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A Study of Water Safety Plan (WSP) For Environmental Risk Management of a Modern North Indian City

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Abstract: *Access to safe drinking water is a basic need for human development, health and well being and because of this it is an internationally accepted human right (WHO, 2011).*
There has been encouraging progress with access to safe drinking water & sanitation in both rural and urban areas since the United Nations water decade of the 1980s. However, more than 1 billion people around the world still lack access to safe water supplies. A substantial majority of these people live in Asia.
Water has many constituents. Some of these are of natural origin & some are manmade and present as contaminants. Some give rise to serious health effects and some will give rise to only aesthetic characteristics.
Over the past decade it has become increasingly evident that the delivery of safe & aesthetically acceptable drinking water cannot be assured if it is based on only measurements of water quality parameters & or the performance of a water filtration plant.
In view of the uncertainties and the practical difficulty in monitoring the quality of treated water, a risk based approach to managing the quality of drinking water is required. A key advantage of a risk based approach is in avoiding the costs associated with installing inappropriate systems of delivering water. It has been shown that investments in water supply and sanitation can yield a net economic benefit, as the reductions in adverse health effects and health care costs outweigh the costs of undertaking these interventions.
The guidelines provided in this thesis are an important contribution to environmental risk assessment and the avoidance of the physical, chemical and microbial contamination of drinking water.
The HACCP plan from which this water safety plan extract has been derived is scoped to cover the entire water system from catchment to tap and is dynamic document continually evolving as increased knowledge and experience and present opportunities for improvement.
Water safety management demands a quantitative understanding of how processes & actions effect water quality, which in turn requires an understanding of environmental risk assessment. This study is intended to provide guidance on using environmental risk assessment while developing water safety plan to ensure the production of high quality drinking water in a modern North Indian City like Chandigarh.

I. Introduction

Managing water resources and supplying safe water are the greatest challenges for the present generation. What makes water safe is the care and consideration people have for activities and actions in the catchment and in treatment, storage and distribution of water.

Water suppliers and Municipalities have a public health responsibility to these communities to provide drinking water that is safe to drink. Safe drinking water is a basic need for human development, health & wealth being and because of this is an internationally accepted human right **(WHO, 2001).**

The most effective means of consistency exercising the safety of a drinking water supply is through the use of comprehensive risk assessment & risk management approach that includes all steps in water supply from catchment to consumers, such approaches are called WATER SAFETY PLANS (WSP).

It is based on the principals of Hazard Analysis and critical control points (HACCP) widely used in Food Industry. In the Food Industry, a HACCP Plan seeks to protect food quality from FARM TO THE FORK. In the water industry, a WSP is a comprehensive approach from CATCHMENT TO CONSUMER.

The WHO has developed guidelines for drinking water quality. The latest edition of the WHO Guidelines for drinking water quality is structured around on overall "Water Safety Framework" used to develop supply specific "Water Safety Plans".

Preparing a water safety plans involves a systematic assessment of every aspect of providing safe drinking water, identifying the events that could cause water to become unsafe to drink & developing plans to manage these.

The present research provides processes for identifying potential problems and managing risks to water quality in a developed modern north Indian city like Chandigarh.

II. Methodology

1. Key Components of WSP

There are 11 modules involved in the developing & implementation of Water Safety Plan (WSP).

Preliminary and preparation — Module-1 (Assemble WSP Team)
System Risk Assessment — Module-2 (Describe the system)
Module-3 (Hazard identification & initial risk assessment)
Module-4 (Control measures and reassess risk)
System Upgrade — Module-5 (Improvement Plan)
Quality monitoring & verification — Module-6 (Control measure monitoring)
Module-7 (Verification)
Supporting WSP Management & verification Procedures — Module-8 (Management procedure)
Module-9 (Supporting programmes)
Feedback/ Reviews — Module-10 (Review)
Module-11 (Incidents)

Based on the above Modules, the Water Safety Plan has been developed for Chandigarh city, which is a modern city of North India known as "THE CITY BEAUTIFUL".

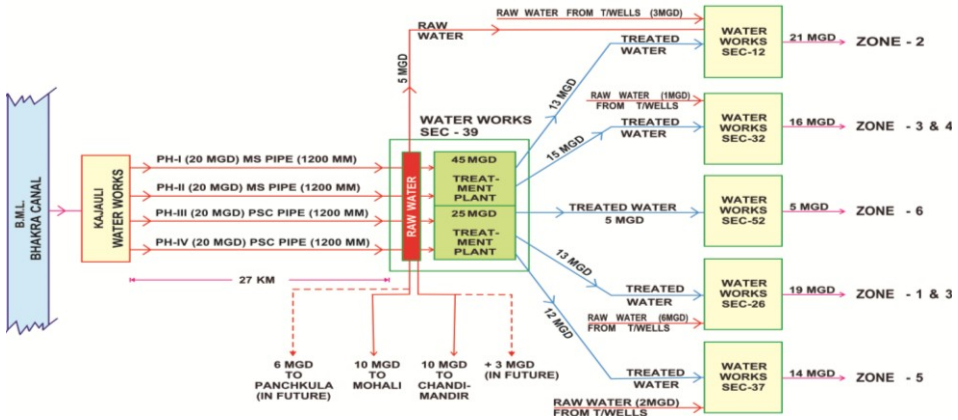
2. Description of Water Supply System in Chandigarh

As per Module-2, it is necessary to understand and describe the water supply system of Chandigarh right from catchment, pumping, treatment, distribution and upto the consumer end (Household).

There are two sources of raw water supply in city Chandigarh:

1. 80 MGD surface water pumped from Bhakra Canal at a distance of 27 KM from Chandigarh.
2. 20 MGD ground water from deep bore tubewells located across the city.

The raw water is treated at water works sector 39 (known as Mother Water Works) & water works Sector 12 is pumped to all other Water Works located in Sector 12, 26, 32, 37 & 52 which act as intermediate pumping stations for supplying the treated water to their localized areas/ zones as illustrated in the following flow diagram:



Flow diagram-water supply scheme of Chandigarh

3. Selection of Pilot Zone (Study area)

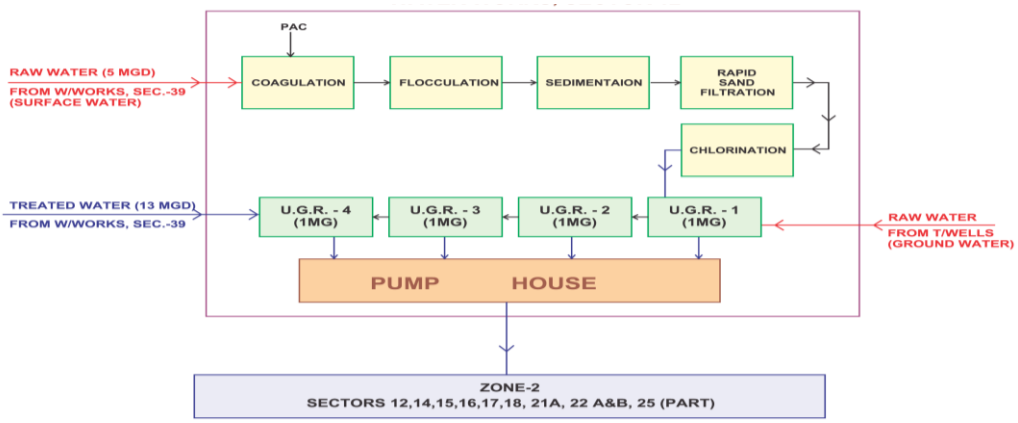
Out of 6 zones in which Chandigarh is divided for its water supply distribution, Zone No 2 has been selected as Pilot Zone for initial development & implementation of Water Safety Plan in city Chandigarh. Zone No 2 is being fed through Water Works Sector 12 & supply drinking water to Sector 12 to 18, 21-A, 22 A & B, 25.

3.1 Intake of Water in WTP of Pilot Zone No 2

i. 5 MGD of raw water from Bhakra Canal through the Water Works Sector 39.
ii. 3 MGD of raw water from 19 No deep bore tubewells (Ground water).
iii. 13 MGD of treated water from Water Works Sector 39.

5 MGD raw water received at Water Works Sector 12 is being treated in different stages (Coagulation, Flocculation, Sedimentation, Filtration and Post Chlorination).

Water supply treatment process/ distribution in Pilot Zone 2 as illustrated in the following flow diagram:



Flow diagram water supply distribution in pilot zone 2 (From water works sector 12)

4. Summary of Historical Water Quality Data for Pilot Zone

The data for the five years (2008 to 2012) has been analyzed for the samples taken from:

i. Raw Water.
ii. Treated water (At outlet of WTP i.e. Water Works Sector 12).
iii. Distribution system-cum-consumer end.

For each year; average, maximum, minimum, standard variation and median values have been calculated for pH, Turbidity, Hardness, Total dissolved solids & for free Residual Chlorine available.

III. Results And Discussion

1. Analysis of treated water data at Water Works Sector 12 (Pilot Zone)

For the year 2013-14, the daily sampling data for treated water at the outlet of WTP Sector 12 has been analyzed and the variation in maximum recorded values and its desirable limits as per IS: 10500:2012 are as under:

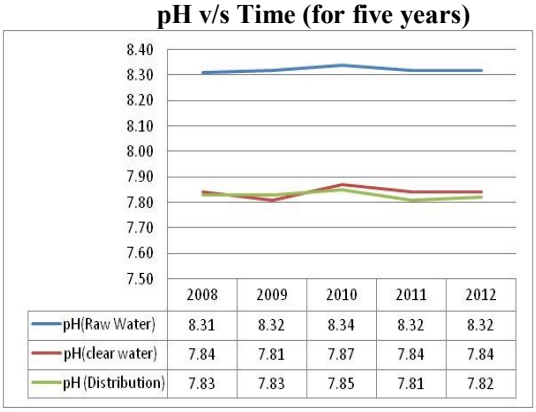
Variations (Actual data Vs acceptable limits) For Treated Water at outlet of Water Works Sector-12

Year	Parameter	Maximum recorded data	Desirable limit as per IS 10500: 2012	Remarks
2014	pH	7.87	6.5 - 8.5	Within limits
	Turbidity (NTU)	1.20	5	-do-
	TDS (mg/l)	190	500	-do-
	Hardness (mg/l)	110	300	-do-
	Chlorides (mg/l)	6.0	250	-do-
	FRC (mg/l)	0.3	0.2	-do-
	MPN Coliform Index	0	0	-do-

2. Analysis of water quality historical data in pilot zone

Historical sampling data for the 5 years (2008-2012) has been analyzed for raw water, treated water (at outlet of WTP Sector 12) & distribution system-cum-consumer end & the results are plotted as under:

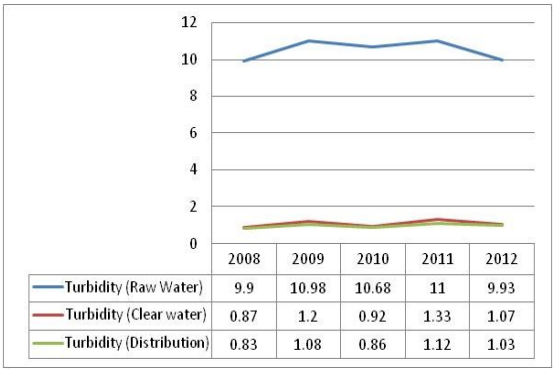
pH v/s Time (for five years)



	2008	2009	2010	2011	2012
pH(Raw Water)	8.31	8.32	8.34	8.32	8.32
pH(clear water)	7.84	7.81	7.87	7.84	7.84
pH (Distribution)	7.83	7.83	7.85	7.81	7.82

Acceptable Limit as per IS = 6.5-8.5

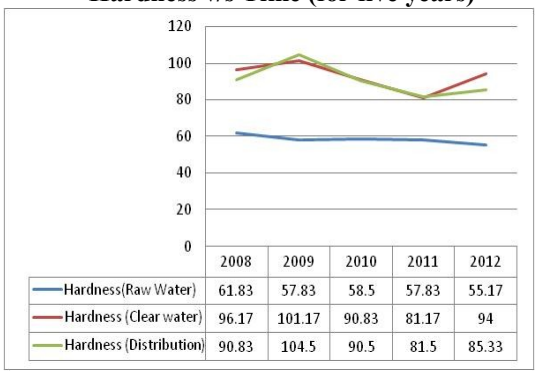
Turbidity v/s Time (for five years)



	2008	2009	2010	2011	2012
Turbidity (Raw Water)	9.9	10.98	10.68	11	9.93
Turbidity (Clear water)	0.87	1.2	0.92	1.33	1.07
Turbidity (Distribution)	0.83	1.08	0.86	1.12	1.03

Acceptable Limit as per IS = 5 (Max)

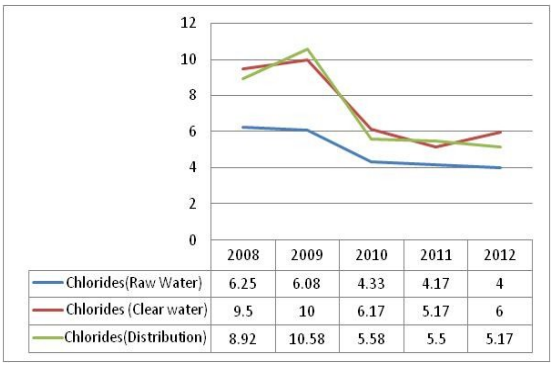
Hardness v/s Time (for five years)



	2008	2009	2010	2011	2012
Hardness(Raw Water)	61.83	57.83	58.5	57.83	55.17
Hardness (Clear water)	96.17	101.17	90.83	81.17	94
Hardness (Distribution)	90.83	104.5	90.5	81.5	85.33

Acceptable limit as per IS=300 (Max)

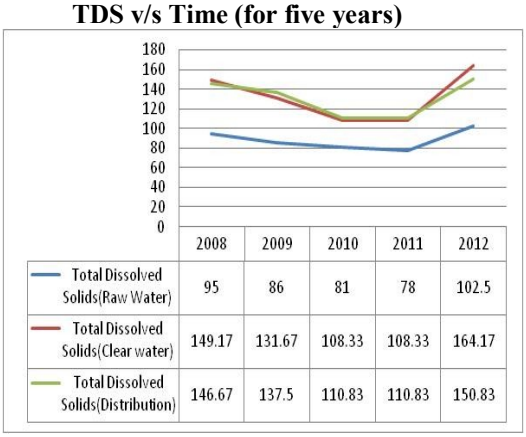
Chloride v/s Time (for five years)



	2008	2009	2010	2011	2012
Chlorides(Raw Water)	6.25	6.08	4.33	4.17	4
Chlorides (Clear water)	9.5	10	6.17	5.17	6
Chlorides(Distribution)	8.92	10.58	5.58	5.5	5.17

Acceptable limit as per IS=250 (Max)

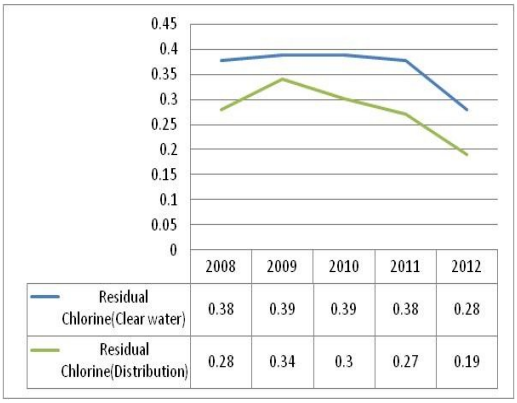
TDS v/s Time (for five years)



	2008	2009	2010	2011	2012
Total Dissolved Solids(Raw Water)	95	86	81	78	102.5
Total Dissolved Solids(Clear water)	149.17	131.67	108.33	108.33	164.17
Total Dissolved Solids(Distribution)	146.67	137.5	110.83	110.83	150.83

Acceptable limit as per IS=500 (Max)

FRC v/s Time (for five years)



	2008	2009	2010	2011	2012
Residual Chlorine(Clear water)	0.38	0.39	0.39	0.38	0.28
Residual Chlorine(Distribution)	0.28	0.34	0.3	0.27	0.19

Acceptable limit as per IS=0.2 (Min)

3. Preparation of Chandigarh Hazard Analysis Matrix

As per Module No 3 of WSP, all the possible visible & hidden hazards that can contaminate the drinking water supplied to the City Chandigarh in the Pilot Study Zone No 2 have been looked into thoroughly at actual site right from Bhakra Catchment, raw water mains from Kajauli, in different stages of treatment process, treated water rising mains, distribution lines, consumer interface & household storage & handling practices.

The following 3 types of hazards have been looked into:

i. **Physical Hazard (Denoted by P in the Matrix)**
ii. **Chemical Hazard (Denoted by C in the Matrix)**
iii. **Microbial Hazard (Denoted by M in the matrix)**

Any hazardous event can give rise to one, two or to all the three types of hazards.

The risk Matrix has been developed using semi quantitative approach.

The consequence or severity of a particular hazardous event has been rated from 1 to 5 started from the lowest impact to the highest impact.

Insignificant or no impact : Rating-1.
Minor impact : Rating-2
Moderate impact : Rating-3
Major impact : Rating-4
Catastrophic impact : Rating-5

The likelihood or frequency of occurrence of a particular hazardous event has been rated from 1 to 5 starting from the lowest frequency to the highest frequency.

Rare/ Once every 5 years : Rating-1.
Unlikely/ Once a year : Rating-2
Moderate/ once a month : Rating-3
Likely/Once a week : Rating-4
Almost/ certain once a day : Rating-5

Depending upon the severity and likelihood score/ rating, the overall risk for that particular hazardous event has been calculated as under:

Risk Score = Severity rating x Likelihood rating

The risk score has been calculated as raw risks completely ignoring all the control measures that actually are in place in the water supply distribution system.

Depending upon the risk score, the risk band range for that particular hazardous event is taken in the following intervals in the hazard analysis matrix:

Low (L) : 1-5 (Denoted by Green Colour)
Medium (M) : 6-15 (Denoted by Yellow Colour)
High (H) : 16-25 (Denoted by Red Colour)

As per Module No 4, the risk score is recalculated taking into account all the control measures that exist in the system to keep check on that particular hazardous event. So the severity and frequency of that hazardous event becomes low which ultimately brings down the risk score of that hazardous event.

This reassess risk has been incorporated in the Chandigarh Hazard Analysis Matrix to see whether the raw risk band has come down or not.

The complete Chandigarh Hazard Analysis Matrix as per Module No 3 & 4 has been prepared for all the possible hazardous events and is given in the next pages.

Chandigarh Hazard Analysis Matrix

No	Source of Risk/ Process Step	Hazard	Hazardous Event	Likeli hood	Conse quence	Risk Rating or Raw Risk (with no controls)	Risk Band	BASIS (Reasons for selection of likelihood & Consequence Sources)	Control Measures	Likeli hood	Conse quence	Risk Rating or Raw Risk (with no controls)	Risk Band
1.	Bhakra Catchment	M	Sewage overflows from human habitation during monsoon period	2	5	10	M	Human settlement present near BML	Septic tanks are in place	1	5	5	L
		C, P, M	Idol immersion, Religious activities	2	4	8	M	There is no fencing temple present close to river	Provision of separate tanks for immersion	1	4	4	L
		C, P	Agricultural activities in the river bed	3	4	12	M	Visual inspection during visit	Agricultural activities are restricted in river bed	1	4	4	L
		C, P, M	Contaminants in storm water runoff during monsoon	4	3	12	M	May happen in rainy season due to storm water runoff	No current control measures	4	3	12	M
		M	Unauthorized access for recreation (swimming, fishing)	2	1	2	L	There is no fencing	Security in place	1	1	1	L
		C,P,M	Growth of aquatic weeds increasing nutrients in BML	4	3	12	M	Aquatic weeds are observed near bank	Screens are provided at inlet	1	3	3	L
		C,P	Corrosion of screens, gates and mechanical parts	4	3	12	M	Observed during visit to BML	Periodic repair & maintenance program	1	3	3	L
2.	Raw Water Mains	P, M	Increased sediments load, weeds and debris	3	3	9	M	This phenomena is observed during monsoon season	No current control measures	3	3	9	M
		P,C	Failure of the sluice gates, valves etc	2	3	6	M	As per information provided by MC officers	Periodic repair and maintenance program	1	3	3	L
		P	Leakage in MS Pipe of Phase I & II	1	5	5	L	As per information provided by MC officers	Immediate repair & Mtc programme (or priority)	1	5	5	L
		P	Leakage in PSC Pipe of Phase III & IV	3	5	15	M	As per information provided by MC officers	Immediate repair & Mtc programme (or priority)	1	5	5	L
3.	Treatment plant												
3a	Chemical dosing system	C, P	Over/ under dosing	3	3	9	M	Dosing is monitored daily	Chemist determines required dose by Jar test daily.	1	3	3	L
		C,P	Mishandling of chemicals	2	4	8	M	Visual inspection during visit	Standard operating procedures are being followed	1	4	4	L

No	Source of Risk/ Process Step	Hazard	Hazardous Event	Likeli hood	Conse quence	Risk Rating or Raw Risk (with no controls)	Risk Band	BASIS (Reasons for selection of likelihood & Consequence Sources)	Control Measures	Likeli hood	Conse quence	Risk Rating or Raw Risk (with no controls)	Risk Band
3b	Flash mixing	P,C	Electrical failure	1	4	4	L	Power failure from electricity board not frequent	Plant will shut down automatically since water cannot be pumped.	1	2	2	L
		C,P,M	Improper settling	3	4	12	M	If settler is overloaded, or short detention time	Testing of Turbidity after every 2 hours and maintaining the flow rate at inlet	1	4	4	L
3d	Rapid Sand Filtration	C,P,M	Improper filtration	4	4	16	H	Online monitors for all filters were found to be not working	Backwashing is done depending on head loss at each filter. turbidity of filtered water is tested once in 2 hours	1	4	4	L
		C,P,M	Loss of efficiency of filter media	2	4	8	M	Information given by Plant Operator	SOP's are developed for Op & Mtc of filters	1	4	4	L
		C,P,M	Sand loss during back wash resulting in reduction of efficiency	3	3	9	M	Reduced efficiency may lead to improper filtration	Filter media is top up on its loss	1	3	3	L
3e	Post-chlori-nation	C	Overdosing (formation of DBP's, can exceed health limits- 5mg/l)	3	4	12	M	Based on water testing records for residual chlorine	Online monitors are present. Residual chlorine is tested in laboratory daily every 2 hours	1	4	4	L
		M	Under dosing	3	5	15	M	Based on water testing records for residual chlorine and bacteriological analysis	Online monitors are present	1	5	5	L
		M	Unavailability of gas cylinders	1	4	4	L	No such incident has occurred in the experience of the Plant operator	Gas cylinders are always present in spare	1	4	4	L
		M	Electrical failure	4	4	16	H	Power failure from Elecy board not frequent	Plant will shut down.	2	2	4	L
4	Treated Water Rising Mains	C,P,M	Microbial re growth, Taste and Odour complaints due to stripping of Bio-films	3	5	15	M	Post chlorination at treatment plants reduces the consequences	Periodic cleaning and maintenance program	1	5	5	L

No	Source of Risk/ Process Step	Hazard	Hazardous Event	Likeli hood	Conse quence	Risk Rating or Raw Risk (with no controls)	Risk Band	BASIS (Reasons for selection of likelihood & Consequence Sources)	Control Measures	Likeli hood	Conse quence	Risk Rating or Raw Risk (with no controls)	Risk Band
		C,P,M	Contamination from pipe bursts	2	4	8	M	There is continuous supply with high pressure	Leak repair program on priority basis	1	4	4	L
		C,P,M	Contamination from drains during Mtc of pipes or fittings	2	5	10	M	As per difficulties faced by MC officials	Super chlorination is done after repair	1	5	5	L
		C,P	Chemical contamination due to internal corrosion	2	4	8	M	Good quality materials are used.	Periodic repair and maintenance activities are done	1	4	4	L
5		C	High Fe levels in water due to internal corrosion of unlined Cast Iron mains	4	2	8	M	Due to oxidation of Fe by chlorine in unlined CI pipe network	No current control measures	4	2	8	M
		P,M	Ingress of contaminants due to leakage from hydrants, fittings & perforations	2	4	8	M	Intermittent supply	Leakage repair program	1	4	4	L
		P,M	Ingress of contaminants from crossing of natural drains/nallah's	3	5	15	M	Control measures in place, this problem occurs only in monsoon season when drains are full	Pipes are laid on piers to avoid contact with drains.	2	5	10	M
6	Distri-bution mains (MS, DI, CI)	C,P,M	Contamination due to ingress of foreign matter from perforations in corroded pipes	3	5	15	M	Public Health department records	Existing visual detection and repair of leaks.	2	5	10	M
		C	High Fe levels in water due to internal corrosion of unlined CI mains	4	2	8	M	Due to oxidation of Fe by chlorine in unlined CI pipe network	No current control measures	4	2	8	M
		C	Potential of corrosion in fittings	3	2	6	M	Due to oxidation of Fe by chlorine in fittings	No current control measures	3	2	6	M
		P,M	Ingress of contaminants due to tampering/ tapping of mains	4	4	16	H	Some cases experienced by officials of P.H Deptt	Periodic inspection and control	2	4	8	M
		C,P,M	Ingress of contaminants from crossing of natural drains/nallah's	3.5	5	17.5	H	Control measures in place, this problem occurs only in monsoon season when drains are full	Pipes are laid on piers/ piles to avoid contact with drains.	2	5	10	M
		P,M	Contamination due to ingress of foreign matter from bursts/accidental breakage	3.5	5	17.5	H	Public Health department records	Existing visual detection and repair of leaks.	2	5	10	M

No	Source of Risk/ Process Step	Hazard	Hazardous Event	Likeli hood	Conse quence	Risk Rating or Raw Risk (with no controls)	Risk Band	BASIS (Reasons for selection of likelihood & Consequence Sources)	Control Measures	Likeli hood	Conse quence	Risk Rating or Raw Risk (with no controls)	Risk Band
		C,P	Use of substandard material for pipes	3	4	12	M	Lead joints are used in old network, pipes are prone to breakage	Hydraulic testing is done, check for ISI mark, certificate from manufacturer	2	4	8	M
7	Consumer interface	M,P	Backflow from domestic properties due to absence of check valves	4	5	20	H	Customer complaints for contaminated water	Periodic inspection and control	3	5	15	M
		P,M	Internal cross contamination from sewer lines	4	5	20	H	Customer complaints and visual inspection	No current control measures	4	5	20	H
		C	Corrosion of GI house service connection	3	5	15	M	Maximum customer complaints for contaminated water due to corroded service connections	No current control measures only pipe from ferrule to meter is charged on consumer's expense.	2	5	10	M
		P,M	Contamination in sump/deep pits and overhead tanks within the property	5	5	25	H	Studies have shown the prevalence of water-borne diseases	Only after an event, advise customers. There is no current control measure to manage this, existing regulation-sump should be 0.6m above ground level.	5	5	25	H
		P,M,C	Contamination due to illegal pumps causing pressure loss downstream	3	4	12	M	Insufficient data	Periodic checking and control	2	4	8	M
	House-hold Storage	P,M	Storage vessel is designed for dipping	5	5	25	H	Visual inspection during sanitary surveillance	Use of storage vessel with tap	4	5	20	H
		P,M	Using dipper with short or no handle	5	5	25	H	Visual inspection during sanitary surveillance	Use of ladle with long handle to access water	4	5	20	H
		P,M	Vessel accessible to children	4	4	16	H	Discussion with consumers during sanitary surveillance	Keep vessels at appropriate height	3	4	12	M
		M	Use pour back excess water into the storage vessel	3	4	12	M	Discussion with consumers during sanitary surveillance	In some households, excess water was not poured back into storage vessel but was used for other purposes	3	4	12	M

4. WSP Improvement Plans

As per Module No 5, the improvement plans for the hazardous events which still remain on the higher side even after the control measures installed (as observed from the Chandigarh Hazard Analysis matrix) are being suggested in the proper format as per WSP Module. The improvement plans are also suggested to further lower the risk band even if already in control. The improvement plans clearly pin point the agencies responsible to execute that improvement in a clearly mentioned time frame.

WSP Improvement Plan (Chandigarh City)

Process Step	Issue Identified	Improvements Required	Responsibility	Time Frame	Remarks
BHAKRA CATCHMENT					
	Sewage Over – flow from human habitation during monsoon period	1. Proper sewage collection, treatment & disposal in catchment. 2. No approval to habitations without proper sewage management.	1. Public Health Department of MC Chandigarh 2. Local NGOs	3 years	As catchment area is not under MC Chd & correspondence will be done with authorities of nearby habitations
	Human Defection	1. Strictly prohibiting. Unauthorized access. 2. Awareness programs to educate people about proper sanitary practices.	1. Public Health Department of MC Chandigarh 2. Local NGOs	Uncertain	Awareness programs will be carried out
	Contamination due to idol immersion and other religious activities.	1. Protect streams connected to reservoir in catchment. 2. Prohibit idol immersion along with other religious activities in these streams. 3. Awareness programs to educate people about possible Water contamination & their health effects. 4.Provide separate dedicated pond for idol immersion.	1. Public Health Department of MC Chandigarh 2. Local NGOs	Uncertain	Awareness programs will be carried out
	Agricultural activities in the river bed	Agricultural activities in the river bed should be restricted	1. Health & Sanitation Deptt. 2. D.C. Morinda	1 year	Major agricultural activities in the river bed are already restricted

	Contaminants in storm water runoff during monsoon	Ensure plant cover around the reservoir	Forest Deptt.	Uncertain	
	Corrosion of screens, gates and mechanical parts	Screens, gates, & valves should be replaced &their proper cleaning & Mtc should be ensured	Public Health Deptt of MC Chd	1 year	
RAW WATER MAINS					
	Increased sediment load, weeds and debris	Screens should be installed at intake & these should be properly cleaned & maintained	Public health Deptt of M.C. Chandigarh	1 year	
	Growth of Bio film	Periodic cleaning of mains should be done	Public health Deptt of M.C. Chandigarh	1 year	
WATER TREATMENT PLANT WATER WORKS SECTOR 12					
Inlet	Floating debris, grass in raw water	Inlet screens should be installed to prevent debris & grass from entering at inlet	Public health Deptt of M.C. Chandigarh		
	Hydraulic overloading at Inlet chamber	New flow measuring devices should be installed and properly calibrated	Public health Deptt of M.C. Chandigarh		
	Leakage in inlet valve	Leak repair programme is needed	Public health Deptt of M.C. Chandigarh		
Pre-chlorination	Leakage in chlorine pipe leading to ineffective pre-treatment	Pipe should be repaired and chemical dosing should be monitored	Public health Deptt of M.C. Chandigarh		
PAC dosing	Under/ over dosing	Regular inspection should be done, automatic dosing system should be installed	Public health Deptt of M.C. Chandigarh		
	Mishandling of chemicals	SOP's should be followed for storage & handling of coagulant	Public health Deptt of M.C. Chandigarh		
	Algal growth in open channel	Adequate pre-chlorination should be done	Public health Deptt of M.C. Chandigarh		
Flash mixing	Mechanical failure results in improper mixing	Motor and agitator blades should be replaced	Public health Deptt of M.C. Chandigarh		
	Electrical failure	Electricity Board should ensure uninterrupted power supply to treatment plants	Public health Deptt of M.C. Chandigarh		
Sedimentation	Improper settling	Settling tank should be cleaned periodically, growth of aquatic weeds and plants should be checked	Public health Deptt of M.C. Chandigarh		
	Improper de-sludging	Periodic de-sludging should be done	Public health Deptt of M.C. Chandigarh		
Rapid sand filters	Loss of efficiency of filter media	Complete over hauling of all 12 filters & replacement of filter media	M.C. Chandigarh		
	Inefficient backwash cycle	Well-defined pressure drop/ head loss & continuous online monitoring of pressure differential should be done. Standard operating procedures for back washing should be followed. Shut down of filters when pressure drop is less than 1.5m & turbidity standards are exceeded	M.C. Chandigarh		
Post Chlorination	Under dosing	Chlorine demand should be checked daily and flow rate should be maintained	Public health Deptt of M.C. Chandigarh		
	Electrical failure	Plant should be shut down Provision for closing inlet valves within seconds should be made	Public health Deptt of M.C. Chandigarh		
U.G.R./s					
	Contamination due to inspection chambers not properly covered	Daily inspection by responsible person should be done; strict instructions to the valve operator should be given	Public health Deptt of M.C. Chandigarh	6 month	
	Corrosion of ladder due to contact with	Non-corrosive for e.g. plastic coated ladders should be used	Public health Deptt of M.C. Chandigarh	6 month	

	chlorine				
	Security breach at W/W Sec 12	Strict security measures should be kept in place	Public health Deptt of M.C. Chandigarh	3 month	
DISTRIBUTION MAINS					
	Contamination due to ingress of foreign matter from perforations in corroded pipes	Use of non-corrosive pipes, limited number of joins	Public health Deptt of M.C. Chandigarh	2 years	The rehabilitation program for improvement of water distribution is in the process
	Potential backflow from tappings into mains due to absence of backflow prevention devices	Non returning valves should be installed.	Public health Deptt of M.C. Chandigarh	3 years	
	Potential backflow from illegal tapings into mains	Strict action should be taken to eliminate illegal tappings into mains. Regular inspection program should be carried out.	M.C. Chandigarh	3 years	
	Biofilm formation due to lack of chlorine	A schedule for routine monitoring of chlorine should be done at specified points in distribution system.	M.C. Chandigarh	1 year	
CONSUMER INTERFACE					
	Contamination in open sump/deep pits within the property.	1. Measures should be taken for periodic cleaning of sumps/deep pits and overhead tanks by MC. 2. MC to develop & carry out awareness programs e.g. radio & television announcements, posters.	M.C. Chandigarh	3 years	
	Backflow from domestic properties due to absence of check valves	Installation of non-returning valves	Water Works Department M.C. Chandigarh	5 years	
	Internal cross contamination from sewer lines	Laying of pipe network should be as per norms & Non return valves should be fitted	Water Works Department, MC & Sanitation Deptt, M.C. Chandigarh	2 year	
	Corrosion of GI house service connection	Suggest customers to replace existing GI pipes by non-corrosive MDPE pipes	1. Water Works Department, M.C. Chandigarh 2. Consumers	Uncertain	As it depends on the financial status as well as willing of consumers
	Digging pit outside the house during low pressure	Regular inspection should be done and 24x7 supply will prevent low pressure	Water Works Department M.C. Chandigarh	6 years	
	Contamination due to illegal pumps causing pressure loss downstream	Legal action should be taken against those who install illegal pumps	Water Works Department M.C. Chandigarh	2 year	
	Over flow of storm water drain near consumer connection	Separate storm water drains should be laid to prevent overflow in sewer.	1. Water Works Department, MC and Health & Sanitation Department M.C. Chandigarh 2. Consumer	Uncertain	As it depends on the financial status as well as willing of consumers.
HOUSEHOLD STORAGE					
	Storage vessels designed for dipping	Consumers should be made aware about the advantages of using vessels with a narrow mouth and a tap	1. M.C. Chandigarh 2. Local NGOs 3. Local Media	1 Year	
	Using dipper with short or no handle	Ladle with long handle should be used to take out water from vessel	1. M.C. Chandigarh 2. Local NGOs 3. Local Media	1 year	
	Vessel accessible to children	Consumers should be made aware of risks associated with lack of hygiene. Children should be discouraged from accessing the storage vessels.	1. M.C. Chandigarh 2. Local NGOs 3. Local Media	1 year	
	Users pour back excess water into the storage vessel	Consumers should be made aware about the risks of unsanitary drinking water	1. M.C. Chandigarh 2. Local NGOs 3. Local Media	1 year	

		practices			
	Vessel is made on non-durable material	Consumers should be encouraged to use steel or plastic vessels	1. M.C. Chandigarh 2. Local NGOs 3. Local Media	1 year	
	Handling of drinking water without washing hands	Consumers should be made aware about risks of unsanitary drinking water practices & importance of personal & domestic hygiene	1. M.C. Chandigarh 2. Local NGOs 3. Local Media	1 year	

5. Monitoring of Control Measures

As per Module No 6, the monitoring requirement and corrective actions have been described for the raw water, treatment plant, UGR and consumer interface in the prescribed format under the Module.

All the critical limits for the different parameters at designated points have been described in the format. When it will be monitored, how it will be monitored and who will monitor it has been clearly stated in the said format. What corrective actions need to be taken in case the critical limit for that particular parameter is exceeded is also shown in the format.

Monitoring Requirements & Corrective Actions

RAW WATER						
What	**Critical Limit**	**Where**	**When**	**How**	**Who**	**Corrective Actions in case critical limit is exceeded**
pH						
	6.0 to 9.0	At intake well of raw water body	Daily	pH meter	Chemist/Water Quality Officer	Adjust buffer dose in treatment scheme & regulate effluent discharge into water body
Total Suspended Solids (mg/L)						
	<500	At intake well of raw water body	Daily	Turbidity Analyzer	Water Quality Officer	Regular coagulant dose
TREATMENT PLANT						
pH						
	6.0 to 9.0	Inlet	Online	pH meter	Chemist	pH adjustment
	6.5 to 7.5	At entry point to distribution system	Online	pH meter	Chemist	pH adjustment
Turbidity						
	<1000 NTU	Inlet	Batch Sample	Turbidity Analyzer	Chemist	Regulate Coagulant dose
	<10 NTU	After settler	Online	Turbidity Analyzer	Chemist	Regulate Coagulant dose
	<1 NTU	After Filter	Online	Turbidity Analyzer	Chemist	Proper filtration cycle
Chlorine						
	1.5-2.0 mg/l	At entry point to distribution system	Online	Chlorine Analyzer	Chemist	Regulate Chlorine dose
Coliform (MNP/100 ml)						
	NIL	At entry point to distribution system	Daily	MPN test	Chemist	Regulate Chlorine dose
UGR						
Turbidity						
	<1 NTU	At outlet of UGR	Daily	Turbidity Analyser	Water Quality Officer	Inform to treatment plant operator immediately
Residual Chlorine						
	0.5-1.0 mg/L	AT outlet of UGR	Online	Chlorine analyser	Water Quality Officer	Regulate Chlorine dose
pH						
	6.5 to 7.5	AT outlet of UGR	Online	pH meter	Water Quality Officer	pH adjustment
Fecal Coliform						
	NIL	At outlet of UGR	Daily	MPN/ MFT test	Water Quality Officer	Regulate Chlorine dose

CONSUMER INTERFACE						
Turbidity						
	<1 NTU	At randomly selected representative consumer taps	Daily	Turbidity Analyzer	Water Quality Officer	Inform to Service Engineer at ESR immediately
Residual Chlorine						
	0.2-0.5 mg/L	At randomly selected representative consumer taps	Daily	Chlorine Analyzer	Water Quality Officer	Regulate Chlorine dose
Fecal Coliform						
	NIL	At randomly selected representative consumer taps	Daily	MPN/ MFT test	Water Quality Officer	Regulate Chlorine dose
pH						
	6.5 to 7.5	At randomly selected representative consumer taps	Daily	pH meter	Water Quality Officer	pH adjustment

IV. Conclusion

In the present study, the semi-quantitative risk matrix approach has been used for the development of Chandigarh Hazard analysis matrix considering the raw risks without any control measures and re-assessed risks with control measures in place. In case the re-assessed risk is still on a higher side, improvement and modification plans have also been suggested. Standard operating procedures in case critical limits of various parameters go out of control have also been developed.

The study area taken in the scope of this thesis is one of the six zones in which whole of the Chandigarh city has been divided for water supply distribution. In the present thesis, WSP has been developed for 1 zone only i.e. Pilot zone No. 2. This concept is applicable to any model city like Chandigarh. At the start, it is advisable to develop and implement the WSP in a Pilot area of the city and then depending upon its outcome / success, it can be extended to whole of the city.

The present study will also certainly be helpful in giving guidance to the WSP team selected for developing and implementing water safety plan for any other modern north Indian city like Chandigarh.

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