In slow sand filtration, the rate of filtration normally ranges between 0.1-0.4 $m^3/m^2/h$, whereas in the rapid sand filters filtration rate can be on the higher side between 5-15 $m^3/m^2/h$ (Huisman et al., 1974). Hamoda et al. (2004) evaluated the performance of three activated sludge based wastewater treatment plants in Kuwait. The effluent quality was highly variable due to nitrification and de-nitrification during different seasons. However, after tertiary filtration in the form of sand filtration, the effluent quality improved significantly as shown by elevated removals of VSS, BOD_5^{20} and COD. Apart from increased effluent quality, tertiary sand filtration also resulted in the stability of the effluent quality.

Assayed et al. (2014) presented a new concept of sand filtration and designed a lab-scale drawer compacted sand filter for the treatment of grey water. The sand filter was operated for 330 days by varying the hydraulic loading rate from 72 to 142 $L/m^2.d$ and organic loading rate from 23 to 30 g $BOD_5^{20}/m^2.d$. Experimental outcomes demonstrated that organic matter and TSS removal rate was more than 90% at all loading rates. Vijayaraghavan et al. (2014) performed their study on the removal of suspended and dissolved pollutants from eutrophic ponds. Filters were loaded with activated carbon, sargassum and zeolite to monitor the removal efficiencies. It was found that algal biomass removal and a decrease in pH was measured in all the studied filters during the operation. Sargussam loaded filter exceeded the removal efficiency of heavy metals among all the filters. Ama et al. (2015) conducted the treatability studies of domestic wastewater on a sand filter having three compartments and made up of polyvinyl chloride. Each compartment was further divided into two columns, a filter and a settling column. Filter columns were filled with granite. Authors concluded that medium grain size was inversely related with the treatment efficiency. On increasing the hydraulic load from 1.5 L/m^2.h to 15 L/m^2.h decreased the TSS and COD removal from 83% to 77% and 89.5% to 49%, respectively.

Nassar and Hajjaj (2013) determined the relationship between the depth of the sand filter with the removal rate of suspended solids and fecal coliform from the stormwater in Gaza, Palestine. They concluded that around 80% removal of fecal coliforms occurred at 150 cm depth of the filter and suspended solids concentration was found to be less than 20 mg/L at 75 cm depth.

2.5.2 Stormwater management

Developmental activities like construction of residential areas, roads etc. result in the increased imperviousness of rural settlements and modification of natural drainage systems. Increase in surface imperviousness translates into increased volumes of stormwater runoff during rainfall events and modifications in the land use practices can result in the drainage problems in rural areas (Protection, 1999). Development in agricultural practices also leads to change in land use and management practices in rural areas thus contributing to the increased flooding in small sized rural catchments (O'Connell et al., 2005). Rate of rural stormwater runoff within the catchment influence the flood risk (Parrott et al., 2009) and land use solutions like wetlands have the potential to mitigate the flood risk in rural areas (Defra, 2005)

Hooda et al. (2000) illustrated that increased runoff in rural areas combined with the agricultural chemicals, pesticides and microbiological pollution increases the risk of surface and groundwater quality degradation. McIntyre and Marshall (2010) modeled the spatial variations of runoff in a rural area in UK and concluded that runoff rates were higher in improved grasslands rather than in natural grasslands. Presence of lakes had strong influence on the spatial runoff variation whereas catchment area was weakly affecting the spatial runoff variability.

Nicholson et al. (2012) stated that by devoting 2-10 percent of land to runoff mitigation features, the risk of flooding can be reduced drastically. By placing the mitigation structures in the corners of fields to capture runoff and sediment, providing temporary storage of flood water and by increasing the flow pathway, stormwater runoff can be regulated.

Very few attempts have been made in the treatment of rural stormwater, however, significant amount of research have been conducted for urban and highway stormwater treatment. Treatment systems employed for urban stormwater runoff were studied to develop a suitable system for rural areas taking into account the characteristics of stormwater runoff generated from rural settlements. Davis et al. (2001) proposed a bio-retention facility including porous soil, hardwood mulch, and different plant species for stormwater of a small developed area. High reduction in the concentrations of metals were observed (>90%), whereas, reductions in TKN, ammonium, and phosphorus levels were found to be moderate (60 to 80%). Authors highlighted the significance of the mulch layer in the removal of metals. Birch et al. (2005) assessed contaminant removal efficiency of a Stormwater Infiltration Basin (SIB), installed in eastern Sydney (Australia). The removal of total suspended solids (TSS), nutrients, trace metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn), organochlorine pesticides and fecal coliforms (FC) was assessed from stormwater. Weighted average concentration of TSS in the stormwater was reduced by an average of 50%, and WAC of Cu, Pb and Zn were reduced by an average of 68%, 93% and 52%, respectively.

2.6 Groundwater recharge systems

In most of the arid and semi-arid areas, people are completely dependent upon groundwater resources for domestic and agricultural purposes. Due to unplanned groundwater abstraction and over pumping of wells with no or little replenishment of aquifers with rainwater, the groundwater table had started declining (Ghaly, 2001). Moreover, flooding of stormwater and public health hazards associated with it are the major issues in developing countries, especially the regions which are suffering from water scarcity (Chocat et al., 2007).

Thus, artificial recharging techniques come into existence and the augmentation of ground water resources by treated stormwater is one of the most effective techniques to recharge groundwater. Artificial recharge to groundwater is the planned, human activity of augmenting the ground water reservoir by modifying the natural movement of surface water utilizing suitable civil construction techniques, resulting in a corresponding increase in the amount of groundwater available for abstraction. The basic idea of artificial recharge is to restore groundwater resources but it has been used for many other purposes as conservation and storage of excess surface runoff, groundwater quality improvement by dilution, control of salt water intrusion and storage of water to reduce pumping and piping costs (Asano, 1985).

Artificial ground water recharge by treated wastewater although seems to be a promising solution but it could be associated with technical challenges along with health and environment risks. Etteieb et al. (2014) conducted a study to assess the environmental risk of groundwater quality and treated waste water reuse for Korba, Tunisia. Study revealed higher concentration of electrical conductivity, chloride concentration and sodium adsorption ratio (SAR) in groundwater as well as in treated wastewater. The heavy metal concentrations were under permissible limits but groundwater was contaminated by pesticides. Takashi et al. (2004) considered health and regulatory considerations of groundwater recharge with reclaimed municipal wastewater. It was proposed in California regulations that disinfection of non-potable reuse of water is to be done where a high degree of public exposure is expected. These studies could act as a caution ascertaining us that for safe reuse of aquifer recharge, the environmental risk monitoring of treated waste water is essential.

Artificial ground water recharge is one of the optimum solutions to manage stormwater and to achieve this different methods have been developed and adopted in various parts of the world (Todd and Mays, 2005; Huisman and Olsthoorn, 1983; Asano, 1985). Direct method, indirect method and combination of both methods can be carried out for artificial recharging (CGWB, 2007).

1. In direct surface technique method (surface spreading basins), water from surface sources is made to percolate and recharge ground water, whereas in direct sub-surface technique method, water store in-situ above the aquifer areas is made to percolate and recharge ground water.
2. In indirect methods (dug wells and borehole wells), surface water is injected to groundwater by locating abstraction wells near influent streams which is induced as a result of human activity.

3. In combined methods (percolation tanks with pit shaft), water from deeper aquifers where shallow or superficial formations are highly impermeable or clayey is transferred with certain modification.

The advantage of the direct-surface techniques lies in the ability to replenish underground water supplies in the locality of metropolitan and agricultural areas, where the groundwater condition is severe; and there is an added benefit from the filtering effect of soils and the transmission of water through the aquifer (Bouwer, 1978; Asano, 1985). Manual on artificial recharge of groundwater (CGWB, 2007) comprises various aspects of artificial groundwater recharge including planning of artificial recharge projects, artificial recharge techniques and their structural design, monitoring of augmented water levels and water quality, economic evaluation of recharge projects and issues related to operation and maintenance of artificial recharge structures.

The Central Ground Water Board had identified number of techniques which can be worked out for augmenting the groundwater aquifer. But the selection of technique and its structural design should be carefully considered to ensure that the size of recharge facility should be sufficient to meet abstraction demands as well as contain adequate amount of storm water runoff (Muralidharan and Athavale, 1998). It was examined that artificial recharging also helped in reducing the salinity in groundwater **(**Patel et al., 2011). Infiltration of rain water is best technique for areas with low rainfall and high rate of drought, that can be accomplished by developing an integrated series of techniques which may include inhibiting the gullies of minor streams, constructing percolation tanks, placing farm ponds in the foot hills, contour binding and trenches on slopes and installing check dams on the main stream wherever possible (Kumar et al. 2007). Surface dike is suitable structure for country like India as it is safe from floods, do not require broad areas of land for implementation, least susceptible to silting, needs no overflow devices and hence, have minimal ecological ramification following their construction. In addition to this, evaporation losses are also minimum as the entire structure is underground (Muralitharan and Athavale, 1998).

Vadose zone wells or dry wells are normally bored into permeable formations in the vadose zone that can allow the runoff water at sufficient rates. Dry wells are much cheaper than recharge wells, where groundwater is deep (100–300 m or more), and hence it is beneficial to use dry wells for groundwater recharge instead of aquifer wells (Bouwer, 2002). Floodwater spreading system is also an effective low cost recharge technique in dry areas as well as areas with moderate rainfalls (Hashemi et al., 2015).

2.7 Gaps in previous studies

Fragmented approach has been followed for tackling the water supply and sanitation problems in India, especially in rural areas. Water supply and sanitation have been dealt with separately, quite often by altogether different agencies. This approach has resulted in the neglect of the originally all important village ponds to the extent that they have either become extinct or if present they serve no water resource management purpose.

Some attempts have been made for the restoration of the village ponds but efforts have not been directed towards the integration of village pond with the water supply and sanitation requirements in rural areas. Implementation of technology intensive options has lead to the failure of most of such pond rehabilitation initiatives.

To find a solution for the water supply and sanitation problems in villages, it is imperative to adopt the IWRM approach that will integrate water supply and sanitation sector in the rural areas. Review of literature revealed that principles of IWRM have mostly been applied to the larger catchments such as river basins and urban watersheds. Very few applications of IWRM have been reported in the predominantly rural settings.

Application of IWRM requires quantification, characterization, treatment and safe disposal of wastewater and stormwater being generated from rural areas. Although, some work has been reported on wastewater quantification and characterization from rural areas, but stormwater characterization and quantification has been an altogether neglected area.

Wastewater treatment has been undertaken in some rural areas in Punjab, but sustainability of such treatment systems is always in question. Stormwater treatment has never been included in the scope of rural wastewater treatment and disposal through groundwater recharge.

Keeping in view the above mentioned issues, development of an integrated water resource management system for rural human settlements with emphasis on village ponds has been attempted under research for this Ph.D work.

Chapter-3
Methodology

Objectives of the study have been achieved through working on the following work elements:

1. Survey of the rural human settlements (villages) and demarcation of the pond catchments
2. Analysis of village ponds and characterization of their catchments.
3. Quantification and characterization of wastewater of the villages.
4. Quantification and characterization of stormwater of the villages.
5. Development of village level integrated water resources management (IWRM) system.
6. Conceptualization of a village pond system.
7. Design of the village pond system.

3.1 Survey of the rural human settlements (villages) and demarcation of the pond catchments

This study was aimed at developing integrated water resources management system for rural human settlements wherein the village ponds play a pivotal role. Demarcation of the area contributing water (wastewater and stormwater) to the pond and thus serving as the catchment of the pond was performed with the help of a GPS system (Garmin- eTrex vista). Starting from the inlet point of the pond, drainage system of the pond was traced and catchment boundaries were worked out. The demarcated area was then superimposed on the Google earth images of the selected villages to obtain the catchment basin map of the village ponds.

Detailed physical survey of the demarcated catchments was then carried out with the help of a survey schedule (given in appendix–A), to collect the information about the catchment population, cattle population, land use patterns, existing water demand and supply systems, sanitation facilities, wastewater generation patterns, and wastewater treatment and disposal systems. A secondary data source, detailed survey maps of the concerned rural settlements procured from the Department of Water Supply and Sanitation, Government of Punjab, was also used. These maps provided information on elevation, drainage patterns, and land use patterns. The physical survey also served the purpose of ground verification of the elevation and drainage details obtained from the survey maps.

3.2 Analysis of village ponds and characterization of their catchments

As a part of the physical survey, pond specific information, like, depth, overflow patterns, sources of water and pollution, pond water use patterns, historical and present status of the pond, etc. was collected. Local people were interviewed for the historical information, such as, overflow patterns of the ponds, development pressures and encroachments of the ponds.

Characterization of pond catchments was facilitated mainly by physical survey. Secondary data sources, such as, survey maps and aerial photographs (available from the Google Earth package) were also used for the catchment characterization. The catchment characterization included, obtaining information on, land cover-land use (LCLU), soil type, impervious surfaces, drainage system, hydraulic path length, channel slope, etc.

3.3 Quantification and characterization of wastewater of the villages

V-notches installed in the village pond inlets were used for the quantification of the wastewater discharged by the pond catchments. Hourly flow measurements were made on dry days (days of no rainfall events) over 24 hour period for 7 days during April to June, 2013 for all the 10 demarcated catchments. The following equation (Hendricks, 2010) was used for calculating the flow rates from the measured flow depths over the V-notch:

$$Q = \left(\frac{8}{15} \times C_d \times (2g)^{1/2} \times \tan\left(\theta/2\right) \times H^{5/2} \right) \times 3600 \qquad (3.1)$$

Where,

Q is hourly wastewater flow rate (m^3/hr)

C_d is weir coefficient (C_d=0.58 determined from onsite flow rate measurement)

θ is V-notch angle (degrees)

H is height of water level above weir crest (m)

Figure 3.1: V-notch installed at Masitan village

From the measured flows, peak factors were determined for each of the 10 catchments by the following equation:

$$PF = \frac{Q_P}{Q_{ave}} \qquad (3.2)$$

Where,

PF is peak factor

Q_P is peak hourly wastewater flow rate (m^3/hr)

Q_{ave} is average hourly wastewater flow rate (m^3/hr)

Because of the existence of independent dwelling level water supply systems, parallel to the piped water supply, no attempt was made to assess the wastewater generation from the water supply data through using return factor.

For the wastewater characterization, hourly wastewater samples were collected at the inlet of the village ponds and composited over 24 hours period. The sampling was done for six days for each of the 10 catchments between January - October, 2012. The collected composite wastewater samples were analyzed for the parameters given in table-3.1. Catchment characteristics and review of literature have been the basis for the selection of the parameters. The sampling and analysis techniques employed in the wastewater characterization are indicated in table 3.1.

Table 3.1: Analytical techniques for testing of wastewater and stormwater parameters

Parameter	Method	References
BOD_5^{20}	Respirometric Method	APHA (2012): (5210: D)
COD	Closed reflux colorimetric method	APHA (2012): (5220: D)
TSS	Drying at 103-105°C	APHA (2012): (2540: D)
TDS	Drying at 180°C	APHA (2012): (2540: C)
Ammonical nitrogen	Preliminary distillation step, titrimetric method	APHA (2012): (4500-NH3: B, E)
Organic nitrogen	Macro Kjeldahl method	APHA (2012): (4550- org: B)
Nitrates	Ultraviolet spectrophotometric method	APHA (2012): (4500- NO_3: B)
Total phosphorous	Stannous chloride method	APHA (2012): (4500-P: B, D)
Coliforms	Membrane Filtration	Hach method no. 10029 (USEPA approved)
Heavy Metals	Inductively Coupled Plasma method	APHA (2012): (3120: B)

3.4 Quantification and characterization of stormwater runoff of the villages

3.4.1 Quantification of stormwater runoff

Runoff volumes from any rainfall event and peak runoff for a rainfall event with 2 years return period were estimated for each of the pond catchments. United States Soil Conservation Service Runoff Curve Number (US-SCS-CN) method (NRCS, 2000) was used for the runoff volumes assessment, and rational method (Hydraulic Design Manual, 2011) was employed for the peak runoff assessments. Daily rainfall data for fifteen years (from January, 1998 to December, 2013), for the five close by rain gauge stations (Kapurthala, Nawanshahar, Nakodar, Jalandhar and Phagwara stations), was obtained from India Meteorological Department (IMD) and used in the study. Further, pond catchments characteristics obtained from the study under the work element-2 were used in the assessments.

3.4.1.1 Runoff volume assessment by US-SCS-CN method

Each of the village pond catchments was divided into a finite number of sub-areas on the basis of the land cover and land use (LCLU), and Curve Numbers (CN) for each of the sub-areas were obtained through using Table 2-2a to Table 2-2d, given in TR-55 manual (NRCS, 1986). Each of the sub-areas was assigned with a hydrological classification code, and CN was determined for AMC-II condition (Antecedent Moisture Condition –II applicable to normal soil). Weighted CN, for each of the village pond catchments, was then estimated by the following equation (Subramanya, 2012):

$$\text{Weighted CN} = \frac{\sum_{i=1}^{n} A_i \times CN_i}{\text{Total Area}} \tag{3.3}$$

Where,

n is number of sub-areas

A_i is area of the i^{th} sub-area of the catchment

CN_i is curve number of the i^{th} sub-area of the catchment

With the help of the following formula, from the weighted CN, potential maximum retention of rainfall (S) was obtained for the pond catchments:

$$S = \frac{25400}{CN} - 254 \tag{3.4}$$

From the potential maximum retention (S), initial abstraction (I_a) was estimated by the following equation (Subramanya, 2012):

$$I_a = \lambda \times S \tag{3.5}$$

Where,

λ is some fraction of S assumed as initial abstraction (taken as 0.2 for small size catchments)

Rainfall events that yield no runoff were identified for each of the ten catchments by the following equation:

$$P_{min} = I_a = 0.2 \times S \tag{3.6}$$

Where,

P_{min} is rainfall event that yield no runoff

From the rainfall data, all the rainfall events smaller than the P_{min} were neglected (or eliminated), and then different percentile rainfall events were worked out for each of the pond catchments.

Runoff depth or effective rainfall was estimated for different size rainfall events by using the following equation (NRCS 2000):

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \tag{3.7}$$

Where,

Q is runoff depth / effective rainfall (mm)

P is 24 hour rainfall depth (mm)

I_a is initial abstraction

S is potential maximum retention of rainfall (mm)

Equation 3.7 is valid for the condition '$P>I_a$'.

Runoff volume from a rainfall event (> P_{min}) was then determined by the following equation:

$$V = Q \times A \tag{3.8}$$

Where,

V is the runoff volume (m^3)

Q is the daily runoff depth (m)

A is area of the pond catchment (m^2)

In the current study, runoff volumes corresponding to 10, 35, 50, 65, and 90 percentile rainfall events were determined for all the pond catchments.

3.4.1.2 Peak runoff assessment by Rational method

Peak runoff for 2 years return period was estimated using the following Rational method formula:

$$Q_T = \frac{C \times I_T \times A}{360} \tag{3.9}$$

Where,

Q_T is the peak stormwater runoff rate (m^3/s) for some return period of T years

C is the runoff coefficient for the contributing catchment area

I_T is the average rainfall intensity (mm/hr) for some return period of T years

A is the contributing catchment area (hectares)

Rainfall Intensity for each of the village catchments was obtained from the Intensity-Duration-Frequency (IDF) curves developed for the region. Time of concentration for each of the catchments was estimated and used in the IDF curves for reading the rainfall intensity.

3.4.1.2.1 Development of IDF curves

Gumbel's method (Chow et al., 1988) was employed for developing the IDF curves. From the daily rainfall data extreme daily rainfall events for each of the 15 years (1998 to 2013) were identified. From these rainfall events, using the following India Meteorological Department (IMD) empirical reduction formula (Chowdhury et al., 2007), data on short duration rainfalls (10 min, 15 min, 30 min, 1hr, and 2hr duration rainfalls) was generated:

$$P_t = P_{24} \times (t/24)^{1/3} \quad (3.10)$$

Where,

P_t is rainfall of 't' hours duration (mm)

P_{24} is daily rainfall (mm)

t is a shorter duration (hr)

Averages of the short duration rainfalls (P_t) were then estimated and used in the following equation for the determination of rainfall depth (mm) for different return periods (Wilson, 1990):

$$P_T = P_{ave} + K_T \times S \quad (3.11)$$

Where,

P_T is rainfall depth (mm) for a return period of T (years)

P_{ave} is average of annual extreme short rainfall data (mm)

S is standard deviation of annual extreme rainfall data (mm)

K_T is the Gumbel's frequency factor

The Gumbel's frequency factor (K_T) was computed by the following equation:

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\} \quad (3.12)$$

Where, T is return period (years)

Average rainfall intensities (I_T) for different short duration rainfalls and for different return periods were then obtained by the following equation:

$$I_T = \frac{P_T}{t} \quad (3.13)$$

IDF curves were then developed by plotting rainfall intensity (mm/hr) against rainfall duration (minutes). The IDF curve relationship between rainfall intensity (I_T), rainfall duration (t) and return period (T) was then generalized in the form of the following power-law relation (Koutsoyiannis et al., 1998; AlHassoun, 2011):

$$I_T = \frac{CT^m}{t^n} \quad (3.14)$$

In the equation 3.14, constants C, m, and n are empirical parameters, and their values depend on the location, shape, and scale of the catchment area (Madsen et al., 2002; Aronica and Freni, 2005).

3.4.1.2.2 Time of concentration

Time of concentration (t_c) is the time required for a drop of water falling on the most remote point of a catchment to reach the outlet or point of collection. The time of concentration values for the pond catchments in question were obtained by the following equation:

$$t_c = t_{sh} + t_{ch} \quad (3.15)$$

Where,

t_c is time of concentration (minutes)

t_{sh} is sheet flow time (overland flow) (minutes)

t_{ch} is channel flow time (minutes)

Sheet flow time (t_{sh}) was determined by the following equation of National Resources Conservation Service (NRCS) method (NRCS, 2000):

$$t_{sh} = \left[\frac{0.007 \times (n \times L_{sh})^{0.8}}{(P_2)^{0.5} \times S_{sh}^{0.4}} \right] \times 60 \qquad (3.16)$$

Where,

t_{sh} is sheet flow time (min)

n is overland flow roughness coefficient

L_{sh} is sheet flow length (meters)

P_2 is 2-year, 24 hour rainfall depth (mm)

S_{sh} is sheet flow slope

Similarly, the channel flow time (t_{ch}) was obtained by the following equation:

$$t_{ch} = \frac{L}{60 \times V} \qquad (3.17)$$

Where,

t_{ch} is channel flow time (min)

L is channel flow length (meters)

V is velocity of flow (m/s)

3.4.1.2.3 Runoff coefficient

Runoff coefficient (C) for 2 years return period was computed by the following equation:

$$\text{Composite C} = \frac{Q}{P_2} \qquad (3.18)$$

Where,

Q is runoff depth (mm) corresponding to P_2 (estimated by using equation 3.7)

P_2 is 2-year, 24-h rainfall depth (mm)

3.4.2 Characterization of stormwater runoff

The same drainage system is used for the drainage of both the storm water and the wastewater. And, hence, no stormwater could be directly sampled and analysed for the characterization purposes. Combined flows of stormwater and wastewater were thus sampled and analysed and wet weather flows were in fact characterized.

Since the rainfall events are random and their sizes are highly variable, and since the stormwater characteristics heavily depend on the antecedent dry days (dry spell between two successive rainfall events), characterization of the wet weather flows have proved not to be a straight forward job of sampling and analysis.

Characterization of the wet weather flows of rainfall events thus involved the following steps:

1. Sampling and analysis of wet weather flows for the characterization of wet weather flows of a few independent rainfall events.
2. Regression modelling of the characteristics of wet weather flows against the rainfall event size and the antecedent dry days.
3. Predicting the characteristics of wet weather flow resulting from a rainfall event of any size with any number of antecedent dry days with the help of the regression models.

3.4.2.1 Sampling and analysis of wet weather flows

For the characterization of the wet weather flows, village pond inlets were sampled during twelve rainfall events between April, 2011 and September, 2014 in case of 5 villages, namely, Palli Jhiki, Kultham, Pippa Rangi, Nijjran and Masitan. In case of the other 5 villages (Tayabpur, Sodhian, Majari, Mandiala and Samrai), 15 rainfalls events were sampled and analyzed. The samples were collected at regular intervals (from the inlets of the ponds) from the start of the rainfall event and till it subsided. Specifically, one sample was collected every 5 min within 30 min after the runoff started, every 10 min during a period of 30 to 60 min, and thereafter every 30 min till the end of the rainfall. Then the samples were composited and analyzed for the same parameters by the same methods as were being followed for the wastewater samples.

Rainfall event sizes (in mm) and antecedent dry days (ADD) were obtained and recorded for each of the rainfall events being sampled and analyzed.

3.4.2.2 Regression modeling

Using the wet-weather flow characterization data, multiple linear regression models of the following generic structure were developed on MiniTab Version 17 software:

$$P = a + b\,(ADD) + c\,(R_D) \tag{3.19}$$

Where,

P is wet weather flow characterization parameter (like BOD_5^{20}, COD, FC, etc.)

'a', 'b' and 'c' are the regression model parameters

ADD is antecedent dry days (days)

R_D is depth of the rainfall event (mm)

The multiple linear regression models were developed for all the characterization parameters and for each of the ten village pond catchments.

Coefficient of determination (R^2) values was computed for the developed models in order to understand the goodness of fit of the models. Hypothesis testing was then conducted on the developed multiple linear regression models, prior to accepting the models for prediction purposes. Chi square (χ^2) values were obtained by using the following equation and compared with the chi square distribution table for $\alpha = 0.05$ significant level at n-1 degrees of freedom for accepting the null-hypothesis:

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i \times E_i)^2}{E_i} \tag{3.20}$$

Where,

χ^2 is chi-square test value

O_i is an observed frequency or concentration of pollutant obtained via analysis

E_i is an expected frequency, predicted through regression equations

n is the number of storm events sampled

The developed multiple regression models were then validated for their ability to make predictions.

3.4.2.3 Prediction of the characteristics of the wet weather flows

The multiple linear regression models developed were used for predicting the characteristics of the wet-weather flows, provided the models were found acceptable through hypothesis testing. The characterization parameters were predicted at 10 percentile, mean and 90 percentile values of rainfall depth (R_D) and Antecedent Dry Days (ADD). Parameter values corresponding to 10 percentile rainfall depth (R_D) and 90 percentile antecedent dry days (ADD) were considered as the worst condition and the parameter value corresponding to 10 percentile ADD and 90 percentile rainfall depth as the best condition. Average parameter values were obtained for mean ADD and mean R_D.

In cases where the models were not acceptable, the parameter values have been taken as not dependent on the rainfall event size and on the antecedent dry days, and their values are randomly varying. For all such parameters, mean, 90 percentile and 10 percentile values from the characterization results were used to describe the parameter.

3.5 Development of village level integrated water resources management (IWRM) system

Water management even at the rural human settlements level has been believed as not successful if it is setup as a stand-alone system. This belief was the driving force for the integrated water resource management (IWRM) approach.

IWRM has been taken as a process promoting coordinated development and management of water and other resources of the rural human settlements, for maximizing environmental health and socio-economic benefits in an equitable manner without compromising on sustainability. It has been used as an approach to solve water supply and sanitation related problems. However, the holistic and integrated approach to water management was preserved. The IWRM addressed the issues and questions indicated below:

1. Protection and development of groundwater sources for ensuring secured supply of sufficient water of adequate quality (in the face of conflict, scarcity, pollution of the water resource) without compromising on the water supply to the competing agricultural and ecological use.
2. Minimizing the impacts of groundwater abstraction and of pollution from the wastewater and stormwater on the groundwater and surface waters, on the health, environment and land resources, and on the agriculture and animal husbandry activities.
3. Putting in place the processes that lead to sustainable solutions to the water supply and sanitation problems that resolve the local water conflicts (specially related to water access), minimize the infrastructure requirements and reduce costs.

A generic IWRM (just a system framework and applicable to all the ten pond catchments) was developed and it did not get into detailed planning for a case-by-case implementation. No stakeholders were involved in the development, and it did not look into the resource requirements and the technological capabilities for implementation. Further, no efforts were made to assign economic value to the water being managed.

3.6 Conceptualization of a village pond system

Village ponds traditionally performed the job of collection and storage of the storm water and the grey water generated in the pond catchments. Holding of the water in the ponds over extended periods resulted in the natural treatment of water and water quality improvement. The pond water was put to both in-stream uses and off-stream uses. Further, the pond waters were disposed off through evapo-transpiration and through percolation for groundwater recharging.

Increased population and per capita water consumption, black water discharge into the village drains, increased imperviousness, altered land cover and land use, and altered cattle management practices (especially manure management) have increased both volumes and pollution strengths of both dry weather and wet weather flows. The pond water has become unfit for any of the in-stream and off-streams uses, and in many cases the ponds were reported overflowing during rains. Further, pond water disposal through ground water recharging is not occurring properly due to muck accumulation and pond floor becoming relatively impervious.

A village pond system was conceptualized with the objective of a functional transition of the existing village pond systems towards the traditional village ponds. The conceptualized village pond system is having the following functional components:

- Stormwater and wastewater treatment
- Treated water storage to facilitate the pond water use
- Disposal of excess pond water through ground water recharging
- Making the pond system aesthetically acceptable and sustainable

3.7 Design of the village pond system

3.7.1 Drainage system of the village pond catchments

The drainage system was supposed to carry both the stormwater and the grey water of the catchments to the village pond. The drains were planned to have the cross section as shown in the figure 3.2. These drains were sized to carry peak wet weather flows (peak runoffs, expected from the design storm events of 2 year return period, plus peak wastewater flows). These drains will be carrying the peak dry weather flows at above self cleansing velocity (≥0.5 m/sec.) and peak wet weather flows at below the drain scour velocity (≤2.5 m/sec.). The drainage system was designed for only one of the ten pond catchments.

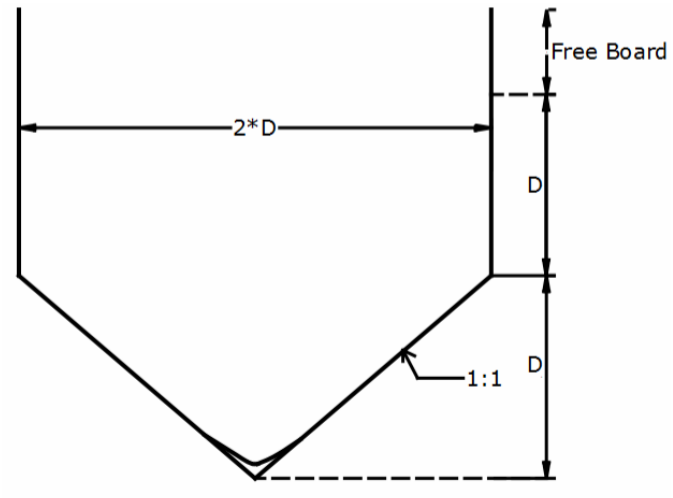


Figure 3.2: Cross section of the composite drain

3.7.2 Village pond system

The village pond system included the following components:

1. Catch basin
2. Free water surface constructed wetland system
3. Facultative pond
4. Up-flow multi-grade roughing filter

5. Treated water reservoir
6. Slow sand filter
7. Groundwater recharge well

The village pond system has been accommodated as far as possible within the existing village pond or in other words the existing village pond was modified into the conceptualized village pond system. Schematic process diagram of the village pond system is shown in figure 3.3.

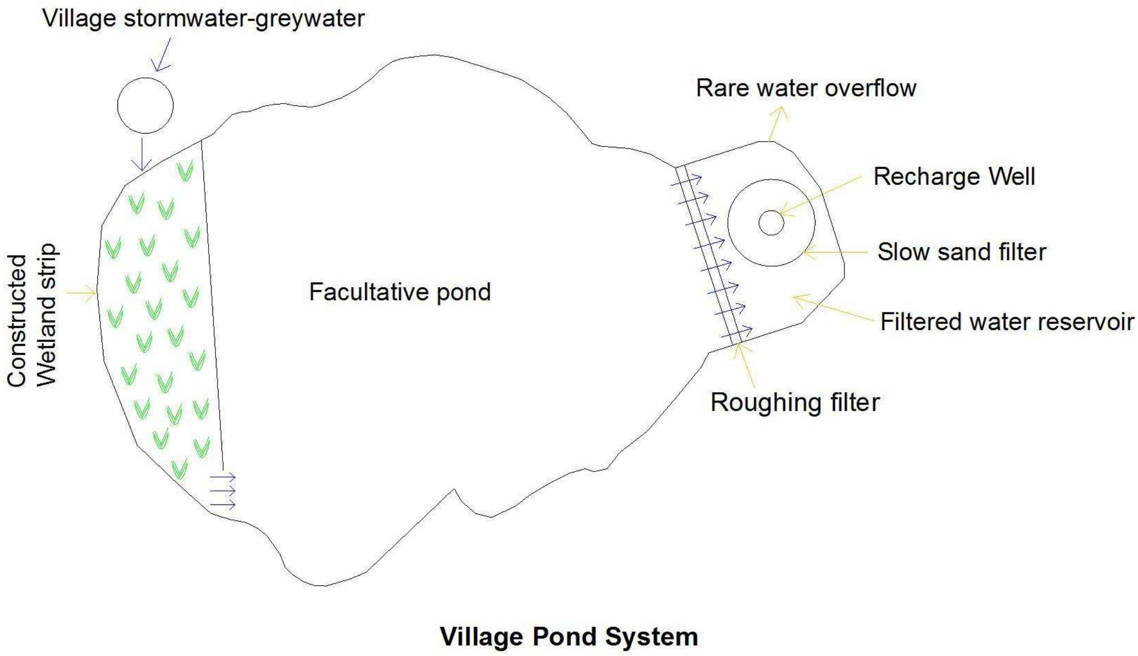


Figure 3.3: Schematic process diagram of the village pond system

3.7.2.1 Catch basin

Catch basin is meant to remove the grit and the floating materials from the incoming grey water and stormwater flows. The catch basin is supposed to be occasionally cleaned (pre-monsoon cleaning). This basin was designed for peak wet weather flows to remove 1 mm size grit having specific gravity of 2.65 with 100% efficiency, and it has storage space for the removed grit and floating material. Outlet of the basin was designed to avoid draining out of the floating material and the settlable grit.

3.7.2.2 Free water surface constructed wetland system

Most of the suspended solids of the incoming wet weather and dry weather flows are supposed to be removed in this constructed wetland system. This system with high aspect ratio will be provided in the form of strip along the perimeter of the village pond on the up-stream side. The wetland system included 3 cells connected in series and emergent aquatic macrophytes will be planted in order to create quiescent conditions for TSS settling. This system was designed to remove organic particles of size 0.2 mm and specific gravity of 1.05 with 100% efficiency. The wetland system may require occasional (once in a few years) harvesting of the macrophyte biomass.

Catch basin and the constructed wetland system were designed by determining the particle settling velocity using the following equation (MetCalf & Eddy, 2003):

$$v_p = \sqrt{\frac{4 \times g}{3 \times C_d}\left(\frac{\rho_p - \rho_w}{\rho_w}\right) \times d_P} \quad (3.21)$$

Where,

v_P is particle settling velocity (m/s)

ρ_p is density of organic particles (kg/m^3)

ρ_w is density of water (kg/m^3)

d_p is average diameter of particle (m)

C_d is coefficient of drag

3.7.2.3 Facultative pond

The facultative pond is supposed to take care of the BOD_5^{20} loaded to pond and algal photosynthesis and surface re-aeration are supposed to supply the oxygen needed for the bio-oxidation removal of the BOD_5^{20}. Coincidental removal of pathogens and nutrients, especially nitrogen, is supposed to occur in the facultative pond.

The existing village pond will be used as a secondary facultative pond. The pond was designed to handle the wet weather flow resulting from the 90 percentile rainfall event. Surface area of the pond required was estimated on the basis of surface organic loading rate determined by the following equation (Mara, 1987):

$$\lambda_s = 350(1.107 - 0.002 \times T_o)^{T_o - 25} \quad (3.22)$$

Where,

λ_s is BOD_5^{20} loading (kg/ha.day)

T_o is average ambient air temperature of the wettest month of the year (°C)

If available pond area was more than the required pond area then the existing pond was taken as the design pond area, otherwise the existing pond size was recommended for expansion to the desired pond area. The pond depth was not altered, provided the depth was >1.0 m. The pond was provided with a fluctuating volume to hold the design wet weather flow (from 90 percentile rainfall event) for one day.

3.7.2.4 Up-flow Multi-grade Roughing filter

Facultative pond water will be very turbid and have relatively high TSS levels of around 100 mg/L (algal cells of the pond will be the major contributor). For facilitating reuse of this water as reclaimed water, the facultative pond output water is filtered in an up-flow multi-grade roughing filter. The upflow roughing filter, since has enough removed solids storage capacity, does not require regular backwashing.

The upflow roughing filter was designed to handle the design wet weather flow over 72 hour period. Its design filtration rate was ≤ 2 $m^3/m^2/hr$. The filter was provided in the dividing wall of the facultative pond and the treated water storage reservoir as a 2.0 m wide strip. The filter will be covered from the top for shading from the sun light.

For better performance and for avoiding dry run, the roughing filter was positioned hydraulically in such a way that the filter bed will always remain submerged in water. Inlets of the filter were designed in such a way that only sub-surface water of the facultative pond will be filtered (washout of algal cells is avoided). Outlets of the filter were provided at such a level that the filter will operate only when the water level in the facultative pond crosses a set limit.

3.7.2.5 Treated water reservoir

Treated water storage reservoir is provided for the storage of filtered water from the up-flow multi-grade roughing filter and makes available the water for reuse as reclaimed water. Storage capacity of this reservoir was designed for 8 hours average dry weather flow. Filtered water from this reservoir was designed to flow into the ground water recharge well through the slow sand filter when the water level in the reservoir crosses a set value. Further, the reservoir was provided with an overflow drain for emergency disposal of the filtered water.

3.7.2.6 Slow sand filter

Slow Sand Filter (SSF) is meant for the removal of turbidity/TSS and for the reduction of coliform count from the water being disposed off through ground water recharging. In order to prevent entry of untreated or not filtered water into the recharge well, SSF was provided as an annular ring to the recharge well. The filter was designed for ≤ 0.5 $m^3/m^2/hr$ filtration rate.

For better performance and for avoiding dry run, the SSF was positioned hydraulically below the filtered water reservoir. Inlets of the SSF were designed in such a way that only sub-surface water of the filtered water reservoir will be filtered (washout of the algal cells is avoided). Outlet of the SSF was designed in such a way that the SSF will operate only when the water level in the filtered water reservoir crosses a set limit, and the filter bed remains submerged in water all the time.

Carman-Kozeny equation (MetCalf and Eddy, 2003) given below was used for headloss calculations in both the roughing filter and slow sand filter:

$$h = \frac{f \times (1-\alpha) \times L \times v_s^2}{\phi \times \alpha^3 \times d \times g} \tag{3.23}$$

Where,

h is headloss (m)

f is friction factor

α is porosity of the filter bed

L is depth of filter bed (m)

v_s is approach filtration velocity (m/s)

Φ is particle shape factor

d is grain size diameter (m)

g is acceleration due to gravity (9.81 m/s^2)

3.7.2.7 Groundwater recharge system

Vadose zone wells are suggested for the ground water recharging into the surface aquifers. Recharge pipe, perforated within the aquifer zone, will be discharging the water into the aquifer. Hydraulic conductivity of the aquifer sand and water head available were used as the basis for sizing the recharge pipe. The recharge well was sized to handle the wet weather flow (resulting from the 90 percentile rainfall event) from the pond catchments in 72 hour period.

The perforated pipe portion of the recharge well was filled with hard non-carbonate stone ballast for energy dissipation of the incoming water. Placement of the recharge well within the pond system, and design of the recharge well were such that only the output water of the slow sand filter (and no other water) can enter the recharge well. Water would be recharged into the first pervious layer, provided it is having sufficient storage capacity. The recharge well together with the SSF will be capped for shading from the sun light.

Chapter-4
Results and Discussion

Results obtained from working on the work elements mentioned under methodology chapter are presented and discussed in this chapter.

4.1 Rural human settlements, water management and village ponds

4.1.1 Rural human settlements

To achieve the objectives of this study, ten rural human settlements (villages) hereafter referred as rural settlements, were selected in three districts .i.e. Jalandhar, Kapurthala and Nawanshahar of Doaba region of Punjab state (Figure 4.1). The details of the selected rural settlements are shown in table 4.1.

The study region lies in the sub-tropical belt and the climate is determined by hot conditions in summer and cold conditions in winter. The mean minimum and maximum temperatures vary between 5.2°C in January to 41.1°C in June in the study area. The annual average rainfall in the region ranges from 650 to 900 mm, of which 75% rainfall occurs during the monsoon months, from July to September. Groundwater table in the selected rural settlements varied from 20 to 27 m below ground level (bgl) during pre monsoon periods and 18 to 25 m bgl during post monsoon periods.

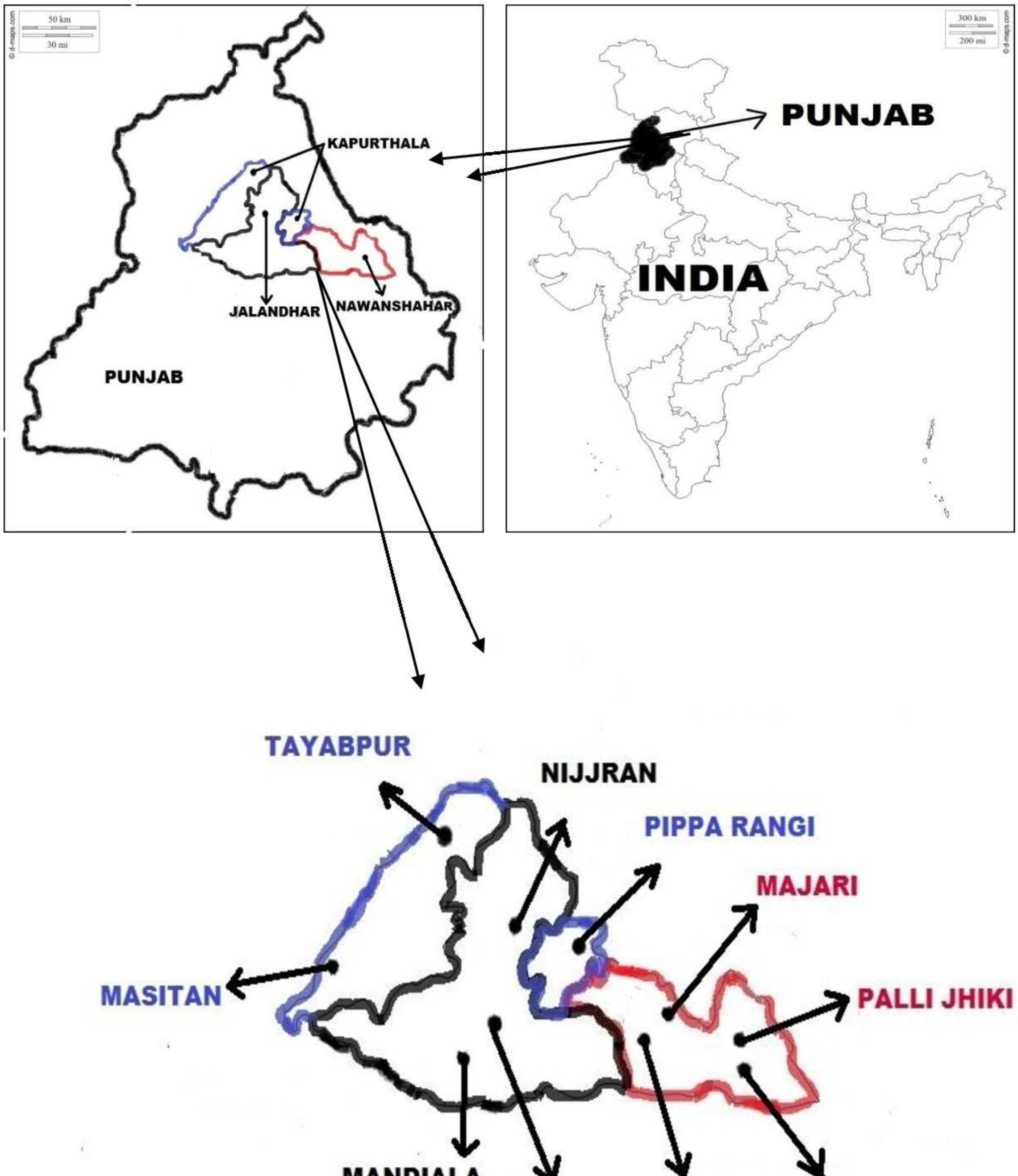


Figure 4.1: Map showing the location of selected rural human settlements

Table 4.1: Details of the selected rural settlements

Rural settlement	Area, (m^2)	Population	Number of ponds	Nearest meteorological station	Water supply system*
Tayabpur	35951	662	01	Kapurthala	SP, HP
Sodhian	80002	940	01	Nawanshahar	PWS, SP, HP
Majari	97830	1780	01	Nawanshahar	PWS, SP, HP
Palli Jhiki	125644	2055	01	Nawanshahar	SP, HP
Mandiala	119087	2045	01	Nakodar	PWS, SP, HP
Kultham	88661	2182	02	Nawanshahar	PWS, SP, HP
Pippa Rangi	65492	1506	01	Phagwara	PWS, SP, HP
Nijjran	82028	1410	02	Jalandhar	SP, HP
Samrai	247562	2935	02	Phagwara	PWS, SP, HP
Masitan	81985	1287	01	Kapurthala	PWS, SP, HP

* PWS- Piped water supply, SP- Submersible pump (household level), HP- Motorised hand pump (household level)

4.1.2 Water management in the selected rural settlements

4.1.2.1 Water supply systems

Groundwater is the source of water in the studied rural settlements. Water consumption in the studied rural settlements includes human consumptive and non-consumptive purposes; cattle and other domesticated animal consumption; religious, educational and other institutional consumption; and irrigational use in kitchen gardens. The fraction of water used for the human non-consumptive purposes was found to be relatively less as compared to urban settlements. But, on the other side, large amounts of water was found to be used in cattle consumption like drinking and bathing of cattle, cleaning of cattle sheds etc. Physical survey of the rural settlements revealed that around 70-75% of the cattle bathing takes place within the rural settlements. A brief description of the water supply systems in the study areas is given below:

1. Tayabpur: Tayabpur is a small village in Kapurthala district. This village is not having a piped water supply network and people depend on individual submersible pumps and motorized hand pumps for their water demands.

2. Sodhian: Sodhian village is located in Nawanshahar district on the highway connecting Nawanshahar with Phillaur. Piped water supply scheme is present in this village. Dwelling level hand pumps and submersible pumps are also used by the residents to fulfill their water demands.

3. Majari: This village is located in Nawanshahar district along the state highway connecting Nawanshahar with Phagwara. Majari is a mid-sized village with water being supplied through piped water supply. Motorized hand pumps and submersible pumps are also used in this village.

4. Palli Jhiki: Palli Jhiki village in Nawanshahar district is situated on major district road connecting Banga with Garhshankar. This village is not having a piped water supply. People use motorized hand pumps and submersible pumps for their water needs. Almost all the houses have motorized hand pumps installed in their premises.

5. Mandiala: Mandiala village is located in Nakodar block of Jalandhar district. Residents depend on piped water supply as well as on motorized hand pumps and submersible pumps to fulfill their water needs.

6. Kultham: Village Kultham is situated in Nawanshahar district around 2 kms away from Phagwara-Nawanshahar highway. In this rural settlement, government sponsored water supply network is available. Around one third of the houses also have the provision of submersible pumps.

7. Pippa Rangi: Pippa Rangi village is situated in Phagwara block of Kapurthala district. In this village, people depend on piped water supply for their water demands. Very few houses have submersible pumps installed in their premises and motorized hand pumps are available in majority of the houses.

8. Nijjran: Nijjran village is situated on Jalandhar-Kala Sanghian road in Jalandhar district. This village is not having a piped water supply. People depend on motorized hand pumps and submersible pumps to fulfill their water needs. Submersible pumps are installed in almost half of the houses in this village.

9. Samrai: This rural settlement is largest of all the selected rural settlements and located in Rurka Kalan block in Jalandhar district. Water distribution network is present in this settlement. People also use hand pumps and submersible pumps to fulfill their water demands.

10. Masitan: Masitan village is located in Sultanpur Lodhi block of Kapurthala district. Water supply scheme is present in this rural settlement. A large number of houses also have the provision of submersible pumps.

4.1.2.2 Wastewater and stormwater management and village ponds

In the selected rural settlements, wastewater generated is discharged into roadside open drains which carry the wastewater to one or more disposal points (usually village ponds, natural drain or any low lying area). Studied rural settlements have no defined stormwater drainage system. Usually, the road side gutters and drains carry and convey the stormwater to the disposal point. Village ponds in the studied areas are found to be receiving the untreated wastewater and stormwater generated from the rural settlements, which form the major water sources for the ponds. During the non-rainfall periods, only source of water for the ponds is raw wastewater and continuous addition of untreated wastewater renders the pond water unfit for any use. Open defecation and solid waste dumping are also observed near these ponds which further aggravated the pollution level of the pond water. Pond water which used to be an important source of water for cattle bathing and drinking has now been abandoned for this use due to heavy pollution.

Information of the current wastewater and stormwater management practices followed and pond specific information collected from each of the rural settlements are given below:

1. Tayabpur: In Tayabpur village, only one pond is present which normally overflows during monsoon season onto the adjacent areas. Wastewater and stormwater is collected and conveyed by open drains to the pond.

2. Sodhian: This village has the largest pond of all the studied rural settlements which is located outside the village and is surrounded by agricultural fields from two sides. During the physical survey of the village, it was observed that drains did not overflow even during the heavy rainfall events and pond also had sufficient capacity to hold the incoming stormwater. Residents of this village use pond water for irrigation purpose by installing temporary pumps during irrigation season.

3. Majari: Majari village is divided in two areas. Wastewater and stormwater generated from the larger area drains into a near by flowing natural drain, whereas the smaller area serves as catchment for the village pond. Solid waste is also found to be dumped in the pond.

4. Palli Jhiki: Wastewater and stormwater of Palli Jhiki village flow out of the village through three outlets, one outlet falls into a natural drain, another into an open space near the entrance of the village and the remaining outlet falls into the village pond.

5. Mandiala: Only one pond is present in Mandiala village, which receives the major fraction of wastewater and stormwater generated from the village. A small fraction of wastewater and stormwater generated in the village is conveyed to a man made pond. Residents of this village use water from both the ponds for irrigation purpose.

6. Kultham: Kultham village has two ponds which receive the wastewater and stormwater generated from the human settlement through road side open drains. The larger pond out of the two ponds is heavily infested with water hyacinth and is linked to a nearby drain, thus not performing the role of water storage. The smaller pond has the history of overflowing during heavy rains.

7. Pippa Rangi: This village has only one pond which receives wastewater and stormwater generated from around 60% of the village area. The generated water from rest of the area accumulates in the open spaces along the railway line passing through this village. As pond is surrounded by houses, so, pond water is not being used for irrigation purposes and overflowing of the pond has been observed during rainfall season.

8. Nijjran: This village has two ponds which receives the wastewater and stormwater flows in almost equal proportions. The smaller of the two ponds which is adjacent to a religious place, overflows during the monsoon periods and water from this pond is used for irrigation purposes.

9. Samrai: Wastewater and stormwater generated from this rural settlement gets distributed into three parts, one part flows into a pond which is surrounded by the human habitations, another part flows into a second pond which is on the outskirts of the village and a significant part of the wastewater and stormwater flows into a near by flowing natural drain.

10. Masitan: Only one pond is present with in the boundaries of this human settlement. Pond is surrounded by fields and human habitations. Pond water is not used for any purpose and it overflows during the monsoon season. Severe overflow of the open drains also occurs during monsoon season in this village.

Details of the ponds in each of the rural settlements are given in table 4.2.

Table 4.2: Details of the ponds in the selected rural settlements

Rural settlement	Pond area, (m^2)	Average depth, (m)
Tayabpur	2812	4.6
Sodhian	5061	5.5
Majari	1252	4.6
Palli Jhiki	3894	5.2
Mandiala	3249	5.5
Kultham	714	4.6
	9260	5.2
Pippa Rangi	815	3.9
Nijjran	1808	5.2
	5700	5.2
Samrai	3325	4.3
	2671	4.3
Masitan	2846	4.6

4.1.3 Village pond catchments

In the studied rural settlements, where more than one pond was present, only one pond was selected for catchment demarcation. For each of the selected ponds in the rural settlements, the area contributing wastewater and stormwater to the pond .i.e. pond catchment was demarcated using handheld GPS (Garmin- eTrex vista) and then super imposed on the Google earth images of the studied villages. The pond catchments were also demarcated on the survey maps of the selected rural settlements obtained from Department of Water Supply and Sanitation, Govt. of Punjab. Characterization of the demarcated catchments was done by collecting information through physical survey and by topographical maps of the selected rural settlements. The village pond catchments, hereafter referred as catchment are described in brief:

1. Tayabpur village pond catchment: This catchment had the lowest percentage of impervious cover and highest percentage of grass cover among all the studied pond catchments. The demarcated catchment area is shown in the aerial photograph in figure 4.2 and also in the survey sheet in sheet-1. Land use pattern of the demarcated catchment as percentage of total area is shown in figure 4.3. The catchment characteristics are mentioned in table 4.3.

Figure 4.2: Tayabpur catchment

Table 4.3: Characteristics of Tayabpur catchment

Pond Location	**Latitude**	31°23'48.29''N
	Longitude	75°18'50.34''E
Catchment area (m^2)		25177
Human population		540
Cattle population		141
(Human : cattle) ratio		3.83
Catchment soil type		Alluvial
Number of households		88
Household water supply system		SP*, HP**
Percent of households having submersible pumps		51%
Percent of households having sanitation facilities		77%
Drainage facilities		Open drains (constructed)
Hydraulic flow path length (m)		318
Channel slope		0.007
Land use pattern (%)	**Impervious cover**	65
	Grass cover	25
	Crop cover	6
	Tree canopy	4

*SP- Submersible pump, **HP- Hand pump

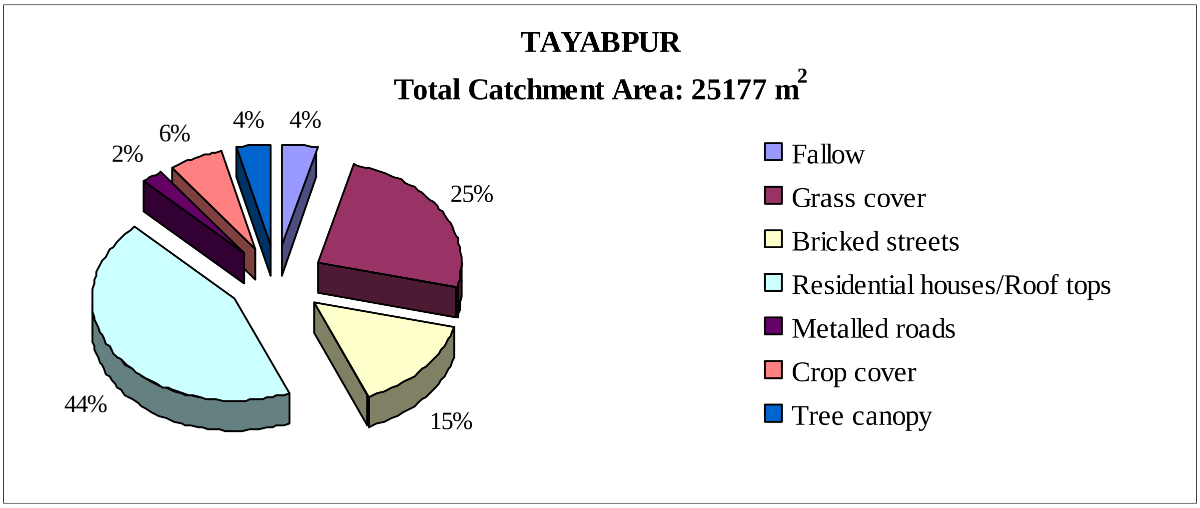
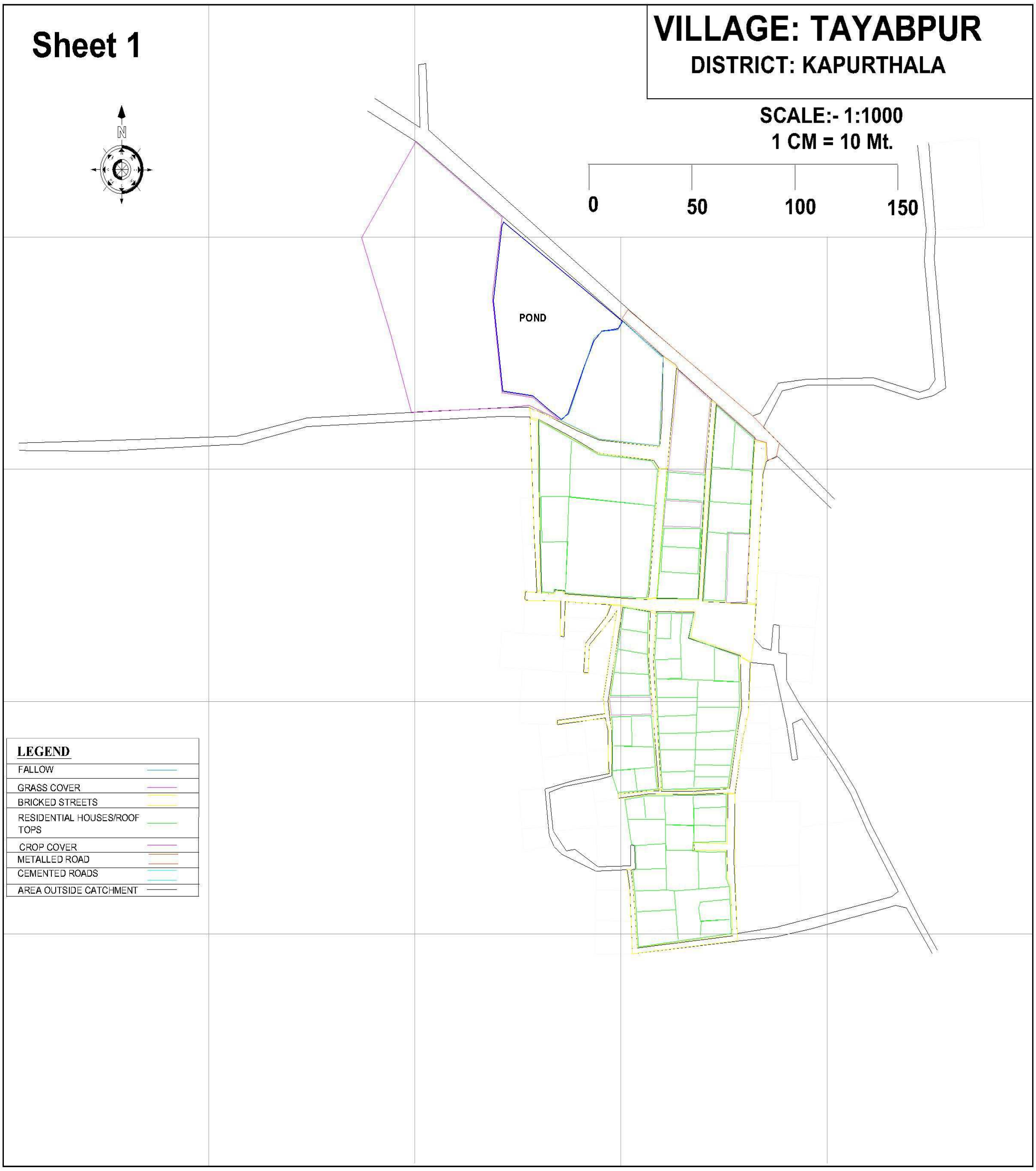


Figure 4.3: Land use pattern of Tayabpur catchment



Sheet 1: Survey sheet of Tayabpur catchment

2. Sodhian village pond catchment: This catchment had the large number of cattle and around 85% area of the village formed the catchment of the pond as shown in figure 4.4 and in survey sheet-2. Figure 4.5 shows the land use pattern of the catchment. The catchment characteristics are mentioned in table 4.4.

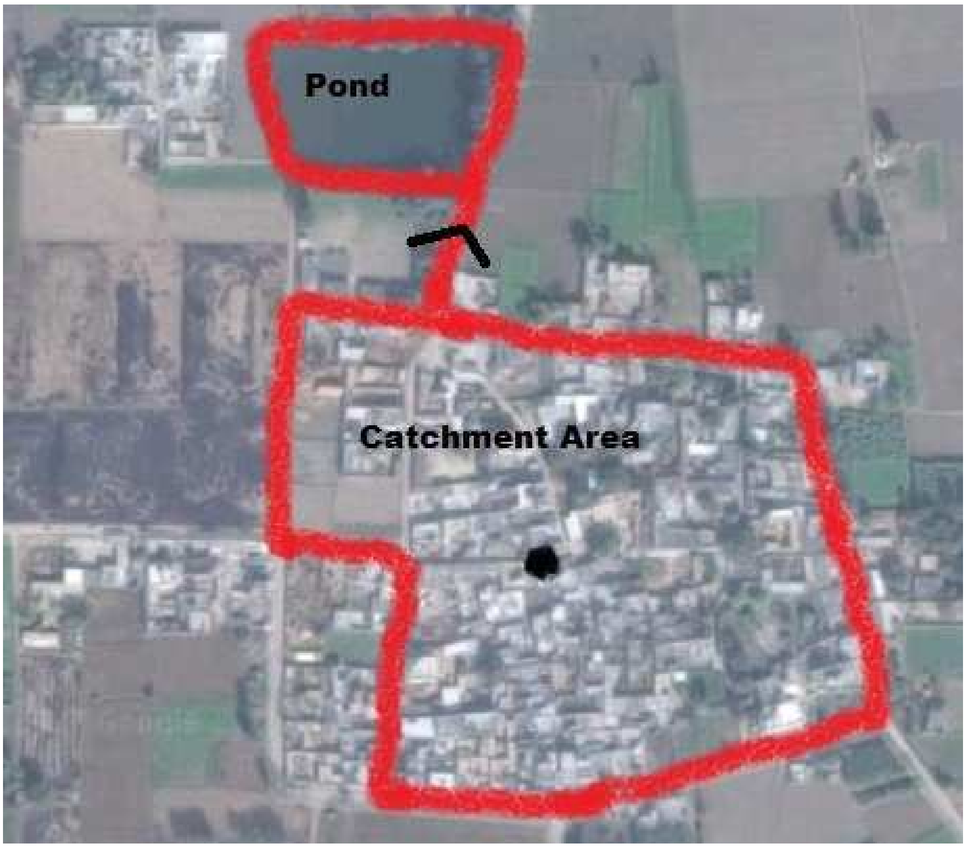


Figure 4.4: Sodhian catchment

Table 4.4: Characteristics of Sodhian catchment

Pond Location	**Latitude**	31°05'38.87''N
	Longitude	76°01'37.90''E
Catchment area (m^2)		67720
Human population		905
Cattle population		203
(Human : cattle) ratio		4.46
Catchment soil type		Sandy loam
Number of households		216
Household water supply system		PWS#, SP*, HP**
Percent of households having submersible pumps		37%
Percent of households having sanitation facilities		84%
Drainage facilities		Open drains (constructed)
Hydraulic flow path length (m)		580
Channel slope		0.0011
Land use pattern (%)	**Impervious cover**	79
	Grass cover	13
	Crop cover	6
	Tree canopy	2

#PWS- Piped water supply, *SP- Submersible pump, **HP- Hand pump

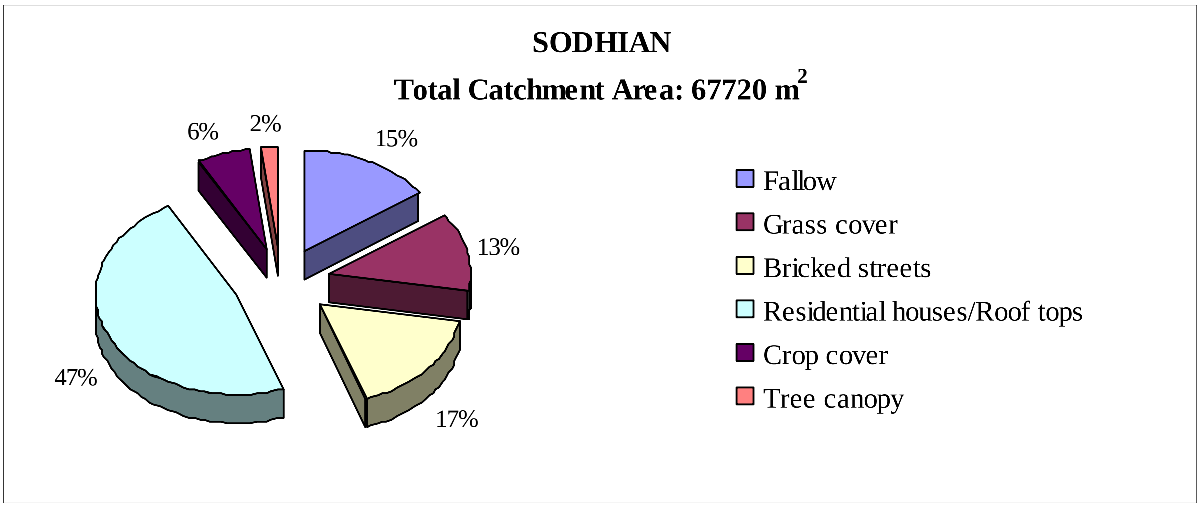
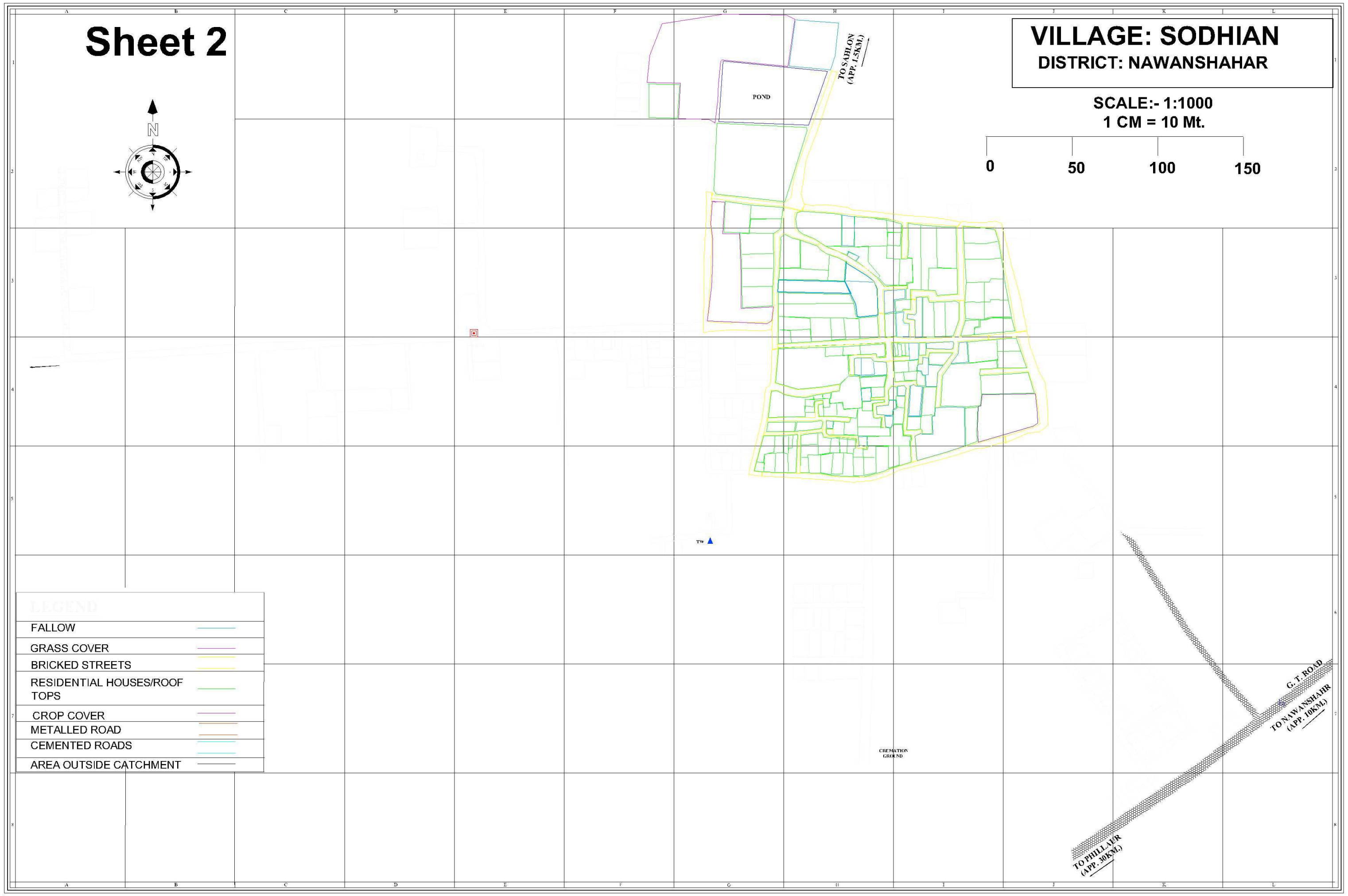


Figure 4.5: Land use pattern of Sodhian catchment



Sheet 2: Survey sheet of Sodhian Catchment

3. Majari village pond catchment: Around 40% of the total area of this village served as the catchment for the village pond as shown in figure 4.6 and in survey sheet-3. This catchment was one of the smallest and most impervious of all the selected catchments. Land use pattern of the catchment is shown in figure 4.7. The catchment characteristics are mentioned in table 4.5.

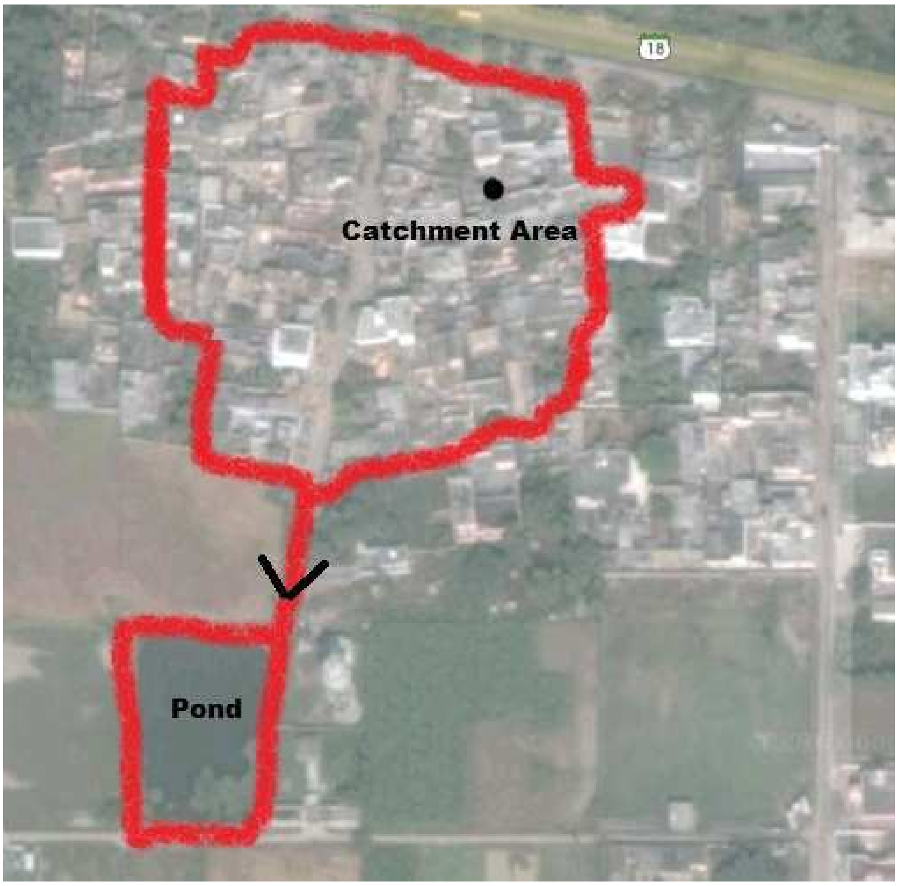


Figure 4.6: Majari catchment

Table 4.5: Characteristics of Majari catchment

Pond Location	**Latitude**	31°11'20.40''N
	Longitude	75°58'12''E
Catchment area (m^2)		38277
Human population		783
Cattle population		95
(Human : cattle) ratio		8.24
Catchment soil type		Sandy loam
Number of households		201
Household water supply system		PWS[#], SP[*], HP[**]
Percent of households having submersible pumps		30%
Percent of households having sanitation facilities		82%
Drainage facilities		Open drains (constructed)
Hydraulic flow path length (m)		448
Channel slope		0.0011
Land use pattern (%)	**Impervious cover**	90
	Grass cover	8
	Crop cover	0
	Tree canopy	2

[#]PWS- Piped water supply, [*]SP- Submersible pump, [**]HP- Hand pump

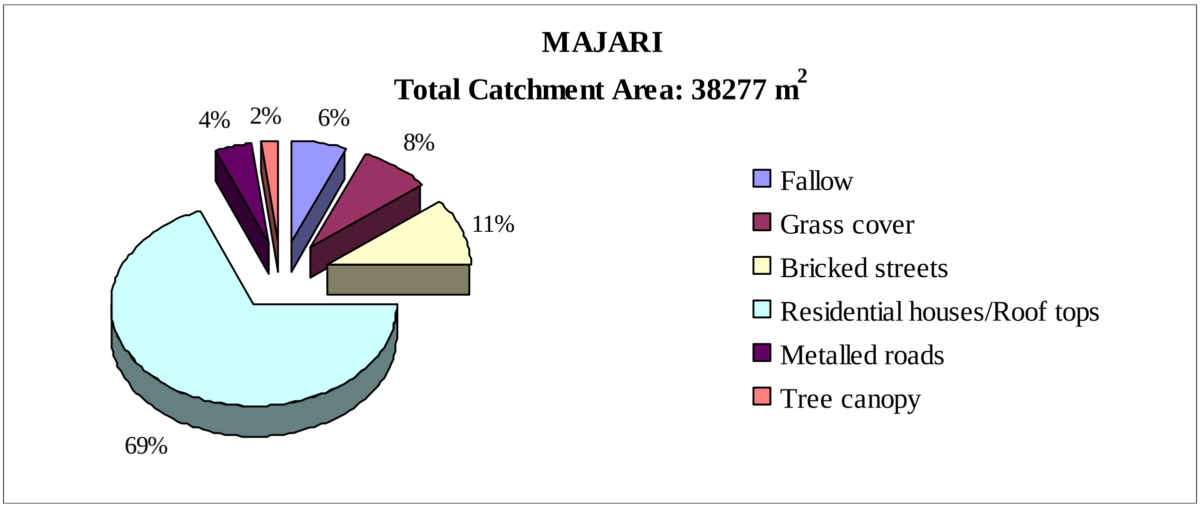


Figure 4.7: Land use pattern of Majari catchment

Sheet 3: Survey sheet of Majari catchment

4. Palli Jhiki village pond catchment: This catchment had highest percentage of submersible pumps installed due to the non-availability of piped water supply. Pond catchment area constituted around 35% of the total area of the village. Demarcated catchment is shown in figure 4.8 and in survey sheet-4. Land use pattern of the demarcated catchment is shown in figure 4.9. The catchment characteristics are tabulated in table 4.6.

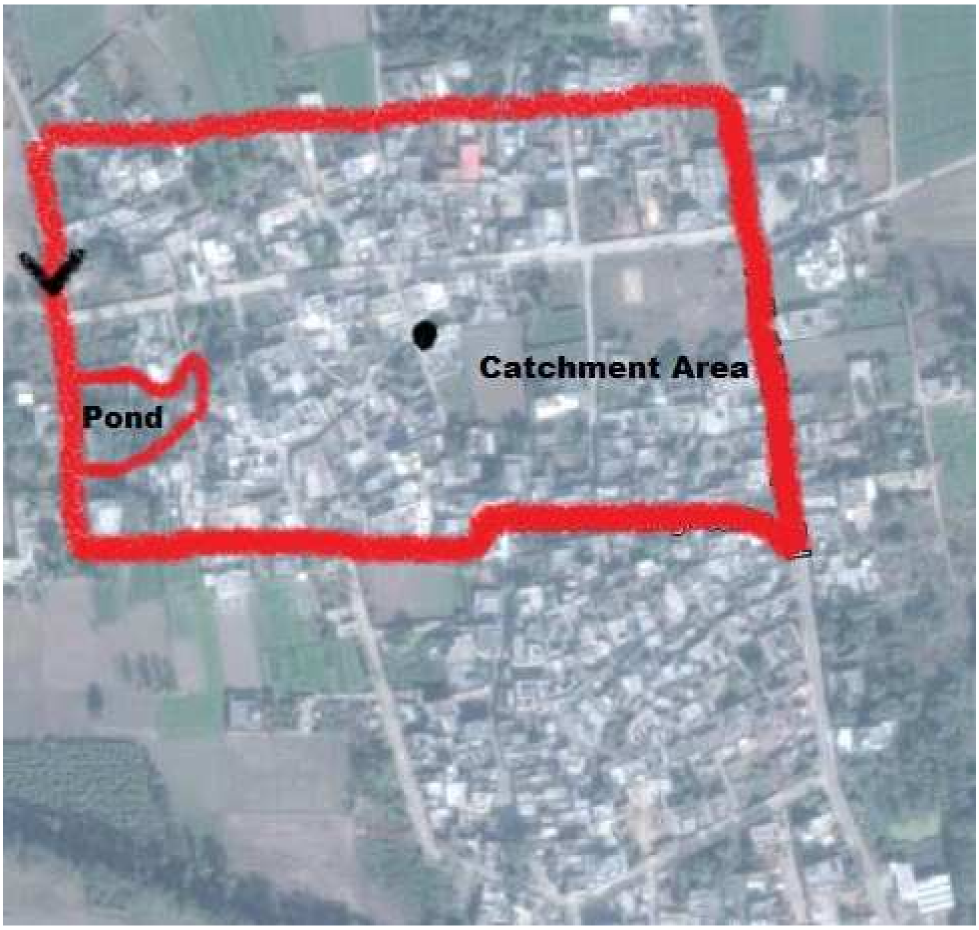


Figure 4.8: Palli Jhiki catchment

Table 4.6: Characteristics of Palli Jhiki catchment

Pond Location	**Latitude**	31°11'24''N
	Longitude	76°04'48''E
Catchment area (m^2)		43578
Human population		815
Cattle population		72
(Human : cattle) ratio		11.32
Catchment soil type		Sandy loam
Number of households		159
Household water supply system		SP*, HP**
Percent of households having submersible pumps		53%
Percent of households having sanitation facilities		81%
Drainage facilities		Open drains (constructed)
Hydraulic flow path length (m)		485
Channel slope		0.0016
Land use pattern (%)	**Impervious cover**	80
	Grass cover	10
	Crop cover	2
	Tree canopy	8

*SP- Submersible pump, **HP- Hand pump

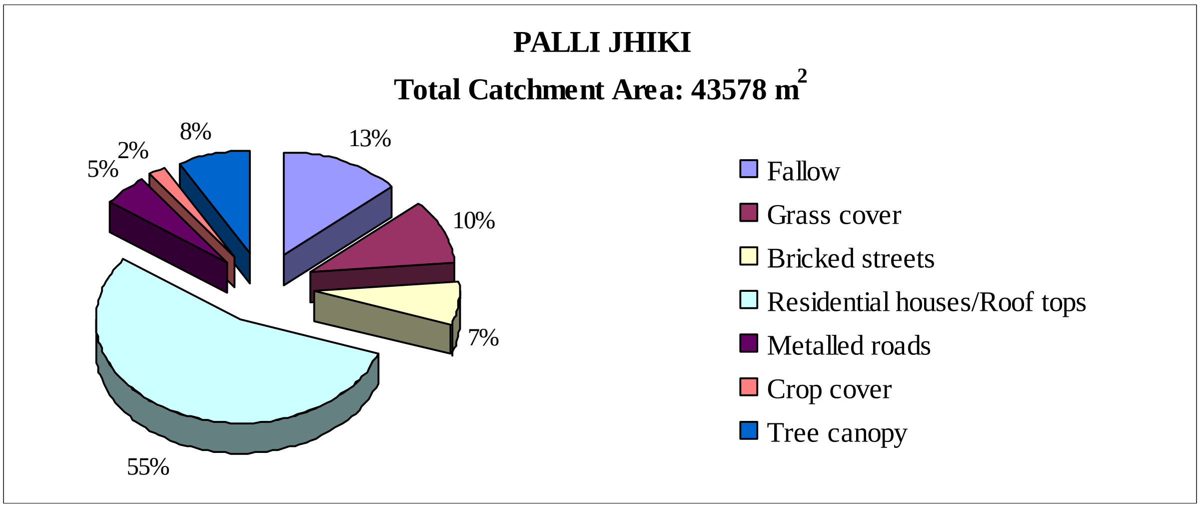
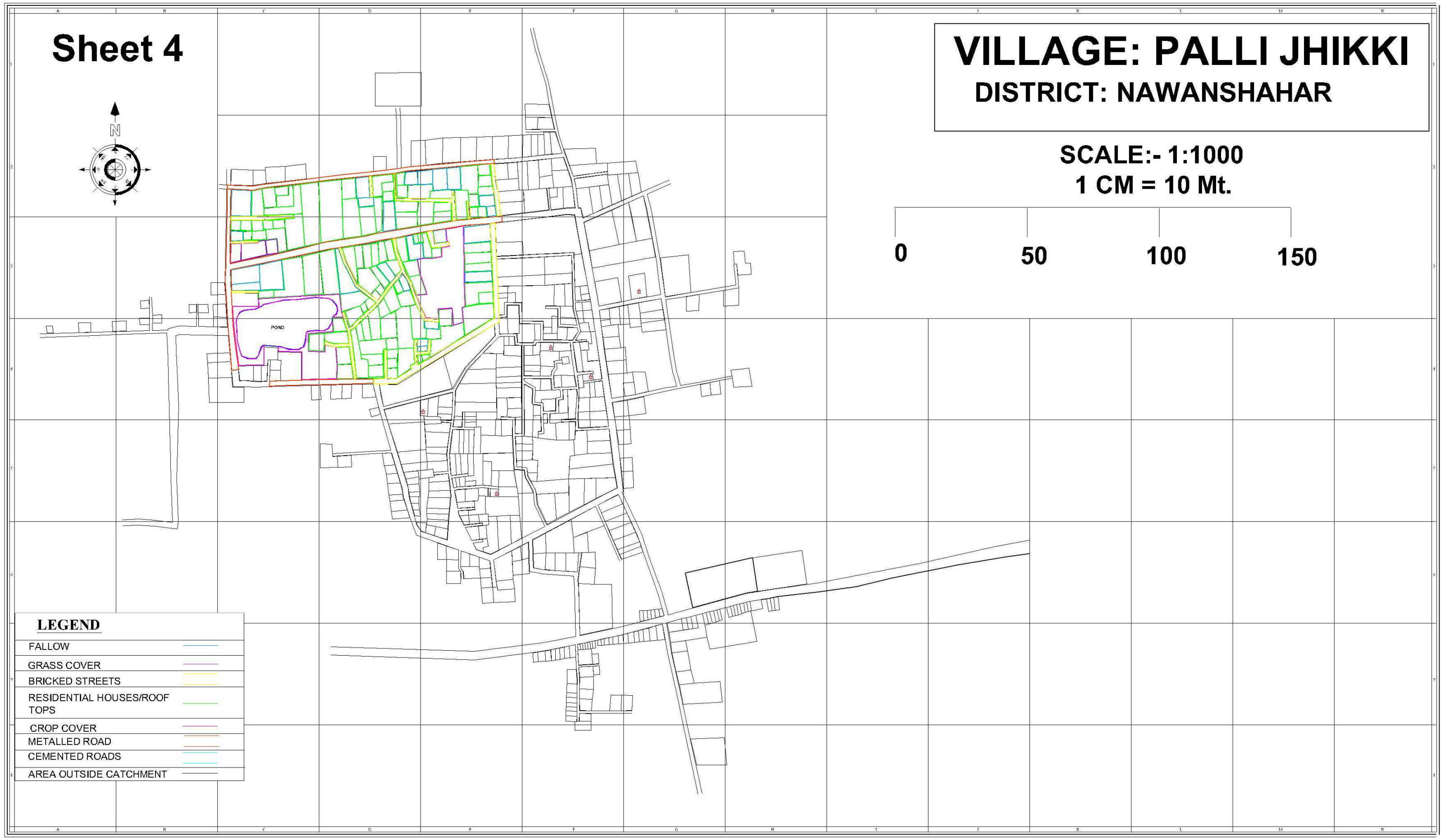


Figure 4.9: Land use pattern of Palli Jhiki catchment



Sheet 4: Survey sheet of Palli Jhiki catchment

5. Mandiala village pond catchment: This catchment had the high level of imperviousness and constituted 65% of the total area of the village (Figure 4.10 and survey sheet-5). Land use pattern of the Mandiala catchment is shown in figure 4.11. The catchment characteristics are mentioned in table 4.7.

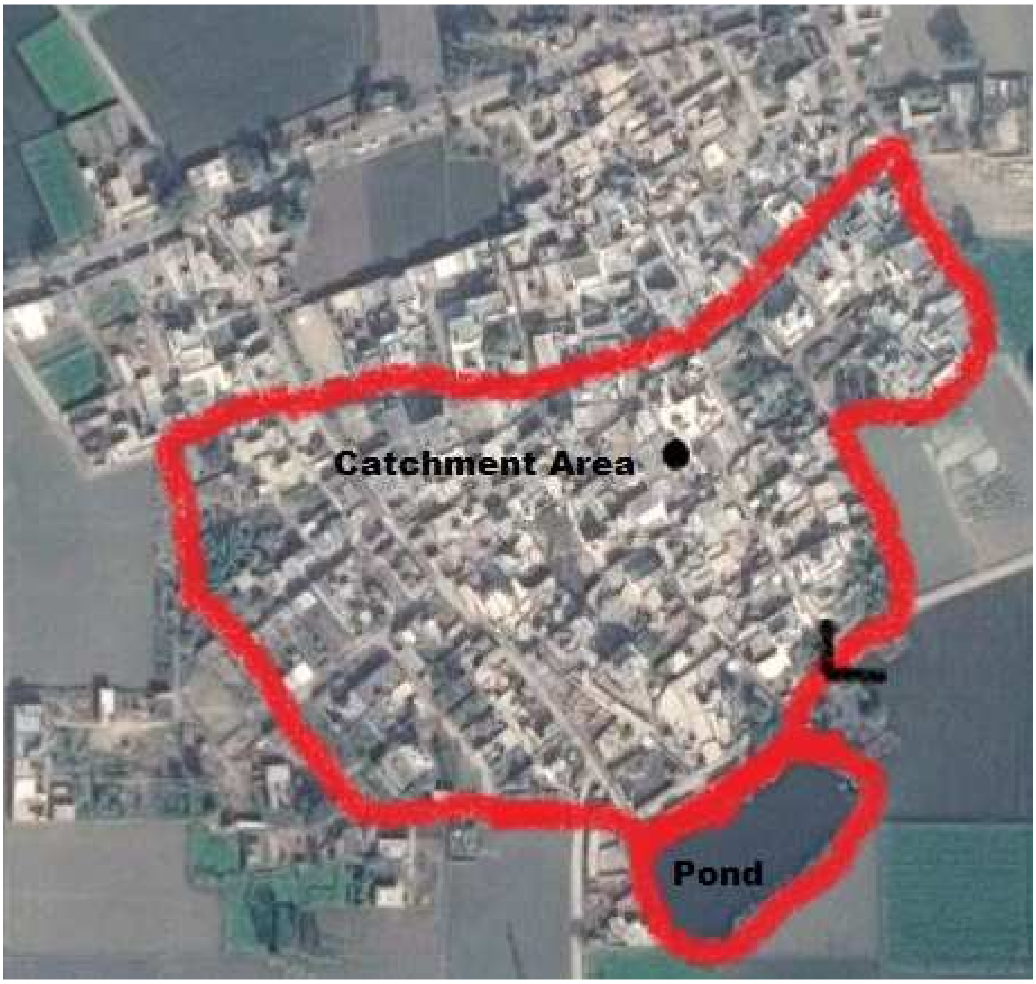


Figure 4.10: Mandiala catchment

Table 4.7: Characteristics of Mandiala catchment

Pond Location	**Latitude**	31°33'1.44''N
	Longitude	74°50'51.36''E
Catchment area (m^2)		77057
Human population		1420
Cattle population		204
(Human : cattle) ratio		6.96
Catchment soil type		Alluvial
Number of households		263
Household water supply system		PWS#, SP*, HP**
Percent of households having submersible pumps		38%
Percent of households having sanitation facilities		85%
Drainage facilities		Open drains (constructed)
Hydraulic flow path length (m)		822
Channel slope		0.009
Land use pattern (%)	**Impervious cover**	90
	Grass cover	7
	Crop cover	0
	Tree canopy	3

#PWS- Piped water supply, *SP- Submersible pump, **HP- Hand pump

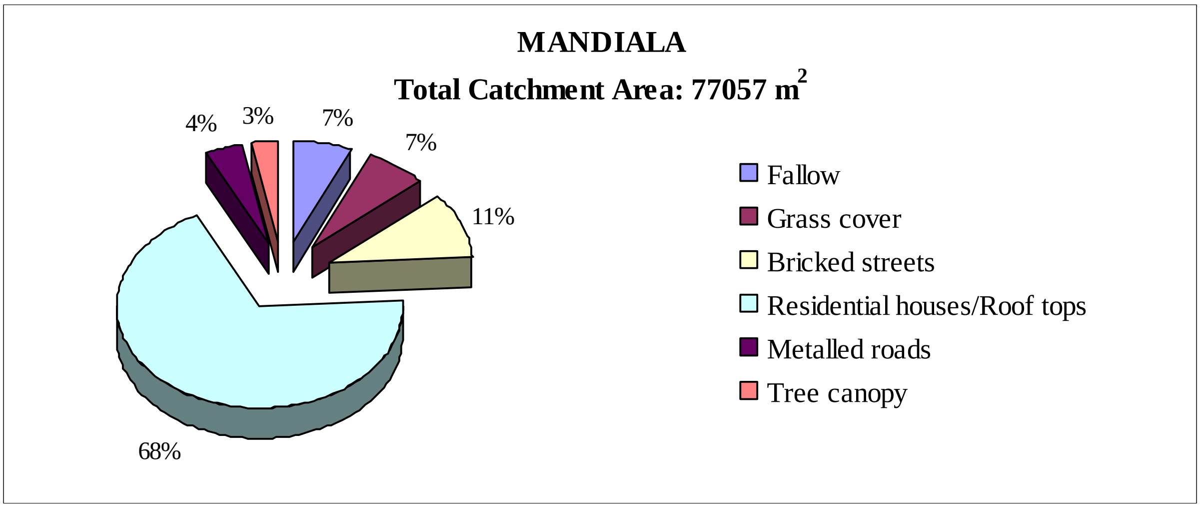


Figure 4.11: Land use pattern of Mandiala catchment

Sheet 5: Survey sheet of Mandiala catchment

6. Kultham village pond catchment: The demarcated catchment constituted around 35% of the total area of the village. The demarcated catchment area is shown in figure 4.12 and in survey sheet-6. This catchment had the highest percentage of crop cover and metalled roads among all the catchments as shown in land use pattern in figure 4.13. The catchment characteristics are given in table 4.8.

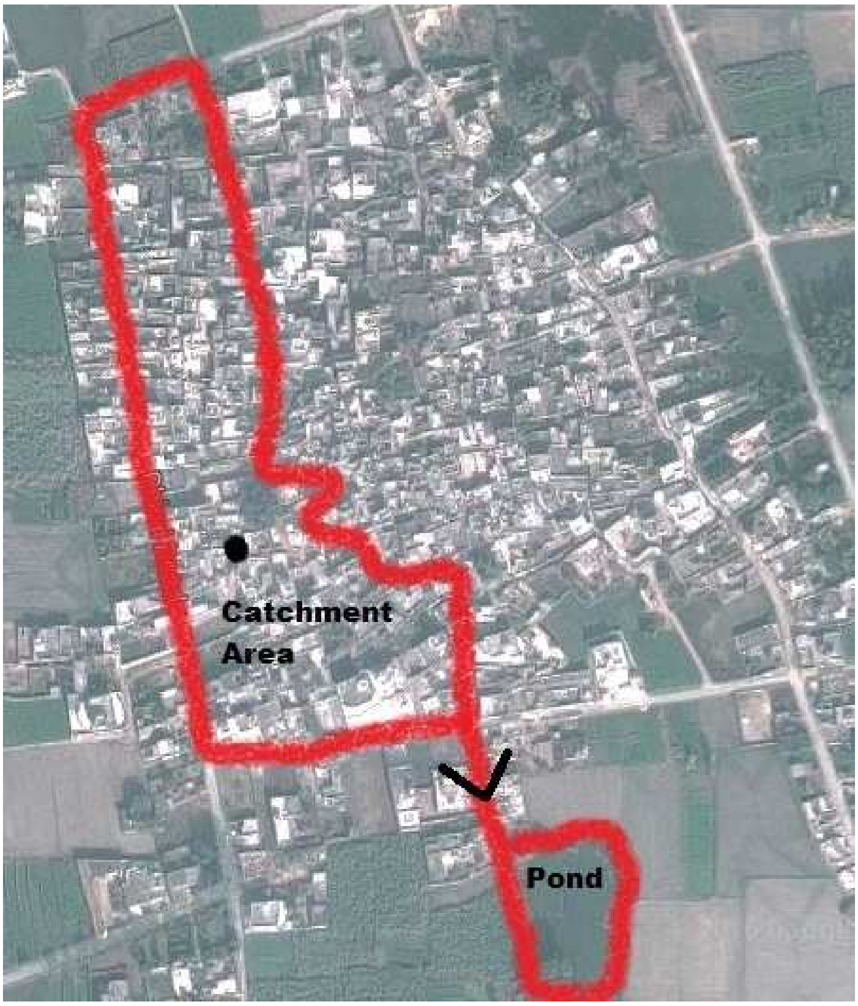


Figure 4.12: Kultham catchment

Table 4.8: Characteristics of Kultham catchment

Pond Location	**Latitude**	31°11’33.07’’N
	Longitude	75°51’01.76’’E
Catchment area (m^2)		31355
Human population		698
Cattle population		48
(Human : cattle) ratio		14.54
Catchment soil type		Sandy loam
Number of households		149
Household water supply system		PWS[#], SP[*], HP[**]
Percent of households having submersible pumps		35%
Percent of households having sanitation facilities		84%
Drainage facilities		Open drains (constructed)
Hydraulic flow path length (m)		600
Channel slope		0.0017
Land use pattern (%)	**Impervious cover**	78
	Grass cover	12
	Crop cover	9
	Tree canopy	1

[#]PWS- Piped water supply, [*]SP- Submersible pump, [**]HP- Hand pump

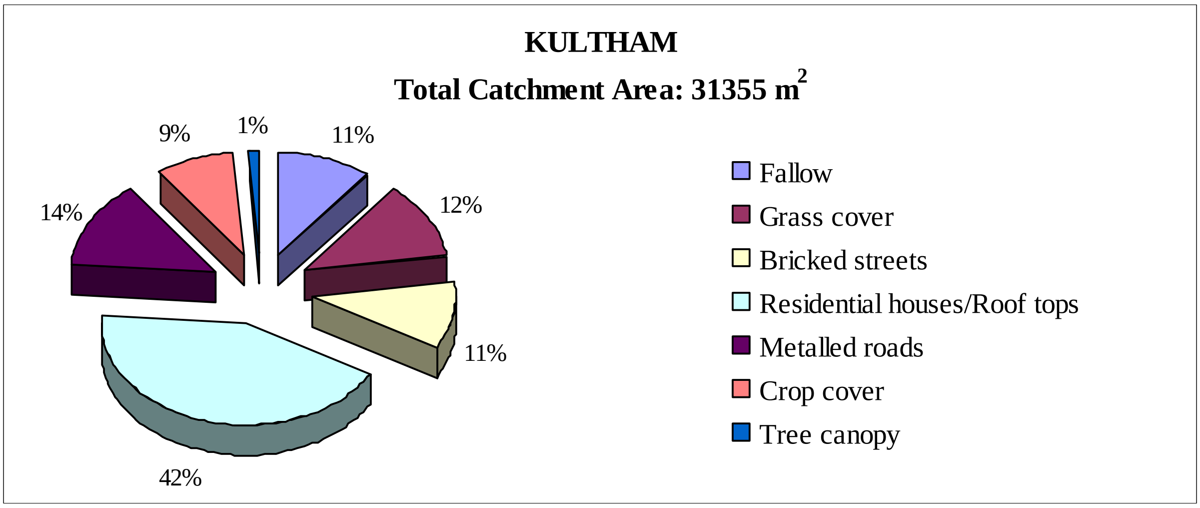
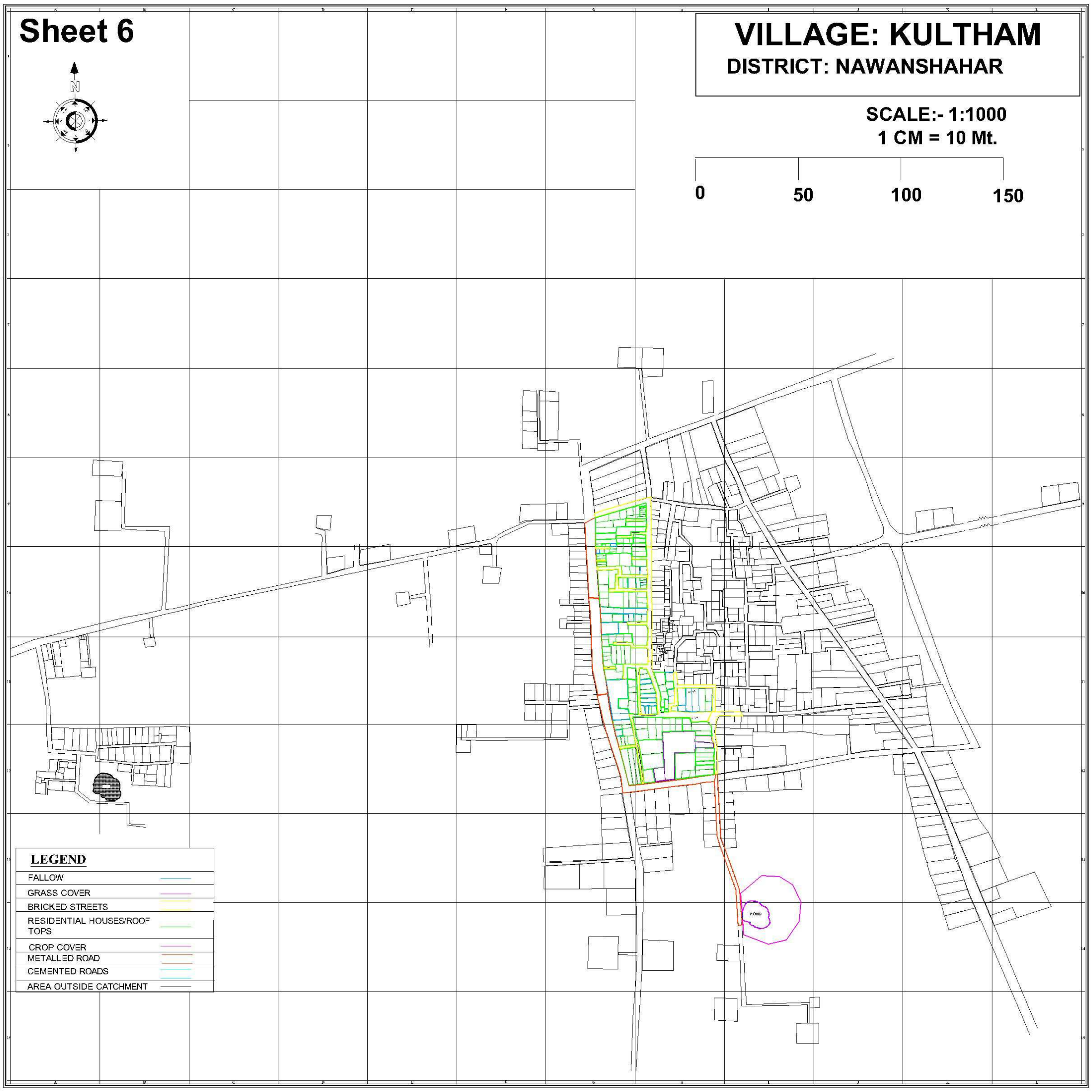


Figure 4.13: Land use pattern of Kultham catchment



Sheet 6: Survey sheet of Kultham catchment

7. Pippa Rangi village pond catchment: The demarcated catchment is shown in figure 4.14 and in survey sheet-7. Only one pond served as an outlet for around 60% of the village area. Cattle population in this catchment was the lowest among all the catchments. One of the highest percentages of grass cover was observed in this catchment as shown in land use pattern in figure 4.15. Table 4.9 tabulates the catchment characteristics.

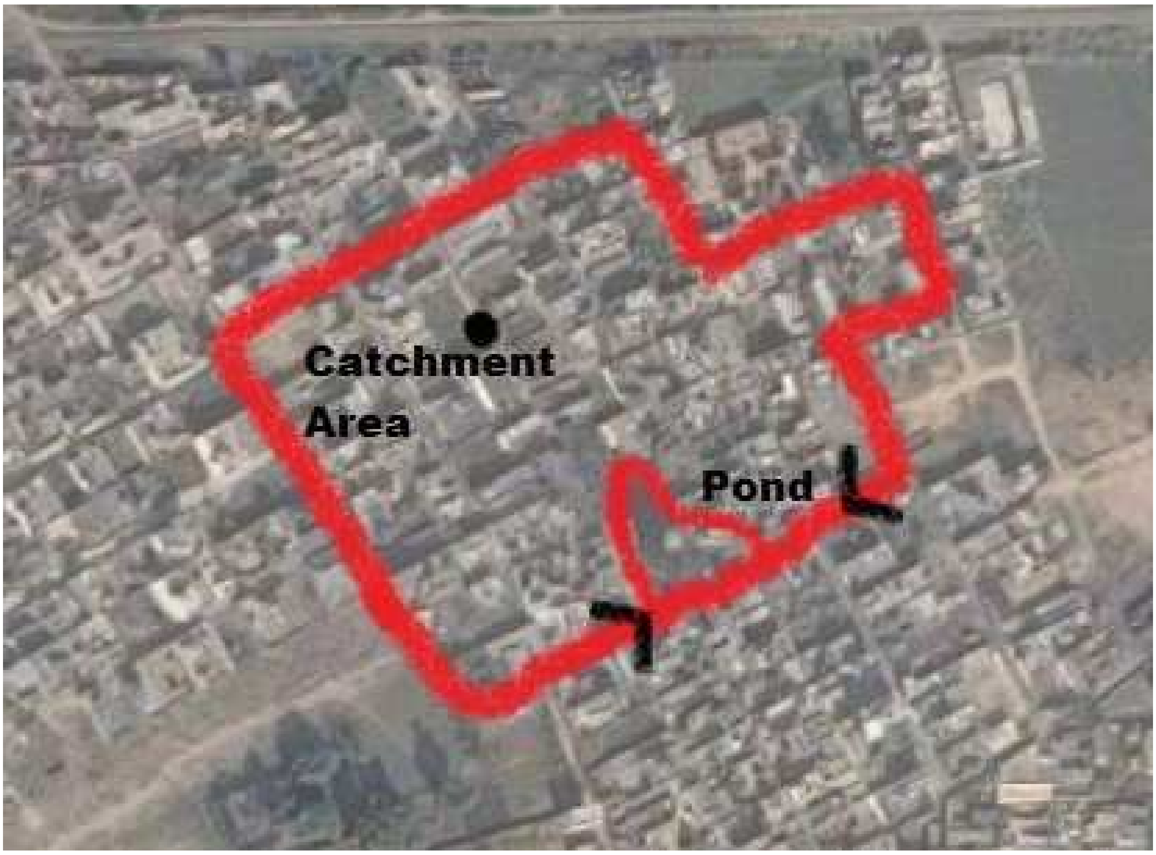


Figure 4.14: Pippa Rangi catchment

Table 4.9: Characteristics of Pippa Rangi catchment

Pond Location	**Latitude**	31°12'22.60''N
	Longitude	75°47'19.01''E
Catchment area (m^2)		40107
Human population		858
Cattle population		24
(Human : cattle) ratio		35.75
Catchment soil type		Alluvial
Number of households		180
Household water supply system		PWS[#], SP[*], HP[**]
Percent of households having submersible pumps		15%
Percent of households having sanitation facilities		91%
Drainage facilities		Open drains (constructed)
Hydraulic flow path length (m)		543
Channel slope		0.004
Land use pattern (%)	**Impervious cover**	78
	Grass cover	18
	Crop cover	0
	Tree canopy	4

[#]PWS- Piped water supply, [*]SP- Submersible pump, [**]HP- Hand pump

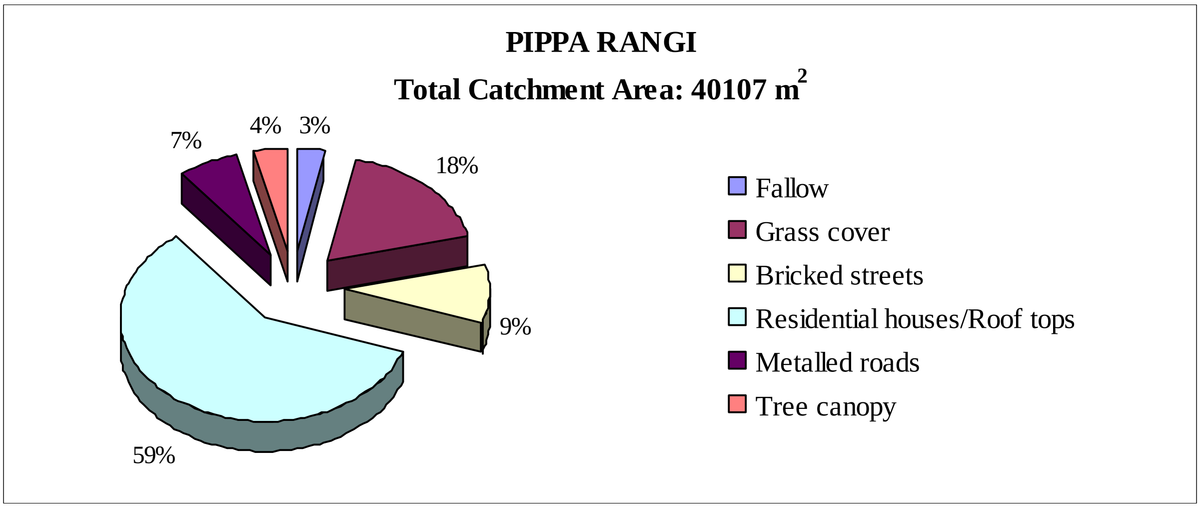
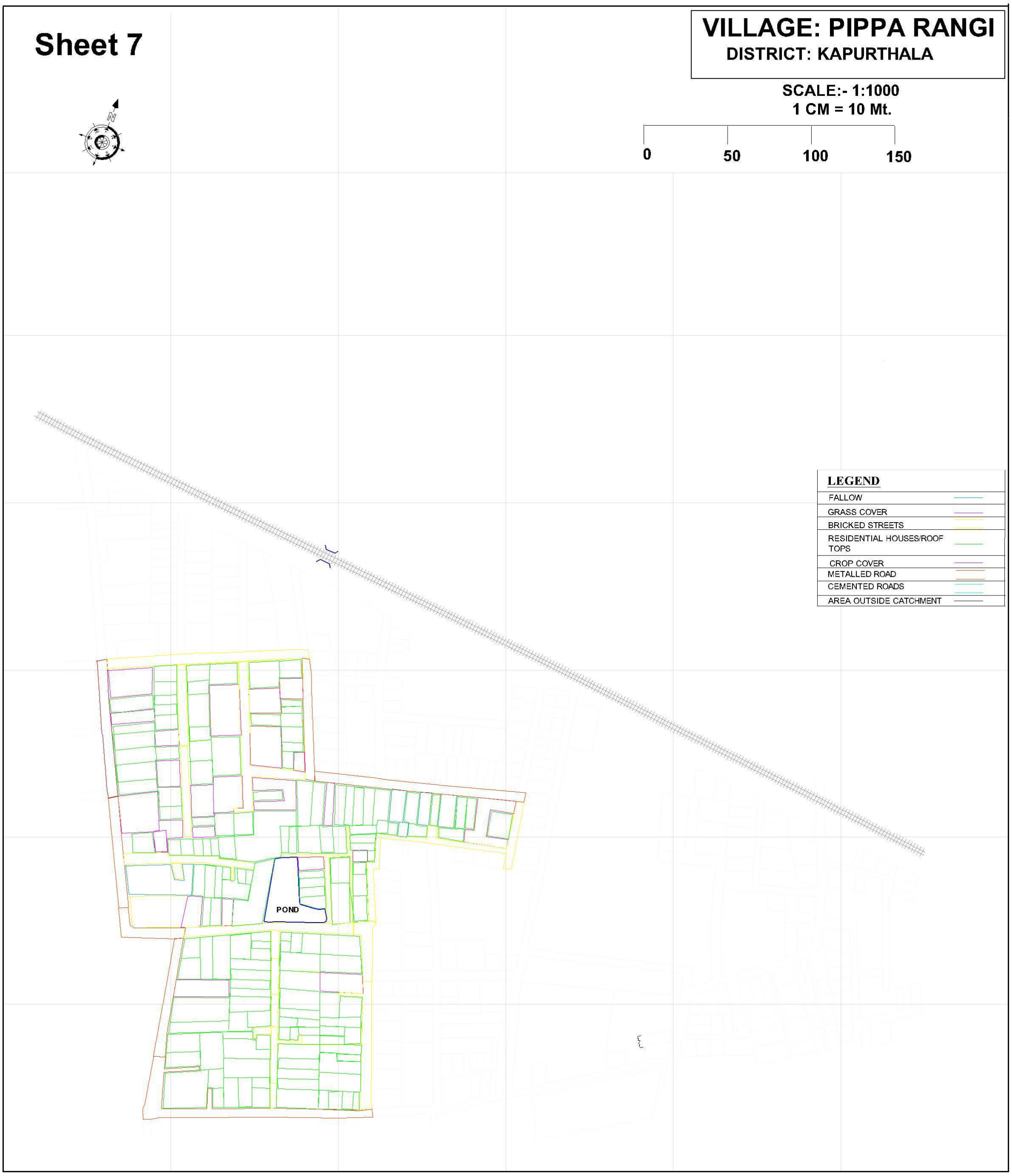


Figure 4.15: Land use pattern of Pippa Rangi catchment



Sheet 7: Survey sheet of Pippa Rangi catchment

8. Nijjran village pond catchment: Around 55% of the area of the village drained into the pond selected for the study (Figure 4.16 and survey sheet-8). Highest percentage of area under tree canopy was present in this catchment. Land use pattern of the catchment area is shown in figure 4.17. The characteristics of this catchment are given in table 4.10.

Figure 4.16: Nijjran catchment

Table 4.10: Characteristics of Nijjran catchment

Pond Location	**Latitude**	31°15’57.6’’N
	Longitude	75°28’39.36’’E
Catchment area (m^2)		45081
Human population		765
Cattle population		75
(Human : cattle) ratio		10.20
Catchment soil type		Alluvial
Number of households		179
Household water supply system		SP*, HP**
Percent of households having submersible pumps		48%
Percent of households having sanitation facilities		78%
Drainage facilities		Open drains (constructed)
Hydraulic flow path length (m)		555
Channel slope		0.0155
Land use pattern (%)	**Impervious cover**	78
	Grass cover	8
	Crop cover	4
	Tree canopy	10

*SP- Submersible pump, **HP- Hand pump

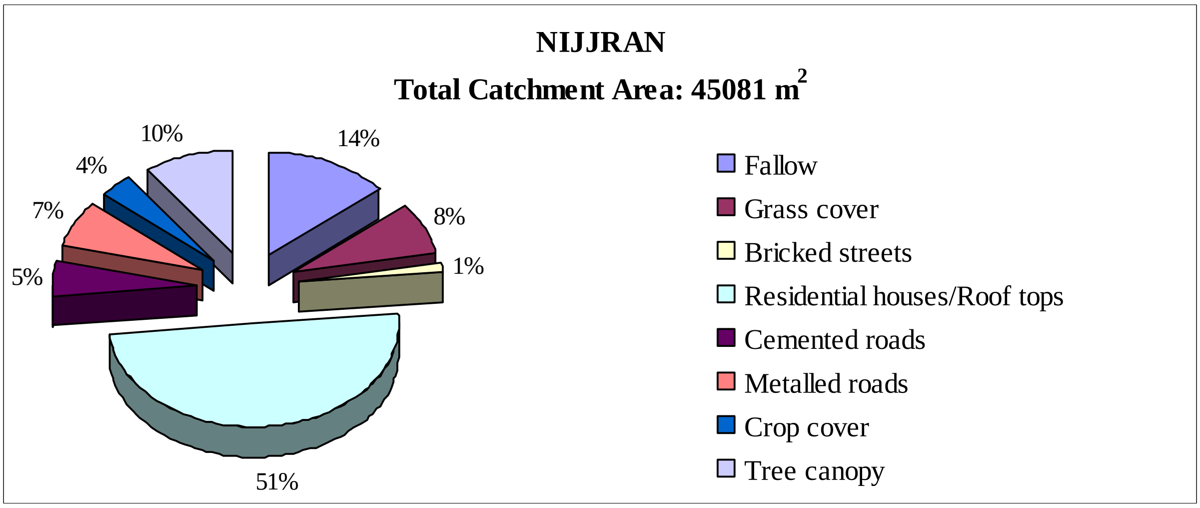


Figure 4.17: Land use pattern of Nijjran catchment

Sheet 8: Survey sheet of Nijjran Catchment

9. Samrai village pond catchment: This was the largest catchment village having highest percentage of impervious area among all the catchments. High percentage of metalled and cemented roads contributed to the high imperviousness of the catchment. Demarcated catchment area is shown in figures 4.18 and in survey sheet-9. Land use pattern as percentage of the total area is shown in figure 4.19. The catchment characteristics are mentioned in table 4.11.

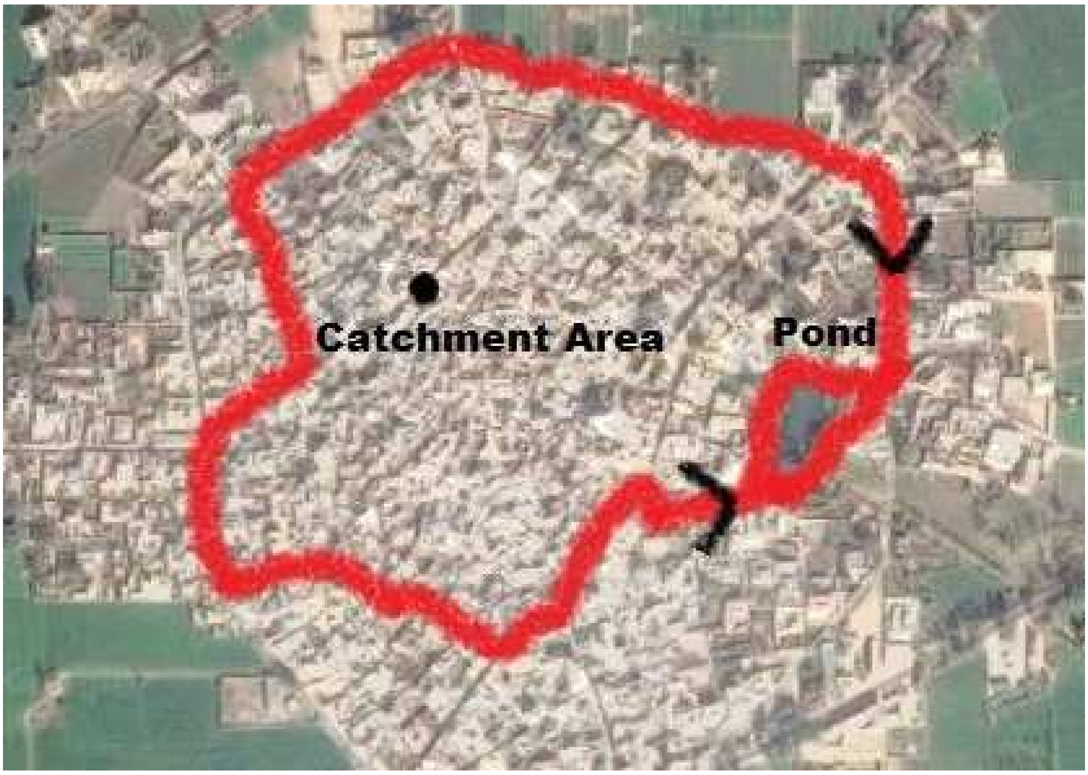


Figure 4.18: Samrai catchment

Table 4.11: Characteristics of Samrai catchment

Pond Location	**Latitude**	31°10'43.30''N
	Longitude	75°37'57.26''E
Catchment area (m^2)		114765
Human population		1879
Cattle population		144
(Human : cattle) ratio		13.05
Catchment soil type		Alluvial
Number of households		364
Household water supply system		PWS[#], SP[*], HP[**]
Percent of households having submersible pumps		31%
Percent of households having sanitation facilities		82%
Drainage facilities		Open drains (constructed)
Hydraulic flow path length (m)		895
Channel slope		0.0039
Land use pattern (%)	**Impervious cover**	92
	Grass cover	6
	Crop cover	0
	Tree canopy	2

[#]PWS- Piped water supply, [*]SP- Submersible pump, [**]HP- Hand pump

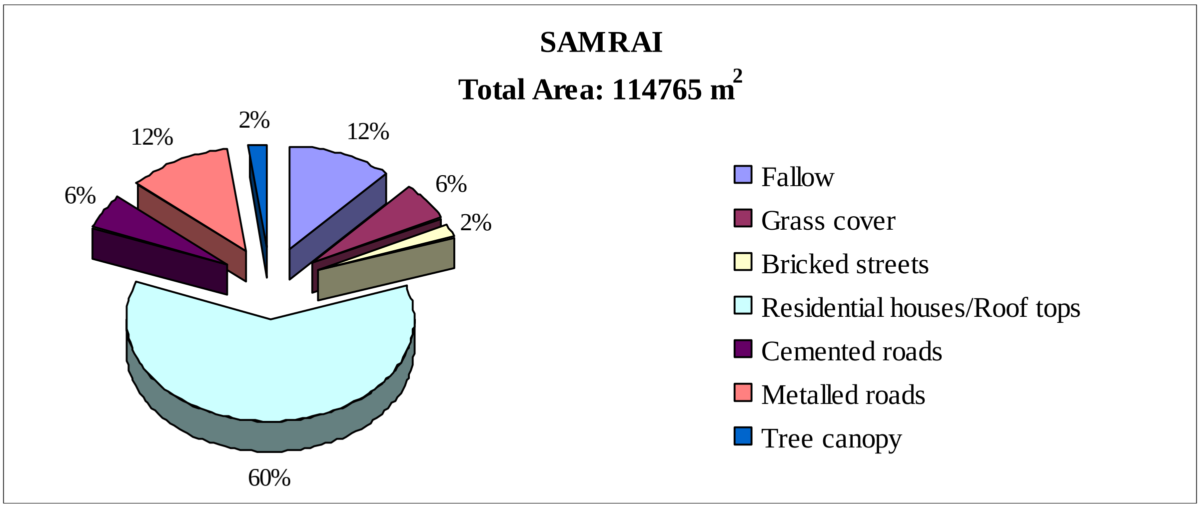


Figure 4.19: Land use pattern of Samrai catchment

Sheet 9: Survey sheet of Samrai catchment

10. Masitan village pond catchment: Almost 85% area of Masitan village formed the catchment area for the village pond. This catchment area was characterised by the high imperviousness and large population of cattle. The aerial photograph of the demarcated area of catchment is shown in figure 4.20 and survey map is shown in sheet-10. Land use pattern of the catchment as percentage of the total area is given in figure 4.21 and catchment characteristics are mentioned in table 4.12.

Figure 4.20: Masitan catchment

Table 4.12: Characteristics of Masitan catchment

Pond Location			
Pond Location	**Latitude**	31°17'3.48''N
	Longitude	75°12'45''E
Catchment area (m^2)		69137
Human population		1153
Cattle population		231
(Human : cattle) ratio		4.99
Catchment soil type		Alluvial
Number of households		198
Household water supply system		PWS#, SP*, HP**
Percent of households having submersible pumps		41%
Percent of households having sanitation facilities		84%
Drainage facilities		Open drains (constructed)
Hydraulic flow path length (m)		727
Channel slope		0.002
Land use pattern (%)	**Impervious cover**	88
	Grass cover	6
	Crop cover	5
	Tree canopy	1

#PWS- Piped water supply, *SP- Submersible pump, **HP- Hand pump

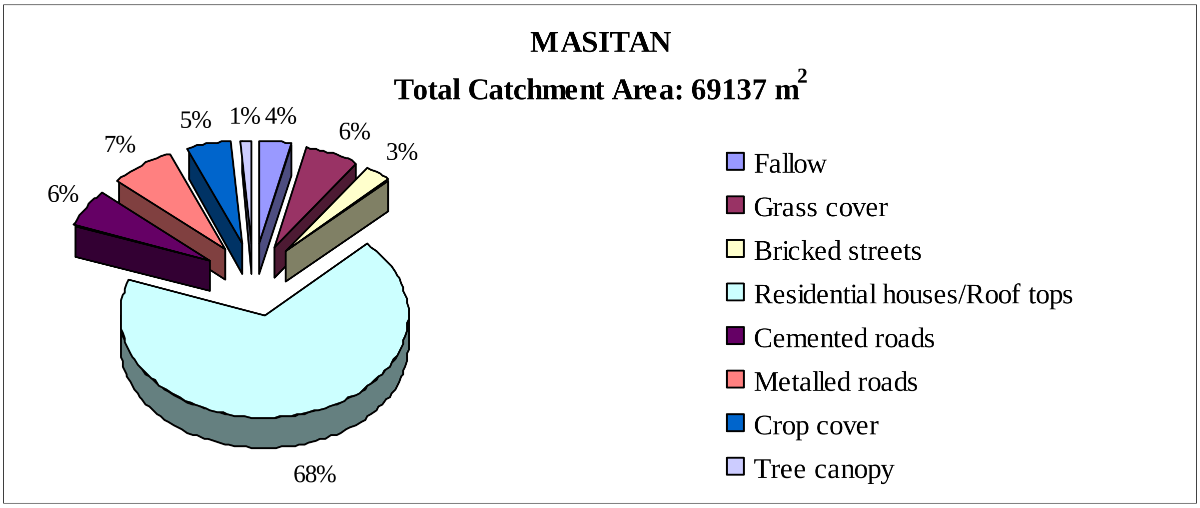
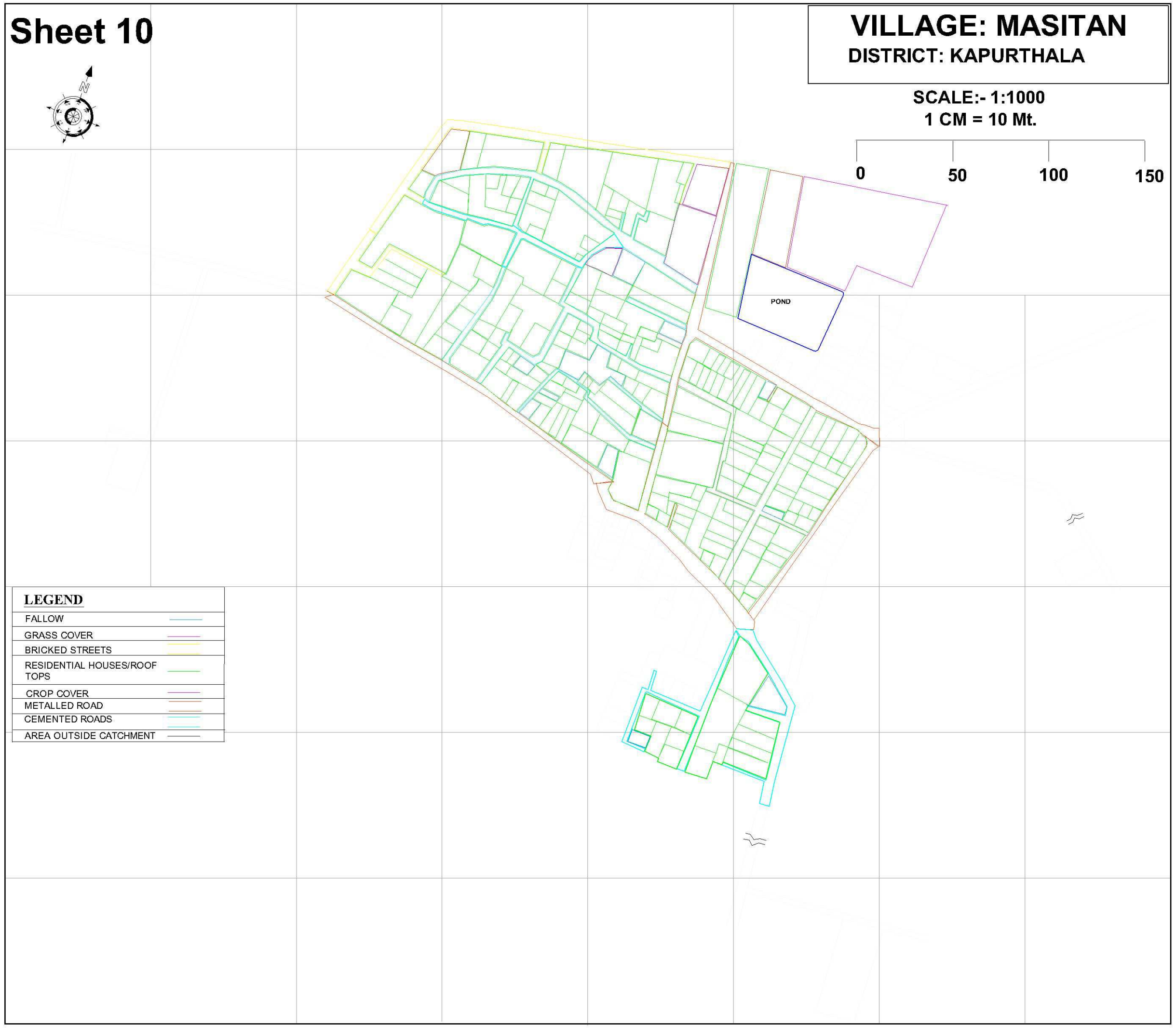


Figure 4.21: Land use pattern of Masitan catchment



Sheet 10: Survey sheet of Masitan catchment

4.2 Quantification and characterization of wastewater of the villages

4.2.1 Wastewater flow rates

Wastewater generated from the studied rural catchments included the wastewater generated from two sources .i.e. from human water consumption and cattle water consumption. Human water consumption resulted in the contribution of grey and black water into the dry weather flows of studied rural catchments, whereas cattle water consumption resulted in the contribution of cattle shed wastewater. Provision of village level water supply system (piped water supply) along with individual water supply systems (submersible pumps and motor operated hand pumps) increased the water usage as well as the wastewater generation in the pond catchments. Therefore, instead of determining the wastewater flow rates by assuming any return factor for the wastewater generated from pond catchments, actual wastewater flow rates at the outlet of the catchments were determined by using a V-notch. Wastewater quantification was carried out for seven days from April to June, 2013. Hourly wastewater flow rates were determined using equation 3.1 (Chapter 3). Wastewater flow rates during the mid-night periods were assumed to be the same as the lowest flow rates observed during the day time. Average hourly wastewater flow rates were then estimated and peak factors (using equation 3.2) were computed for the catchments.

Higher than expected volume (per capita day) of wastewater was observed to be generated from studied catchments. Table 4.13 shows the results of the wastewater quantification studies.

4.2.2 Characterization of wastewater

Characterization of the wastewater was carried out from January, 2012 to October, 2012 for six days in each catchment. Mean concentrations and standard deviations are presented in table 4.13 and detailed characterization results are given in appendix B (B-1 to B-10). Wastewater quality from rural catchments was found to be closely related with human to cattle ratio in the catchments. High solids content, organic loads and nutrients concentration (TKN and TP) were observed in Tayabpur, Sodhian, Masitan and Mandiala catchments. This could be due to low human to cattle ratio in these catchments. Fecal coliform count was also observed to be high in Tayabpur, Sodhian and Masitan. This again could be due to large cattle population in these catchments. High concentrations of nitrates were observed in the studied catchments particularly in Majari, Mandiala, Kultham and Samrai catchments. High nitrates content poses a substantial danger to the groundwater of the area as during infiltration all the nitrogen and nitrates leaches to groundwater alongwith the wastewater (Walker et al., 1973).

Elemental analysis showed that concentration of iron (Fe) was marginally higher in the catchments of Tayabpur, Sodhian, Pippa Rangi, Samrai and Masitan villages. Concentrations of other heavy metals were found to be within the limits of Indian standards for discharge of environmental pollutants in surface water (EP Rules, 1986).

Table 4.13: Summary of wastewater flow quantification and characterization in studied catchments

Rural settlements	Tayabpur	Sodhian	Majari	Palli Jhiki	Mandiala	Kultham	Pippa Rangi	Nijjran	Samrai	Masitan
Average hourly flow, m^3/hr	4.08	6.42	4.63	4.32	9.20	3.19	3.26	4.28	9.37	7.98
Peak flow, m^3/hr	12.47	19.35	16.23	14.45	28.35	10.03	10.03	14.27	29.77	25.59
Peak factor	3.05	3.02	3.51	3.34	3.08	3.15	3.07	3.33	3.18	3.20
Per capita w/w* flow, L/capita/d	181	170	142	127	155	109	91	134	120	166
TSS, mg/L	765 ± 279	760 ± 286	612 ± 233	441 ± 80	650 ± 229	527 ± 206	488 ± 189	517 ± 200	559 ± 216	757 ± 221
BOD_5^{20}, mg/L	337 ± 117	307 ± 82	261 ± 86	276± 72	295 ± 84	299 ± 58	278 ± 72	212 ± 47	259 ± 82	323 ± 82
COD, mg/L	795 ± 226	765 ± 187	667 ± 184	664 ± 177	687 ± 157	654 ± 91	597 ± 112	487 ± 152	650 ± 164	741 ± 163
TKN, mg/L	80.20±23.32	68.51±16.58	58.93±10.41	59.07±16.47	63.16±11.04	47.86±11.59	41.98±8.16	54.17±8.36	54.27±10.86	65.23±11.72
NO_3^- N, mg/L	35.32±4.88	39.20 ± 3.96	61.47±11.36	51.90±5.94	59.83±12.20	59.98±6.43	49.80±7.28	48.95±4.02	61.53±4.83	36.80±4.82
TP, mg/L	42.43±27.79	41.92±18.64	33.18±13.96	23.32±7.06	35.73±17.80	23.92±10.53	20.20±8.16	25.36±12.05	30.72±16.72	39.40±19.24
TC**	6.68±6.24	6.77±6.26	6.73±6.30	6.81±5.96	6.65±5.93	6.50±6.17	6.62±6.11	6.47±6.23	6.44±6.20	6.71±6.46
FC**	5.73±5.17	5.77±5.06	5.42±5.03	5.48±4.89	5.28±4.91	5.49±4.93	5.52±5.11	5.30±5.13	5.44±5.26	5.54±5.17
As, mg/L	0.004 ±0.003	0.012±0.008	0.011±0.004	0.009±0.005	0.024±0.007	0.003±0.002	0.004±0.002	0.014±0.05	0.001±0.001	0.016±0.010
Cd, mg/L	0.012 ±0.008	0.009±0.004	0.059±0.040	0.10±0.059	0.170±0.092	0.003±0.001	0.004±0.002	0.020±0.013	0.01±0.016	0.008±0.006
Cr, mg/L	0.30 ±0.08	0.43±0.20	0.40±0.30	0.60±0.31	1.00±0.33	0.61±0.77	0.87±0.91	1.70±0.79	0.47±0.12	0.40±0.06
Cu, mg/L	0.107 ±0.086	0.052±0.029	0.557±0.203	0.446±0.211	0.983±0.440	0.204±0.372	0.109±0.105	0.792±0.491	0.108±0.099	0.114±0.131
Fe, mg/L	2.94 ±0.77	3.29±0.79	1.08±0.50	1.13±0.47	1.45±0.47	1.96±0.43	3.26±1.58	1.92±0.60	3.52±1.01	3.97±0.92
Mn, mg/L	0.205 ±0.063	0.243±0.101	0.082±0.027	0.116±0.063	0.333±0.220	0.300±0.238	0.201±0.124	0.217±0.078	0.134±0.049	0.197±0.036
Ni, mg/L	0.145 ±0.106	0.142±0.063	0.079±0.019	0.101±0.043	0.098±0.058	0.056±0.012	0.046±0.010	0.193±0.096	0.054±0.013	0.077±0.032
Pb, mg/L	0.064 ±0.040	0.018±0.011	0.022±0.018	0.022±0.013	0.027±0.027	0.085±0.105	0.051±0.039	0.014±0.006	0.059±0.044	0.082±0.063
Zn, mg/L	0.45 ± 0.22	0.23±0.22	1.41±0.43	0.72±0.26	0.88±0.38	0.67±0.74	0.39±0.30	0.77±0.30	0.49±0.24	0.46±0.30

*Wastewater, **Total coliforms and fecal coliforms expressed in log (base 10) values

4.3 Quantification and characterization of stormwater of the villages

4.3.1 Stormwater runoff volume and peak stormwater flow rates estimation

For the determination of stormwater runoff volumes, each of the studied catchments was divided into sub-areas on the basis of land cover and land use. According to Statistical abstract of Punjab, soil type in Jalandhar and Kapurthala districts is alluvial, whereas in Nawanshahar district, the prominent soil type is sandy loam. Both of these soils are classified under hydrologic soil group B. So, the hydrologic soil group 'B' was adopted to assess the Curve Numbers (CN). Weighted CN were then determined for all the catchments using the equation 3.3.

In this study, stormwater runoff volumes corresponding to 10, 35, 50, 65 and 90 percentile rainfall event sizes were determined for each of the catchments. Two extreme rainfall event sizes were also considered for stormwater runoff volume assessment to highlight the difference between the 90 percentile rainfall event and the extreme rainfall event stormwater runoff generation. The required percentile rainfall event sizes were determined after excluding the rainfall events that yielded no stormwater runoff (equation 3.6).

For estimating the stormwater runoff volumes generated from the catchments, runoff depth or effective rainfall corresponding to each percentile rainfall event size was determined using equation 3.7. These effective rainfall values were used to compute the stormwater runoff volumes generated in each of the catchments (equation 3.8)

IDF curves were developed for the meteorological stations for the determination of peak stormwater runoff flow rates. Procedure adopted for the development of IDF curves for each of the meteorological stations is given in appendix C. Generalized IDF relationship (equation 3.14) formulated is shown in table 4.14.

Table 4.14: Derived IDF equations for different meteorological stations

Meteorological station	Gumbel's constant			IDF equation
	C	m	n	
Nawanshahar	469.77	0.24	0.667	$I_T = (469.77*T^{0.24})/t^{0.667}$
Kapurthala	305.96	0.26	0.667	$I_T = (305.96*T^{0.26})/ t^{0.667}$
Jalandhar	340.29	0.27	0.667	$I_T = (340.29*T^{0.27})/ t^{0.667}$
Phagwara	379.9	0.29	0.667	$I_T = (379.9*T^{0.29})/ t^{0.667}$
Nakodar	344.91	0.31	0.667	$I_T = (344.91*T^{0.31})/ t^{0.667}$

Stormwater flow quantification for each of the pond catchments is discussed below:

1. Tayabpur catchment: Tayabpur catchment generated minimum runoff volumes among all the catchments because of the smallest catchment area and low effective rainfall values as shown in figure 4.22. Weighted CN and average rainfall depth at different percentile rainfall event sizes for Tayabpur catchment are shown in table 4.15. Table 4.16 provides the summary of the peak runoff estimations for Tayabpur catchment.

Table 4.15: Summary of stormwater runoff volume quantification in Tayabpur catchment

Land Use	CN	Area, (m^2)	Percentile rainfall event sizes	Average rainfall depth, (mm)
Fallow	86	1011	**10**	10.0
Grass cover	69	6294	**35**	15.0
Bricked streets	85	3779	**50**	20.0
Residential houses/roof tops	98	10980	**65**	27.0
Cemented roads	98	--	**90**	60.0
Metalled roads	98	595	**Extreme rainfall event 1**	102.0
Crop cover	85	1511	**Extreme rainfall event 2**	137.0
Tree canopy	65	1007	**Minimum rainfall depth for runoff generation (mm)**	8.12
Total catchment area (m^2)	**25177**		**90 percentile rainfall event runoff volume (m^3)**	733
Weighted CN	**86.22**			

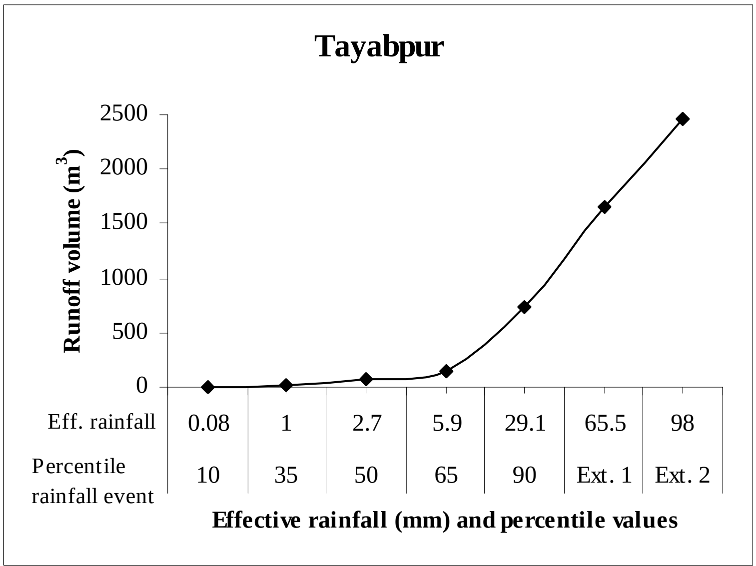


Figure 4.22: Variation of runoff volume with effective rainfall in Tayabpur

Table 4.16: Summary of stormwater flow rate estimated for Tayabpur catchment

2 year 24-hr rainfall, P_2 (mm)	80
Effective rainfall, Q (mm)	45.93
Composite runoff coefficient, C	0.57
Time of concentration, t_c (min.)	10
Rainfall intensity, I_T (mm/hr)	78.93
Peak runoff rate, Q_P (m^3/s)	0.32

2. Sodhian catchment: In this catchment, large stormwater volume increase was observed between 90 percentile rainfall event size and first extreme rainfall event as shown in figure 4.23. Weighted CN and average rainfall depth at different percentile rainfall event size for Sodhian catchment are shown in table 4.17. Table 4.18 provides the summary of the peak runoff estimations.

Table 4.17: Summary of stormwater volume quantification in Sodhian catchment

Land Use	CN	Area, (m^2)	Rainfall percentile values	Average rainfall depth, (mm)
Fallow	86	10064	**10**	7.6
Grass cover	69	8803	**35**	12.0
Bricked streets	85	11497	**50**	17.7
Residential houses/roof tops	98	31938	**65**	24.1
Cemented roads	98	--	**90**	54.4
Metalled roads	98	--	**Extreme rainfall event 1**	158.6
Crop cover	85	4063	**Extreme rainfall event 2**	203.0
Tree canopy	65	1354	**Minimum rainfall depth for runoff generation (mm)**	6.41
Total catchment area (m^2)	**67720**		**90 percentile rainfall event runoff volume (m^3)**	1949
Weighted CN	**88.80**			

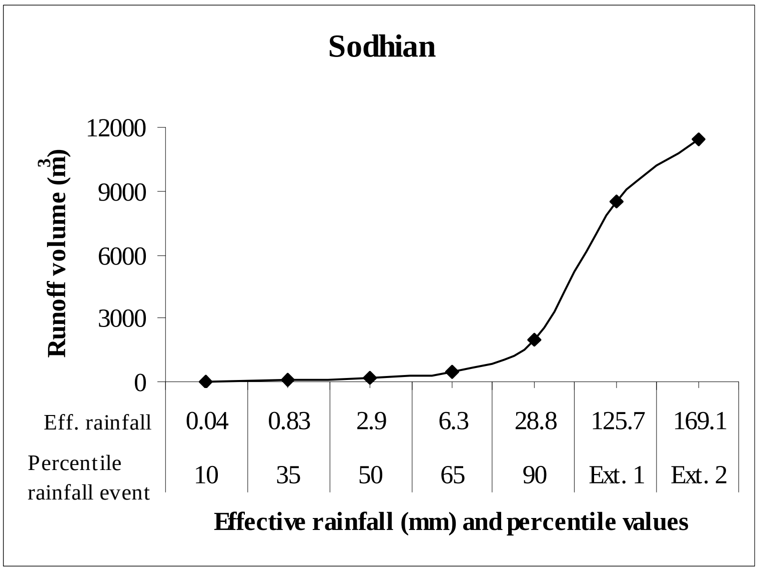


Figure 4.23: Variation of runoff volume with effective rainfall in Sodhian

Table 4.18: Summary of stormwater flow rate estimated for Sodhian catchment

2 year 24-hr rainfall, P_2 (mm)	110
Effective rainfall, Q (mm)	79.12
Composite runoff coefficient, C	0.72
Time of concentration, t_c (min.)	12.89
Rainfall intensity, I_T (mm/hr)	100.91
Peak runoff rate, Q_P (m^3/s)	1.38

3. Majari catchment: Majari catchment was one of the most impervious of all the catchments resulting in the generation of high effective rainfall for a given percentile of rainfall depth. Weighted CN and average rainfall depth at different percentile event sizes for Majari catchment are tabulated in table 4.19 and results of the peak runoff estimations are given in table 4.20. Figure 4.24 presents the variation of stormwater runoff volumes at different effective rainfalls.

Table 4.19: Summary of stormwater volume quantification in Majari catchment

Land Use	CN	Area, (m^2)	Rainfall percentile values	Average rainfall depth, (mm)
Fallow	86	2384	**10**	4.8
Grass cover	69	3062	**35**	8.4
Bricked streets	85	4126	**50**	12.2
Residential houses/roof tops	98	26334	**65**	20.0
Cemented roads	98	--	**90**	47.6
Metalled roads	98	1606	**Extreme rainfall event 1**	158.6
Crop cover	85	--	**Extreme rainfall event 2**	203.0
Tree canopy	65	765	**Minimum rainfall depth for runoff generation (mm)**	3.90
Total catchment area (m^2)	**38277**		**90 percentile rainfall event runoff volume (m^3)**	1157
Weighted CN	**92.87**			

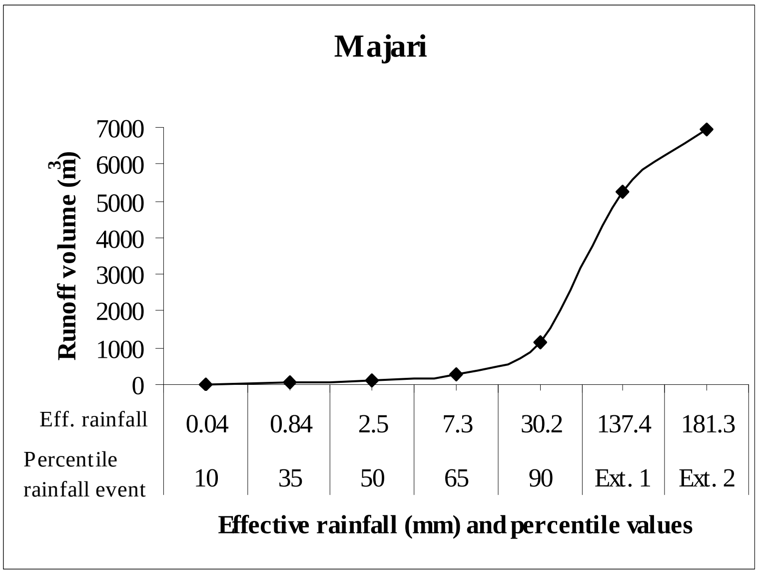


Figure 4.24: Variation of runoff volume with effective rainfall in Majari

Table 4.20: Summary of stormwater flow rate estimated for Majari catchment

2 year 24-hr rainfall, P_2 (mm)	110
Effective rainfall, Q (mm)	89.63
Composite runoff coefficient, C	0.81
Time of concentration, t_c (min.)	10
Rainfall intensity, I_T (mm/hr)	119.52
Peak runoff rate, Q_P (m^3/s)	1.04

4. Palli Jhiki catchment: In this catchment, stormwater runoff volume increased by more than four times between 90th percentile rainfall event size and first extreme rainfall event size. The runoff volumes variation with effective rainfalls is presented in figure 4.25. Weighted CN and average rainfall depth at different percentile rainfall event size are given in table 4.21 and results of the peak stormwater runoff estimations are shown in table 4.22.

Table 4.21: Summary of stormwater volume quantification in Palli Jhiki catchment

Land Use	CN	Area, (m^2)	Rainfall percentile values	Average rainfall depth, (mm)
Fallow	86	5802	**10**	7.0
Grass cover	69	4456	**35**	11.2
Bricked streets	85	2984	**50**	16.3
Residential houses/roof tops	98	23802	**65**	23.0
Cemented roads	98	--	**90**	54.0
Metalled roads	98	2176	**Extreme rainfall event 1**	158.6
Crop cover	85	872	**Extreme rainfall event 2**	203.0
Tree canopy	65	3486	**Minimum rainfall depth for runoff generation (mm)**	5.87
Total catchment area (m^2)	**43578**		**90 percentile rainfall event runoff volume (m^3)**	1303
Weighted CN	**89.65**			

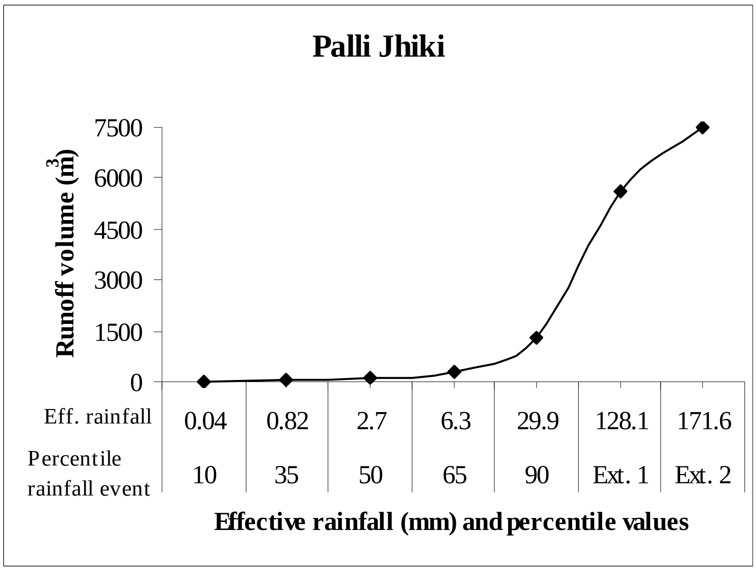


Figure 4.25: Variation of runoff volume with effective rainfall in Palli Jhiki

Table 4.22: Summary of stormwater flow rate estimated for Palli Jhiki catchment

2 year 24-hr rainfall, P_2 (mm)	110
Effective rainfall, Q (mm)	81.25
Composite runoff coefficient, C	0.74
Time of concentration, t_c (min.)	10.78
Rainfall intensity, I_T (mm/hr)	113.68
Peak runoff rate, Q_P (m^3/s)	1.03

5. Mandiala catchment: Mandiala catchment was the second largest catchment in terms of area therefore large volumes of stormwater runoff was generated from this catchment as presented in figure 4.26. Weighted CN and average rainfall depth at different percentile rainfall event sizes are shown in table 4.23 and results of the peak runoff flow rate estimation are given in table 4.24.

Table 4.23: Summary of stormwater volume quantification in Mandiala catchment

Land Use	CN	Area, (m^2)	Rainfall percentile values	Average rainfall depth, (mm)
Fallow	86	5061	**10**	5.0
Grass cover	69	5398	**35**	9.4
Bricked streets	85	8270	**50**	14.0
Residential houses/roof tops	98	52729	**65**	18.0
Cemented roads	98	--	**90**	45.0
Metalled roads	98	3287	**Extreme rainfall event 1**	136.0
Crop cover	85	--	**Extreme rainfall event 2**	237.0
Tree canopy	65	2312	**Minimum rainfall depth for runoff generation (mm)**	3.94
Total catchment area (m^2)	**77057**		**90 percentile rainfall event runoff volume (m^3)**	2137
Weighted CN	**92.80**			

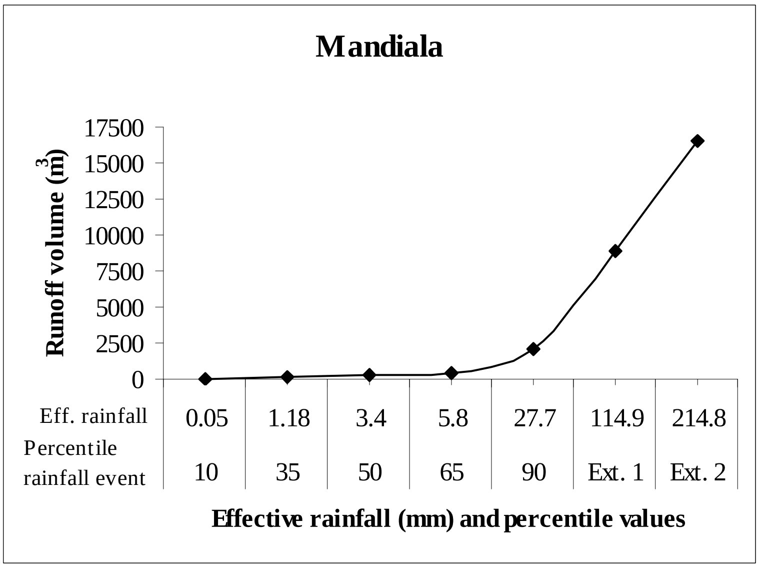


Figure 4.26: Variation of runoff volume with effective rainfall in Mandiala

Table 4.24: Summary of stormwater flow rate estimated for Mandiala catchment

2 year 24-hr rainfall, P_2 (mm)	75
Effective rainfall, Q (mm)	55.62
Composite runoff coefficient, C	0.74
Time of concentration, t_c (min.)	18.27
Rainfall intensity, I_T (mm/hr)	61.63
Peak runoff rate, Q_P (m^3/s)	0.98

6. Kultham catchment: Large runoff volume variation was observed between 90 percentile rainfall event and first extreme rainfall event in this catchment. Figure 4.27 presents the variation of runoff volumes with effective rainfall. Weighted CN and average rainfall depth at different percentile event sizes are shown in table 4.25 and peak runoff estimations are given in table 4.26.

Table 4.25: Summary of stormwater volume quantification in Kultham catchment

<table>
<tr><th>Land Use</th><th>CN</th><th>Area, (m^2)</th><th>Rainfall percentile values</th><th>Average rainfall depth, (mm)</th></tr>
<tr><td>Fallow</td><td>86</td><td>3349</td><td>10</td><td>6.9</td></tr>
<tr><td>Grass cover</td><td>69</td><td>3763</td><td>35</td><td>11.0</td></tr>
<tr><td>Bricked streets</td><td>85</td><td>3326</td><td>50</td><td>16.0</td></tr>
<tr><td>Residential houses/roof tops</td><td>98</td><td>13457</td><td>65</td><td>22.5</td></tr>
<tr><td>Cemented roads</td><td>98</td><td>--</td><td>90</td><td>53.2</td></tr>
<tr><td>Metalled roads</td><td>98</td><td>4324</td><td>Extreme rainfall event 1</td><td>158.6</td></tr>
<tr><td>Crop cover</td><td>85</td><td>2822</td><td>Extreme rainfall event 2</td><td>203.0</td></tr>
<tr><td>Tree canopy</td><td>65</td><td>314</td><td>Minimum rainfall depth for runoff generation (mm)</td><td>5.42</td></tr>
<tr><td>Total catchment area (m^2)</td><td colspan="2">31355</td><td rowspan="2">90 percentile rainfall event runoff volume (m^3)</td><td rowspan="2">956</td></tr>
<tr><td>Weighted CN</td><td colspan="2">90.36</td></tr>
</table>

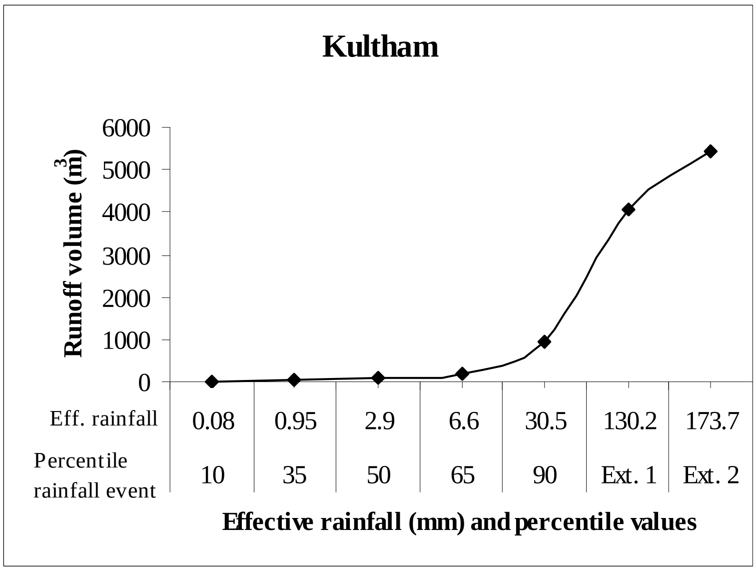


Figure 4.27: Variation of runoff volume with effective rainfall in Kultham

Table 4.26: Summary of stormwater flow rate estimated for Kultham catchment

2 year 24-hr rainfall, P_2 (mm)	110
Effective rainfall, Q (mm)	83.06
Composite runoff coefficient, C	0.76
Time of concentration, t_c (min.)	13.34
Rainfall intensity, I_T (mm/hr)	98.63
Peak runoff rate, Q_P (m^3/s)	0.66

7. Pippa Rangi catchment: For Pippa Rangi catchment, variation of runoff volume with effective rainfall is shown in figure 4.28 which shows relatively high effective rainfall and more runoff volume generation corresponding to 90 percentile rainfall event than the bigger catchments like Palli Jhiki and Nijjran. Weighted CN and average rainfall depth at different percentile rainfall events are tabulated in table 4.27 and results of the peak runoff estimations are given in table 4.28.

Table 4.27: Summary of stormwater volume quantification in Pippa Rangi catchment

Land Use	CN	Area, (m^2)	Rainfall percentile values	Average rainfall depth, (mm)
Fallow	86	1250	**10**	7.0
Grass cover	69	7219	**35**	13.0
Bricked streets	85	3645	**50**	18.0
Residential houses/roof tops	98	23765	**65**	26.0
Cemented roads	98	--	**90**	65.0
Metalled roads	98	2625	**Extreme rainfall event 1**	126.0
Crop cover	85	--	**Extreme rainfall event 2**	203.0
Tree canopy	65	1604	**Minimum rainfall depth for runoff generation (mm)**	5.70
Total catchment area (m^2)	**40107**		**90 percentile rainfall event runoff volume (m^3)**	1606
Weighted CN	**89.91**			

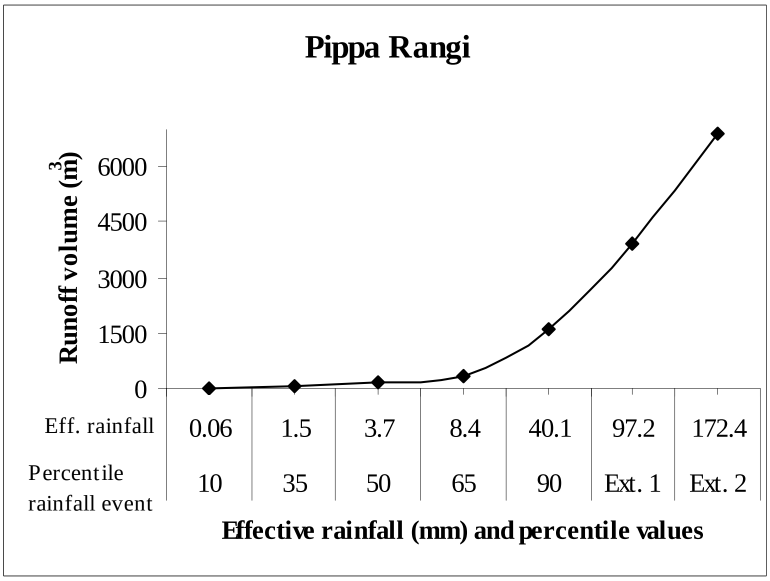


Figure 4.28: Variation of runoff volume with effective rainfall in Pippa Rangi

Table 4.28: Summary of stormwater flow rate estimated for Pippa Rangi catchment

2 year 24-hr rainfall, P_2 (mm)	75
Effective rainfall, Q (mm)	49.09
Composite runoff coefficient, C	0.65
Time of concentration, t_c (min.)	12.07
Rainfall intensity, I_T (mm/hr)	88.27
Peak runoff rate, Q_P (m^3/s)	0.64

8. Nijjran catchment: Runoff volume variation with effective rainfall is presented in figure 4.29 and summary of runoff volume quantification and peak runoff estimations are given in table 4.29 and 4.30, respectively.

Table 4.29: Summary of stormwater volume quantification in Nijjran catchment

Land Use	**CN**	**Area, (m^2)**	**Rainfall percentile values**	**Average rainfall depth, (mm)**
Fallow	86	6242	**10**	7.9
Grass cover	69	3624	**35**	13.0
Bricked streets	85	667	**50**	18.0
Residential houses/roof tops	98	22508	**65**	25.0
Cemented roads	98	2474	**90**	51.0
Metalled roads	98	3255	**Extreme rainfall event 1**	130.0
Crop cover	85	1803	**Extreme rainfall event 2**	164.0
Tree canopy	65	4508	**Minimum rainfall depth for runoff generation (mm)**	5.65
Total catchment area (m^2)	**45081**		**90 percentile rainfall event runoff volume (m^3)**	1260
Weighted CN	**89.99**			

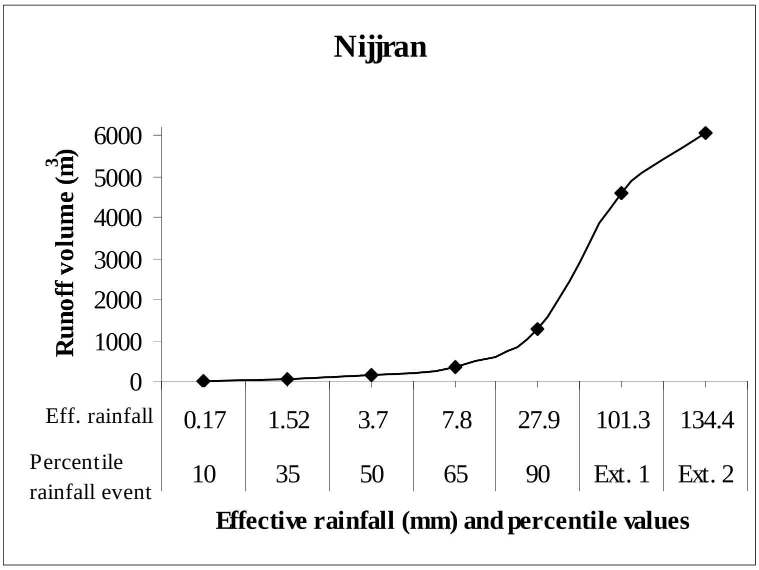


Figure 4.29: Variation of runoff volume with effective rainfall in Nijjran

Table 4.30: Summary of stormwater flow rate estimated for Nijjran catchment

2 year 24-hr rainfall, P_2 (mm)	75
Effective rainfall, Q (mm)	49.28
Composite runoff coefficient, C	0.66
Time of concentration, t_c (min.)	12.34
Rainfall intensity, I_T (mm/hr)	76.83
Peak runoff rate, Q_P (m^3/s)	0.64

9. Samrai catchment: Maximum runoff volumes and highest peak runoff rates were observed to be generated from Samrai catchment due to the largest pond catchment area and high weighted CN. Weighted CN and average rainfall depth at different percentile rainfall event size are given in table 4.31 and results of the peak runoff estimations are shown in table 4.32. Figure 4.30 shows the variation of runoff volume with effective rainfall.

Table 4.31: Summary of stormwater volume quantification in Samrai catchment

Land Use	CN	Area, (m^2)	Rainfall percentile values	Average rainfall depth, (mm)
Fallow	86	13311	**10**	4.7
Grass cover	69	7043	**35**	10.0
Bricked streets	85	2176	**50**	14.0
Residential houses/roof tops	98	70229	**65**	20.0
Cemented roads	98	6337	**90**	60.0
Metalled roads	98	13374	**Extreme rainfall event 1**	126.0
Crop cover	85	--	**Extreme rainfall event 2**	203.0
Tree canopy	65	2295	**Minimum rainfall depth for runoff generation (mm)**	3.29
Total catchment area (m^2)	**114765**		**90 percentile rainfall event runoff volume (m^3)**	5046
Weighted CN	**93.92**			

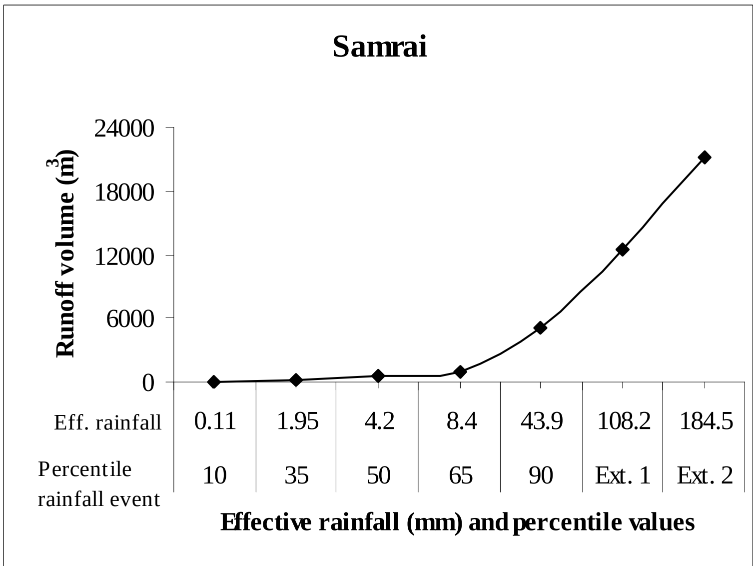


Figure 4.30: Variation of runoff volume with effective rainfall in Samrai

Table 4.32: Summary of stormwater flow rate estimated for Samrai catchment

2 year 24-hr rainfall, P_2 (mm)	75
Effective rainfall, Q (mm)	58.34
Composite runoff coefficient, C	0.78
Time of concentration, t_c (min.)	19.89
Rainfall intensity, I_T (mm/hr)	63.27
Peak runoff rate, Q_P (m^3/s)	1.59

10. Masitan catchment: Masitan catchment exhibited highest weighted CN among all the catchments owing to its high imperviousness as shown in table 4.33. Figure 4.31 presents the stormwater volume variation with effective rainfall. Peak stormwater estimations are given in table 4.34.

Table 4.33: Summary of stormwater volume quantification in Masitan catchment

Land Use	CN	Area, (m^2)	Rainfall percentile values	Average rainfall depth, (mm)
Fallow	86	2536	**10**	4.0
Grass cover	69	4148	**35**	9.0
Bricked streets	85	2187	**50**	13.0
Residential houses/roof tops	98	46837	**65**	20.0
Cemented roads	98	4270	**90**	50.0
Metalled roads	98	5012	**Extreme rainfall event 1**	102.0
Crop cover	85	3456	**Extreme rainfall event 2**	137.0
Tree canopy	65	691	**Minimum rainfall depth for runoff generation (mm)**	3.00
Total catchment area (m^2)	**69137**		**90 percentile rainfall event runoff volume (m^3)**	2464
Weighted CN	**94.43**			

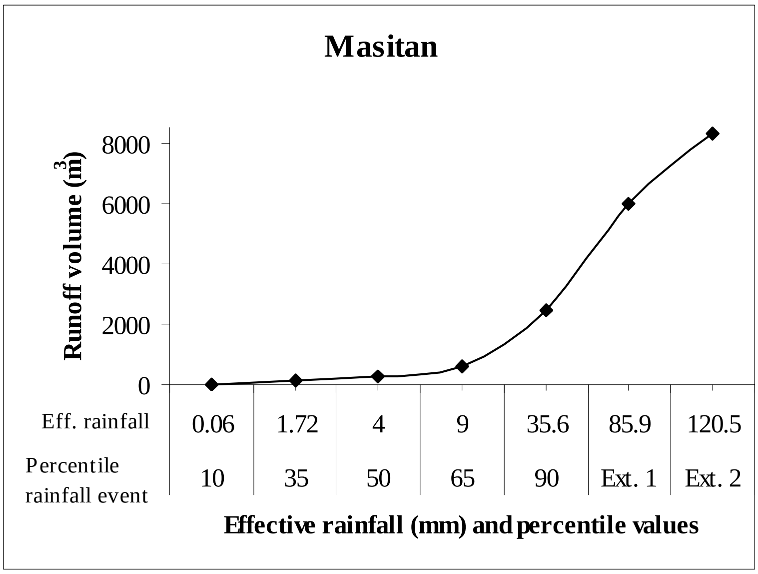


Figure 4.31: Variation of runoff volume with effective rainfall in Masitan

Table 4.34: Summary of stormwater flow rate estimated for Masitan catchment

2 year 24-hr rainfall, P_2 (mm)	80
Effective rainfall, Q (mm)	64.46
Composite runoff coefficient, C	0.81
Time of concentration, t_c (min.)	16.16
Rainfall intensity, I_T (mm/hr)	57.31
Peak runoff rate, Q_P (m^3/s)	0.90

4.3.2 Characterization of stormwater runoff (wet weather flows)

During the characterization of the wet weather flows, a minimum gap of 4 days was maintained between any two successive sampling events (Caltrans 2000). Results of the characterization are given in table 4.35. Raw data of stormwater characterization studies is given in appendix D (Tables D-1 to D-10).

On the basis of the characterization results, following inferences can be drawn:

- Large variations in the pollutant concentrations were observed between among the catchments. This observation could be attributed to the complex interactions among the factors, like, drainage area, extent of development, land use pattern and amount and distribution of impervious area.

- High standard deviations (std. dev.) were observed for TSS, BOD_5^{20}, COD, TKN, TP, TC and FC in Samrai, Mandiala, Masitan and Sodhian catchments showing the large temporal fluctuations in the wet weather flow pollutant concentrations in large sized catchments. Large size of the catchments might be responsible for contributing different concentrations of pollutants at different times.
- As stormwater samples were taken from the drains feeding wet weather flows to the pond, therefore in this study, high mean pollutant concentrations of suspended solids and organic constituents were observed in comparison to the stormwater characterization results of some other researchers who had monitored strictly stormwater flows (Smullen et al. 1999, Arora and Reddy, 2014).

The characterization results indicate that the wet weather flows from pond catchments was high in solids content, organic loads and bacterial count and therefore cannot be used in irrigation and groundwater recharge without subjecting to treatment (EP Rules, 1986).

Table 4.35: Summary of wet weather flow quality parameters

Parameters→	TDS	TSS	BOD_5^{20}	COD	TKN	NO_3^- -N	TP	TC	FC	Zn	Cu	Fe
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	log to base 10	log to base 10	mg/L	mg/L	mg/L
	Tayabpur											
mean	389	184	102	303	10.20	5.68	2.47	5.57	4.51	0.09	0.02	1.52
std. Dev.	50	48	26	52	1.77	0.91	0.66	5.08	4.09	0.02	0.01	0.38
	Sodhian											
mean	349	133	96	231	11.21	5.27	2.43	5.59	4.77	0.12	0.02	0.97
std. Dev.	86	72	54	117	2.22	2.53	0.57	5.15	4.32	0.03	0.01	0.16
	Majari											
mean	418	206	102	305	10.99	5.25	1.42	5.03	4.24	0.07	0.02	1.45
std. Dev.	76	53	27	59	1.78	1.02	0.74	4.89	4.22	0.03	0.01	0.40
	Palli Jhiki											
mean	362	218	84	206	7.32	4.29	1.32	5.52	4.36	0.07	0.02	1.24
std. Dev.	71	52	40	77	2.67	1.38	0.58	5.16	3.88	0.03	0.01	0.28
	Mandiala											
mean	372	211	108	290	10.38	5.96	2.85	5.66	4.85	0.14	0.01	1.59
std. Dev.	81	110	70	125	3.32	2.79	1.49	5.39	4.33	0.04	0.01	0.53
	Kultham											
mean	455	222	95	238	9.62	5.32	1.53	5.48	4.41	0.15	0.02	0.88
std. Dev.	70	57	35	83	3.15	2.95	0.64	5.12	4.22	0.06	0.01	0.35
	Pippa Rangi											
mean	430	213	93	266	7.93	3.76	1.86	5.51	4.49	0.10	0.02	1.36
std. Dev.	74	66	39	76	1.70	1.01	0.75	5.12	4.05	0.04	0.02	0.41
	Nijjran											
mean	355	147	67	195	8.84	4.41	2.08	5.72	4.57	0.13	0.02	1.41
std. Dev.	74	55	42	87	1.82	1.37	0.81	5.41	4.29	0.02	0.01	0.29
	Samrai											
mean	359	225	115	315	12.35	6.46	2.44	5.61	4.57	0.15	0.02	1.42
std. Dev.	91	134	80	130	3.79	3.49	1.37	5.45	4.37	0.05	0.01	0.44
	Masitan											
mean	421	230	116	294	9.45	6.44	2.41	5.72	4.65	0.11	0.01	1.51
std. Dev.	82	100	57	103	2.64	2.30	1.03	5.36	4.29	0.03	0.01	0.36

4.3.3 Regression models

Since the rainfall events showed high spatial and temporal variability, and since it is not feasible to monitor all the effective rainfall events, therefore, in the present study, the characterization results of stormwater runoff and storm variables i.e. ADD and rainfall depth (R_D) have been used to develop predictive models for the assessment of stormwater quality parameters in the studied catchments.

For Tayabpur, Sodhian, Majari, Mandiala and Samrai catchments, 10 rainfall events were used for regression model development and 5 were used for the validation of the developed regression models. While for the remaining catchments (Palli Jhiki, Kultham, Pippa Rangi, Nijjran and Masitan), 8 storms were used for model development and validation was done against 4 rainfall events.

Validation of the developed regression models was done by applying the chi square test on additional rainfall events and evaluating the goodness of fit at the level of significance set at α = 0.05. The obtained chi square values were found to be less than the tabulated chi square values (9.49 at df=4, 7.82 at df=3) for most of the cases. The developed regression models (equation 3.19) for estimating the mean pollutant concentrations for each of the catchments are discussed below:

1. Tayabpur catchment: In Tayabpur catchment, measured pollutant loads of BOD_5^{20}, TKN and Fe demonstrated high variability with ADD and average rainfall depth, which was evident from high values of coefficients of determination ($R^2 \geq 0.95$). For other measured parameters, moderate relationship was observed between dependent parameters and independent rainfall variables ($0.68 < R^2 < 0.95$). Characteristics of storm events monitored are mentioned in table 4.36 and developed regression models are shown in table 4.37.

Table 4.36: Characteristics of storm events monitored in Tayabpur catchment

Date of Storm event	Antecedent Dry Days	Rainfall depth (mm)
09 August, 2011	23	20
14 August, 2011	4	53
16 September, 2011	5	22
27 April, 2012	9	10
10 September, 2012	11	30
15 September, 2012	4	40
04 February, 2013	15	50
13 June, 2013	47	135
28 June, 2013	11	102
08 July, 2013	7	75
25 July, 2013	4	13.5
30 July, 2013	4	20
30 August, 2013	11	40
25 September, 2013	25	37
22 January, 2014	30	14.6

Table 4.37: Regression models for mean pollutant concentrations Tayabpur catchment

Parameter	**a**	**ADD b**	**R_d^* c**	**R^2**	**Test of hypothesis**	
					X^2	**Null Hypoth.**
TDS	539.88	5.49	-2.12	0.91	5.30	Accept
TSS	56.49	2.93	0.54	0.91	7.76	Accept
BOD_5^{20}	128.50	1.37	-0.95	0.98	4.12	Accept
COD	256.32	3.79	-1.79	0.94	6.48	Accept
TKN	13.58	0.09	-0.076	0.95	5.75	Accept
NO_3-N	5.87	0.22	-0.077	0.39	14.40	Reject
TP	3.55	0.16	-0.042	0.94	1.49	Accept
Zn	0.127	0.003	-0.001	0.93	1.55	Accept
Cu	0.025	0.002	-0.0002	0.89	0.98	Accept
Fe	2.10	0.033	-0.015	0.98	1.16	Accept

R_d^* - Average rainfall depth

2. Sodhian catchment: In this catchment, except BOD_5^{20} and TP other measured parameters showed moderate variability with independent variables as indicated by low R^2 values (R^2<0.95). For NO_3-N and Cu parameters, validation of the developed regression models failed therefore, developed regression models were not significant for making assessment of these pollutant concentrations. Characteristics of storm events monitored for Sodhian catchment are given in table 4.38 and developed regression models are shown in table 4.39.

Table 4.38: Characteristics of storm events monitored in Sodhian catchment

Date of Storm event	Antecedent Dry Days	Rainfall depth (mm)
25 June, 2011	7	45
05 August, 2011	4	44.4
07 September, 2011	13	9
07 January, 2012	27	7
16 January, 2012	8	29
22 August, 2012	6	24.2
9 September, 2012	10	13.2
14 September, 2012	4	20.8
17 February, 2013	12	14.3
24 March, 2013	34	17.2
13 June, 2013	16	47.6
26 June, 2013	7	10.4
01 August, 2013	10	26.6
09 August, 2013	7	33.8
22 January, 2014	30	19.7

Table 4.39: Regression models for mean pollutant concentrations in Sodhian catchment

Parameter	a	ADD b	R_d^* c	R^2	Test of hypothesis	
					X^2	Null Hypoth.
TDS	628.25	15.85	-6.28	0.93	6.70	Accept
TSS	27.72	3.30	0.056	0.85	7.42	Accept
BOD_5^{20}	104.29	1.56	-1.20	0.95	1.63	Accept
COD	246.51	4.96	-2.60	0.73	6.45	Accept
TKN	8.32	0.366	-0.005	0.53	3.47	Accept
NO_3-N	7.29	0.32	-0.098	0.67	14.60	Reject
TP	4.63	0.082	-0.054	0.95	1.78	Accept
Zn	0.10	0.01	-0.003	0.80	2.54	Accept
Cu	0.016	0.001	-0.0002	0.85	1.43	Accept
Fe	1.46	0.001	-0.013	0.82	1.17	Accept

R_d^* - Average rainfall depth

3. Majari catchment: In this catchment, high R^2 values ($R^2 \geq 0.95$) were observed for measured pollutant concentrations of BOD_5^{20}, COD, NO_3-N and Fe as shown in table 4.41. Surprisingly, two runoff quality parameters .i.e. TKN and TP failed in validation due to extremely low R^2 values ($R^2 < 0.5$). Characteristics of storm events monitored for Majari catchment are shown in table 4.40 and developed regression models are tabulate in table 4.41.

Table 4.40: Characteristics of storm events monitored in Majari catchment

Date of Storm event	Antecedent Dry Days	Rainfall depth (mm)
18 April, 2011	43	21
25 June, 2011	7	45
05 August, 2011	4	44.4
16 January, 2012	8	29
22 August, 2012	6	24.2
09 September, 2012	10	13.2
14 September, 2012	4	20.8
17 February, 2013	12	14.3
24 March, 2013	34	17.2
13 June, 2013	16	47.6
26 June, 2013	7	10.4
08 July, 2013	4	23.8
01 August, 2013	10	26.6
09 August, 2013	7	33.8
22 January, 2014	30	19.7

Table 4.41: Regression models for mean pollutant concentrations in Majari catchment

Parameter	a	ADD b	R_d^* c	R^2	Test of hypothesis	
					X^2	Null Hypoth.
TDS	291.24	20.82	1.97	0.95	4.30	Accept
TSS	29.37	19.24	0.70	0.91	4.80	Accept
BOD_5^{20}	57.11	1.78	-0.74	0.96	2.94	Accept
COD	147.06	6.43	-1.57	0.97	2.23	Accept
TKN	4.76	0.06	-0.08	0.41	19.64	Reject
NO_3-N	3.25	0.584	-0.053	0.98	1.24	Accept
TP	2.88	0.064	-0.052	0.43	17.82	Reject
Zn	0.164	0.007	-0.003	0.87	1.28	Accept
Cu	0.012	0.002	-0.0003	0.91	0.56	Accept
Fe	2.13	0.090	-0.026	0.96	0.78	Accept

R_d^* - Average rainfall depth

4. Palli Jhiki catchment: Regression models of this catchment are characterized by moderate variability of measured pollutant loads with independent rainfall variables ($0.68<R^2<0.95$). Only three parameters i.e. TSS, TP and Fe demonstrated $R^2 \geq 0.90$ thus indicating that measured pollutant parameters have strong relationship with rainfall variables. Characteristics of storm events monitored for Palli Jhiki catchment are shown in table 4.42 and developed regression models are given in table 4.43.

Table 4.42: Characteristics of storm events monitored in Palli Jhiki catchment

Date of Storm event	Antecedent Dry Days	Rainfall depth (mm)
27 May, 2011	38	33
25 June, 2011	7	45
13 August, 2011	4	203
16 January, 2012	8	29
22 August, 2012	6	24.2
9 September, 2012	10	13.2
14 September, 2012	4	20.8
17 February, 2013	12	14.3
24 March, 2013	34	17.2
13 June, 2013	16	47.6
26 June, 2013	7	10.4
01 August, 2013	10	26.6

Table 4.43: Regression models for mean pollutant concentrations in Palli Jhiki catchment

Parameter	**a**	**ADD b**	**R_d^* c**	**R^2**	**Test of hypothesis**	
					X^2	**Null Hypoth.**
TDS	520.06	8.72	-0.44	0.89	5.63	Accept
TSS	112.10	2.87	0.59	0.94	3.80	Accept
BOD_5^{20}	36.61	1.80	-0.11	0.80	2.78	Accept
COD	201	3.14	-2.23	0.86	4.55	Accept
TKN	7.25	0.121	-0.02	0.40	13.54	Reject
NO_3-N	3.35	0.076	-0.002	0.75	1.95	Accept
TP	3.15	0.12	-0.065	0.90	0.86	Accept
Zn	0.073	0.001	-0.0002	0.70	1.47	Accept
Cu	0.015	0.0004	-0.0001	0.83	1.25	Accept
Fe	1.21	0.005	-0.002	0.93	0.65	Accept

R_d^* - Average rainfall depth

5. Mandiala catchment: Moderate relationships were observed between measured pollutant loads and ADD and rainfall depth for this catchment as depicted by R^2 values ($0.68<R^2<0.9$). Characteristics of storm events monitored for Mandiala catchment are given in table 4.44 and developed regression models are presented in table 4.45.

Table 4.44: Characteristics of storm events monitored in Mandiala catchment

Date of Storm event	Antecedent Dry Days	Rainfall depth (mm)
26 June, 2011	15	36
08 July, 2011	7	58
29 July, 2011	13	45
30 August, 2011	16	18
16 September, 2011	16	17
07 January, 2012	28	81
23 August, 2012	10	25
28 August, 2012	4	12
05 September, 2012	7	15
15 September, 2012	9	12
06 February, 2013	17	12
26 June, 2013	11	15
5 July, 2013	6	11.4
26 July, 2013	10	14
15 August, 2013	7	40

Table 4.45: Regression models for mean pollutant concentrations in Mandiala catchment

Parameter	a	ADD b	R_d^* c	R^2	Test of hypothesis X^2	Null Hypoth.
TDS	422.80	15.73	-1.94	0.84	6.87	Accept
TSS	252.86	4.09	-2.45	0.65	24.34	Reject
BOD_5^{20}	94.30	1.66	-0.92	0.60	7.88	Accept
COD	279.39	5.42	-2.58	0.72	7.25	Accept
TKN	13.17	0.45	-0.12	0.95	2.66	Accept
NO_3-N	7.09	0.51	-0.082	0.79	2.76	Accept
TP	2.11	0.44	-0.049	0.77	3.55	Accept
Zn	0.015	0.01	0.0002	0.69	1.67	Accept
Cu	0.022	0.001	-0.0003	0.55	0.67	Accept
Fe	2.65	0.073	-0.028	0.57	1.74	Accept

R_d^* - Average rainfall depth

6. Kultham catchment: High dependence of the measured end points .i.e. COD, TKN and NO_3-N on the independent variables was observed in this catchment ($R^2 \geq 0.95$). For TP, the validation of the developed regression model failed thus developed regression model was not significant for the prediction of TP in this catchment. Characteristics of storm events monitored for Kultham catchment are tabulated in table 4.46 and developed regression models are given in table 4.47.

Table 4.46: Characteristics of storm events monitored in Kultham catchment

Date of Storm event	Antecedent Dry Days	Rainfall depth (mm)
18 April, 2011	43	21
27 May, 2011	38	33
25 June, 2011	7	45
16 January, 2012	8	29
22 August, 2012	6	24.2
17 February, 2013	12	14.3
24 March, 2013	34	17.2
13 June, 2013	16	47.6
26 June, 2013	7	10.4
08 July, 2013	4	23.8
01 August, 2013	10	26.6
05 September, 2013	19	23.8

Table 4.47: Regression models for mean pollutant concentrations in Kultham catchment

Parameter	a	ADD b	R_d^* c	R^2	Test of hypothesis	
					X^2	Null Hypoth.
TDS	367	15.27	-1.48	0.86	4.38	Accept
TSS	80.57	3.69	1.34	0.78	6.83	Accept
BOD_5^{20}	126.51	1.66	-1.72	0.94	2.77	Accept
COD	418.05	3.09	-5.78	0.95	3.54	Accept
TKN	14.93	0.10	0.22	0.96	1.47	Accept
NO_3-N	8.05	0.097	-0.093	0.98	2.35	Accept
TP	4.85	0.26	-0.061	0.64	15.67	Reject
Zn	0.14	0.003	-0.002	0.93	1.53	Accept
Cu	0.026	0.0003	-0.0004	0.85	0.66	Accept
Fe	0.873	0.01	-0.011	0.94	0.82	Accept

R_d^* - Average rainfall depth

7. Pippa Rangi catchment: In Pippa Rangi catchment high variability in BOD_5^{20}, TP and Fe was found to be covered by ADD and average rainfall depth as $R^2 \geq 0.95$ was observed for these parameters in this catchment. Details of the storm events monitored are given in table 4.48 and regression models are shown in table 4.49.

Table 4.48: Characteristics of storm events monitored in Pippa Rangi catchment

Date of Storm event	Antecedent Dry Days	Rainfall depth (mm)
17 June, 2011	4	98
05 August, 2011	5	58
09 September, 2011	7	15
16 September, 2011	5	60
24 September, 2011	7	31
14 July, 2012	73	28
01 August, 2012	10	62
11 August, 2012	9	19
28 June, 2013	11	36
24 August, 2013	6	25
22 January, 2014	30	16.2
15 February, 2014	21	13.5

Table 4.49: Regression models for mean pollutant concentrations in Pippa Rangi

Parameter	a	ADD b	R_d^* c	R^2	Test of hypothesis	
					X^2	Null Hypoth.
TDS	510.45	9.73	-2.58	0.78	6.86	Accept
TSS	187.46	3.78	0.93	0.85	5.72	Accept
BOD_5^{20}	167.33	2.55	-1.37	0.95	3.87	Accept
COD	421.17	1.91	-2.73	0.82	3.55	Accept
TKN	11.09	0.05	-0.062	0.82	2.65	Accept
NO_3-N	5.25	0.107	-0.033	0.94	1.49	Accept
TP	3.76	0.02	-0.029	0.95	0.43	Accept
Zn	0.19	0.001	-0.002	0.75	1.78	Accept
Cu	0.02	0.001	-0.0001	0.88	0.87	Accept
Fe	1.63	0.088	-0.016	0.96	0.76	Accept

R_d^*- Average rainfall depth

8. Nijjran catchment: In this catchment, except BOD_5^{20} all other runoff quality parameters were observed to have R^2<0.95 thus indicating moderate dependence of measured end points on independent rainfall variables. Table 4.50 presents the storm events monitored in Nijjran catchment and developed regression models are given in table 4.51.

Table 4.50: Characteristics of storm events monitored in Nijjran catchment

Date of Storm event	Antecedent Dry Days	Rainfall depth (mm)
25 June, 2011	4	25.2
15 July, 2011	4	113
13 August, 2011	4	42
07 January, 2012	30	40
15 January, 2012	7	14
22 August, 2012	5	12
04 February, 2013	16	15
13 June, 2013	47	40
08 July, 2013	9	45
18 July, 2013	9	16
25 September, 2013	8	60
22 January, 2014	30	15.1

Table 4.51: Regression models for mean pollutant concentrations in Nijjran catchment

Parameter	a	ADD b	R_d^* c	R^2	Test of hypothesis	
					X^2	Null Hypoth.
TDS	293.35	23.54	-4.73	0.89	3.14	Accept
TSS	130.98	4.33	-0.58	0.93	1.56	Accept
BOD_5^{20}	49.48	1.98	-0.28	0.96	1.87	Accept
COD	158.89	4.41	-0.49	0.90	3.22	Accept
TKN	11.57	0.01	-0.05	0.46	9.38	Reject
NO_3-N	5.28	0.16	-0.02	0.83	2.65	Accept
TP	2.065	0.025	-0.006	0.63	13.74	Reject
Zn	0.165	0.0002	-0.001	0.62	1.93	Accept
Cu	0.019	0.002	-0.0003	0.83	0.50	Accept
Fe	1.56	0.016	-0.004	0.77	1.32	Accept

R_d^* - Average rainfall depth

9. Samrai catchment: In Samrai catchment, except BOD_5^{20} all other stormwater quality parameters demonstrated low R^2 values (R^2<0.8). Regression models were not found to be significant in the assessment of loads of TDS and TP in this catchment. Characteristics of storm events monitored for Samrai catchment are given in table 4.52 and developed regression models are shown in table 4.53.

Table 4.52: Characteristics of storm events monitored in Samrai catchment

Date of Storm event	Antecedent Dry Days	Rainfall depth (mm)
08 July, 2011	8	24
30 July, 2011	11	13
05 August, 2011	5	58
09 September, 2011	7	15
16 September, 2011	5	60
14 July, 2012	73	28
21 July, 2012	6	40
01 August, 2012	10	62
11 August, 2012	9	19
14 September, 2012	4	20
27 May, 2013	29	15
28 June, 2013	11	36
08 July, 2013	7	21
22 January, 2014	30	16.2
15 February, 2014	21	13.5

Table 4.53: Regression models for mean pollutant concentrations in Samrai catchment

Parameter	a	ADD b	R_d^* c	R^2	Test of hypothesis X^2	Null Hypoth.
TDS	251.14	35.59	-0.78	0.73	17.88	Reject
TSS	305.50	4.87	-1.73	0.78	6.88	Accept
BOD_5^{20}	99.48	1.73	-0.64	0.93	4.56	Accept
COD	245.42	6.88	-1.26	0.67	8.67	Accept
TKN	5.78	0.83	-0.07	0.66	1.40	Accept
NO_3-N	8.45	0.654	-0.067	0.56	4.69	Accept
TP	2.52	0.053	-0.048	0.35	16.87	Reject
Zn	0.042	0.011	-0.0001	0.67	3.35	Accept
Cu	0.026	0.001	-0.0003	0.77	0.42	Accept
Fe	1.869	0.014	-0.015	0.69	3.57	Accept

R_d^* - Average rainfall depth

10. Masitan catchment: Except TSS, majority of other runoff quality parameters demonstrated moderate variability with independent rainfall variables ($0.68<R^2<0.95$). For assessment of COD, developed regression models were not found to be significant as validation of the developed models failed for this parameter. Characteristics of storm events monitored for Masitan catchment are shown in table 4.54. Developed regression models are mentioned in table 4.55.

Table 4.54: Characteristics of storm events monitored in Masitan catchment

Date of Storm event	Antecedent Dry Days	Rainfall depth (mm)
09 August, 2011	23	20
14 August, 2011	4	53
16 September, 2011	5	22
13 July, 2012	17	87
10 September, 2012	11	30
15 September, 2012	4	40
04 February, 2013	15	50
08 July, 2013	7	75
25 July, 2013	4	13.5
30 August, 2013	11	40
25 September, 2013	25	37
22 January, 2014	30	14.6

Table 4.55: Regression models for mean pollutant concentrations in Masitan catchment

Parameter	a	ADD b	R_d^* c	R^2	Test of hypothesis	
					X^2	Null Hypoth.
TDS	570.19	15.31	-3.93	0.88	3.93	Accept
TSS	179	8.51	-1.84	0.98	1.42	Accept
BOD_5^{20}	118.28	4.58	-1.59	0.85	5.23	Accept
COD	322.88	12.29	-3.96	0.68	32.38	Reject
TKN	8.99	0.27	-0.062	0.70	4.76	Accept
NO_3-N	6.42	0.16	-0.058	0.68	0.95	Accept
TP	2.61	0.11	-0.03	0.94	0.68	Accept
Zn	0.132	0.007	-0.002	0.73	0.84	Accept
Cu	0.020	0.0005	-0.0001	0.54	0.32	Accept
Fe	1.34	0.048	-0.004	0.64	0.73	Accept

R_d^*- Average rainfall depth

Pollutant concentrations in the wet weather flows were influenced positively by ADD and negatively by rainfall depth. However, the TSS parameter, in six of the ten catchments was found to be positively correlated with rainfall depth. It was observed that in the smaller catchments such as Tayabpur, Kultham and Majari, the measured pollutant loads demonstrated strong relationships with ADD and rainfall depth. This is evident from the high R^2 values. In contrast, the larger pond catchments like Samrai, Mandiala and Masitan demonstrated weak relationships between measured pollutant parameters and rainfall event parameters. This is evident from the low R^2 values obtained. These observations showed that due to homogeneity of smaller catchments the mean pollutant concentrations are less prone to be influenced by the variables other than ADD and rainfall depth.

For stormwater quality parameters mentioned in table 4.56, the developed regression models were found to be not fitting (models with $R^2<0.5$ or the models for which null hypothesis test failed were considered as not fitting). Values of these parameters were found to be not dependent on ADD and rainfall event depth. Regression models of total phosphorus and total kjeldhal nitrogen demonstrated such behaviour more frequently than other parameters.

Table 4.56: Not fitting regression models

Catchment	Parameter	Characterization results			R^2	Validation	
		10 percentile	50 percentile	90 percentile		X^2	Null Hypoth.
Tayabpur	NO_3-N	4.51	5.68	6.85	0.39	14.40	Reject
Sodhian	NO_3-N	2.03	5.27	8.51	0.67	14.60	Reject
Majari	TKN	8.71	10.99	13.26	0.41	19.64	Reject
	TP	0.47	1.42	2.37	0.43	17.82	Reject
Palli Jhiki	TKN	3.90	7.32	10.74	0.40	13.54	Reject
Mandiala	TSS	70	211	352	0.65	24.34	Reject
Kultham	TP	0.71	1.53	2.35	0.64	15.67	Reject
Nijjran	TKN	6.51	8.84	11.16	0.46	9.38	Reject
	TP	1.04	2.08	3.12	0.63	13.74	Reject
Samrai	TP	0.69	2.44	4.19	0.35	16.87	Reject
Masitan	COD	162	294	426	0.68	32.38	Reject

4.3.4 Assessment of stormwater characteristics

The developed regression models were used for the assessment of the wet weather flow quality characteristics. The assessments were done for the following three scenarios:

1. Best scenario- 10% ADD and 90% rainfall depth
2. Average scenario- 50% ADD and 50% rainfall depth
3. Worst scenario- 90% ADD and 10% rainfall depth

Table 4.57: Independent variables combinations for assessment of stormwater quality

Catchment	Independent variables	Best scenario	Average scenario	Worst scenario
Tayabpur	ADD (days)	4	8	22
	Rainfall depth (mm)	60	20	10
Sodhian	ADD (days)	4	9	27
	Rainfall depth (mm)	54.4	17.7	7.6
Majari	ADD (days)	4	9	27
	Rainfall depth (mm)	47.6	12.2	4.8
Palli Jhiki	ADD (days)	4	9	27
	Rainfall depth (mm)	54	16.3	7
Mandiala	ADD (days)	4	7	44
	Rainfall depth (mm)	45	14	5
Kultham	ADD (days)	4	9	27
	Rainfall depth (mm)	53.2	16	6.9
Pippa Rangi	ADD (days)	4	6	25
	Rainfall depth (mm)	65	18	7
Nijjran	ADD (days)	4	9	30
	Rainfall depth (mm)	51	18	7.9
Samrai	ADD (days)	4	6	25
	Rainfall depth (mm)	60	14	4.7
Masitan	ADD (days)	4	8	22
	Rainfall depth (mm)	50	13	4

ADD and rainfall depth values for the above three scenarios were determined by analyzing the 10 years meteorological data from the nearest meteorological stations. ADD and rainfall data used in the assessment of the stormwater characteristics is shown in the form of box plots in appendix E. Table 4.58 presents the assessed wet weather flow characteristics for all the ten catchments studied.

Table 4.58: Predicted stormwater quality parameters of the catchments

Catchment→ Parameter	Tayabpur	Sodhian	Majari	Palli Jhiki	Mandiala	Kultham	Pippa Rangi	Nijjran	Samrai	Masitan
TSS, mg/L	91-126 (101)	44-117 (58)	140-552 (211)	148-194 (156)	70-352* (211)	135-189 (167)	226-288 (263)	119-256 (159)	221-419 (310)	**121-359 (223)**
BOD_5^{20}, mg/L	**77-149 (120)**	**32-172 (103)**	**29-102 (64)**	50-86 (55)	59-163 (93)	41-159 (114)	**88-221 (158)**	**43-107 (62)**	68-140 (101)	57-213 (134)
COD, mg/L	164-322 (251)	125-361 (245)	**98-313 (186)**	93-270 (193)	185-505 (281)	**123-461 (353)**	251-450 (383)	152-287 (190)	197-412 (269)	162-426* (294)
TKN, mg/L	**9.38-14.80 (12.78)**	7.06-17.82 (10.73)	8.71-13.26* (10.99)	3.90-10.74* (7.32)	**9.58-32.54 (14.66)**	**3.89-16.15 (12.39)**	7.26-11.91 (10.27)	6.51-11.16* (8.84)	4.90-26.20 (9.78)	6.95-14.62 (10.32)
NO^-_3 –N, mg/L	4.51-6.85* (5.68)	2.03-8.51* (5.27)	**3.06-18.76 (7.86)**	3.54-5.38 (4.00)	5.44-29.21 (9.52)	**3.49-10.03 (7.43)**	3.74-7.79 (5.37)	4.90-9.92 (6.36)	7.05-24.48 (11.44)	4.15-9.66 (6.93)
TP, mg/l	1.67-6.65 (3.99)	**2.02-6.43 (4.41)**	0.47-2.37* (1.42)	0.12-5.93 (3.17)	1.65-21.05 (4.47)	0.71-2.35* (1.53)	**1.95-4.06 (3.35)**	1.04-3.12* (2.08)	0.69-4.19* (2.44)	1.55-4.91 (3.10)
Zn, mg/L	0.08-0.18 (0.13)	0.0-0.34 (0.14)	0.05-0.34 (0.19)	0.06-0.09 (0.08)	0.06-0.45 (0.08)	0.05-0.21 (0.14)	0.064-0.20 (0.16)	0.12-0.16 (0.15)	0.08-0.32 (0.11)	0.06-0.28 (0.16)
Cu, mg/L	0.021-0.07 (0.037)	0.009-0.04 (0.021)	0.005-0.06 (0.026)	0.011-0.025 (0.017)	0.012-0.06 (0.024)	0.006-0.03 (0.022)	0.017-0.04 (0.024)	0.012-0.07 (0.032)	0.012-0.05 (0.027)	0.017-0.03 (0.022)
Fe, mg/L	**1.33-2.67 (2.06)**	0.75-1.38 (1.24)	**1.25-4.43 (2.62)**	1.12-1.33 (1.22)	1.68-5.72 (2.77)	0.33-1.07 (0.78)	**0.94-3.72 (1.87)**	1.42-2.00 (1.63)	1.025-2.15 (1.74)	1.33-2.38 (1.67)

* 10 percentile and 90 percentile values from analysis.

values in bold have $R^2 \geq 0.95$

values in parentheses are average parameter values

4.4 Integrated water resources management (IWRM) for the village pond catchments

The goal of the developed IWRM is tackling the water supply and sanitation problems (and concerns/issues) of the village pond catchments, in an equitable manner, without compromising on the issues and concerns of the groundwater and the irrigation water, while protecting the village environment.

The IWRM envisioned is a goal directed continual process involving the following phases/steps:

1. Current situation assessment and identification of problems and prospects of water resources management
2. Critical analysis of the identified problems and prospects and finding opportunities, options and solutions, and developing the IWRM framework
3. Evaluation of the opportunities, options and solutions, involving various stakeholders and different levels of the village governance, and development of detailed designs and plans for implementation.
4. Implementation of the prepared designs and plans, and monitoring, measurement, assessment and evaluation of the implemented designs and plans.

The IWRM is in fact an iterative spiral process of the above steps. The monitoring, measurement, assessment and evaluation are supposed to provide the necessary feedback for the continuity of the spiral process of water resources management.

The IWRM will be a coordinated action by the village community and the other stakeholders (water supply and sanitation departments/boards, public health department, environment departments/ boards, stake holders of other water use sectors, the village governance, NGOs, etc.). The IWRM will require institutional support, policy and legislation support and also the resources (financial, technological and other) for implementation. At the macro-level, the government should have a vision and strategy for the IWRM implementation.

On the basis of the current situation assessment the following problems were identified in the area of water supply and sanitation:

- The ground water table was declining and the groundwater quality was deteriorating.
- In all the villages studied groundwater sources were depended on for meeting the rural water demands.
- The supplied water was neither monitored for quality nor it was treated prior to supply
- Some of the villages were not having piped water supply schemes
- Per capita water consumption was quite high, and the consumption levels were inversely related with the humans to cattle population ratio. Parallel dwelling level water supply provisions are also believed as contributing the higher per capita water consumption.
- The villages had road side open channels/drains for the collection and conveyance of both stormwater and domestic wastewater (both black water and grey water, and wastewater and cattle dung) into the village ponds.
- The existing drains were apparently sized to carry the storm water and domestic wastewater generated.
- Strength and flow rates of the wastewater from the rural human settlements are also on the higher side. Cattle sheds (especially the cattle bathing) and uncontrolled use of parallel dwelling level water supply systems are believed as the contributors.
- Open defecation was still significant in the villages studied.
- The village ponds were heavily polluted and their water was not fit for any use.
- Majority of the village ponds overflow during rainy season and spread land pollution.

The IWRM is recommended to implement the following actions for the sustainable water resources management:

- Minimize ground water extraction through adopting the following
  - Prohibit the use of parallel dwelling level water supply systems and exclusively depend on the centralized village level piped water supply system
  - Implement water conservation measures specially at the individual dwelling level, such as, replacing the commonly used flush toilets with Eco-San toilets, shifting cattle bathing activity to village pond, etc.
  - Meter water consumption and charge the water consumed (no charges upto a fixed minimum water consumption and then exponentially increasing charges for the additional water consumption);
- Assured access and supply of water of adequate quantity and quality
  - Treat the water for improving the biological water quality (disinfection!) and, if needed, also for the TDS removal by cheap and sustainable water treatment technologies that generate the minimum of secondary wastes
- Separate handling and management of the black water and the cattle shed wastewater (prohibiting discharge of these wastewaters into the drainage system of the village pond catchments)
  - Replace the existing flush toilets with ecological toilets at the household level to minimize black water generation
  - Provide centralized toilet facilities (based on ecological sanitation approach) at the community level to minimize black water generation

    - Provide septic tank or anaerobic baffled reactor – soak pit systems for the treatment and disposal of black water
    - Provide anaerobic co-digestion facilities for the treatment and stabilization of cattle manure, cattle-shed wastewater and residential black water
- Design and construction of a combined grey water – storm water drainage system for the village pond catchments
    - This drainage system will include the drains that carry the dry weather flows at above self-cleansing velocity and peak wet weather flows below the scour velocity
- Modify and/or restructure the existing village ponds into sustainable village pond systems that serve the following purposes:
    - Treatment of the received grey water and storm water
    - Making available of the treated dry weather flows for reuse as reclaimed water (for crop land irrigation, cattle bathing, etc.)
    - Groundwater recharging of the treated wet weather flow after the necessary further treatment.

As a part of the evaluation of the options and development of detailed designs and plans (for implementation), the IWRM included the following

- Design of the grey water – storm water drainage system for one of the ten village pond catchments studied.
- Design of all the ten village pond systems

The IWRM developed in the present context is just a system framework and it did not seriously get into the 3rd and 4th steps of the IWRM process. Designs and plans development are limited just to the grey water – storm water drainage system and to the village pond system. Village community and other stakeholders were however have not yet been involved in the evaluation and planning processes. Implementation, monitoring, and evaluation of the IWRM implementation are however not attempted in the integrated water resources management system development.

4.5 Conceptualized village pond system

The conceptualized village pond system is comparable to a sustainable wastewater treatment plant and having the following treatment units:

- Catch basin
- Constructed wetland system
- Facultative pond
- Up-flow roughing filter
- Treated water storage reservoir
- Slow sand filter
- Groundwater recharge well

The process and material flow diagram of the village pond system is shown in figure-4.32.

The system is a sustainable solar energy powered system. The system is simple, easy to operate, requires no conventional energy sources and no human intervention for its operation and functioning. It is capable of treating the wet weather flows (and also the dry weather flows) of the pond catchments and making them fit for reuse as reclaimed water. Further, the system polishes the excess pond water to make it compatible for disposal through groundwater recharging. The conceptualized village pond system has been accommodated as far as possible within the existing village pond, or in other words, the existing village pond was modified into the conceptualized village pond system.

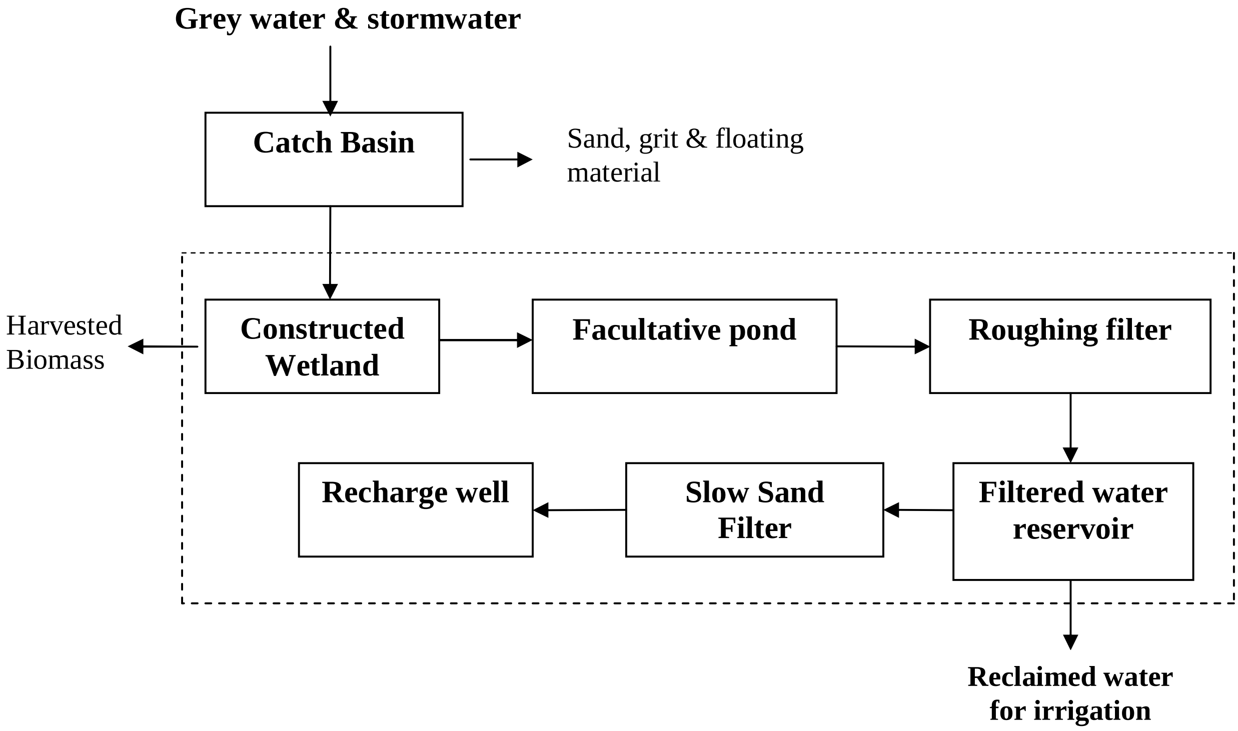


Figure 4.32: Flow diagram of village pond system

4.6 Drainage system of the village pond catchments

In this study, grey water and stormwater collection system was designed for largest of the studied catchments .i.e. Samrai. The collection system was designed by dividing the entire catchment into smaller sub-catchments contributing the grey water and stormwater to the nearest stretch of the composite drain. The dry weather flow rates from the sub-catchments were determined from the peak hourly wastewater flow rates of the catchment given in table 4.13. The minimum peak dry weather flow rate was assumed as 0.0015 m^3/s, the rate at which water is being discharged by the flush toilets. Peak stormwater flow rates from the sub-catchments were computed by finding out the time of concentration of the sub-catchments by distributing the stormwater flow into sheet flow and channel flow components. Equations 3.16 and 3.17 were used to determine the time of concentration for these two flows. Rainfall intensity was found out by using the IDF equation for Phagwara meteorological station (Samrai is covered by Phagwara meteorological station) from table 4.14. Finally, stormwater runoff flow rates originating from the sub-catchments were determined by using equation 3.9. The triangular bottom of the drain was designed for peak dry weather flows and the complete section was designed to carry peak wet weather flows. Free board of 0.1 m was also provided to avoid the overflow of the drains during the unexpected high flows. The cross section of the composite drain is shown in figure 4.33. The computed dimensional details of drain network for Samrai catchment are given in table 4.59 and drain network is shown in sheet-11.

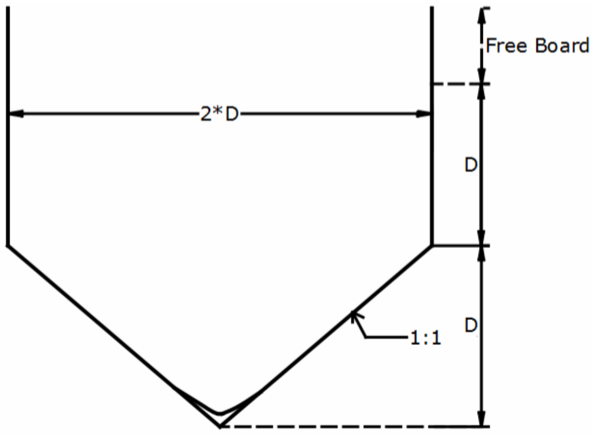
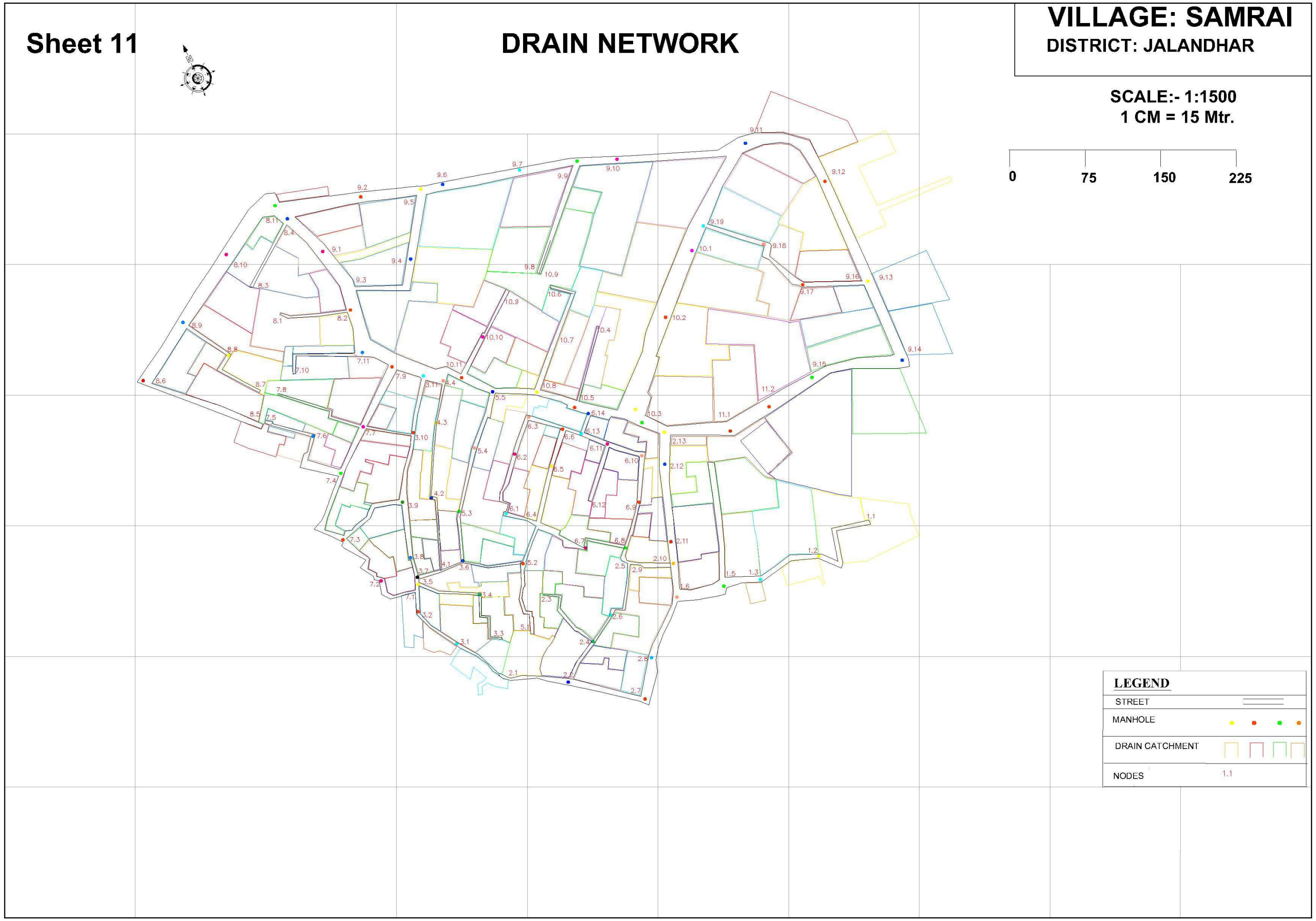


Figure 4.33: Cross section of the composite drain



Sheet 11: Drain network of Samrai catchment

Table 4.59: Dimensional details of the composite drain network for Samrai catchment

Drain no.	**DWF* (m^3/s)**	**WWF* (m^3/s)**	**D* (cm)**	**Slope**	**Flow velocity during WWF, (m/s)**	**Flow velocity during DWF, (m/s)**
1.1-1.2	0.0015	0.055	9.17	0.049	2.18	0.88
1.2-1.3	0.0015	0.103	11.75	0.046	2.50	0.86
1.4-1.5	0.0015	0.069	9.98	0.048	2.30	0.88
1.3-1.6	0.0015	0.202	16.40	0.030	2.50	0.73
2.1-2.2	0.0015	0.018	6.09	0.047	1.63	0.87
2.3-2.4	0.0015	0.012	5.27	0.046	1.46	0.86
2.5 - 2.6	0.0015	0.013	5.44	0.046	1.49	0.86
2.6-2.4	0.0015	0.036	7.82	0.048	1.95	0.88
2.4-2.2	0.0015	0.071	10.07	0.049	2.33	0.88
2.2 - 2.7	0.0015	0.100	11.52	0.047	2.50	0.87
2.7-2.8	0.0015	0.112	12.23	0.044	2.50	0.84
2.8-1.6	0.0015	0.130	13.16	0.040	2.50	0.81
2.9-2.10	0.0015	0.016	5.87	0.046	1.58	0.86
1.6-2.11	0.0015	0.368	22.16	0.020	2.50	0.63
2.11-2.12	0.0015	0.388	22.73	0.019	2.50	0.62
2.12-2.13	0.0015	0.383	22.60	0.019	2.50	0.62
2.1-3.1	0.0015	0.018	6.12	0.047	1.64	0.87
3.1-3.2	0.0015	0.040	8.12	0.048	2.00	0.88
3.3-3.4	0.0015	0.014	5.54	0.046	1.51	0.86
3.4-3.5	0.0015	0.024	6.73	0.048	1.76	0.87
3.6-3.7	0.0015	0.013	5.44	0.046	1.50	0.86
3.2-3.8	0.0015	0.089	10.96	0.049	2.47	0.88
3.8-3.9	0.0015	0.109	12.06	0.045	2.50	0.85
3.9-3.10	0.00167	0.137	13.53	0.038	1.72	0.82
3.10-3.11	0.0015	0.157	14.45	0.035	2.50	0.78

Drain no.	**DWF* (m^3/s)**	**WWF* (m^3/s)**	**D* (cm)**	**Slope**	**Flow velocity during WWF, (m/s)**	**Flow velocity during DWF, (m/s)**
4.1-4.2	0.0015	0.013	5.47	0.046	1.50	0.86
4.2-4.3	0.0015	0.029	7.24	0.048	1.84	0.87
4.3-4.4	0.0015	0.040	8.16	0.048	2.01	0.88
5.1-5.2	0.0015	0.022	6.53	0.048	1.72	0.87
5.2-3.6	0.0015	0.036	7.87	0.048	1.96	0.88
3.6-5.3	0.0015	0.047	8.65	0.049	2.10	0.88
5.3-5.4	0.0015	0.071	10.09	0.049	2.33	0.88
5.4-5.5	0.0015	0.094	11.20	0.049	2.50	0.88
5.2-6.1	0.0015	0.017	6.00	0.047	1.61	0.87
6.1-6.2	0.0015	0.033	7.62	0.048	1.92	0.88
6.2-6.3	0.0015	0.052	9.00	0.049	2.16	0.88
6.4-6.5	0.0015	0.023	6.64	0.048	1.74	0.87
6.5-6.6	0.0015	0.037	7.91	0.049	1.97	0.88
6.4-6.7	0.0015	0.019	6.21	0.047	1.66	0.87
6.7-6.8	0.0015	0.037	7.93	0.049	1.98	0.88
2.5-6.9	0.0015	0.049	8.77	0.049	2.12	0.88
6.9-6.10	0.0015	0.063	9.65	0.049	2.27	0.88
6.12-6.11	0.0015	0.020	6.35	0.047	1.68	0.87
6.10-6.13	0.0015	0.102	11.65	0.047	2.50	0.86
6.3-6.13	0.0015	0.101	11.59	0.047	2.50	0.87
6.13-6.14	0.0015	0.119	12.59	0.042	2.50	0.83
7.1-7.2	0.0015	0.008	4.64	0.044	1.31	0.85
7.2-7.3	0.0015	0.018	6.08	0.047	1.63	0.87
3.9-7.3	0.0015	0.019	6.20	0.047	1.65	0.87
7.3-7.4	0.0015	0.051	8.89	0.049	2.14	0.88
7.5-7.6	0.0015	0.008	4.55	0.044	1.29	0.84
7.6-7.4	0.0015	0.024	6.70	0.048	1.75	0.87

Drain no.	DWF* (m^3/s)	WWF* (m^3/s)	D* (cm)	Slope	Flow velocity during WWF, (m/s)	Flow velocity during DWF, (m/s)
7.4-7.7	0.0015	0.093	11.15	0.049	2.50	0.88
3.10-7.7	0.0015	0.007	4.38	0.043	1.25	0.84
7.8-7.7	0.0015	0.032	7.46	0.048	1.89	0.88
7.7-7.9	0.0015	0.154	14.35	0.035	2.50	0.78
7.10-7.11	0.0015	0.022	6.56	0.048	1.72	0.87
8.1-8.2	0.0015	0.032	7.55	0.048	1.90	0.87
8.3-8.4	0.0015	0.031	7.42	0.048	1.89	0.88
8.5-8.6	0.0015	0.038	8.00	0.048	1.99	0.88
8.7-8.8	0.0015	0.017	5.96	0.047	1.61	0.87
8.8-8.9	0.0015	0.042	8.28	0.048	2.03	0.88
8.6-8.9	0.0015	0.102	11.68	0.046	2.50	0.86
8.9-8.10	0.0015	0.131	13.20	0.039	2.50	0.81
8.10-8.11	0.0015	0.145	13.90	0.037	2.50	0.79
7.11-8.2	0.0015	0.069	9.98	0.049	2.32	0.88
8.2-9.1	0.0015	0.086	10.80	0.049	2.45	0.88
9.1-8.11	0.0015	0.139	13.64	0.038	2.50	0.80
8.11-9.2	0.0015	0.251	18.30	0.026	2.50	0.69
9.3-9.4	0.0015	0.049	8.77	0.049	2.12	0.88
9.4-9.5	0.0015	0.063	9.64	0.049	2.26	0.88
9.2-9.6	0.0015	0.341	21.31	0.021	2.50	0.64
9.6-9.7	0.0015	0.363	22.01	0.020	2.50	0.63
9.8-9.9	0.0015	0.071	10.09	0.049	2.33	0.88
9.7-9.10	0.0015	0.419	23.64	0.018	2.50	0.61
9.10-9.11	0.0015	0.449	24.47	0.017	2.50	0.60
9.11-9.12	0.0015	0.443	24.31	0.017	2.50	0.60
9.12-9.13	0.0015	0.493	25.65	0.016	2.50	0.58
9.13-9.14	0.00153	0.482	25.34	0.017	2.50	0.59

Drain no.	DWF* (m^3/s)	WWF* (m^3/s)	D* (cm)	Slope	Flow velocity during WWF, (m/s)	Flow velocity during DWF, (m/s)
9.14-9.15	0.00164	0.501	25.85	0.016	2.50	0.59
9.16-9.17	0.0015	0.033	7.56	0.048	1.91	0.88
9.17-9.18	0.0015	0.061	9.53	0.049	2.25	0.88
9.18-9.19	0.0015	0.099	11.48	0.048	2.50	0.87
9.11-10.1	0.0015	0.174	15.24	0.033	2.50	0.76
10.1-10.2	0.0015	0.259	18.58	0.025	2.50	0.68
10.2-10.3	0.0015	0.327	20.87	0.021	2.50	0.65
10.4-10.5	0.0015	0.025	6.83	0.048	1.78	0.87
10.6-10.7	0.0015	0.020	6.27	0.047	1.67	0.87
10.7-10.8	0.0015	0.046	8.54	0.049	2.08	0.88
10.9-10.10	0.0015	0.033	7.59	0.048	1.92	0.88
10.10-10.11	0.0015	0.058	9.35	0.049	2.22	0.88
7.1-3.11	0.0021	0.359	21.87	0.020	2.50	0.68
3.11-10.11	0.0026	0.460	24.77	0.017	2.50	0.68
10.11-5.5	0.0033	0.545	26.95	0.015	2.50	0.69
5.5-10.8	0.0035	0.565	27.45	0.015	2.50	0.70
10.8-10.5	0.0037	0.573	27.63	0.015	2.50	0.71
10.5-10.3	0.0057	0.946	35.51	0.011	2.50	0.69
10.3-11.1	0.0073	1.249	40.81	0.009	2.50	0.69
11.1-11.2	0.0073	1.255	40.91	0.009	2.50	0.69
11.2-9.15	0.0088	1.978	51.36	0.006	2.50	0.64

* DWF- Dry weather flow, WWF- Wet weather flow, D- Depth of drain

4.7 Design of village pond system

The village pond systems were designed for handling the 90 percentile wet weather flow volumes from the pond catchments (Iowa Stormwater Management Manual, 2009). For the design of the pond system, characteristics of the wet weather flows were determined corresponding to 10% ADD and 90% rainfall depth scenario and presented in table-4.60.

Table-4.60: Assessed quantities and predicted characteristics of the wet weather flows from the catchments

Villages	90% Wet flow	Peak Flow	TSS	BOD_5^{20}	COD	TKN	NO_3-N	Total-P	TC	FC
	m^3/d	m^3/s	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Log to base 10	Log to base 10
Tayabpur	831	0.323	91	77	164	9.38	4.51	1.67	5.35	4.21
Sodhian	2104	1.386	44	32	125	7.06	1.92	2.02	5.32	4.51
Majari	1267	1.044	140	29	98	8.70	3.06	0.49	3.9	Insignificant
Palli Jhiki	1407	1.037	148	50	93	3.88	3.54	0.12	5.17	4.13
Mandiala	2355	0.987	70.2	59	185	9.58	5.44	1.65	5.17	4.64
Kultham	1033	0.663	135	41	123	3.89	3.49	0.76	5.13	3.67
Pippa Rangi	1687	0.643	226	88	251	7.26	3.74	1.95	5.2	4.24
Nijjran	1360	0.644	119	43	152	6.5	4.9	1.04	5.31	4.11
Samrai	5263	1.598	221	68	197	4.9	7.05	0.7	4.70	3.84
Masitan	2653	0.907	121	57	163	6.95	4.15	1.55	5.36	4.29

Catch Basin: This will be the first treatment unit of pond treatment system through which the wet weather flow passes. Water level in the catch basin will always be maintained above the intake of the outlet pipe for the effective separation of floating materials. Annual pre monsoon cleaning of the basin is recommended to remove the accumulated grit and floating material from the basin. The computed dimensions of the catch basins for ten catchments are tabulated in table 4.61. Area of the inlet and outlet pipes has been added in the area of the basin (A_{cb}) while determining the dimensions of the basin as these pipes occupied substantial amount of area in the basin.

Table 4.61: Catch basin design details for the selected catchments

Catchment	Peak wet weather flow, (m^3/s)	Total catch basin area, (m^2)	Catch basin diameter, (m)	Inlet & outlet pipe diameter, (m)	Catch basin HRT*, T_{cb} (sec)
Tayabpur	0.323	1.22	1.25	0.45	1.95
Sodhian	1.386	5.25	2.59	0.94	1.95
Majari	1.044	3.96	2.24	0.82	1.95
Palli Jhiki	1.037	3.93	2.24	0.81	1.95
Mandiala	0.987	3.74	2.18	0.79	1.95
Kultham	0.663	2.51	1.79	0.65	1.95
Pippa Rangi	0.643	2.44	1.76	0.64	1.95
Nijjran	0.644	2.44	1.76	0.64	1.95
Samrai	1.598	6.05	2.78	1.01	1.95
Masitan	0.907	3.44	2.09	0.76	1.95

*HRT- Hydraulic Retention Time

Water depth in the catch basin is kept at 0.7 m and minimum water depth below the intake of outlet pipe is maintained at 0.5 m. A minimum free board of 0.3 m is provided to handle the unforeseen high flows during heavy storms. The sectional view of the catch basin is given in figure 4.34.

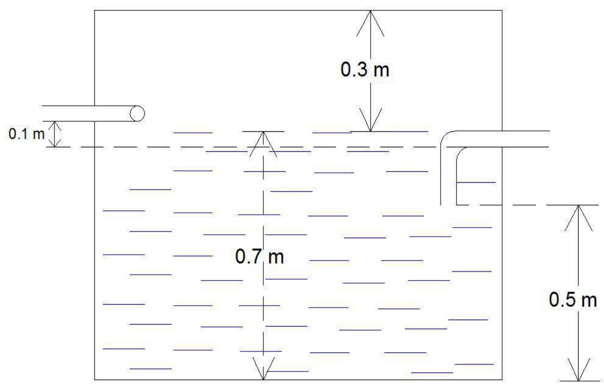


Figure 4.34: Catch basin sectional view

Free water surface constructed wetland system: Grey water and stormwater will be distributed along the width of the wetland. By dividing the length of the wetland into three cells as shown in figure 4.35, it can be ensured that settled particles will not be re-suspended and will not go out of the wetland thus reducing the efficiency of the system. Capacity of the wetland is decided by determining the depth required to handle the volume of wet weather flow generated during the detention period of 15 minutes. Terminal settling velocities of targeted organic particles are computed (equation 3.21) and used in the estimation of surface area of the wetland. Dimensional details of the wetland for each of the catchments are given in table 4.62. It is believed that 35% of BOD loads of the incoming peak wet weather flows will be removed in the constructed wetlands.

Table 4.62: Constructed wetland design details for the selected catchments

Catchment	Influent BOD to CW, (mg/L)	Effluent BOD from CW, (mg/L)	Wetland surface area, A_{cw} (m^2)	Wetland Depth, (m)
Tayabpur	77	50	297	1.0
Sodhian	32	21	1275	1.0
Majari	29	19	961	1.0
Palli Jhiki	50	33	954	1.0
Mandiala	59	38	908	1.0
Kultham	41	27	610	1.0
Pippa Rangi	88	57	592	1.0
Nijjran	43	28	593	1.0
Samrai	68	43	1470	1.0
Masitan	57	37	834	1.0

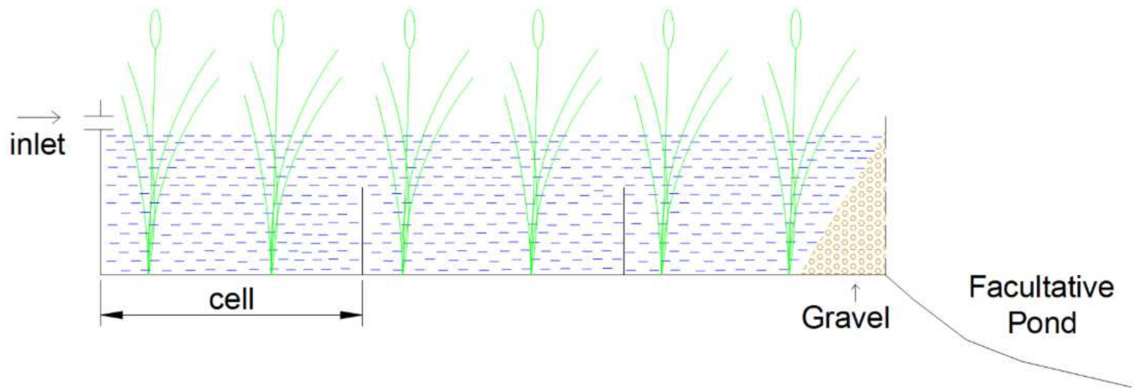


Figure 4.35: Constructed wetland sectional view

Facultative pond (FP): Area of the pond is determined for 65% of the incoming BOD_5^{20} loads due to the removal of 35% of influent BOD_5^{20} in the constructed wetlands. BOD_5^{20} loading is computed at 25°C ambient temperature which has been taken as average minimum temperature of the month of August (equation 3.22). Facultative pond area can be provided in either of the following ways:

1. If available village pond area is sufficiently higher than the calculated facultative pond area, then the wetland is provided inside the pond area and rest of the entire pond area has been used for facultative pond. This kind of arrangement is given in the catchments of Tayabpur, Sodhian and Palli Jhiki. In this condition, actual BOD_5^{20} loading of the pond is less than the design BOD loading during peak wet weather flows .i.e. 350 kg/ha.d.
2. If available pond area is not sufficient to accommodate wetland and facultative pond, then the wetland is provided outside the pond area and the available pond area has been used exclusively for the provision of facultative pond. If there is requirement, then more area has been included in the existing area of the pond. This kind of arrangement is given in the catchments of Mandiala, Kultham, Pippa Rangi, Samrai and Masitan. Facultative pond operates on the design BOD_5^{20} loading during peak flows under this condition.

Facultative pond depth has been divided into three different levels .i.e minimum level, maximum dry weather level and 90 percentile runoff volume level. These levels are shown in figure 4.36. 90 percentile wet weather volume will be stored above the maximum dry weather level and a freeboard of 1 m is provided over and above the maximum capacity of the pond to store the flow volumes in case of extremely large rainfall events which are however rare to occur. Soluble effluent BOD_5^{20} is estimated to be less than 20 mg/L in all the catchments. Design details of the facultative pond are shown in table 4.63.

Table 4.63: Design details of facultative pond for studied catchments

Catchment	90th percentile wet weather flow, (m^3)	Influent BOD_5^{20} to FP, L_i (mg/L)	FP area provided, A_f (m^2)	Add. Area required, (m^2)	Actual BOD_5^{20} loading, (kg/ha.d)	Max. dry weather water level, (m)	Minimum water level*, (m)	HRT, θ_f (days)	Effluent BOD_5^{20}, L_e (mg/L)	BOD_5^{20} removal efficiency, (%)	Bacterial removal rate, (%)
Tayabpur	831	50	2515	0.0	172.3	3.3	2.3	11.3	10.1	80	98
Sodhian	2104	21	3785	0.0	194.1	3.9	2.7	7.7	3.6	82	98
Majari	1267	19	1252	0.0	270.2	2.6	2.3	2.8	4.0	78	95
Palli Jhiki	1407	33	2940	0.0	190.2	3.7	2.6	8.5	6.5	80	98
Mandiala	2355	38	3373	124.7	350.0	3.8	2.7	6.1	8.8	77	97
Kultham	1033	27	994	280.1	350.0	2.6	2.3	2.7	6.2	77	94
Pippa Rangi	1687	57	3251	2435.6	350.0	2.5	1.9	5.0	13.5	76	97
Nijjran	1360	28	1808	0.00	276.4	3.3	2.6	4.7	6.1	78	97
Samrai	5263	43	7684	4360.0	350.0	2.6	2.1	3.9	10.5	76	96
Masitan	2653	37	4714	1867.3	350.0	3.1	2.3	5.8	8.1	78	97

* Minimum depth= 0.5 x avg. depth (determined through physical survey)

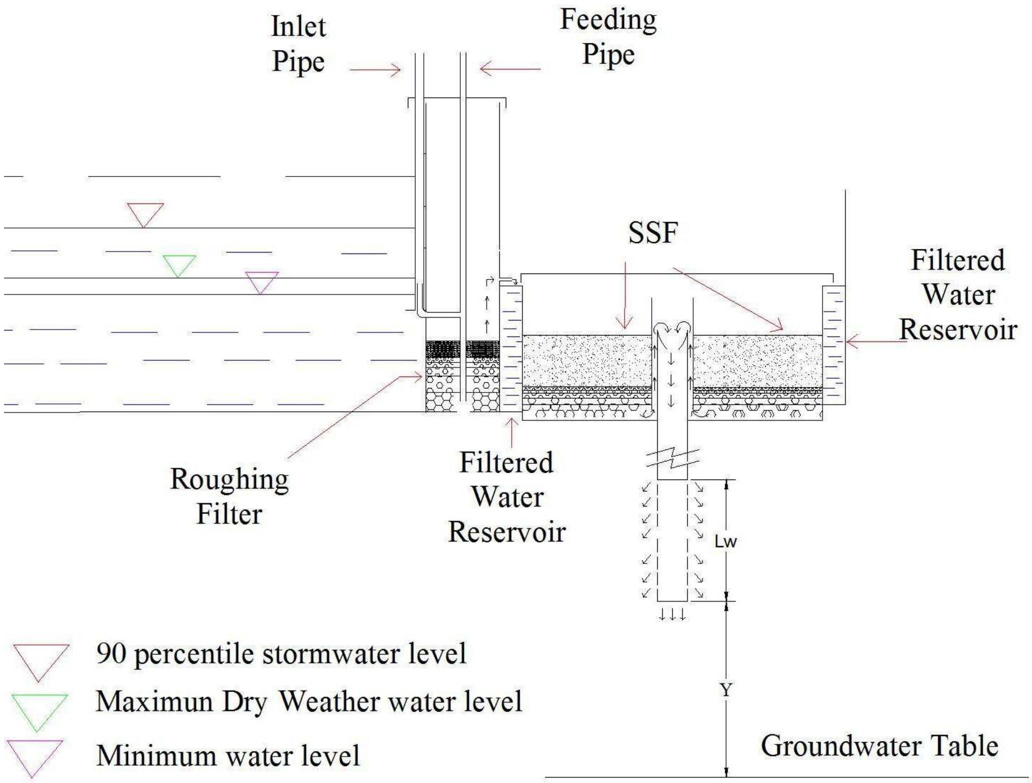


Figure 4.36: Sectional view of treatment scheme

Up-flow multi grade roughing filter (RF): Roughing filter is designed to handle the 90 percentile wet weather flow over 72 hour period at a filtration rate of 2 m/h. The filter will operate in upflow mode and will require no backwashing. The filter has been deigned in such a way that it will remain submerged under water at all the times to avoid air binding in the filter bed. This is achieved by providing the inlet to the roughing filter at minimum water level of facultative pond and keeping the outlet of the roughing filter above the top of the filter. The inlet pipe is sized for the inlet velocity of 0.1 m/s and intake of the inlet pipe is kept 0.5 m above entrance of water into inlet pipe to minimize the entry of algal cells from facultative pond effluent into roughing filter. The water will be filtered to the filtered water reservoir when water level in the facultative pond crosses the maximum dry weather water level. The arrangement of roughing filter in the treatment scheme is shown in figure 4.36 (sectional view) and 4.37 (top view).

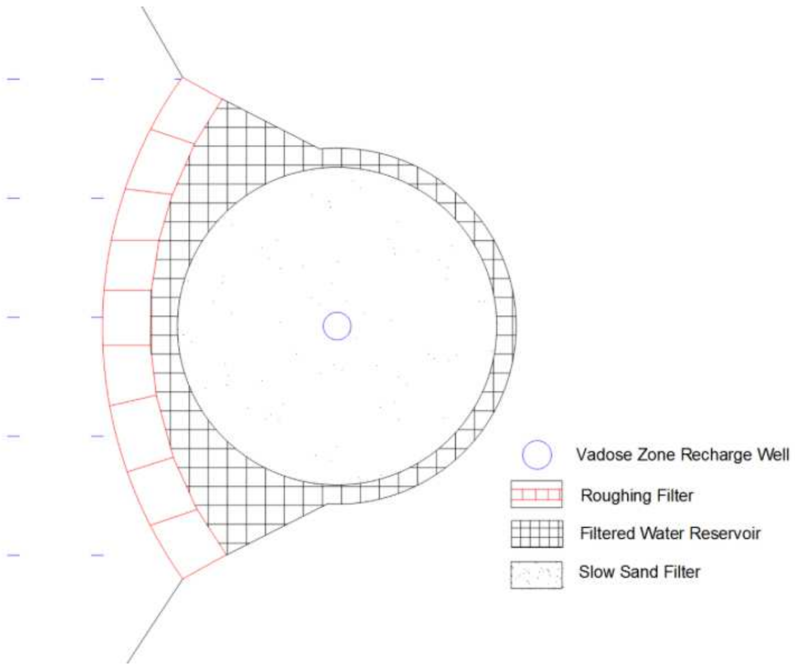


Figure 4.37: Top view of roughing filter, slow sand filter and water reservoir

The central feeding pipe in roughing filter is designed for a velocity ≤0.2 m/s so that air bubbles do not enter the filter alongwith the influent. A separate inlet is provided for 2 m length of the filter for effective distribution of water from facultative pond to the filter. The depth of the filter bed is kept at 1 m which is distributed in the different sized gravel layers as shown in table 4.64:

Table 4.64: Description of gravel layers provided in the roughing filters

Filter Layer	Gravel size (mm)	Layer depth (mm)
Top	1.25-2.5	320
Second	2.5-5	100
Third	5-10	100
Fourth	10-20	160
Bottom	20-40	320

The details of the designed roughing filter for each of the catchment are given in table 4.65:

Table 4.65: Roughing filter, treated water reservoir and slow sand filter details

Catchment	90 percentile wet weather flow rate, (m^3/h)	Roughing filter area, (m^2)	Filter length, (m)	Filtered water reservoir area, (m^2)	Slow sand filter area, (m^2)
Tayabpur	10.18	5	2.54	23	21
Sodhian	27.07	14	6.77	43	54
Majari	16.10	8	4.02	30	32
Palli Jhiki	18.10	9	4.54	52	36
Mandiala	29.68	15	7.42	58	60
Kultham	13.28	7	3.32	25	27
Pippa Rangi	22.30	11	5.58	31	44
Nijjran	17.50	9	4.38	36	35
Samrai	70.10	35	17.52	70	140
Masitan	34.22	17	8.56	74	68

The cumulative clean water headloss through the filter layers (equation 3.23) was 9.69 mm. For the headloss determination, the porosity of gravels was taken as 0.4 and particle shape factor as 0.71.

Treated water reservoir: Water from roughing filter will be stored in treated water storage reservoir for use in irrigation or cattle bathing. Storage capacity of eight hours of average hourly wastewater flow is provided for this reservoir. The required areas of filtered water reservoir for each of the catchment are shown in table 4.65.

Slow sand filter (SSF): Excess water of filtered water reservoir after crossing a set limit will be passed through SSF into the recharge well. Capacity of the slow sand filter is designed to filter

90 percentile wet weather flow over 72 hour period at a filtration rate of 0.5 m/h. A bed of 1 m thickness of fine sand of effective size 0.27 mm and uniformity coefficient 4.0 is provided for the filtration of water through SSF. Headloss through the filter is computed using equation 3.23 in which the values of porosity and particle shape factor is taken as 0.3 (fine sand) and 0.75 (average sand), respectively. Maximum clean water headloss through the sand bed is 0.94 m. Therefore, a head of 0.94 m is provided in filtered water reservoir for flow to occur. SSF will always be kept in submerged conditions by keeping the inlet of dry well 100 mm higher than SSF sand bed. The area details of SSF are shown in table 4.65.

Groundwater recharge system: In the current study, medium sand stratum was used for the disposal of treated water through dry wells. This stratum was available nearest at 5-6 meters depth from the ground level in the studied catchments (Department of Irrigation, Govt. of Punjab). From literature, the saturated hydraulic conductivity of medium sand was taken as 1.8 m/h and is used for the determination of radius of well by equation 4.1 (Bouwer, 2002). The required saturation depth (Y) was then computed by using equation 4.2 (Todd and Mays, 2005). The total depth of the dry well required below ground level was determined by adding three depths .i.e. depth of soil layer used for disposal of water below ground level (6 meters in the studied catchments), depth of water in well (L_w) and saturation depth (Y). Design details of vadose zone wells are shown in table 4.66.

$$Q_r = \frac{2\pi \times K \times L_w^2}{\ln(2 \times L_w / r_w) - 1} \tag{4.1}$$

$$\frac{Y}{r_w} = (\lambda_y - 1)\sqrt{\frac{\lambda_r \ln \lambda_y}{2(\lambda_y^2 - 1)}} \tag{4.2}$$

Where,

Q_r is recharge rate (m^3/s)

K is hydraulic conductivity of soil material

r_w is radius of the well (m)

Table 4.66: Vadose zone recharge well design details for catchments

Catchment	Diameter of well, D_w (m)	Water depth in well, L_w (m)	Saturation depth, Y (m)	Total depth reqd. below ground level, (m)	Post monsoon spring level, (m)
Tayabpur	0.27	1.34	2.02	9.36	20.3
Sodhian	0.44	2.19	3.29	11.48	19.5
Majari	0.34	1.68	2.54	10.22	18.6
Palli Jhiki	0.36	1.79	2.69	10.48	22.3
Mandiala	0.46	2.29	3.45	11.74	22.8
Kultham	0.31	1.53	2.31	9.84	18.0
Pippa Rangi	0.4	1.99	2.99	10.98	25.4
Nijjran	0.35	1.76	2.65	10.41	20.5
Samrai	0.7	3.52	5.30	14.82	25.4
Masitan	0.49	2.46	3.71	12.17	22.5

From the table 4.66, it can be concluded that in the studied catchments sufficient subsurface hydraulic gradient was available thus preventing mounding conditions underneath the dry well.

4.8 Village pond system drawings

Summarised design results of the village pond system for all the catchments are shown in table 4.67. The designed treatment and disposal units of the village pond system for all the ten selected catchments are shown in the drawings (to the scale) from figure 4.38 to figure 4.47. Two views .i.e. plan and elevation are presented in this work.

Table 4.67: Summarized design results for village pond system

Catchment	Catch basin area, (m^2)	Constructed wetland area, (m^2)	Facultative pond area, (m^2)	Roughing filter area, (m^2)	Treated water reservoir area, (m^2)	Slow sand filter area, (m^2)	Total additional area required, (m^2)
Tayabpur	1.22	297	2515	5	23	21	51
Sodhian	5.25	1275	3785	14	43	54	117
Majari	3.96	961	1252	8	30	32	1035
Palli Jhiki	3.93	954	2940	9	52	36	102
Mandiala	3.74	908	3373	15	58	60	1170
Kultham	2.51	610	994	7	25	27	952
Pippa Rangi	2.44	592	3251	11	31	44	3116
Nijjran	2.44	593	1808	9	36	35	676
Samrai	6.05	1470	7684	35	70	140	6083
Masitan	3.44	834	4714	17	74	68	2865

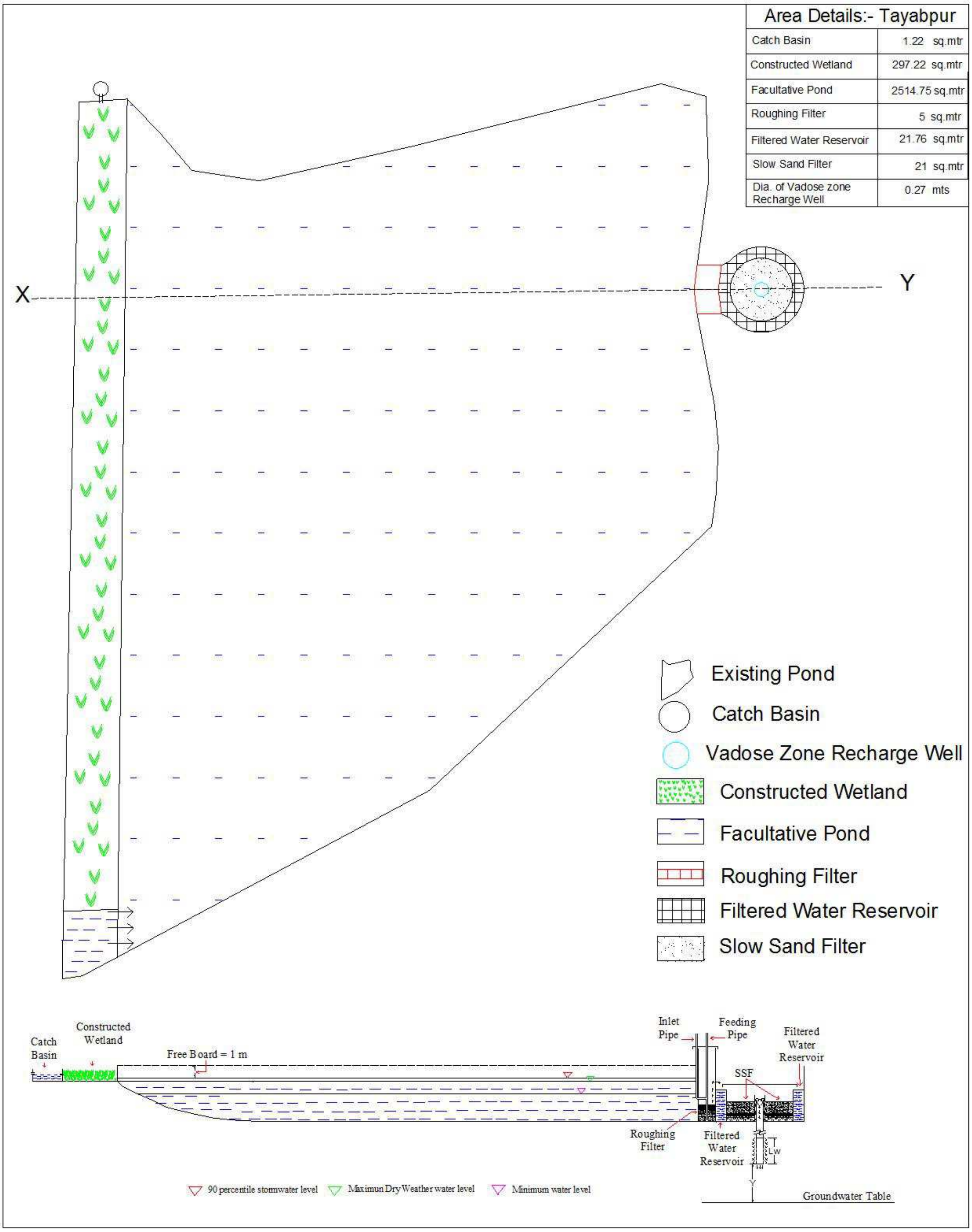


Figure 4.38: Plan and elevation view of Tayabpur village pond system

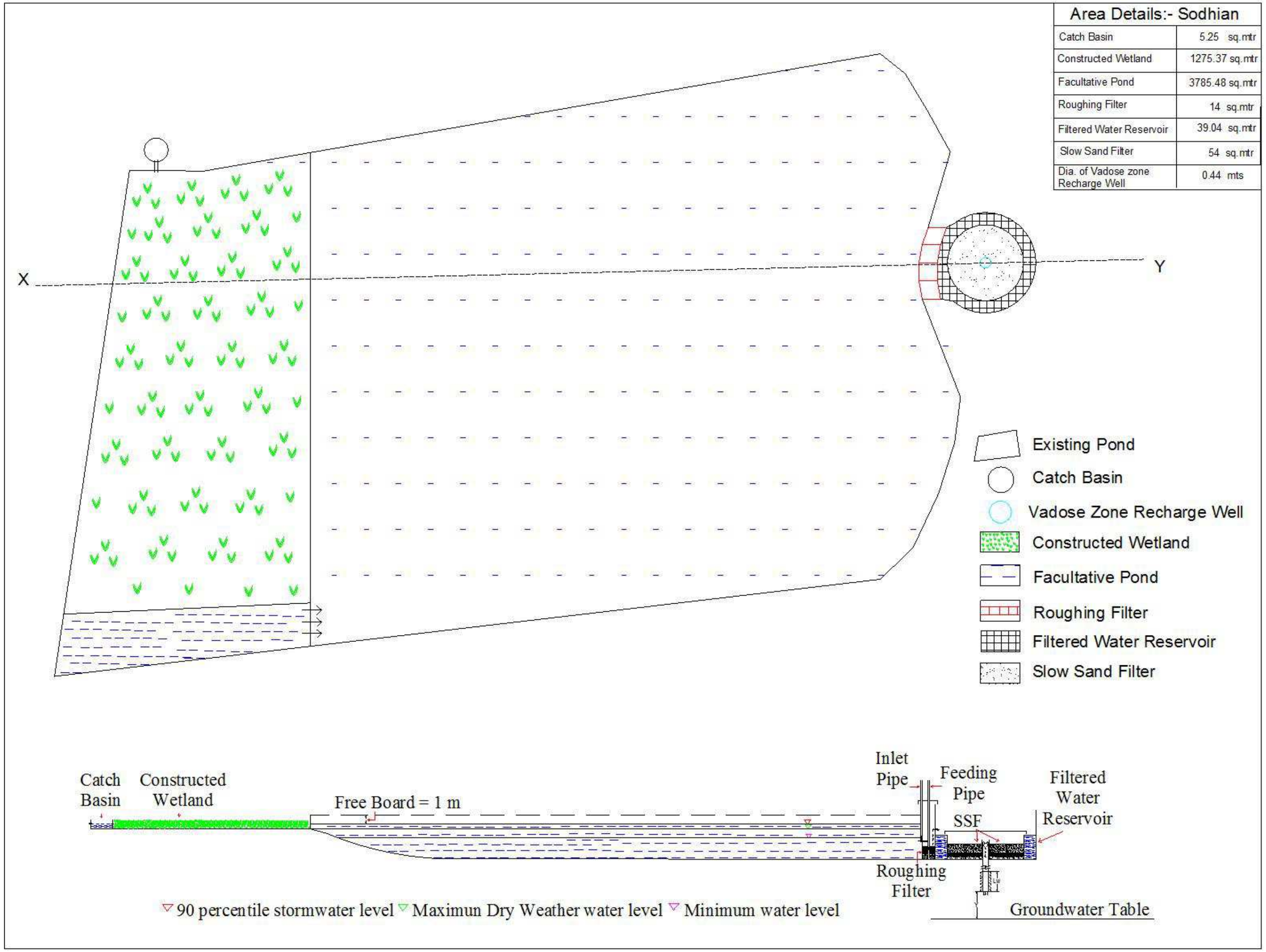


Figure 4.39: Plan and elevation view of Sodhian village pond system

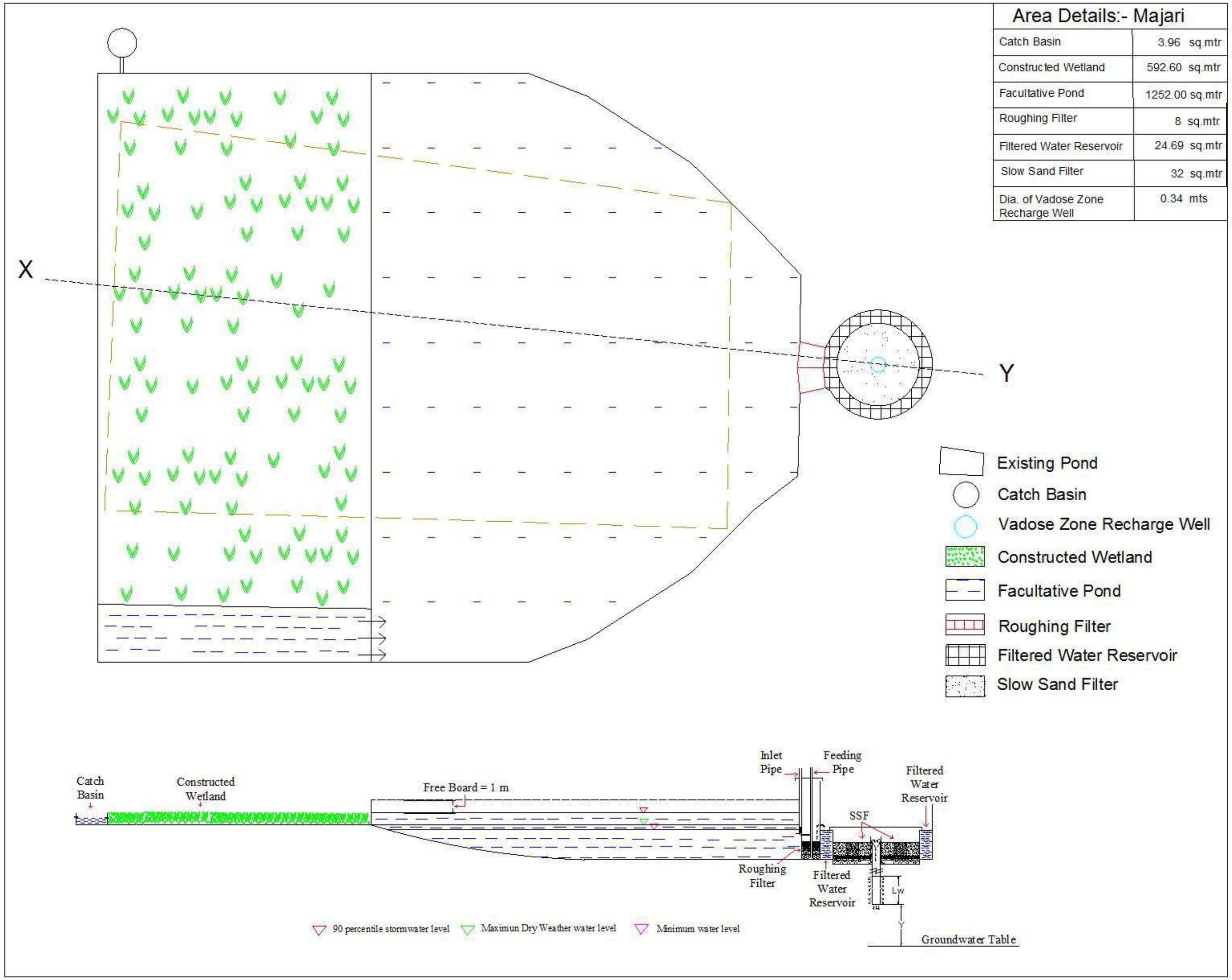


Figure 4.40: Plan and elevation view of Majari village pond system

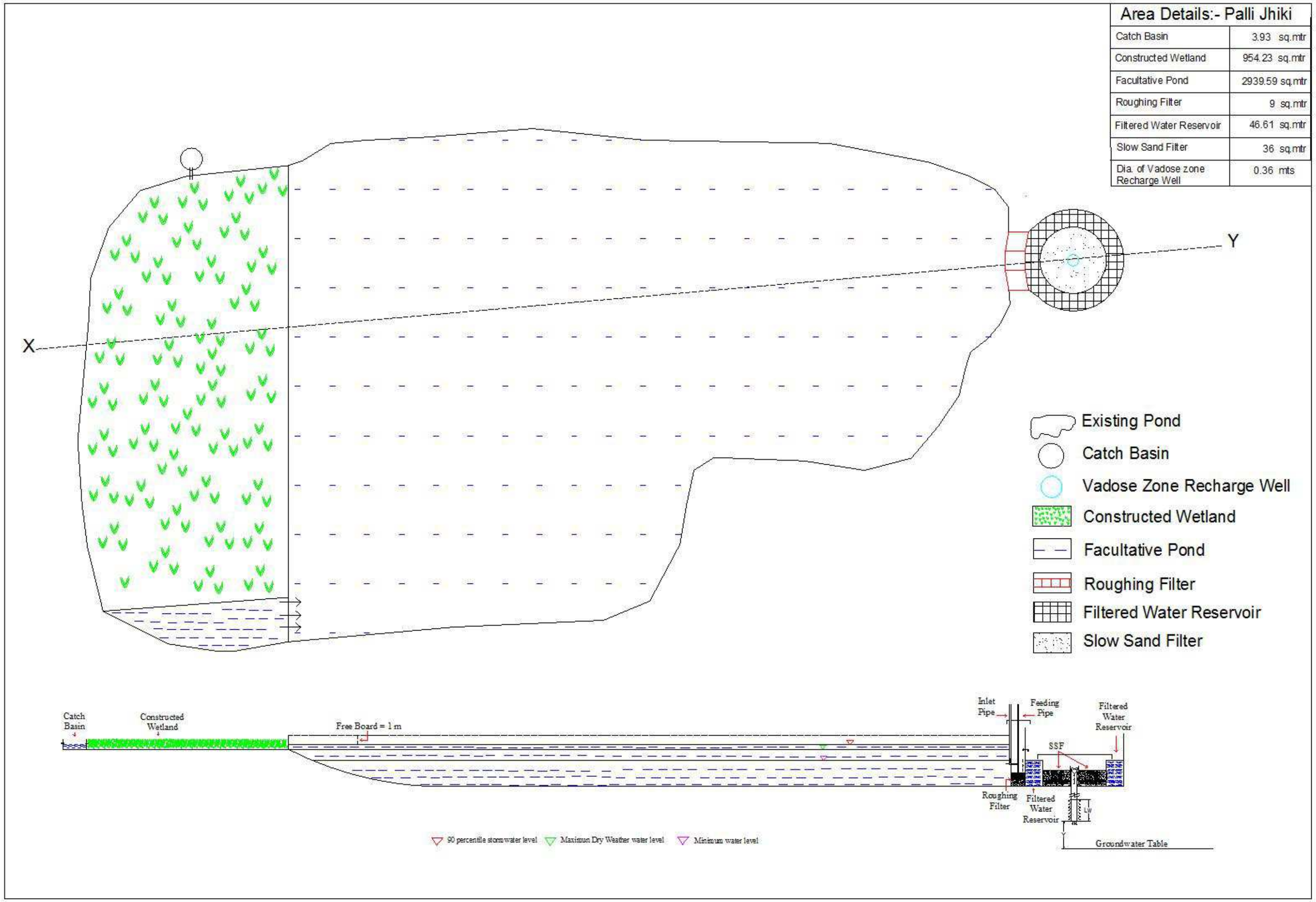


Figure 4.41: Plan and elevation view of Palli Jhiki village pond system

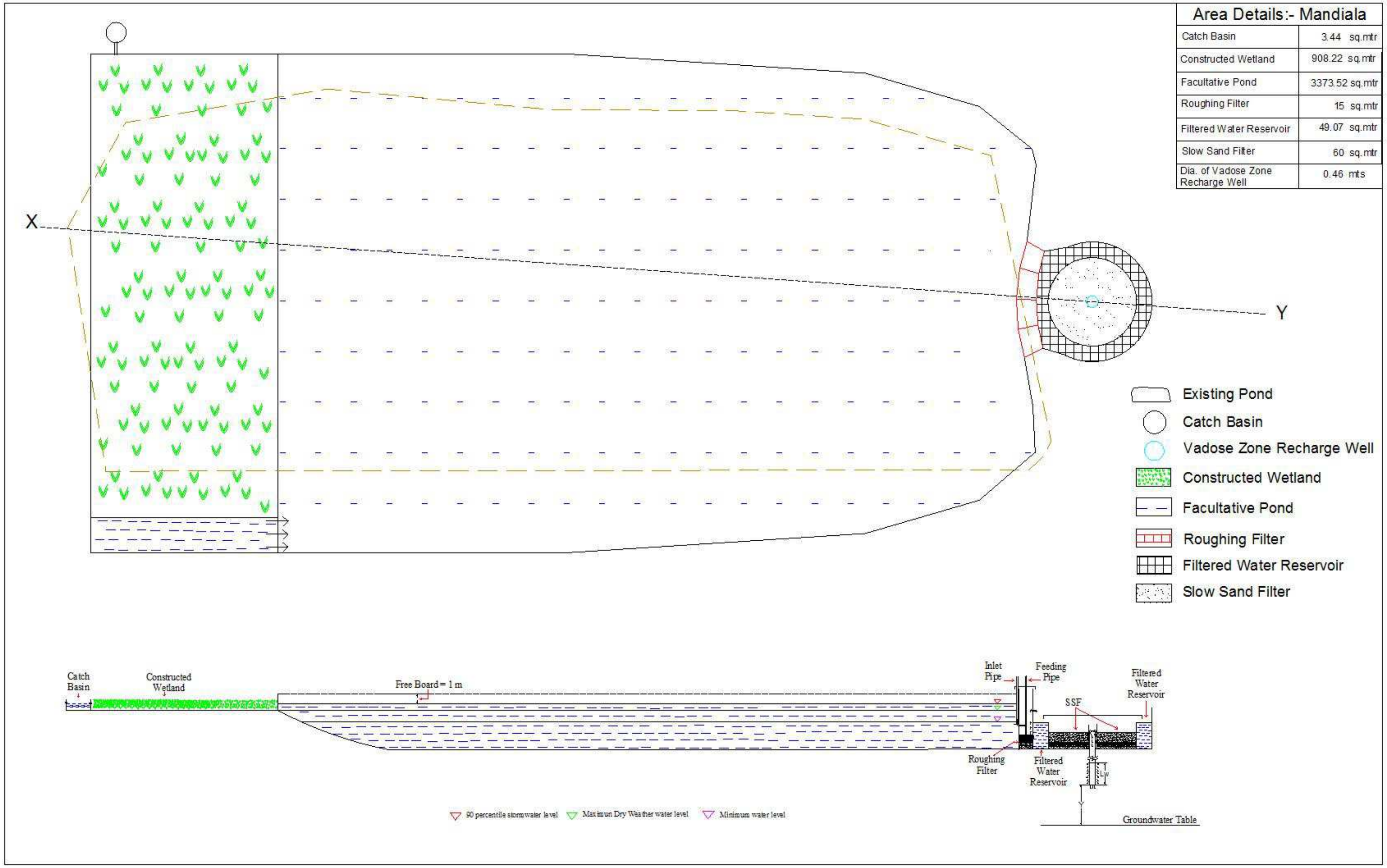
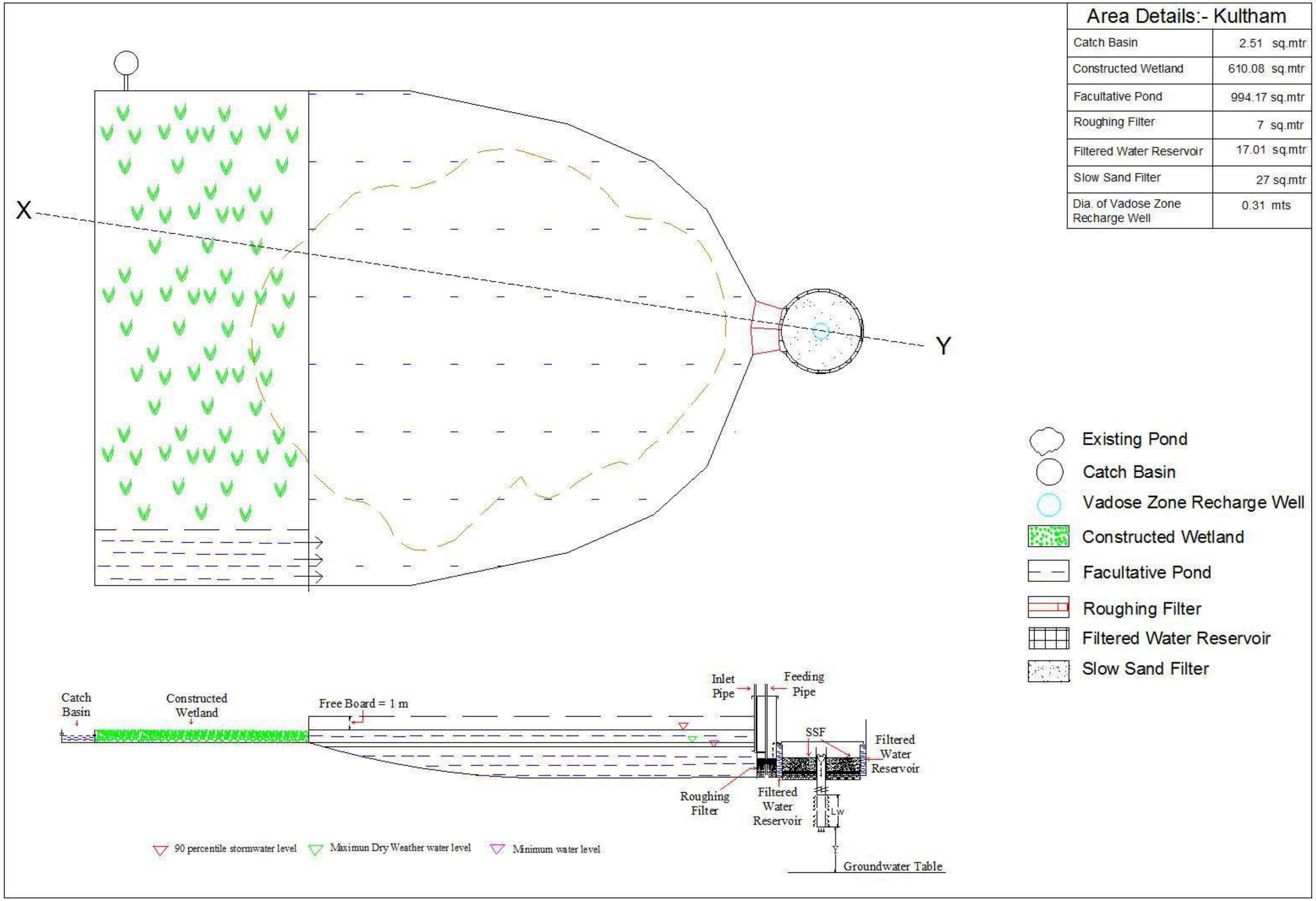


Figure 4.42: Plan and elevation view of Mandiala village pond system



Area Details:- Kultham	
Catch Basin	2.51 sq.mtr
Constructed Wetland	610.08 sq.mtr
Facultative Pond	994.17 sq.mtr
Roughing Filter	7 sq.mtr
Filtered Water Reservoir	17.01 sq.mtr
Slow Sand Filter	27 sq.mtr
Dia. of Vadose Zone Recharge Well	0.31 mts

Figure 4.43: Plan and elevation view of Kultham village pond system

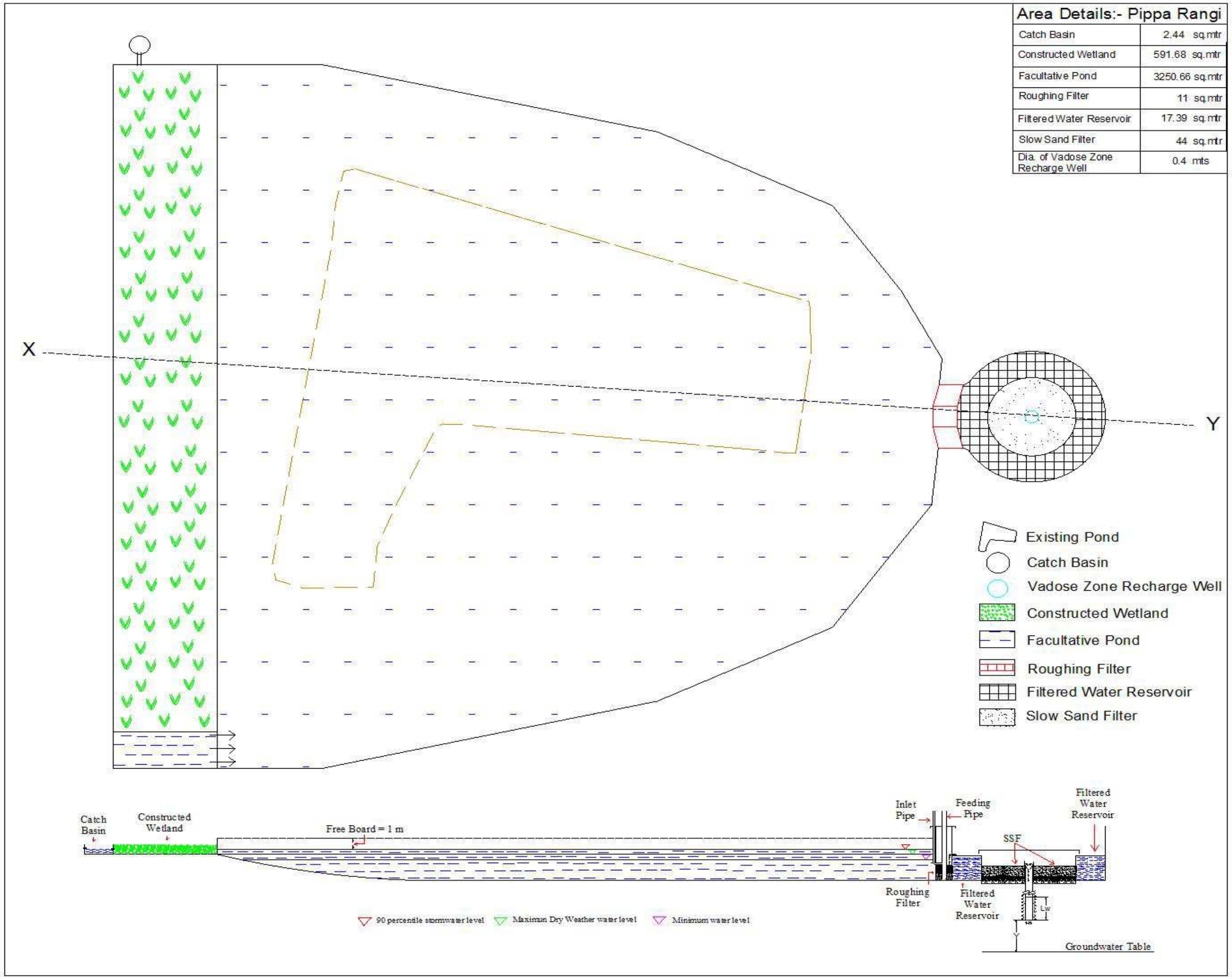


Figure 4.44: Plan and elevation view of Pippa Rangi village pond system

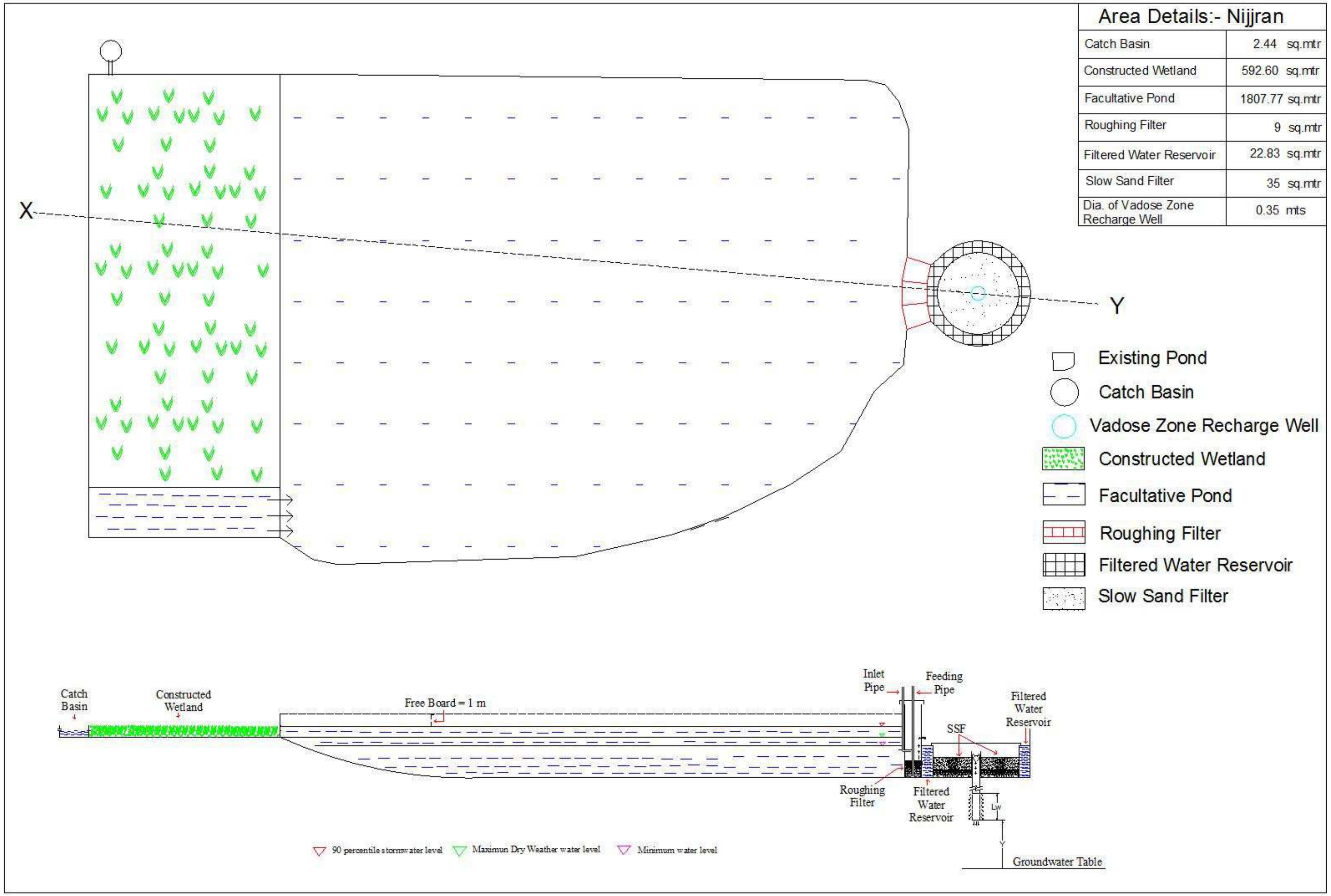


Figure 4.45: Plan and elevation view of Nijjran village pond system

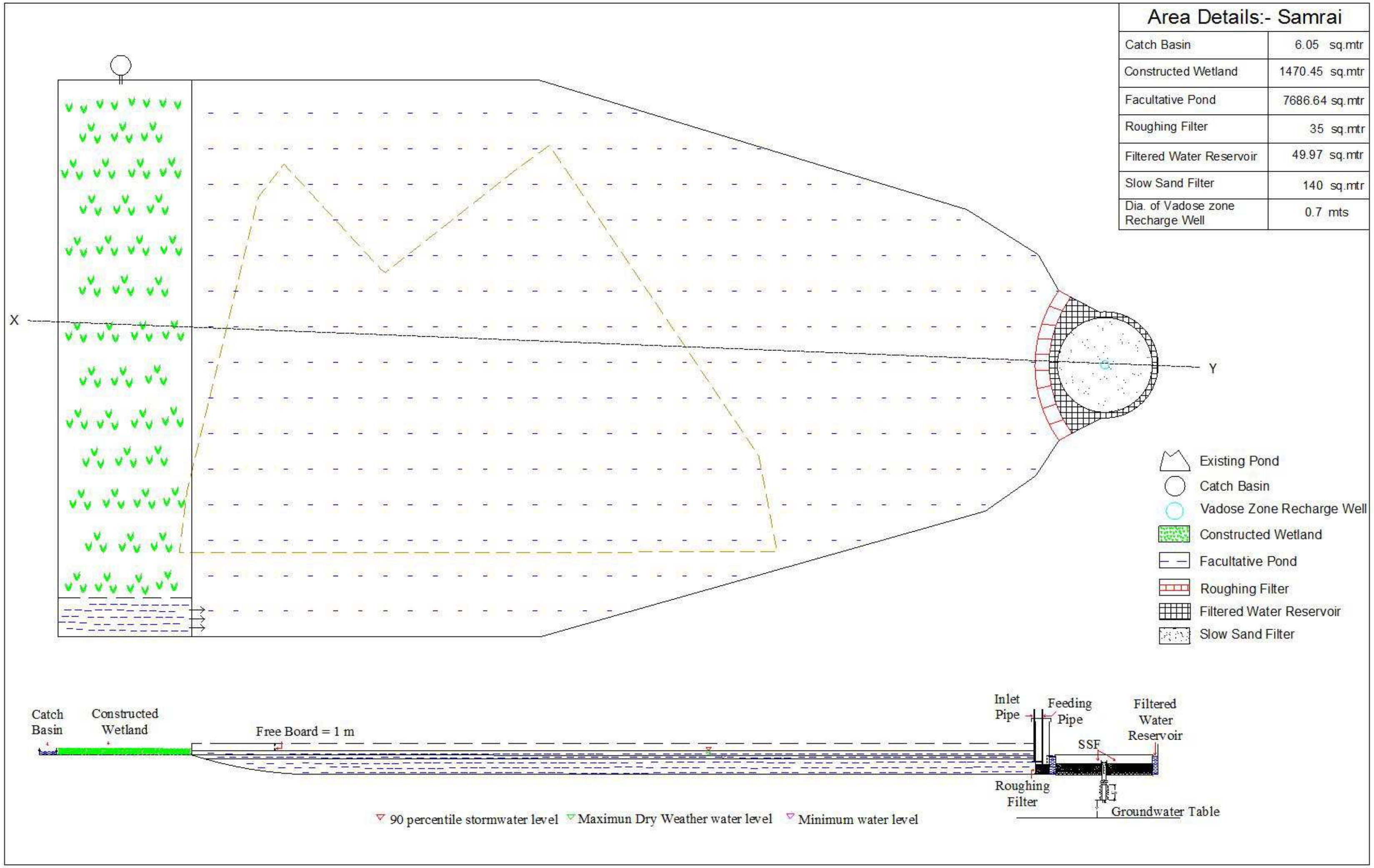


Figure 4.46: Plan and elevation view of Samrai village pond system

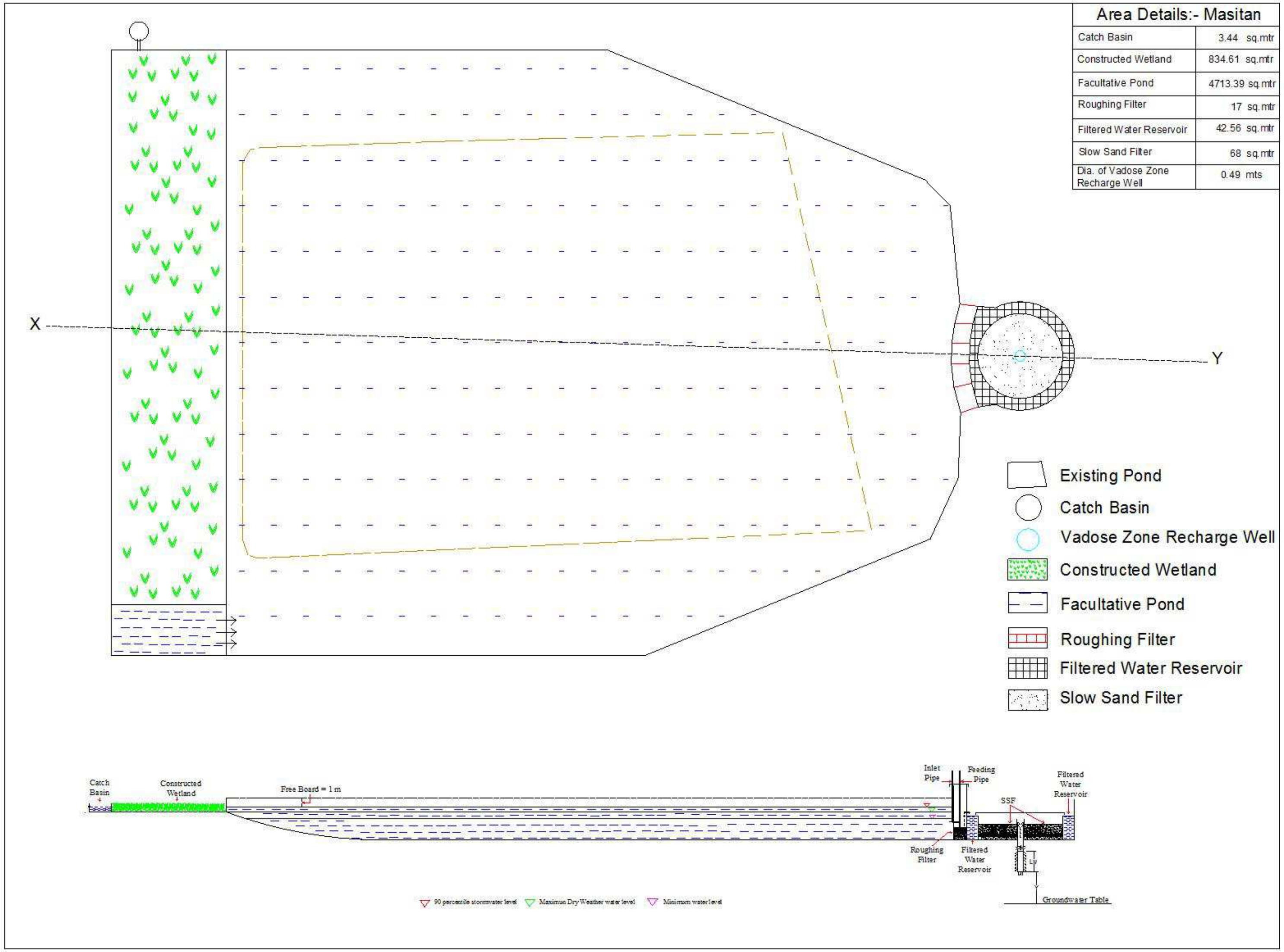


Figure 4.47: Plan and elevation view of Masitan village pond system

Chapter-5
Conclusions

5.1 Conclusions

In the present study, an attempt has been made to develop IWRM (Integrated Water Resources Management) at the village pond catchments level for tackling the rural water supply and sanitation problems in ten selected villages of Doaba region, Punjab.

Household level private water supplies parallel to the piped village water supply, declining groundwater tables and deteriorating groundwater quality, cattle bathing with piped water, higher strength and higher per capita wastewater, discharge of all the wastewaters (grey water, black water, cattle shed wastewater and even the cattle dung) into village drains, undersized village drains specially to carry the storm water, open defecation in the village pond premises, heavily polluted and pest infested village ponds and overflowing village ponds have been the problems identified with the ten villages studied.

Prohibiting the household level private water supplies, ecological sanitation approach for water conservation, discharging only grey water into village drains, segregation of black water and cattle dung - cattle shed wastewater for separate onsite handling and management, design and creation of grey water - storm water drainage system, modification/restructuring the existing village ponds into village pond systems, and disposal of the treated pond effluents through reuse as reclaimed water and through groundwater recharging were suggested as solutions for implementation through IWRM.

Drainage system was designed for one of the villages for carrying the dry weather flows at above the self-cleansing velocity and wet weather flows at below the drain scour velocity. The drains were sized to carry the peak flows expected from a rainfall event with 2 years return period.

The village pond systems were conceptualized to include a catch basin, a constructed wetland system, a facultative pond, an up-flow multi-grade roughing filter, a storage reservoir and a ground water recharge well. Sustainability feature of the village ponds was preserved in these systems. Further, these systems are passive (solar) requiring negligible human intervention and using no machinery and conventional energy inputs.

The village pond systems were designed for all the ten villages for the treatment and disposal of the wet weather flows expected from a 90 percentile rainfall event. The pond systems were sized to retain the wet weather flows in the system till they are slowly treated and disposed off. The upflow multigrade roughing filters were designed to operate and filter only the daily excess flows that too if consumed as reclaimed water or disposed through ground water recharging. Similarly, the slow sand filters were designed to operate and filter the excess effluent that needs disposal through groundwater recharging. The important positive features of these village pond systems include, a) keeping both the roughing filters and the slow sand filters all the time submerged in water, b) groundwater recharging of only the excess effluent, and c) prevented access of untreated water to the groundwater recharge well.

The designed village pond systems can be mostly accommodated within the existing village ponds. Additional land requirements were worked as ranging between 0.01 acres to 1.5 acres for the ten villages studied.

Development of regression models, relating the wastewater characteristics with the antecedent dry days and the rainfall event size, and their use for predicting characteristics of the wet weather flows from the village pond catchments, is one of key works of the present study.

5.2 Future Research

The designed village pond system need implementation at least in one of the 10 villages on experimental basis for demonstration purposes for widespread use of the proposed IWRM to tackle the rural water supply and sanitation problems. Such an experimental system can help specially in reducing the sizes of the up-flow multi-grade roughing filters and the slow sand filters.

Regression models developed in the present study for the characteristics assessment of wet weather flows are village pond specific. Future studies can concentrate on developing regression models generic to the rural human settlements for the Punjab region. Further, regression models for the storm water flows rather than for the wet weather flows can be attempted.

The study was concentrated on the characterization of the combined dry weather flows and used them in the design of the village pond systems. Since the village pond systems will be handling the village grey water – storm water, future studies can concentrate on the characterization of the grey water flows.

An acceptable and rational method for the design of groundwater recharge wells is apparently not available. Creation of an experimental groundwater recharge and carrying out pilot scale studies on the well may prove quite useful in order to model the ground water recharging processes, and to develop a method for the design of groundwater recharge wells.

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Appendix-A

Data collection form for physical survey of the rural settlements

(A) General

1) Name of village & location………………………………..
2) Block & District……………………………………..........
3) No. of houses in village……………………………………
4) No. of houses in catchment………………………………..
5) Human population in village………………………………
6) Human population in catchment…………………………..
7) Cattle population in village………………………………
8) Cattle population in catchment……………………………
9) Soil type……………………………………………………

(B) Water supply and sanitation at catchment level

1) Mode of water supply……………………………………….
2) No. of households having hand pumps………………………
3) No. of households having submersible pumps………………
4) No. of households having toilets……………………………
5) No. of households having septic tanks…………………………….
6) No. of households having soak pits……………………………….
7) Open defecation……………………………………………..
8) Drainage facilities in catchment…………………………......
9) Wastewater and stormwater outlet…………………………..

(C) Pond information

1) Number of ponds…………………………………………
2) Location of ponds………………………………………..
3) Condition of ponds
   i) Water hyacinth/vegetation growth…………………
   ii) Solid waste dumping………………………………
   iii) Encroachment of pond area……………………….
4) Pond area…………………………………………………

5) Pond depth
    i) Maximum depth……………………………………….
    ii) Minimum depth……………………………………….
    iii) Seasonal depth variation………………………………
6) Overflow pattern…………………………………...........
7) Pond water usage pattern…………………………………….

(D) Land cover and land use

1) Residential houses…………………………………………….
2) Fallow…………………………………………………………
3) Grass cover……………………………………………………
4) Bricked streets………………………………………………..
5) Metalled roads………………………………………………..
6) Cemented roads………………………………………………
7) Crop cover……………………………………………………
8) Any other……………………………………………………..

Appendix-B

Wastewater flow characterization results of Rural Settlements

Table B-1: Wastewater flow characterization results of village Tayabpur

Date	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	TC*	FC*	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
18/02/12	860	326	802	110.10	39.50	78.50	6.73	5.54	0.005	0.009	0.248	0.058	2.587	0.158	0.077	0.058	0.343
11/03/12	1187	351	848	76.50	31.40	54.60	6.90	5.65	0.002	0.015	0.345	0.188	3.375	0.246	0.178	0.043	0.578
02/04/12	732	242	656	70.80	28.00	40.50	6.54	5.89	0.002	0.012	0.287	0.095	3.525	0.184	0.185	0.097	0.629
28/05/12	433	515	1092	82.30	37.00	10.60	6.69	5.72	0.004	0.024	0.185	0.024	1.600	0.112	0.037	0.025	0.162
09/07/12	888	186	439	98.50	40.80	60.60	6.75	5.68	0.008	0.007	0.382	0.038	2.914	0.267	0.071	0.034	0.276
08/08/12	490	404	933	43.00	35.20	9.80	6.47	5.76	0.001	0.002	0.378	0.236	3.653	0.261	0.324	0.126	0.723

*** TC-Total coliform and FC-Fecal coliform (values are in log (base 10) terms)**

Table B-2: Wastewater flow characterization results of village Sodhian

Date	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	TC*	FC*	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
18/02/12	932	238	775	69.50	39.00	68.30	6.66	5.68	0.007	0.009	0.346	0.035	2.386	0.325	0.077	0.008	0.357
11/03/12	780	330	832	77.10	44.20	55.80	6.82	5.75	0.016	0.011	0.418	0.068	3.264	0.236	0.142	0.028	0.085
02/04/12	1020	428	1010	64.70	35.10	25.30	6.82	5.87	0.009	0.008	0.585	0.028	3.174	0.157	0.188	0.019	0.058
28/05/12	532	354	858	67.30	40.80	48.40	6.84	5.80	0.027	0.014	0.745	0.081	4.578	0.398	0.230	0.010	0.046
09/07/12	990	290	645	91.45	42.00	20.70	6.88	5.83	0.009	0.010	0.302	0.017	3.718	0.135	0.067	0.034	0.251
08/08/12	305	201	471	41.00	34.10	33.00	6.46	5.64	0.004	0.002	0.210	0.084	2.645	0.209	0.150	0.007	0.597

*** TC-Total coliform and FC-Fecal coliform (values are in log (base 10) terms)**

Table B-3: Wastewater flow characterization results of village Majari

Date	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	TC*	FC*	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
25/01/12	943	238	678	65.40	55.80	15.90	6.37	5.10	0.008	0.055	0.145	0.435	0.596	0.060	0.087	0.010	1.870
03/03/12	487	280	757	55.80	63.60	30.50	6.68	5.37	0.014	0.134	0.230	0.287	0.458	0.075	0.048	0.012	0.950
25/03/12	790	416	912	44.40	70.10	22.70	6.74	5.46	0.012	0.042	0.165	0.568	0.934	0.048	0.070	0.018	1.587
28/05/12	346	256	740	67.50	43.20	55.80	6.92	5.64	0.006	0.067	0.321	0.530	1.723	0.092	0.085	0.008	1.340
08/07/12	415	162	386	70.30	60.50	34.20	6.71	5.28	0.009	0.035	0.879	0.890	1.305	0.125	0.106	0.027	0.878
03/10/12	690	214	532	50.20	75.60	40.00	6.83	5.52	0.017	0.023	0.630	0.632	1.450	0.090	0.078	0.055	1.855

*** TC-Total coliform and FC-Fecal coliform (values are in log (base 10) terms)**

Table B-4: Wastewater flow characterization results of village Palli Jhiki

Date	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	TC*	FC*	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
24/01/12	425	324	785	36.20	42.90	18.50	6.83	5.35	0.004	0.087	0.176	0.348	0.876	0.055	0.176	0.009	0.940
29/02/12	386	371	843	53.40	52.40	24.70	6.74	5.51	0.007	0.166	0.245	0.260	0.678	0.097	0.054	0.016	0.776
25/03/12	321	310	800	68.10	51.70	17.80	6.89	5.63	0.006	0.010	0.761	0.650	1.545	0.038	0.082	0.012	0.495
02/06/12	495	201	465	45.70	60.20	32.50	6.76	5.45	0.018	0.115	0.820	0.190	1.852	0.164	0.079	0.045	0.320
03/08/12	540	258	660	76.20	55.70	15.80	6.79	5.56	0.009	0.158	0.921	0.530	0.730	0.140	0.122	0.021	0.950
06/09/12	480	190	435	74.80	48.50	30.60	6.86	5.37	0.012	0.065	0.677	0.700	1.105	0.200	0.090	0.030	0.827

*** TC-Total coliform and FC-Fecal coliform (values are in log (base 10) terms)**

Table B-5: Wastewater flow characterization results of village Mandiala

Date	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	TC*	FC*	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
30/01/12	832	388	850	71.00	52.80	49.40	6.56	5.38	0.018	0.143	0.843	0.877	1.965	0.174	0.098	0.005	0.760
01/03/12	988	292	735	61.23	80.50	53.50	6.75	5.51	0.031	0.078	1.550	1.765	1.440	0.576	0.087	0.007	0.982
25/03/12	370	351	825	74.05	45.20	38.60	6.62	5.28	0.026	0.094	0.895	0.421	1.632	0.146	0.182	0.013	1.550
16/05/12	675	198	514	49.13	65.80	22.50	6.59	5.22	0.015	0.187	1.120	0.825	0.927	0.434	0.134	0.028	0.432
08/07/12	543	353	725	51.17	55.75	43.60	6.66	5.16	0.020	0.335	0.576	0.962	1.883	0.097	0.011	0.031	0.645
08/10/12	490	192	478	72.40	58.90	6.80	6.74	4.94	0.033	0.185	0.986	1.050	0.862	0.573	0.073	0.078	0.885

*** TC-Total coliform and FC-Fecal coliform (values are in log (base 10) terms)**

Table B-6: Wastewater flow characterization results of village Kultham

Date	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	TC*	FC*	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
07/02/12	449	323	706	63.10	51.20	35.50	6.64	5.51	0.002	0.004	0.568	0.038	1.463	0.216	0.048	0.046	0.347
29/02/12	587	267	548	51.58	56.20	30.20	6.51	5.51	0.004	0.003	0.325	0.127	2.245	0.327	0.059	0.038	0.453
25/03/12	828	210	603	46.13	68.50	25.60	6.39	5.33	0.004	0.002	0.265	0.042	1.856	0.254	0.062	0.067	0.948
28/05/12	528	377	788	41.55	57.50	17.20	6.32	5.41	0.001	0.002	0.204	0.021	1.724	0.101	0.037	0.034	0.120
08/07/12	575	290	582	55.13	60.50	28.70	6.74	5.67	0.007	0.003	0.126	0.034	2.671	0.144	0.073	0.027	0.120
29/07/12	195	330	700	29.67	66.00	6.30	6.16	5.46	0.002	0.005	2.154	0.959	1.791	0.757	0.054	0.298	2.054

*** TC-Total coliform and FC-Fecal coliform (values are in log (base 10) terms)**

Table B-7: Wastewater flow characterization results of village Pippa Rangi

Date	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	TC*	FC*	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
07/02/12	571	296	636	45.5	40.40	28.65	6.66	5.59	0.002	0.005	0.268	0.044	2.524	0.145	0.047	0.027	0.656
29/02/12	598	267	580	33.2	48.80	20.72	6.81	5.67	0.005	0.004	0.897	0.185	3.476	0.188	0.038	0.035	0.273
25/03/12	756	387	726	40.55	43.80	25.60	6.54	5.44	0.001	0.003	1.258	0.085	3.955	0.289	0.055	0.098	0.388
28/05/12	230	258	594	52.54	49.50	17.20	6.67	5.68	0.004	0.006	0.172	0.023	1.841	0.093	0.032	0.017	0.107
08/07/12	365	165	394	47.86	57.80	23.40	6.47	5.20	0.003	0.002	0.153	0.031	1.785	0.086	0.060	0.026	0.071
29/07/12	410	298	650	32.2	58.50	5.60	6.51	5.39	0.007	0.002	2.481	0.284	5.955	0.403	0.046	0.104	0.833

*** TC-Total coliform and FC-Fecal coliform (values are in log (base 10) terms)**

Table B-8: Wastewater flow characterization results of village Nijjran

Date	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	TC*	FC*	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
27/01/12	290	185	404	54.87	48.90	35.50	6.75	5.62	0.015	0.007	0.786	0.435	2.120	0.097	0.078	0.009	0.547
25/03/12	480	225	597	44.50	53.50	25.60	6.11	5.05	0.009	0.012	1.870	0.256	0.983	0.175	0.187	0.016	0.661
24/05/12	320	190	331	56.10	45.80	17.20	6.43	5.51	0.018	0.014	1.345	0.765	1.675	0.248	0.198	0.014	0.505
08/07/12	815	298	740	66.47	50.70	28.70	6.28	5.16	0.020	0.019	0.980	1.680	2.765	0.312	0.278	0.025	1.324
13/08/12	545	164	438	44.95	52.00	6.30	6.24	5.09	0.010	0.043	2.540	0.784	1.780	0.196	0.321	0.011	0.700
25/09/12	654	210	412	58.10	42.80	38.85	6.66	4.95	0.011	0.024	2.670	0.833	2.198	0.276	0.095	0.007	0.853

*** TC-Total coliform and FC-Fecal coliform (values are in log (base 10) terms)**

Table B-9: Wastewater flow characterization results of village Samrai

Date	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	TC*	FC*	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
7/2/2012	509	200	624	61.60	64.90	48.20	6.75	5.62	0.002	0.005	0.578	0.042	3.425	0.073	0.046	0.041	0.328
29/02/12	590	182	498	48.40	55.70	39.50	6.54	5.75	0.001	0.003	0.465	0.176	3.896	0.132	0.053	0.027	0.455
25/03/12	830	390	882	66.80	69.30	28.60	6.11	5.05	0.002	0.004	0.348	0.074	2.745	0.168	0.057	0.095	0.676
28/05/12	731	330	825	55.38	58.90	14.30	6.43	5.51	0.001	0.002	0.645	0.024	2.030	0.087	0.033	0.018	0.230
8/7/2012	484	216	545	57.43	60.70	45.70	6.28	5.16	0.001	0.002	0.329	0.056	4.184	0.143	0.071	0.042	0.376
29/07/12	210	240	524	36.00	59.70	8.00	6.24	5.09	0.001	0.043	0.448	0.279	4.835	0.202	0.064	0.130	0.874

*** TC-Total coliform and FC-Fecal coliform (values are in log (base 10) terms)**

Table B-10: Wastewater flow characterization results of village Masitan

Date	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	TC*	FC*	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
18/02/12	950	342	795	71.80	32.80	53.90	6.89	5.65	0.009	0.004	0.368	0.245	4.437	0.218	0.095	0.154	0.756
11/03/12	543	445	978	70.10	41.00	50.70	6.82	5.53	0.015	0.015	0.458	0.048	3.876	0.185	0.066	0.064	0.463
02/04/12	870	263	702	71.60	38.40	60.10	6.95	5.75	0.020	0.009	0.326	0.027	2.324	0.159	0.051	0.035	0.218
28/05/12	1024	365	835	61.30	30.60	21.30	6.41	5.59	0.006	0.001	0.430	0.026	3.819	0.199	0.042	0.026	0.125
09/07/12	658	210	520	73.60	43.00	38.50	6.24	5.19	0.012	0.014	0.473	0.024	4.301	0.164	0.077	0.042	0.326
08/08/12	497	312	618	43.00	35.00	11.90	6.57	5.35	0.034	0.003	0.346	0.316	5.045	0.256	0.130	0.168	0.867

*** TC-Total coliform and FC-Fecal coliform (values are in log (base 10) terms)**

Appendix C

Development of IDF curves

Development of IDF curves is discussed here. Short duration rainfalls from the extreme daily rainfall events for fifteen years rainfall data (January, 1998-December, 2013) was generated using equation 3.10. Table C-1 presents the results of annual extreme short rainfall values for Nawanshahar rain gauge station.

Table C-1: Annual extreme rainfall values for Nawanshahar rain gauge station

Year	P (24hr) (mm)	P (10min) (mm)	P (15min) (mm)	P (30min) (mm)	P (1hr) (mm)	P (2hr) (mm)
1998	132	25.18	28.83	36.32	45.76	57.66
1999	119	22.70	25.99	32.74	41.25	51.98
2000	81	15.45	17.69	22.29	28.08	35.38
2001	158.6	30.26	34.64	43.64	54.98	69.27
2002	141	26.90	30.79	38.80	48.88	61.59
2003	69.2	13.20	15.11	19.04	23.99	30.23
2004	54.4	10.38	11.88	14.97	18.86	23.76
2005	64	12.21	13.98	17.61	22.19	27.95
2006	101	19.27	22.06	27.79	35.01	44.12
2007	59	11.26	12.89	16.23	20.45	25.77
2008	120.4	22.97	26.29	33.13	41.74	52.59
2009	62	11.83	13.54	17.06	21.49	27.08
2010	94	17.93	20.53	25.87	32.59	41.06
2011	203	38.73	44.33	55.86	70.38	88.67
2012	53.2	10.15	11.62	14.64	18.44	23.24
2013	63.2	12.06	13.80	17.39	21.91	27.61

The value of Gumbel's frequency factor (K_T) was computed for six different return periods using equation 3.12. These K_T values were used to determine the rainfall depth (P_T) for selected return periods. P_T values were used to compute the average rainfall intensity (I_T) for different short durations and return periods using equation 3.13. Table C-2 shows the values of 'I_T' for six different durations (10min, 15 min, 30 min, 1hr, 2hr, and 24hr) and for six different return periods (2yr, 5yr, 10yr, 25yr, 50yr, and 100yr) for Nawanshahar rainfall station.

Table C-2: Rainfall intensities for different return periods and rainfall durations

Rainfall duration, t (min.)	**Rainfall intensity, I_T (mm/hr)**					
	Return period, T (Years)					
	2	**5**	**10**	**25**	**50**	**100**
10	108.97	157.41	189.48	230.00	260.06	289.90
15	83.16	120.13	144.60	175.52	198.47	221.24
30	52.39	75.68	91.09	110.57	125.03	139.37
60	33.00	47.67	57.39	69.66	78.76	87.80
120	20.79	30.03	36.15	43.88	49.62	55.31
1440	3.97	5.73	6.90	8.37	9.47	10.55

IDF curves were then developed using rainfall intensities and rainfall duration (minutes) for different return periods. For remaining four meteorological stations, annual extreme rainfalls for 15 years (1998-2013) and computed rainfall intensities are given below:

Jalandhar Rain gauge Station

Table C-3: Annual extreme rainfall values for Jalandhar meteorological station

Year	P(24hr) (mm)	P(10min) (mm)	P(15min) (mm)	P(30min) (mm)	P(1hr) (mm)	P(2hr) (mm)
1998	130	24.80	28.39	35.77	45.07	56.78
1999	59	11.26	12.89	16.23	20.45	25.77
2000	46	8.78	10.05	12.66	15.95	20.09
2001	88	16.79	19.22	24.21	30.51	38.44
2002	60	11.44	13.10	16.51	20.80	26.21
2003	118	22.51	25.77	32.47	40.91	51.54
2004	39	7.44	8.52	10.73	13.52	17.03
2005	164	31.29	35.82	45.13	56.86	71.63
2006	120	22.89	26.21	33.02	41.60	52.41
2007	46	8.78	10.05	12.66	15.95	20.09
2008	-	-	-	-	-	-
2009	44	8.39	9.61	12.11	15.25	19.22
2010	25	4.77	5.46	6.88	8.67	10.92
2011	113	21.56	24.68	31.09	39.17	49.36
2012	40	7.63	8.74	11.01	13.87	17.47
2013	45	8.59	9.83	12.38	15.60	19.66

Table C-4: Rainfall intensities for different return periods and rainfall durations

Rainfall duration, t (min.)	Rainfall intensity, I_T (mm/hr)					
	Return period, T (Years)					
	2	**5**	**10**	**25**	**50**	**100**
10	78.75	121.90	150.46	186.56	213.33	239.91
15	60.10	93.02	114.82	142.37	162.80	183.09
30	37.86	58.60	72.33	89.69	102.56	115.34
60	23.85	36.92	45.57	56.50	64.61	72.66
120	15.02	23.26	28.71	35.59	40.70	45.77
1440	2.87	4.44	5.48	6.79	7.77	8.73

Kapurthala Meteorological Station

Table C-5: Annual extreme rainfall values for Kapurthala meteorological station

Year	P(24hr) (mm)	P(10min) (mm)	P(15min) (mm)	P(30min) (mm)	P(1hr) (mm)	P(2hr) (mm)
1998	55	10.49	12.01	15.13	19.07	24.02
1999	54	10.30	11.79	14.86	18.72	23.59
2000	75	14.31	16.38	20.64	26.00	32.76
2001	63	12.02	13.76	17.34	21.84	27.52
2002	69	13.16	15.07	18.99	23.92	30.14
2003	85	16.22	18.56	23.39	29.47	37.13
2004	23	4.39	5.02	6.33	7.97	10.05
2005	80	15.26	17.47	22.01	27.73	34.94
2006	75	14.31	16.38	20.64	26.00	32.16
2007	27	5.15	5.90	7.43	9.36	11.79
2008	-	-	-	-	-	-
2009	62	11.83	13.54	17.06	21.49	27.08
2010	15	2.86	3.28	4.13	5.20	6.55
2011	56.60	10.80	12.36	15.57	19.62	24.72
2012	137	26.14	29.92	37.70	47.50	59.84
2013	135	25.76	29.48	37.15	46.80	58.97

Table C-6: Rainfall intensities for different return periods and rainfall durations

Rainfall duration, t (min.)	Rainfall intensity, I_T (mm/hr)					
	Return period, T (Years)					
	2	**5**	**10**	**25**	**50**	**100**
10	70.88	107.27	131.35	161.79	184.37	206.78
15	54.09	81.86	100.24	123.47	140.70	157.81
30	34.08	51.57	63.15	77.78	88.64	99.41
60	21.47	32.49	39.78	49.00	55.84	62.63
120	13.52	20.46	25.06	30.87	35.18	39.45
1440	2.58	3.90	4.78	5.89	6.71	7.53

Nakodar Rain gauge Station

Table C-7: Annual extreme rainfall values for Nakodar meteorological station

Year	P (24hr) (mm)	P (10min) (mm)	P (15min) (mm)	P (30min) (mm)	P (1hr) (mm)	P (2hr) (mm)
1998	66	12.59	14.41	18.16	22.88	28.83
1999	42	8.01	9.17	11.56	14.56	18.35
2000	41	7.82	8.95	11.28	14.21	17.91
2001	58	11.07	12.67	15.96	20.11	25.33
2002	53.2	10.15	11.62	14.64	18.44	23.24
2003	93	17.74	20.31	25.59	32.24	40.62
2004	25	4.77	5.46	6.88	8.67	10.92
2005	93	17.74	20.31	25.59	32.24	40.62
2006	-	-	-	-	-	-
2007	54	10.30	11.79	14.86	18.72	23.59
2008	45	8.59	9.83	12.38	15.60	19.66
2009	88	16.79	19.22	24.21	30.51	38.44
2010	107	20.41	23.37	29.44	37.09	46.74
2011	237	45.22	51.76	65.21	82.16	103.52
2012	81	15.45	17.69	22.29	28.08	35.38
2013	40	7.63	8.74	11.01	13.87	17.47

Table C-8: Rainfall intensities for different return periods and rainfall durations

Rainfall duration, t (min.)	Rainfall intensity, I_T (mm/hr)					
	Return period, T (Years)					
	2	**5**	**10**	**25**	**50**	**100**
10	131.03	184.97	220.69	265.81	299.29	332.52
15	99.99	141.16	168.42	202.85	228.40	253.76
30	62.99	88.92	106.10	127.79	143.88	159.86
60	39.68	56.02	66.84	80.50	90.64	100.71
120	25.00	35.29	42.10	50.71	57.10	63.44
1440	3.19	5.15	6.45	8.10	9.31	10.52

Phagwara Rain gauge Station

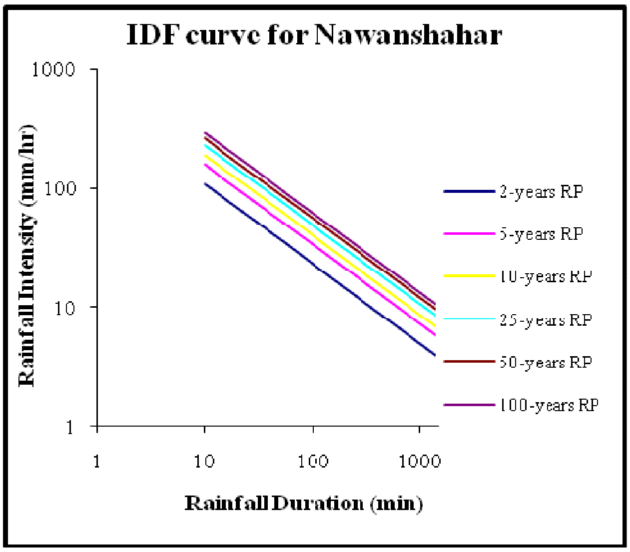
Table C-9: Annual extreme rainfall values for Phagwara meteorological station

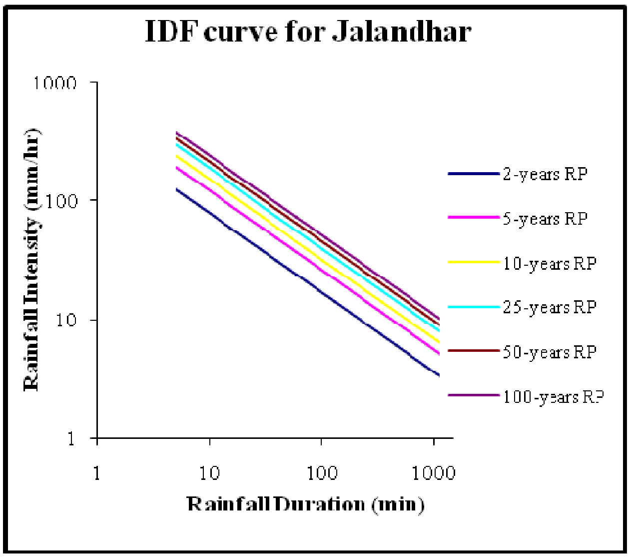
Year	P (24hr) (mm)	P (10min) (mm)	P (15min) (mm)	P (30min) (mm)	P (1hr) (mm)	P (2hr) (mm)
1998	44	8.39	9.61	12.11	15.25	19.22
1999	92	17.55	20.09	25.31	31.89	40.18
2000	35	6.68	7.64	9.63	12.13	15.29
2001	20	3.82	4.37	5.50	6.93	8.74
2002	-	-	-	-	-	-
2003	23	4.39	5.02	6.33	7.97	10.05
2004	41	7.82	8.95	11.28	14.21	17.91
2005	80	15.26	17.47	22.01	27.73	34.94
2006	27	5.15	5.90	7.43	9.36	11.79
2007	170	32.43	37.13	46.78	58.94	74.25
2008	203	38.73	44.33	55.86	70.38	88.67
2009	126	24.04	27.52	34.67	43.68	55.04
2010	73	13.93	15.94	20.09	25.31	31.89
2011	72	13.74	15.72	19.81	24.96	31.45
2012	62	11.83	13.54	17.06	21.49	27.08
2013	91	17.36	19.87	25.04	31.55	39.75

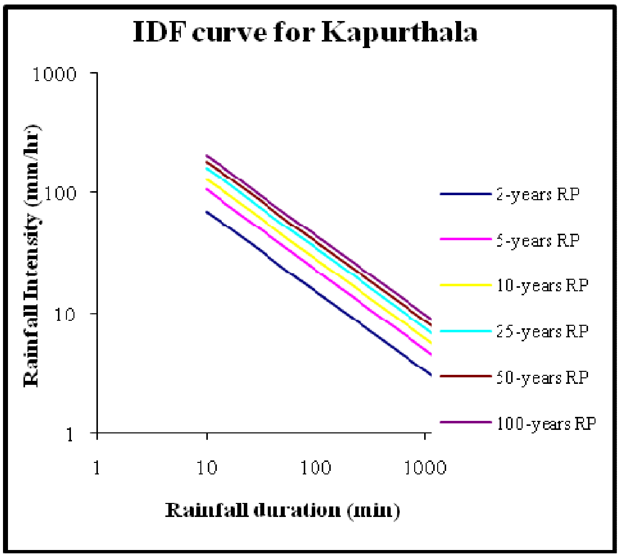
Table C-10: Rainfall intensities for different return periods and rainfall durations

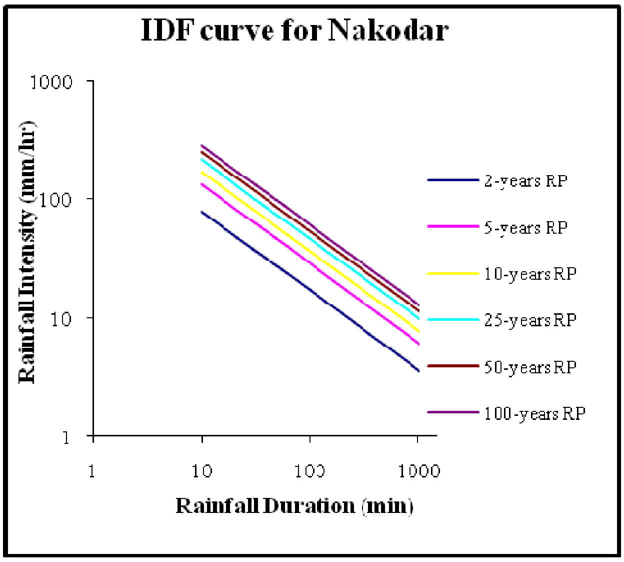
Rainfall duration, t (min.)	Rainfall intensity, I_T (mm/hr)					
	Return period, T (Years)					
	2	**5**	**10**	**25**	**50**	**100**
10	79.27	134.09	170.38	216.23	250.25	284.02
15	60.50	102.33	130.02	165.02	190.98	216.75
30	38.11	64.46	81.91	103.95	120.31	136.54
60	24.01	40.61	51.60	65.49	75.79	86.02
120	15.12	25.58	32.51	41.25	47.74	54.19
1440	2.89	4.88	6.20	7.87	9.11	10.34

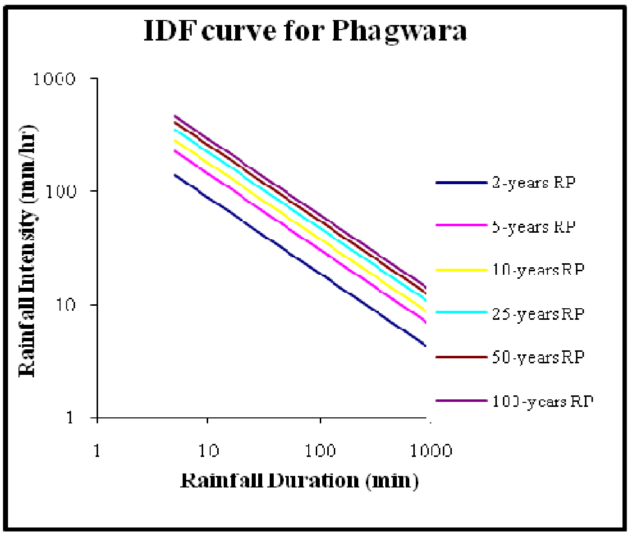
IDF curves developed for all the meteorological stations are shown in figures C-1 to C-5.











Appendix-D

Wet weather flow characterization results of Rural Settlements

Table D-1: Wet weather flow characterization results of village Tayabpur

S.No.	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	Total Coliform*	Fecal Coliform*	Cu (mg/L)	Fe (mg/L)	Zn (mg/L)
1	165	94	272	11.83	4.33	1.54	5.34	4.41	0.009	1.415	0.116
2	228	115	342	12.23	5.67	2.86	5.66	4.32	0.007	1.386	0.083
3	136	73	242	10.55	5.32	3.10	5.45	4.69	0.016	1.867	0.092
4	141	78	270	9.86	6.90	2.90	5.74	4.28	0.012	1.935	0.064
5	182	118	355	7.41	6.45	1.64	5.62	4.46	0.03	0.925	0.127
6	254	143	376	9.29	5.38	2.95	5.54	4.66	0.021	1.734	0.078
7	140	81	255	8.65	4.60	1.87	5.39	4.30	0.017	0.987	0.088
8	211	90	260	8.21	4.97	3.00	5.44	4.37	0.024	1.885	0.072
9	249	140	368	11.90	6.35	1.79	5.68	4.67	0.012	1.8	0.11
10	138	86	286	12.05	6.78	3.00	5.71	4.65	0.02	1.254	0.115
11	141	75	245	7.61	4.39	1.59	5.39	4.28	0.015	1.024	0.086
12	251	139	375	12.11	6.88	3.05	5.74	4.69	0.02	1.934	0.115
13	150	80	251	11.50	5.29	1.70	5.55	4.48	0.014	1.226	0.088
14	237	127	351	11.24	6.60	3.03	5.70	4.66	0.019	1.932	0.095
15	144	91	290	8.60	5.32	2.97	5.41	4.29	0.016	1.422	0.089

*** Total coliform and Fecal coliform values are in log (base 10) terms**

Table D-2: Wet weather flow characterization results of village Sodhian

S.No.	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	Total Coliform*	Fecal Coliform*	Cu (mg/L)	Fe (mg/L)	Zn (mg/L)
1	258	190	465	12.97	9.56	2.34	5.36	4.82	0.024	1.165	0.073
2	109	74	164	8.40	6.70	3.30	5.60	4.80	0.011	0.952	0.152
3	68	45	148	8.80	4.80	1.86	5.81	4.87	0.010	0.762	0.105
4	93	80	210	13.98	2.48	1.80	5.57	4.37	0.014	0.826	0.135
5	90	60	204	11.63	3.51	2.48	5.63	4.82	0.017	1.134	0.145
6	178	128	195	11.49	4.55	2.78	5.47	4.90	0.021	0.985	0.095
7	115	81	169	13.00	6.65	2.69	5.46	4.76	0.012	0.850	0.086
8	79	50	148	9.14	2.65	1.92	5.64	4.86	0.016	1.088	0.108
9	75	66	178	8.90	3.10	1.91	5.37	4.30	0.022	1.147	0.127
10	251	186	433	13.78	8.74	3.25	5.78	4.88	0.024	0.798	0.139
11	70	47	149	9.00	2.79	1.85	5.47	4.52	0.008	0.921	0.096
12	244	187	447	13.81	8.39	3.27	5.73	4.86	0.020	1.162	0.148
13	72	64	151	10.32	2.92	2.07	5.43	4.55	0.015	0.859	0.102
14	187	132	261	13.62	7.59	2.92	5.77	4.90	0.016	1.146	0.134
15	85	48	150	8.58	2.94	1.98	5.43	4.89	0.019	0.765	0.099

*** Total coliform and Fecal coliform values are in log (base 10) terms**

Table D-3: Wet weather flow characterization results of village Majari

S.No.	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	Total Coliform*	Fecal Coliform*	Cu (mg/L)	Fe (mg/L)	Zn (mg/L)
1	176	88	270	10.55	5.28	0.85	4.15	3.30	0.008	1.145	0.102
2	287	140	334	8.27	3.87	0.93	4.88	3.81	0.032	1.964	0.027
3	145	61	228	12.53	5.76	0.75	4.90	3.89	0.012	0.872	0.034
4	172	101	292	10.96	4.48	1.50	5.18	4.45	0.014	1.431	0.086
5	243	100	305	13.31	6.82	2.65	5.39	4.68	0.028	1.784	0.078
6	215	120	400	10.33	5.27	1.86	4.95	3.98	0.030	1.525	0.097
7	160	67	254	8.93	4.35	1.28	4.38	3.34	0.011	1.130	0.057
8	236	91	351	9.47	6.00	2.63	4.61	3.45	0.009	1.734	0.070
9	278	114	377	12.54	6.50	0.90	5.23	4.49	0.020	1.904	0.043
10	151	138	242	12.97	4.12	0.80	5.31	4.56	0.022	0.985	0.060
11	148	89	258	8.37	4.00	2.23	5.29	3.66	0.017	0.875	0.059
12	184	123	372	13.30	4.98	2.40	5.33	4.57	0.023	1.789	0.079
13	162	136	379	10.12	4.30	0.91	4.52	3.63	0.017	1.318	0.061
14	261	96	274	12.57	6.55	0.71	4.78	4.59	0.019	1.958	0.066
15	276	66	243	10.59	6.60	0.94	4.59	3.36	0.017	1.297	0.061

*** Total coliform and Fecal coliform values are in log (base 10) terms**

Table D-4: Wet weather flow characterization results of village Palli Jhiki

S.No.	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	Total Coliform*	Fecal Coliform*	Cu (mg/L)	Fe (mg/L)	Zn (mg/L)
1	165	25	115	3.95	4.30	0.86	5.18	4.39	0.016	1.187	0.105
2	242	84	278	7.06	3.47	0.97	5.54	4.09	0.027	1.123	0.054
3	201	78	166	9.25	4.19	2.35	5.72	4.51	0.012	1.365	0.067
4	235	102	300	11.73	6.50	1.65	5.43	4.34	0.031	0.831	0.032
5	128	46	118	6.70	3.38	1.86	5.08	4.09	0.008	1.249	0.118
6	267	128	228	4.80	2.15	1.18	5.59	4.51	0.024	1.540	0.077
7	220	65	152	5.50	5.78	0.90	5.68	4.44	0.019	1.650	0.048
8	285	145	292	9.60	4.55	0.75	5.61	4.35	0.024	0.950	0.094
9	152	32	124	4.09	2.64	0.99	5.25	4.18	0.797	0.837	1.008
10	237	98	259	7.14	3.66	1.08	5.67	4.45	1.245	2.592	1.575
11	189	73	158	6.34	4.41	1.01	5.28	4.30	0.195	1.179	0.281
12	283	137	287	11.63	6.40	2.26	5.70	4.49	0.302	1.610	0.436

*** Total coliform and Fecal coliform values are in log (base 10) terms**

Table D-5: Wet weather flow characterization results of village Mandiala

S.No.	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	Total Coliform*	Fecal Coliform*	Cu (mg/L)	Fe (mg/L)	Zn (mg/L)
1	230	130	325	15.95	11.20	1.75	5.81	4.93	0.015	2.541	0.118
2	407	238	521	12.65	3.60	2.07	5.44	4.73	0.009	1.467	0.082
3	204	76	201	8.53	3.75	0.85	5.62	4.87	0.020	1.388	0.158
4	158	62	242	7.40	6.48	4.57	5.94	4.92	0.011	0.921	0.183
5	75	48	175	7.87	5.45	3.87	5.32	4.55	0.024	1.556	0.124
6	192	94	273	8.73	5.27	3.98	5.51	4.98	0.008	1.668	0.147
7	90	53	185	7.50	4.28	1.58	5.40	4.57	0.009	0.958	0.097
8	111	58	209	13.25	10.74	4.40	5.36	4.88	0.015	2.340	0.108
9	302	100	268	14.46	4.78	1.15	5.88	4.93	0.018	1.245	0.174
10	338	225	498	7.50	4.00	4.23	5.84	4.96	0.020	1.780	0.170
11	92	55	213	7.44	3.90	1.09	5.35	4.56	0.010	0.994	0.091
12	355	234	501	15.68	10.32	4.45	5.91	4.97	0.022	2.415	0.172
13	96	56	180	7.68	3.78	1.00	5.37	4.76	0.014	1.188	0.096
14	312	130	371	12.91	8.30	4.01	5.86	4.95	0.015	2.018	0.175
15	197	61	192	8.21	3.62	3.71	5.53	4.91	0.014	1.300	0.130

*** Total coliform and Fecal coliform values are in log (base 10) terms**

Table D-6: Wet weather flow characterization results of village Kultham

S.No.	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	Total Coliform*	Fecal Coliform*	Cu (mg/L)	Fe (mg/L)	Zn (mg/L)
1	310	170	401	14.89	10.00	1.15	5.49	4.32	0.037	1.105	0.237
2	148	55	180	5.05	4.20	1.50	5.33	4.07	0.016	0.765	0.082
3	157	82	218	7.35	6.55	2.14	5.06	4.35	0.021	0.520	0.095
4	232	120	255	11.13	8.91	1.86	5.72	4.76	0.011	0.448	0.078
5	190	94	310	10.55	5.34	1.28	5.56	4.39	0.018	0.634	0.155
6	207	78	201	6.70	2.35	2.63	5.37	4.15	0.035	0.894	0.165
7	247	68	146	11.60	2.54	0.90	5.63	4.63	0.020	1.245	0.148
8	285	94	191	9.65	2.68	0.80	5.38	4.06	0.026	1.430	0.210
9	155	63	150	5.69	2.70	1.07	5.32	4.16	0.799	1.482	0.090
10	241	133	364	10.45	3.28	1.67	5.52	4.30	1.248	2.315	1.533
11	192	60	157	8.32	5.31	1.03	5.42	4.14	0.197	0.959	0.106
12	298	125	306	14.21	9.95	2.36	5.61	4.74	0.306	1.488	0.223

*** Total coliform and Fecal coliform values are in log (base 10) terms**

Table D-7: Wet weather flow characterization results of village Pippa Rangi

S.No.	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	Total Coliform*	Fecal Coliform*	Cu (mg/L)	Fe (mg/L)	Zn (mg/L)
1	315	68	282	6.7	2.7	2.13	5.76	4.69	0.016	0.986	0.087
2	275	159	415	10.95	5.37	3.35	5.22	4.40	0.022	1.988	0.184
3	180	70	253	7.4	4.85	2.38	5.33	4.51	0.013	1.721	0.115
4	215	85	295	8.25	2.58	1.25	5.51	4.58	0.006	0.924	0.076
5	165	140	300	8.02	4.26	1.48	5.42	4.13	0.019	1.345	0.095
6	125	50	210	9.34	3.84	1.83	5.65	4.63	0.020	1.420	0.098
7	265	108	206	5.25	3.43	1.10	5.54	4.47	0.024	0.867	0.072
8	164	63	168	7.55	3.05	1.35	5.44	4.38	0.018	1.654	0.056
9	131	53	180	5.62	2.6	1.29	5.36	4.34	0.795	0.919	1.025
10	230	115	289	7.62	4.71	1.52	5.55	4.65	1.242	1.482	1.601
11	183	69	229.912	7.87	3.13	1.61	5.26	4.24	0.192	1.180	0.302
12	305	137	367	10.55	5.25	3.00	5.73	4.63	0.298	1.867	0.468

*** Total coliform and Fecal coliform values are in log (base 10) terms**

Table D-8: Wet weather flow characterization results of village Nijjran

S.No.	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	Total Coliform*	Fecal Coliform*	Cu (mg/L)	Fe (mg/L)	Zn (mg/L)
1	101	39	125	10.00	4.59	1.87	5.66	4.76	0.015	1.132	0.141
2	242	52	173	9.54	5.34	2.46	5.76	4.81	0.029	1.760	0.137
3	132	98	278	11.32	6.72	1.65	5.95	4.02	0.022	1.439	0.094
4	121	57	170	6.10	4.87	1.38	5.98	4.74	0.020	1.368	0.159
5	83	27	144	8.75	4.52	2.54	5.44	4.57	0.006	1.822	0.125
6	138	42	153	10.47	3.98	2.63	5.63	4.59	0.020	1.546	0.133
7	143	68	140	7.10	2.31	3.32	5.52	4.20	0.014	0.976	0.117
8	218	155	375	7.40	2.95	0.80	5.56	4.42	0.010	1.250	0.167
9	92	33	131	6.15	4.21	1.15	5.44	4.19	0.794	1.852	0.095
10	159	47	129	9.60	2.89	2.20	5.76	4.70	1.241	1.600	1.521
11	100	58	160	8.65	3.82	1.80	5.56	4.36	0.192	1.305	0.238
12	231	130	352	11.24	6.69	3.29	5.96	4.81	0.298	1.820	0.162

* **Total coliform and Fecal coliform values are in log (base 10) terms**

Table D-9: Wet weather flow characterization results of village Samrai

S.No.	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- (mg/L)	Total-P (mg/L)	Total Coliform*	Fecal Coliform*	Cu (mg/L)	Fe (mg/L)	Zn (mg/L)
1	200	92	266	14.64	4.38	1.45	5.79	4.44	0.018	1.265	0.135
2	495	276	576	9.45	13.25	2.07	5.61	4.53	0.028	1.823	0.236
3	160	75	260	11.40	5.24	0.55	5.07	4.12	0.014	1.384	0.153
4	140	65	230	12.35	5.40	3.42	5.93	4.92	0.009	0.655	0.086
5	194	88	280	7.84	3.70	2.72	5.13	4.56	0.025	1.764	0.164
6	158	82	241	18.42	6.78	4.21	5.38	4.46	0.023	1.655	0.114
7	454	70	249	8.23	3.92	0.90	5.10	4.25	0.014	0.782	0.094
8	151	80	256	9.25	4.47	1.31	5.32	4.34	0.018	1.544	0.125
9	145	257	542	17.48	12.47	4.04	5.84	4.51	0.022	1.805	0.180
10	148	67	245	14.45	4.98	3.75	5.86	4.89	0.016	1.696	0.212
11	144	72	231	8.30	3.87	1.10	5.21	4.14	0.010	0.707	0.136
12	492	272	573	17.90	12.89	4.13	5.92	4.88	0.026	1.810	0.232
13	150	73	233	9.52	4.18	2.28	5.26	4.39	0.019	1.340	0.144
14	196	85	310	15.95	7.40	3.95	5.82	4.74	0.024	1.773	0.155
15	143	69	235	10.05	4.02	0.79	5.33	4.25	0.018	1.647	0.144

*** Total coliform and Fecal coliform values are in log (base 10) terms**

Table D-10: Wet weather flow characterization results of village Masitan

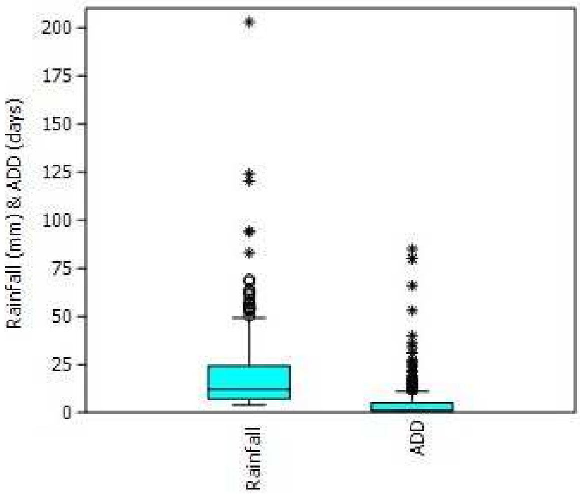
S.No.	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	NO_3^- N (mg/L)	Total-P (mg/L)	Total Coliform*	Fecal Coliform*	Cu (mg/L)	Fe (mg/L)	Zn (mg/L)
1	146	56	165	6.70	5.76	2.32	5.75	4.64	0.021	1.673	0.126
2	218	110	273	7.98	5.82	2.85	5.51	4.75	0.018	1.874	0.155
3	162	90	245	8.50	4.14	1.67	5.92	4.80	0.014	1.424	0.112
4	114	43	146	7.67	3.27	1.48	5.94	4.90	0.005	1.116	0.057
5	176	97	340	10.60	5.60	1.86	5.65	4.35	0.022	1.828	0.120
6	355	205	415	10.15	8.90	1.37	5.72	4.47	0.013	1.573	0.082
7	290	174	390	14.56	9.60	3.58	5.41	4.36	0.009	0.853	0.076
8	381	153	380	12. 38	8.45	4.15	5.54	4.64	0.014	1.727	0.137
9	123	49	151	8.75	3.39	1.38	5.42	4.39	0.793	1.099	1.032
10	315	126	381	12.50	9.20	2.52	5.82	4.75	1.239	2.896	1.612
11	126	100	254	10.50	5.02	1.67	5.55	4.47	0.190	1.421	0.311
12	354	192	401	14.50	8.17	4.05	5.90	4.88	0.020	1.863	0.482

*** Total coliform and Fecal coliform values are in log (base 10) terms**

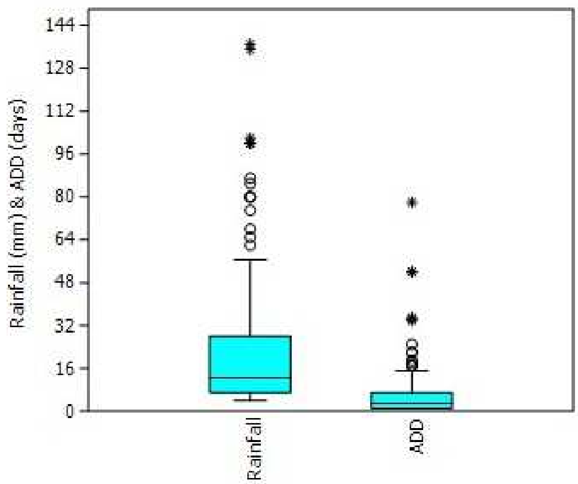
Appendix-E

Box plots of rainfall data from rain gauge stations

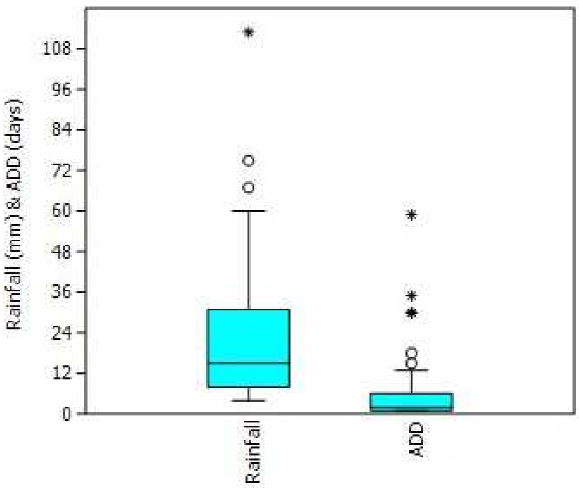
(a) Nawanshahar, (b) Kapurthala, (c) Jalandhar, (d) Phagwara, (e) Nakodar



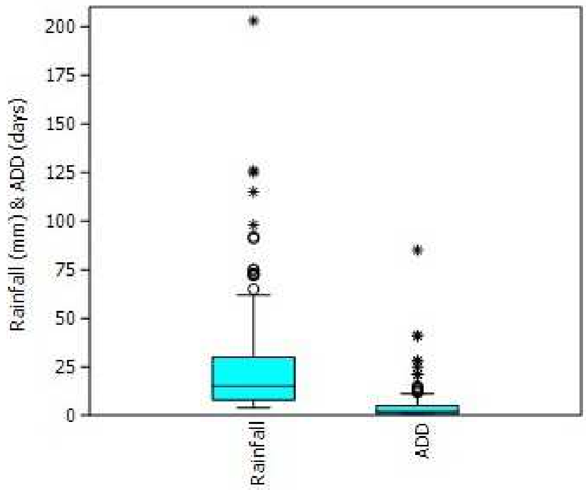
(a)



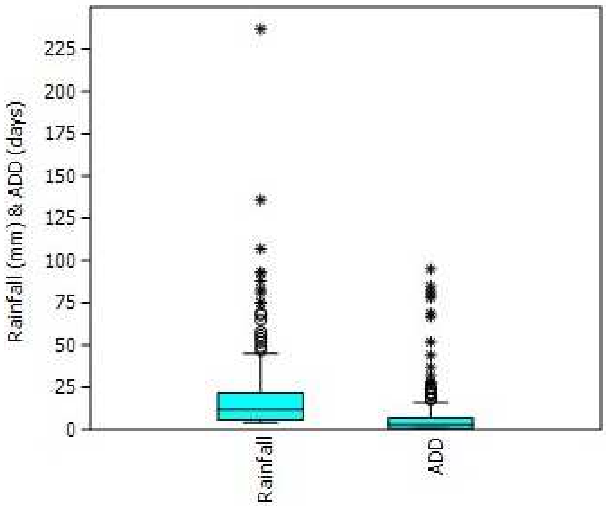
(b)



(c)



(d)



Rainfall (mm) & ADD (days)
225
200
175
150
125
100
75
50
25
0
Rainfall
ADD

(e)