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Operational Paper

Evaluation of water supply system infested with chironomus larvae

P. Nema, K. V. George, M. G. Karemore and J. P. Kotangale

ABSTRACT

A chironomus larvae infested water supply system was studied in detail for detecting its source and remediation. The study covered raw water source, units of water treatment plant, underground water storage reservoir, elevated service reservoir and water distribution pipeline. Since the larvae is the hatching of midge fly, the open ends in the water supply system like water treatment plant, underground storage reservoir, elevated service reservoir were studied first and found to be free from larvae. Finally excavation was carried out at the underground pipeline near the larvae infested tap ends. It was found that some residential units were discharging domestic wastewater just below the ground surface leading to contamination of drinking water. Pipe joints were opened for further study and growth of several species was found inside the pipe. However, the exact location of contamination could not be detected. The closed loop pipeline was opened at one end to scour off any contamination with clean water. After few hours of flushing, the insects were not detected at the consumer ends. This paper describes the systematic methodology that can be adopted for such investigations.

Key words | chironomus larva, overhead service reservoir, rapid sand filter, underground reservoir, water distribution system

P. Nema (corresponding author)
K. V. George
M. G. Karemore
J. P. Kotangale
National Environmental Engineering Research Institute (NEERI),
Nagpur,
India,
440 020
Fax: +91 (712) 2249895
E-mail: *apcneeri_ngp@sancharnet.in*

INTRODUCTION

Treatment of raw water improves its quality as required for any particular use. The treatment plant must be able to cope with variation in quality and quantity of raw water to produce the desired quality of water uniformly. The consumer is particularly interested in the quality of water delivered at the tap at home or the place of business. In this way quality of water needs to be ensured at the treatment plant as well as in the distribution system so that it meets the desired standards at the consumer end. Water supply systems that are old and not well maintained sometimes report the occurrence of chironomus larva at the consumer end. In one such instance, investigation was carried out to find the source of such species in the water supply system. This included source water management practices, the water treatment plant, booster stations, overhead reservoirs and water distribution system. Observations made during the study and corrective measures required to improve the water supply system are discussed in this paper.

Chironomus larva

Usually in the evening during the summer season, a large number of flies (light brown in colour) swarming in the gardens or in the vicinity of ponds, lakes or streams (containing a good deal of vegetation) are encountered. These swarms consist mainly of males ‘dancing’ in the air apparently as a preparation for mating. After coupling, the

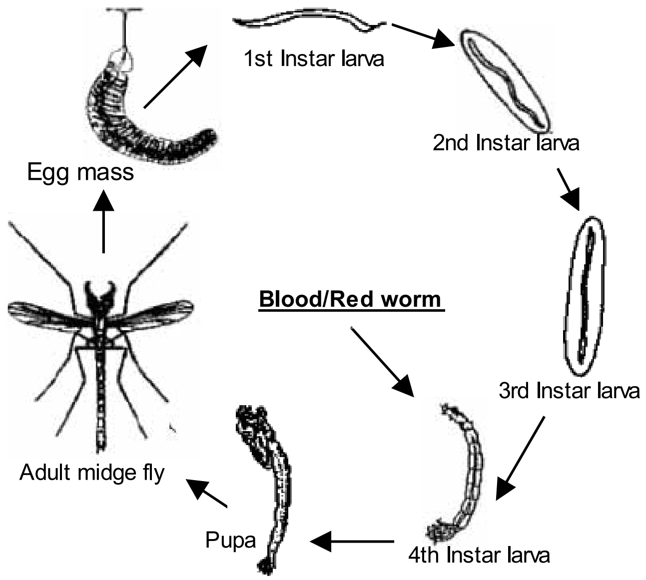

Figure 1 | Life cycle of midge fly–chironomus larva.

pair flies out of the swarm. The female adult midges are two-winged, mosquito-like terrestrial flies and lay large numbers of eggs (sometimes over a thousand) in a gelatinous mass in stagnant pools of water containing vegetation for the survival of their eggs. Some of those egg masses are attached to various objects just below the surface of the water (Busvine 1951). The nuisance caused by midge fly is well documented (Ali 1995). Figure 1 shows the developmental stages of the chironomus larva. The larvae, when newly hatched from the eggs, are thin, worm-like and transparent. They are planktonic and move very swiftly. The larvae feed on microorganisms, phytoplankton, zooplankton, suspended material and dead decaying organic matter present in the benthic zone of the water bodies. The larvae feed and grow rapidly in stages by 'moulting', i.e. by casting off the skin. After each 'moult' the larvae enter a new stage or 'instar'.

There are four larval instars: the first instar larvae are those that are hatched fresh from the eggs. The cutical is soft and transparent. They lack the characteristic red pigment, which develops in later material. The second instar larvae start building tubes from fine silt and algal material. The undulating movement of the larva body within the tube helps to bring microscopic food organisms inside the tube along with the water. The third and fourth instar larvae live mostly in their tubes at the bottom of the water body. These larvae are called chironomus larvae, also commonly known as bloodworms, as mature larvae are bright red in colour because of the presence of haemoglobin in their blood. They feed voraciously, grow rapidly and last for 7–10 weeks. The cuticle becomes sclerotic and hardens gradually in the successive instar. The larvae transfer into pupae with a life of about 2 to 3 days only. The adult emerges from the pupa through a split on the dorsal surface of the pupal skin. They alight on a dry surface and then fly to the shore. The males live for 4 days and the females live for 2–3 days (Mitra and Lakshminarayana 1969).

The larvae are present in water where abundant food supply in the form of phytoplankton and zooplankton is available. They inhabit the bottom of lakes, reservoirs and rivers and live in tubes, which they construct from fine silt, glued with salivary secretion. Their presence in potable waters is undesirable from the point of aesthetic quality of water. The presence of these larvae is always associated with the presence of organic pollution and excessive nutrients and therefore their occurrence in drinking water signifies organic contamination at some point in the water supply system.

Raw water source

The water supply system under study receives water from a river in which storage is created by the construction of a weir. On both banks of the river, there are human settlements 20 km upstream of this weir. Waste discharges from these settlements increased the nutrient level of the water body causing eutrophication and growth of macrophytes. These macrophytes in stagnant pool of water form a breeding ground for midge fly and a favourable environment for hatching of its eggs. The chironomus larvae survive and may pass on to the water treatment plant (WTP) creating nuisance in the water distribution system.

Water treatment plant

The WTP under study has a capacity of 240 million litres per day (MLD) to treat water, with 20% overloading permitted in the case of better raw water quality. River water is pumped to a tank (stilling chamber) through an intake structure located in the river. Raw water gets aerated as it spills out from a vertical pipe and is collected in the stilling chamber. Since the water source is in a highly eutrophic condition, chlorination of water is practised at several locations in the treatment plant. The first stage of chlorination is carried out at the stilling chamber. The pre-chlorinated water passes through a parshall flume where flow rates are measured by sensors and are displayed on analogue and digital meters. Chemicals (lime and alum) are added at the converging section of the parshall flume and flash mixing takes place at the hydraulic jump. Coagulated water flows through a flocculator provided with horizontal baffles.

Second stage chlorination is carried out after flocculation, before it enters the sedimentation basin. The flocculated water enters the sedimentation basin of lamella type consisting of hexagonal plates arranged parallel at an inclination of 60° to the horizontal. During lean periods, i.e. the summer season, the water is in a stagnant condition and its storage in the reservoir results in low turbidity (2–3 NTU). Therefore chemical coagulants are added only once at the parshall flume during such low turbidity periods. During post monsoon season, the raw water turbidity observed was higher (86 NTU) and, during such periods, the practice is to increase the coagulants dose by placing 'jute bags' filled with lumps of alum in the channel carrying flocculated water just at the beginning of the sedimentation basin. The flowing water would dissolve a small amount of alum from the jute bag before it enters the sedimentation basin. It was observed that the turbidity of water at the outlet of the sedimentation basin with alum-filled jute bags at the inlet was less than that from those basins in which additional alum dosing through jute bags was not provided.

Although the water quality at the outlet of the sedimentation basin was improved, the coagulation and flocculation process may not have been completed within the retention time provided by the basins. The flocs travel further and grow in size by the time they reach the filtration units and are deposited on the filter media, thereby reducing the filtration rate. Frequent chocking of the filter bed was reported and the phenomenon discussed above appears to be the reason for it. Table 1 presents the water quality parameters monitored at various stages of treatment. During the flood period, at the outlet of the sedimentation basin, the observed turbidity of the water was 10 NTU, which was further removed by the filtration unit. However the filter backwash interval was observed to be reducing.

One of the likely locations for chironomus larvae accumulation or growth is the sludge in the sedimentation basin. Therefore, a sludge sample collected during the desludging operation of the sedimentation basins was analysed for the presence of mature larvae, as they are visible to the naked eye. However, no larvae were found in the sedimentation basin sludge during the study period. Third stage chlorination was practised between the outlet of the sedimentation basin and the inlet of the rapid sand filters (RSF).

The performance of the filter unit was studied using two critical parameters: namely, coliform removal efficiency and turbidity reduction. In all the samples analysed for bacteriological parameters, the coliform bacteria count reduced to nil indicating that the filtration was efficient in bacterial removal. Turbidity of influent water was very low during the entire sampling period except during the occasional flash flood. During a flood period the turbidity of the influent water to the RSF was 10 NTU and at the outlet it was only 0.1 NTU, thereby meeting the regulatory standards. The high turbidity removal efficiency of the filter unit during flood periods may be attributed to additional alum dose and comparatively frequent filter backwashing. In addition to the water quality parameters, the operation procedure and filter sand quality were also analysed in view of the reported problem of frequent choking of filters. Sand samples from the filter beds were collected randomly after backwashing and particle size analysis was carried out to determine the effective size and uniformity coefficient of the sand. It was found that, in some of the filter units, the effective sand size was coarser than the required size, which may be attributed to wash off during the backwash operation.

During backwash of the filter beds, it was found that a dirty layer accumulated at the top, which was not removed before putting the filter bed into the next batch of operation. The sticky layer contained bird feathers and small, dead fish. Water treatment plant buildings provide shelter

Table 1 | Seasonal variation in physicochemical quality of water at different stages of water treatment

	Summer					Monsoon (pre-flood)					Monsoon (flood condition)					Winter				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Colour (Hazen unit)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	22–35	28–38	21–47	7–33	4–22
Turbidity (NTU)	1–3	2–3	1–2	1	1	2	3	1–2	0–1	0.1	86	74	10	0.1	0.1	2–7	3–7	3–9	3–5	3 –5
pH	7.7–8.0	7.3–7.8	7.1–7.9	7.2–7.5	7.5–7.7	7.5 –7.6	6.8–7.7	6.7–7.8	7.1–7.7	7.3–7.8	7.5	6.6	6.8	6.7	7.1	7.8–8.3	7.8–8.5	7.6–8.0	7.7–7.9	7.7–8.0
TDS	179–194	183–200	190–199	189–199	189–198	221–401	233–415	269–419	250–414	293–429	322	341	336	311	312	271–287	273–285	268–293	273–284	281–283
Alkalinity	124–168	136–176	132–172	128–148	132–168	184–212	176–196	180–196	172–176	182–176	213	193	198	203	197	152–180	107–172	160–174	1 68–196	162–172
Conductivity ($\mu S\ cm^{-1}$)	374–410	389–420	398–418	397–422	401 –418	320–580	343–577	380–574	390–575	408–580	453	467	455	450	438	390–399	383–401	394–402	395–397	395–402
Total hardness	96–140	120–144	112–136	116–144	112–148	152–180	172–188	174–192	176–196	172–184	192	195	193	185	181	144–239	152–174	144–184	180–210	140–172
Ca hardness	12–52	16–76	24–56	12–52	16–56	64–84	64–80	80–92	76–104	92–96	81	76	95	85	81	76–136	72–90	80–100	76–110	72–92
Chloride	44–54	46–56	50–56	44–60	46–58	76–86	82–94	82–92	76–84	82–92	89	82	87	86	79	45–52	40–50	38–50	40–54	40–52
Sulphate	—	—	—	—	—	23–26	30–42	16–32	23–41	26–43	31	46	39	29	28	30–31	31–34	31–34	32–34	32–39
Nitrate	—	—	—	—	—	0.7–1.4	1–7	1–10	1–7	1.0	0.92	1.12	ND	ND	ND	1.3–1.4	1.0–1.4	1.0–1.4	1.2–1.3	1.2–1.3
Phosphate	—	—	—	—	—	1.9–2.3	0.9–8.1	0.8–1.8	0.3–2.7–	0.4–3.7	1.91	1.89	1.61	1.82	0.92	3.3–4.9–	3.2–7.1	3.2–8.2	3.8–5.3–	0.1–4.8

All parameters except colour, turbidity, conductivity and pH are in mg l^{-1}.
A, B, C, D and E are sampling locations as follows: A, raw water (before mixing of chemicals); B, after mixing of alum and lime; C, after sedimentation; D, after filtration; E, clear water sump.

to birds owing to the cool environment, leading to deposition of feathers and droppings in the water. Labourers without a skilled supervisor are not aware of the consequences of the presence of such a dirty layer on top of the filter bed. With the passage of time biological activity starts taking place in this layer. Since larvae feed voraciously on microorganisms, phytoplankton, zooplankton, suspended material and dead, decaying organic matter, the filter bed becomes a host for their growth. The larvae arrested in the RSF get their food from this layer. Therefore it is necessary that the rapid sand filter bed is cleaned of the sticky soil layer, bird feathers and dead fish manually at the end of each backwash operation, which otherwise may not be removed by air scouring and water backwashing. Control of chironomus midge swarms in the slow sand filter using pyrethroid insecticide (Peters *et al.* 2003) was found to be effective but this cannot be used for the rapid sand filter bed because there is less time available between the backwash and the next batch of operation.

A fourth stage of chlorination was carried out for the filtered water which was then stored in the underground treated water reservoir for pumping and distribution. In the entire water treatment process, chlorination is carried out at four points: raw water at inlet (pre-chlorination), before sedimentation, after sedimentation (intermediate chlorination), and after filtration (final chlorination). With the contention that a high chlorine dose will remove the microscopic algae from raw water from a eutrophic water source, multiple chlorination is done in the water treatment process. Waters of eutrophic bodies contain microscopic algae and organic matter consisting of large molecules of fulvic acid, humic acid with carboxylic acid (-COOH) and phenolic (-OH) sites (Hounslow 1995). In this WTP, the chlorine dose was 5–6 mg l^{-1} with residual chlorine of 2–2.5 mg l^{-1}. This high dosing of chlorine may lead to the formation of carcinogens, when organics are present in raw water (Fielding and Farrimond 1999). Therefore large amounts of chlorine dosing cannot be recommended and may require further investigation.

Water distribution system

In 2001 (winter season), chironomus larvae and eggs were reported in the water treatment plants and distribution system. Since chironomus larvae appear during the same period every year owing to their growth cycle, the same months of the next year were chosen for the study. As expected, chironomus larvae and eggs were observed at some consumer taps in the water distribution system during the same months of 2002. Since the investigation at the WTP ruled out the presence of chironomus larvae, the study was further extended to the water distribution system. Midge fly, chironomus larvae or its eggs are expected in the water distribution system wherever water is stagnant and openings exist for the entry of midge fly to lay its eggs together with the entry of organic pollution that favours growth of the larvae. Therefore the booster station where water is received from the WTP was studied first.

At the end of routine daily water supply when the underground booster station was empty, it was inspected from inside. It was found that it contained a layer of mud about 50 cm thick which could be a possible site for growth of larvae. Samples of mud from inside the booster station was collected and sieved through a 500 mm sieve to find the presence of larva or eggs. Samples were collected in order to cover the entire booster station, and none of the samples contained larvae. It was reported that the booster station had never been cleaned for the last 20 years and therefore it is recommended that underground booster stations should be inspected at regular intervals and cleaning performed. Even though intermediate chlorination is carried out at the booster stations, chironomus larvae cannot be killed by chlorination. The next possibility for larval growth was the overhead tank, which is surrounded by tall trees and a damp environment that can be a breeding site for midge fly. Inspection of the water tank did not show the presence of chironomus larvae. Further attention was shifted to the water distribution network at the consumer end where larvae were found.

Investigation of the water distribution network primarily requires a scaled map of the network in the study area. In developing countries such maps of water distribution networks are usually not available. In the initial stages of any water distribution system, particularly in the pre-computer era, such maps were prepared but are not updated over time with new consumer connections. In such instances the assistance of site engineers and workers is of great utility. In this case, comparison of the old water

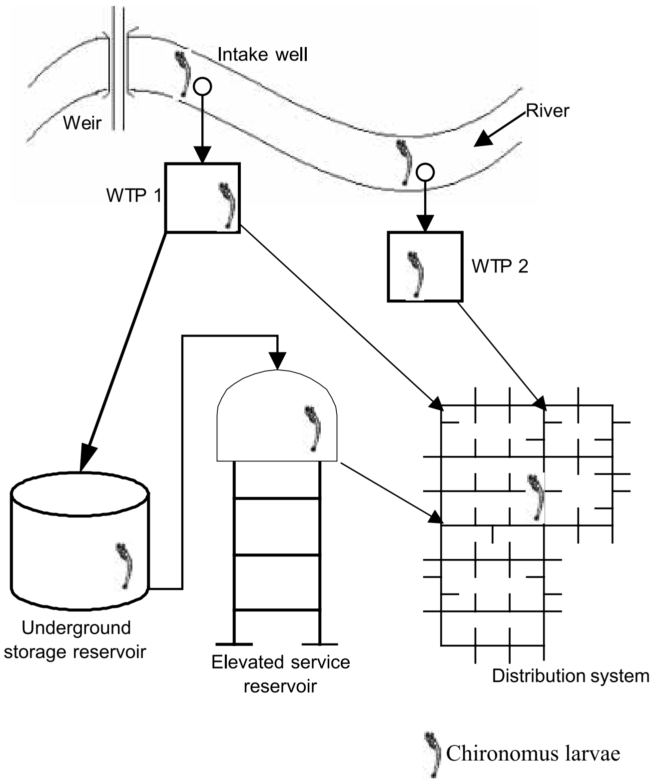

Figure 2 | Possible locations for the growth of chironomus larvae.

distribution network map and actual field observations revealed that there are some new connections, which were not included on the map. Figure 2 shows a schematic diagram of the water distribution network comprising the water source, water treatment plant, underground service reservoir, overhead tank and distribution pipeline, and possible locations requiring investigation for the presence of chironomus larvae. Water can be supplied to an area from more than one supply line, i.e. from the overhead tank and WTP. In such a case investigation for the presence of contamination in both the lines is required. In this study, investigation at the WTP, booster station and overhead tank revealed that chironomus larvae were absent and therefore attention was finally focused near the consumer end.

It was found that only a few consumers were receiving larvae in the water supply and therefore it was initially concluded that a leak in the pipeline could be the location for entry of midge fly, eggs or larvae. A survey was required to detect the leak in the water distribution system. Leak detection instruments are of great help in identifying the leaks; however, in this study, manual observation and subsequent physical inspection was carried out. Water supply staff familiar with the locality were deployed to identify the presence of any wet patch of land on the pipeline route. Some wet patches were identified, one of which was in a street surrounded by houses, the rest in places that are not inhabited. The wet patch in the domestically crowded street was chosen for further investigation. Excavation was carried out and it was noticed that wastewater from nearby houses that had no sewerage system drained into the subsoil near the drinking water pipeline.

In order to observe the pipeline from inside, the water supply was stopped and one segment of pipeline removed at the joint for inspection. The residual water coming from the open end of the pipe was collected in a clean vessel for one full day and it was found that the water contained chironomus larvae of various stages, *Cypris* and some other macro-organisms. It was evident that this particular section of the pipeline contained biological contamination and needed cleaning for which an extensive survey was carried out in the entire pipe network in that area. At the tap end in the pipe network, water samples were collected and analysed for residual chlorine. In all the samples, residual chlorine was about 0.5–2 mg l^{-1} indicating two possibilities. One is absence of any sewage contamination; the other is partial consumption of chlorine due to sewage contamination, leaving little residual chlorine. Since the treated water at the tap contains residual chlorine it is contended that, during non-supply hours when the pipe is under suction, wastewater containing eggs and first-stage instar larvae might have entered the drinking water pipeline where they grow at the dead ends and appear later at the consumer end as the larvae become more mobile at later stages of development.

Cleaning the drinking water pipeline

In order to clean the pipeline water flushing was carried out. The closed loop pipe network was made one way by capping one end and opening the dead end. Flushing with water resulted in the collection of large numbers of larvae

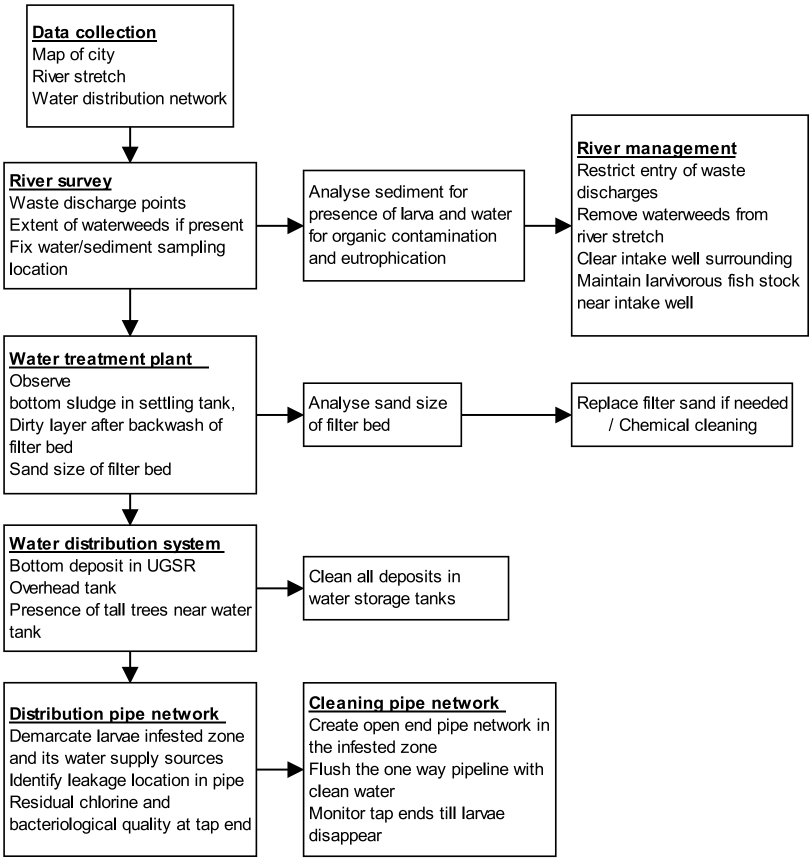

Figure 3 | Investigation/action needed for evaluation of chironomus larvae problem in water supply systems.

at some consumer ends but with prolonged flushing, the larvae disappeared from those consumer ends. With this exercise the pipeline could be cleaned but the exact location of the accumulation of larvae could not be detected. Cleaning by water flushing in open-end pipelines removes larvae at an early stage. If larvae are not removed in this way, they will continue to appear at the consumer end until their population dies out, as they may not have a source of multiplication inside the pipeline.

DISCUSSION

Occurrence of chironomus larvae in the drinking water supply system is reported very frequently during the winter season. The water treatment and supply authorities usually ask what action should be taken on the sudden occurrence of red worms in raw water at the WTP. The simplest answer would be shut down the WTP till the red worm disappears after completing its life cycle. Removal of a macro-biological species from its environment once it has matured is not a feasible option; instead inhibiting its growth by not providing a favourable environment is an acceptable solution. In the context of chironomus larvae, vegetation, a eutrophic water body and organic pollution provide an atmosphere conducive for midge fly to lay its eggs and thereafter the larvae appear in the water. Red worms found in sand filters cannot be removed by mechanical straining, as the small larvae are capable of passing through the sand filter bed due to their wriggling movement. Larvae escaping WTP may appear at the consumer end at some later stage which is not aesthetically acceptable even if this does not cause any adverse health effects.

Chemical control for red worms at the WTP cannot be considered, as a disinfectant such as chlorine does not kill the larva even at a very high dose. Chemicals such as copper sulphate, DDT or dieldrin are not recommended for treating drinking water as they are toxic to humans even at very low concentrations and their half-life is very long. Insects may be a nuisance and intrude into the human environment but they are still part of the ecosystem and are able to develop because of favourable conditions provided by anthropogenic activity such as water pollution in an inhabited area. Therefore preventive measures for the control of red worm are considered to be the best option. Investigation of such species in water treatment systems may be a tedious task as there are several places for the entry of midge fly or its larvae. A schematic diagram is presented in Figure 3 showing the information and action required in the investigation.

CONCLUSION

A WTP may treat water within its design capacity; however, for maintaining the quality of water for macrobiological parameters, it needs to amend its operation and maintenance practices. Some observations in this respect are as follows:

- At the raw water source, the area surrounding the intake well should be cleared of any waterweeds to inhibit growth of microbes.
- Filter bed sand quality should be checked periodically by sieve analysis in order to ensure that it meets the required specifications.
- During filter backwash operation, the dead fish and accumulated sticky, clayey material should be removed manually from the top of the filter bed before feeding the next batch of water.
- On the water distribution network, there should be continuous surveillance at underground reservoirs and overhead service reservoirs.
- Near newly developing residential areas monitoring should be carried out to detect leaks and unauthorized connections, not only to prevent loss of revenue but also to prevent contamination of drinking water.

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