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OPTIMAL SENSOR LOCATIONS TO DETECT ACCIDENTAL CONTAMINATION IN INTERMITTENT WATER DISTRIBUTION NETWORK

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INTRODUCTION

- Water quality monitoring in distribution network is necessary to assure supply of safe water to consumers.
- Online monitoring through sensors is expensive which makes sensor locations crucial in the network to minimize the overall cost.
- Chance of accidental contamination are more in intermittent systems than in continuous systems.
- Therefore, it is more appropriate to locate sensors to detect accidental contamination events at the earliest.

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INTRODUCTION …..

- Probability of occurrence of accidental contamination events depends on:
    - Pipe Condition, i.e. its material, age, diameter, internal and external conditions, breakage history and so on.
    - Proximity with sewer line, open drains or other foul water body that may lead to contamination event
- While monitoring with limited number of sensors, it is essential that risk prone areas are identified and events from high risk prone areas are provided priorities for their detection through sensors.
- Thus, sensor design methodology consists of two steps:

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METHODOLOGY

- Identification of risk prone areas and quantification of risk
    - IRA-WDS (Vairavamoorthy et al. 2007).
- Identifying optimal sensor locations
    - GA based methodology

IDENTIFICATION OF RISK PRONE AREAS

IRA-WDS (Vairavamoorthy et al. 2007)

- IRA-WDS is a GIS based spatial decision support system that predicts the risk associated with contaminated water entering the WDS from a surrounding surface foul water bodies, sewer pipes, drains and ditches.

Pipe Condition Assessment (PCA)

Contaminant Ingress Model (CIM)

Risk Assessment Model (RAM)

Pipe Condition Assessment (PCA)

Physical indicators
- Pipe Indicators
- Installation Indicators

- Material, Decay, Diameter, Length, Internal Protection, External Protection.
- Bedding condition, Workmanship, Joint Method, No. of Joint.

Environmental indicators
- Corrosion Indicators
- Load Strength Indicators

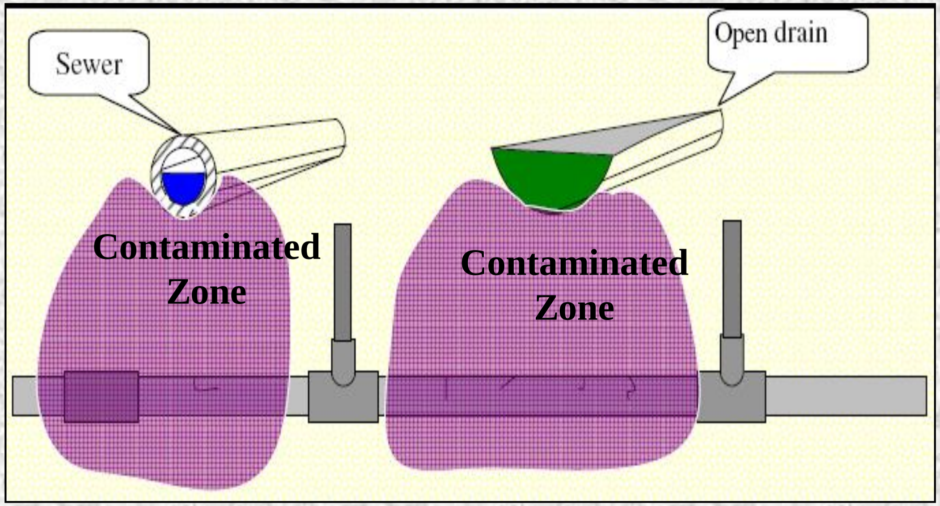
- Year of Installation, Soil Corrosivity, Surface Permeability, GW Condition.
- Buried Depth, Traffic Load, Hydraulic Press

Operational indicators
- Intermittency Indicators
- Failure Indicators

- No. of Valves, No. of turns of WS/day, Duration of WS/day
- Breakage History

Contaminant Ingress Model (CIM)

Fig. Movement of contaminated water (shaded area) from pollution sources towards water distribution pipes (Vairavamoorthy et al., 2006)



- Contaminant Zone (CZ) - Predicts the envelope of pollution emanating from pollution sources.
- Contaminant transport (CT) - Simulates the water flux and the variable concentration of the contaminants within the contaminant zone and then predicts the contaminant loading on the section of pipe in the contaminant zone (SPCZ)

Risk Assessment Model (RAM)

- Estimates the risk of contaminant intrusion.

- This model uses the outputs from the CIM (hazard) and PCA model (vulnerability) with appropriate weights to generate a risk score for each pipe.

OPTIMAL SENSOR LOCATIONS

Assumptions

- Sensors are assumed to be perfect.
- Both ends of a vulnerable pipe are considered as nodes with likely contaminant intrusion locations. Further, equal possibility of contamination is considered at either ends.

Objectives

- Assures the quality of water delivered to the consumers through maximization of demand coverage (DC)
- Early detection of contamination events through maximization of time constrained detection likelihood (TCDL)

Problem formulation

The two objectives are combined into a single objective by using weights.

$$Max\ \ Z = W \times DC + (1 - W) \times TCDL$$

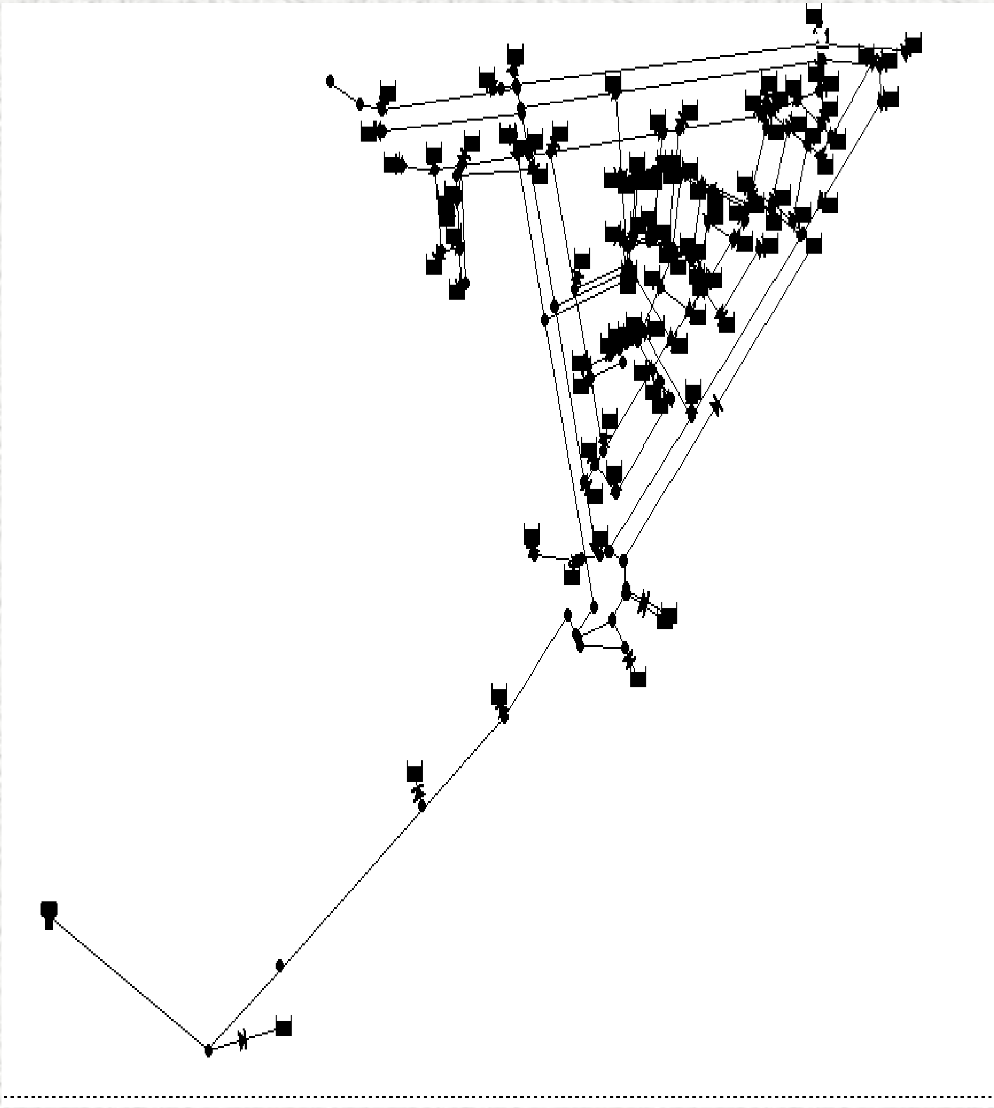
Where,

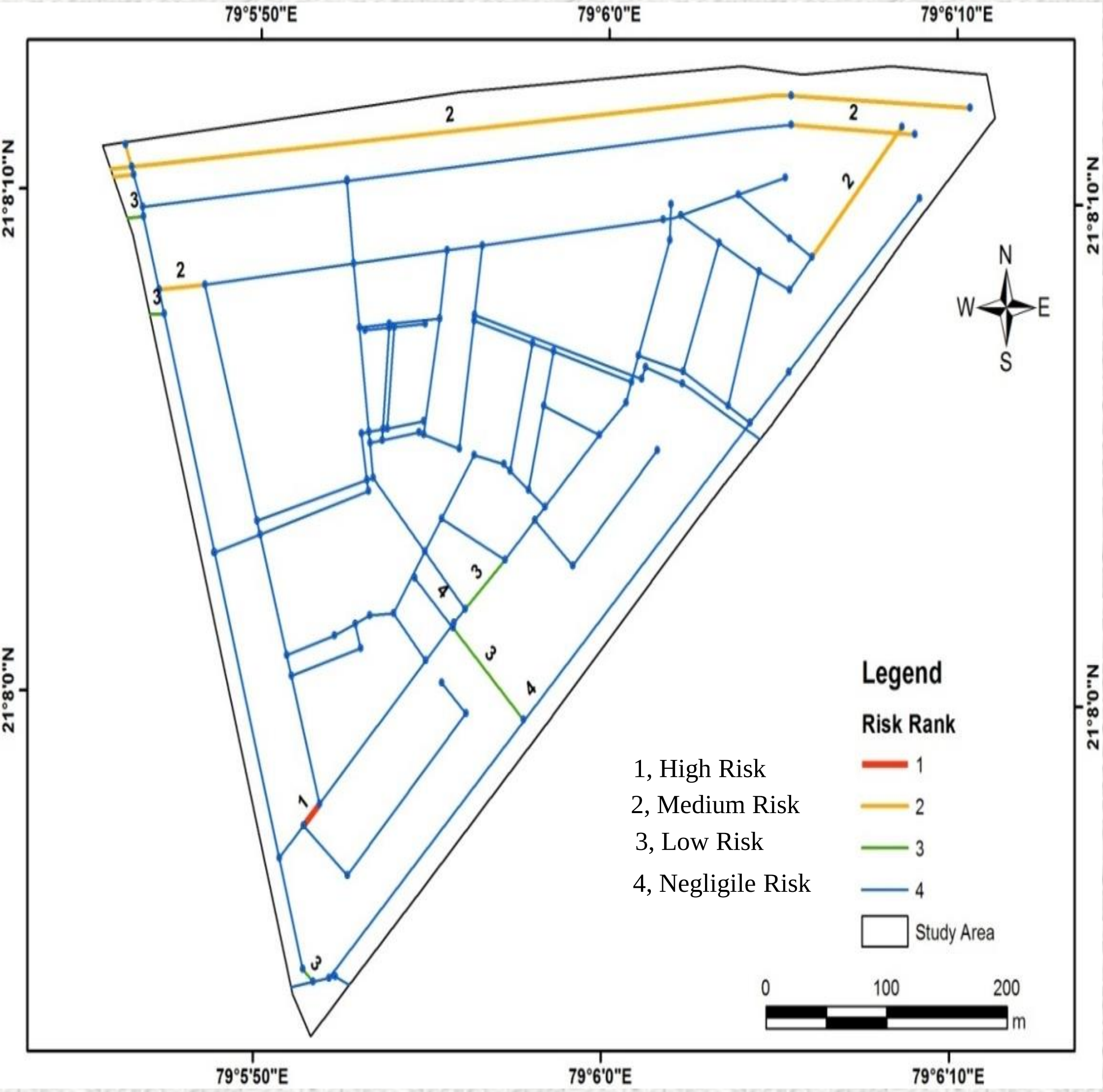
Z = Value of objective function,

W = The percentage weight in fraction associated with the objective DC.

APPLICATION

- WDN of Untkhana area in Nagpur, Maharastra (India)
- 143 nodes
- 96 demand nodes
- 172 pipes.
- 2149.9 m^3/hour.
- Water is supplied for a period of 1 to 2 hours in a day
- Network consist of pipes of mild steel (MS) laid in 1980, DI laid during 2003 to 2011 and GI laid in 2003 with pipe diameter ranging from 75 to 700 mm.





RESULT OF RISK ANALYSIS

- Out of 143 nodes, 25 nodes are in risk prone areas,
- 2 nodes (1 pipe) - High risk areas
- 13 nodes (9 pipes) - Medium risk
- 10 nodes (5 pipes) - low risk area.

SENSOR NETWORK DESIGN

- Sensor network design is carried out using GA based methodology for 3 cases:

  Case 1: Contamination events occurring with equal probability at all the nodes. (Normal Case)
  Case 2: Contamination events occurring with equal probability at nodes on risk prone areas.
  Case 3: Contamination events occurring with probability based on quantified risk at nodes on risk prone areas.

PROBABILITY OF CONTAMINANT INTRUSION IN CASE 3

- The total probability of contamination is obtained based on average risk score
  - 10% at each of the two nodes in high risk areas = 0.2
  - 4.6 % at each of the 13 nodes in medium risk areas = 0.6
  - 2% at each of the 10 nodes at low risk areas are considered = 0.2

Case 1 : Contamination events occurring with equal probability at all the nodes

No. of Sensors	Nodes for sensor location	DC	TCDL	Objective Function Value
5	3, 100, 168, 2000, 5000	0.6634	0.6084	0.6359
10	3, 21, 44, 100, 128, 168, 1000, 2000, 3000, 5000	0.9077	0.7413	0.8245
15	3,5, 21, 43, 100, 104, 128, 137, 143, 168, 173, 1000, 2000, 3000, 5000	0.9428	0.8322	0.8875
20	2, 3, 5, 21, 26, 44, 100, 104, 128, 136, 137, 158, 168, 173, 174, 1000, 2000, 3000, 4000, 5000	0.9579	0.8741	0.9160

Case 2 : Contamination events occurring with probability at risk prone nodes

No. of Sensors	Sensor location at nodes	DC	TCDL	Objective Function Value
5	1, 3, 2000, 3000, 5000	0.7776	0.6800	0.7288
10	2, 3, **5**, 8, **104**, **129**, 168, 2000, 3000, 5000	0.8724	0.9200	0.8962
15	2, 3, **5**, 8, 26, 104, 127, **129**, 137, 168, **180**, 1000, 2000, 3000, 5000	0.9354	1.0000	0.9677
20	2, 3, **5**, 8, 26, **27**, **35**, 44, **81**, 104, 127, **129**, 137, 168, **173**, 180, 1000, 2000, 3000, 5000	0.9588	1.0000	0.9794

Case 3 : Contamination events occurring with probability based on quantified risk

No. of Sensors	Sensor location at nodes	DC	TCDL	Objective Function Value
5	1, 3, 2000, 3000, 5000	0.7776	0.6834	0.7305
10	2, 3, 8, **27, 127, 128**, 168, 2000, 3000, 5000	0.8633	0.9599	0.9116
15	2, 3, 8, **21**, 26, 29, 104, 127, **128**, 137, 168, 1000, 2000, 3000, 5000	0.9419	1.00	0.9709
20	2, 3, 8, **21**, 26, **39, 43**, 44, **51**, 104, 127, **128**, 137, 168, **177**, 180, 1000, 2000, 3000, 5000	0.9604	1.00	0.9802

OBSERVATIONS

- The number of events needs to be considered in case 2 and 3 are only 25 as compared to 143 in case 1 where each node is probable location for accidental contamination. This reduced computational effort and time and would be more useful for large networks.

- The number of risk prone nodes covered by 5 sensor locations in case 1 is 13, while 17 nodes in risk prone area are covered by sensors in case 2 and case 3 for similar sensor locations. Thus, cases 2 and 3 are better than case 1. Similar is observed for higher number of sensor locations.

- For 10 sensor locations, it is interesting to note that 23 out of 25 nodes in risk prone area are covered in case 2; while only 22 out of 25 nodes in risk prone area are covered in case 3. However, the two nodes left to be covered in case 2 are located one each in medium and low risk area. The three nodes left to be covered in case 3 are located in low risk area. Thus, all nodes in medium risk zones are covered under case 3 resulting in higher objective function value.

- Sensor locations provide priority to contamination events occurring at nodes in risk prone area under cases 2 and 3.

- Further sensor locations under case 3 provide priority to contamination events from higher risk area as compared to low or no risk areas.

CONCLUSIONS

- Both regular monitoring and detection of accidental contamination event in allowable time is considered simultaneously.

- The risk of contaminant intrusion is determined using IRA-WDS model and nodes are classified as high, medium and low risk prone nodes.

- Sensor locations based on the risk analysis are observed to detect more number of contamination events and also reduces computational work.

Thank You Very Much.

Any Question Please?