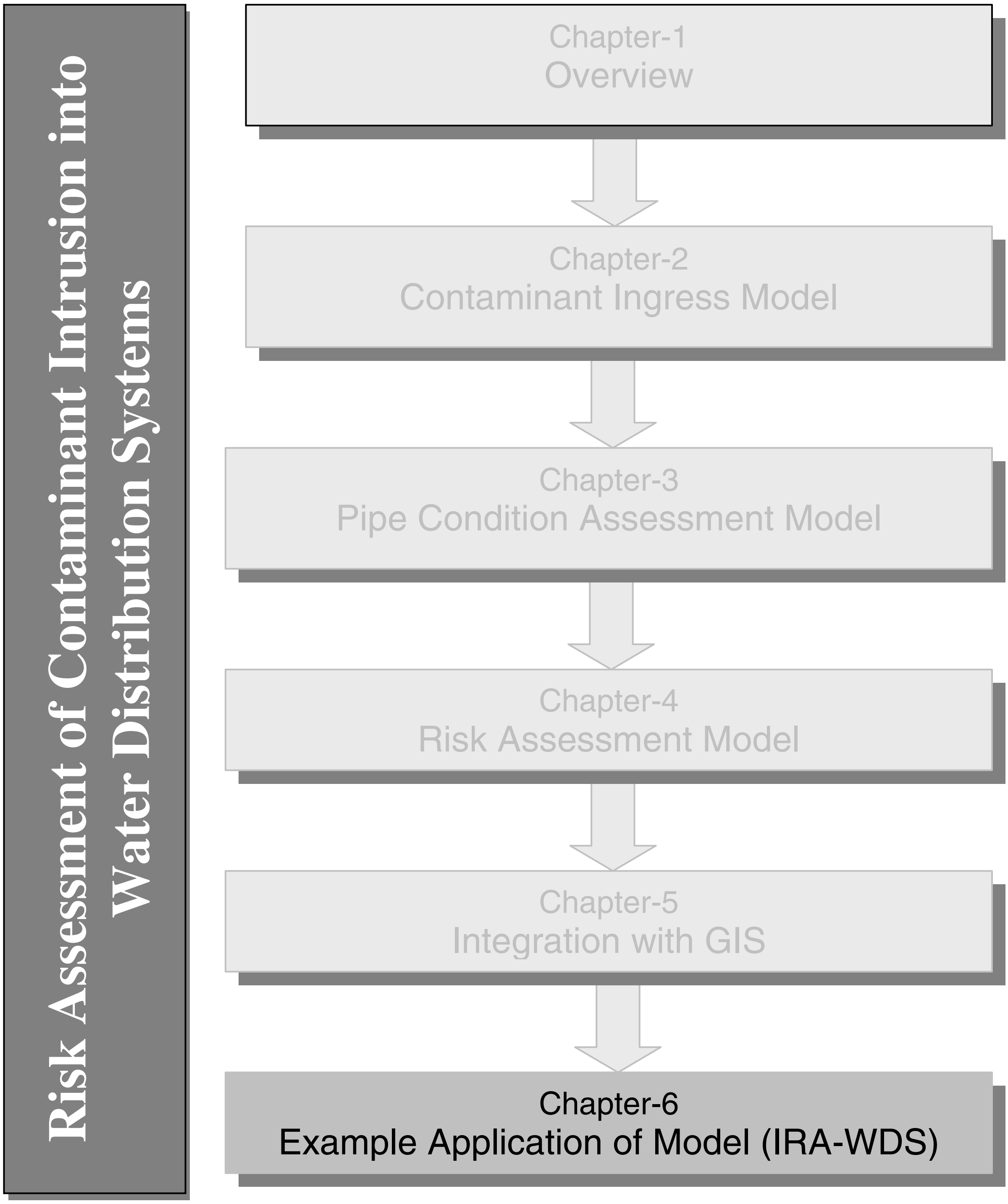
CHAPTER SIX

Example Application of Model (IRA-WDS)


Risk Assessment of Contaminant Intrusion into Water Distribution Systems
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Chapter 6: Example Application of Model (IRA-WDS)

6.1 Introduction

Previous chapters of this book have provided an introduction into the technical background of the mathematical models provided, how the outputs of the model are combined to estimate risk, and how the models are integrated into a GIS framework.

In this chapter an application to a real case study area is presented. The chapter provides details of data collection, model construction, its integration with GIS, and finally interpretation of the results.

As far as possible this chapter is structured in a way that mirrors the steps presented in the previous chapters. It is anticipated that by reading this chapter, the user will get a good insight into all the processes involved in using these models and IRA-WDS.

This chapter is structured in the following way.

- Background to the study area and details of the data collection
- Details of GIS development and model construction
- Application of IRA-WDS and interpretation of the results.

6.2 Case Study – Guntur

Guntur is one of the five largest cities in Andhra Pradesh, India (see Figure 6.1) and is bounded by latitudes 150 50'N and 160 50'N and longitudes 790 10'E and 790 55'E.

The present population of the city is around 580,000 and the city attracts on average approximately 120,000 population every day. The mean annual temperature in Guntur is 28°C with an average annual rainfall of about 800-1000 mm (Sources: NATMO; Indian Meteorological Department, Hyderabad). The climate in the area is very warm and in summer temperatures of as high as 49°C are recorded. The groundwater is available at about 10-20 m depth in this area (Sources: Central Ground Water Board, Irrigation Division, Guntur).

Figure 6.1. Location of Guntur in Andhra Pradesh, India

6.3 The Study Area

Guntur is divided into 10 zones for administrative purpose and the area chosen for the this study is the B R Stadium (zone VIII). Water is supplied for approximately one hour a day and during non-supply hours most of the population depends on groundwater.

The data available for zone VIII include maps of the road network, water distribution networks, sewer networks, surface foul water bodies, stand pipe locations and house connections details.

6.3.1 Water supply distribution system

Guntur Municipal Corporation is responsible for providing the city with its drinking water supply through a piped network. As in most parts of India, Guntur's water supply is intermittent and available for one hour a day. In addition to being intermittent the water supply is also reported to experience frequent ingress of contaminants (particularly in zone VIII). Zone VIII covers an area of approximately 4 km^2 and has a population of about 60,000. The vast majority of the population depends on the public water supply through house connections and standpipes.

The source of water for the study area is the Krishna River. Through canals the water flows to Takkellapadu reservoir. At Takkellapadu reservoir the water is treated and the treated water is collected in clear water sumps. From these sumps the water is pumped and distributed to zone VIII water tanks through cement concrete pipes of 1200 mm diameter. There are two overhead water tanks supplying this zone.

The main supply lines from the tanks are 600 mm diameter RCC pipes. The distribution lines are mainly AC pipes with a few CI and GI pipes ranging in diameter from 60 mm to 600 mm. The total length of the network is 62 km, which includes 829 pipes of various sizes.

There are various points along the network where pipes pass through open drains, and where sewage flows over the pipes. Since, majority of the population depends on public water supply any contamination in the network affects large number of people.

A peculiar feature of this zone is that, once the water supply has stopped, at many locations the public uses handpumps (or even electric pumps) to suck water out of the distribution system. Clearly this will encourage foul water from leaking sewers and open drains to enter the main drinking water network (through leaks at joints, pipe segments or valves etc.).

6.3.2 Underground sewer system

Only a part of the study area is served by underground sewers. There are two types of sewer pipes, viz. RCC and stoneware, the total length of which is approximately 26 km (most of this is RCC). The age of the sewers varies from 1 to 28 years and the buried depth of the sewers varies from 0.9 to 4.5 m. The minimum and maximum diameters of the sewers are 150 mm and 1200 mm respectively. The main sewer of diameter 1200 mm conveys the sewage to the wastewater treatment work located at Suddapalli Donka.

6.3.3 Open drainage system

All but 1 per cent of the study area is covered with the open drains. There are two types of drains, lined (Pucca drain) and unlined (Kutcha drain). The majority of the lined drains are made of brick and lined with cement. Unlined drains exist in only a few locations. The standard width and depth of the drains is approximately 0.3 m (however, there are a few larger drains that connect with several smaller drains). It has been reported that there is considerable seepage from the open drains. As the open drains are at ground level, there is a potential of seepage reaching water supply pipes.

6.3.4 Surface foul water bodies

Stagnant water is found in depressions around the city (especially during the rainy season). There are several such water bodies in the study area, of which four are polluted. In several places, the open drains release water into these water bodies, making them foul. The depth of water in these foul water bodies ranges from 9 to 14 m and the area varies from 1055 to 13266 m^2. Note that water distribution pipelines pass near and in some cases below these water bodies and it is quite common for there to be reports of water supply contamination immediately after rain.

6.3.5 General observations in the study area

Several field visits were undertaken to the study area. To give an indication of the conditions that exist in the area, a brief selection of observations are given below.

Culvert on an open drain in Nandhi Velugu Road with two main water supply lines along the drain was visited in which one of the two pipelines (300 mm) was fully submerged and the other was just above the existing water level in the drain.

- In the main water supply pipeline near the Railway Junction, leakages were found in the 1200 mm main pipeline (18 years old), which conveys water from the water treatment plant to the rest of the pipe network.
- Leakages were also found in the valves and pipelines near the water tank. Treatment of water is being done by adding lumps of bleaching powder at the open source and flocculation (using Alum) in the tank. There are garbage disposal areas at different locations along the opposite side of the road. This poses the threat of contamination in the pipelines as the main pipelines from the treatment plant lie close to this area.
- The facilities at the wastewater treatment plant include screening, two settling tanks, one pumping station and sedimentation canals. At the time of the study, the plant was not functioning and the untreated wastewater was released to the nearby farmlands.
- The local drains empty into the surface foul water body at Balaji Nagar (zone VIII).
- Many open drains were found in the IPD Colony with water supply lines in close proximity.
- Two overhead tanks are located near BR Stadium, each with a capacity of 1500 kilolitres. At present only one tank is in use. The supply pattern is one hour per day in all the areas. At this rate the per capita water supplied is approximately 40 litres per day.
- Drainage channels and water supply pipes run along both sides of the narrow street and at many locations the pipelines are submerged in the sewage water. At some locations the water distribution pipes are corroded to a great extent.

6.4 Data Collection and Database Preparation

Several field visits were undertaken to the study area and a local NGO, KAKATOS, was engaged to collect data.

- Data collected included characteristics of the water supply distribution system, sewer and open drain system and surface foul water bodies.
- Data preparation included the production of thematic layers:
  - base map theme - land use, elevation contour, ward map, etc.
  - network map themes - pipe network, sewer network, canal network, foul water bodies etc.
  - derived themes - population density, proximity of pipeline to sewers etc.

6.4.1 Data collection

The following are the various types of data collected in the study area:

- Base map data (elevation, land use etc.).
- Network data
  - Water distribution data
  - Sewer data
  - Open drains/canals data
  - Surface foul water body data
- Demand data (not required to run models).

With a reference map made available by the Guntur Municipal Corporation, the boundary of the area was marked through physical survey and all the important features were identified and marked on the map.

6.4.2 Compass survey

Data was collected in relation to road type, length of the road and width of the road (using a road meter and tapes), and then plotted using AutoCAD. The total length of the roads is 90 km.

6.4.3 Levelling survey

The levelling survey was performed using the auto level instrument. The Takkellapadu reservoir was taken as the benchmark and levels at all junction points of the roads were measured.

6.4.4 Network surveys

The network maps (water distribution, sewers and open drains) were collected from the Public Health Engineering Department of Guntur. A survey was carried out to verify and add details to the network maps. This was done with the help of municipal engineers, tap inspectors and other workers from the Guntur Municipal Corporation.

6.4.4.1 Water distribution system

The water distribution system is shown in Figure 6.2. Water is distributed twice a day to different areas – area 1, morning 6:00 am to 7:00 am; and area 2, evening 6:00 pm to 7:00 pm. Additional data collected included: pipe characteristics (pipe, material, age, buried depth, diameter, length, road loading, break frequency and reduced levels). Locations and details of pipe joints (bends, tees cross etc.), were also obtained, as they could be potential entry points of pollutants.

Figure 6.2. Water distribution network of Guntur (Zone VIII)

6.4.4.2 Sewer network

The sewer network is shown in Figure 6.3. It can be seen that only a small part the study area is served by underground sewers. Manholes are placed at regular intervals; however, many are now covered over with soil or roads. When there are problems with sewage flow, therefore, it is difficult to locate the manhole for repair.

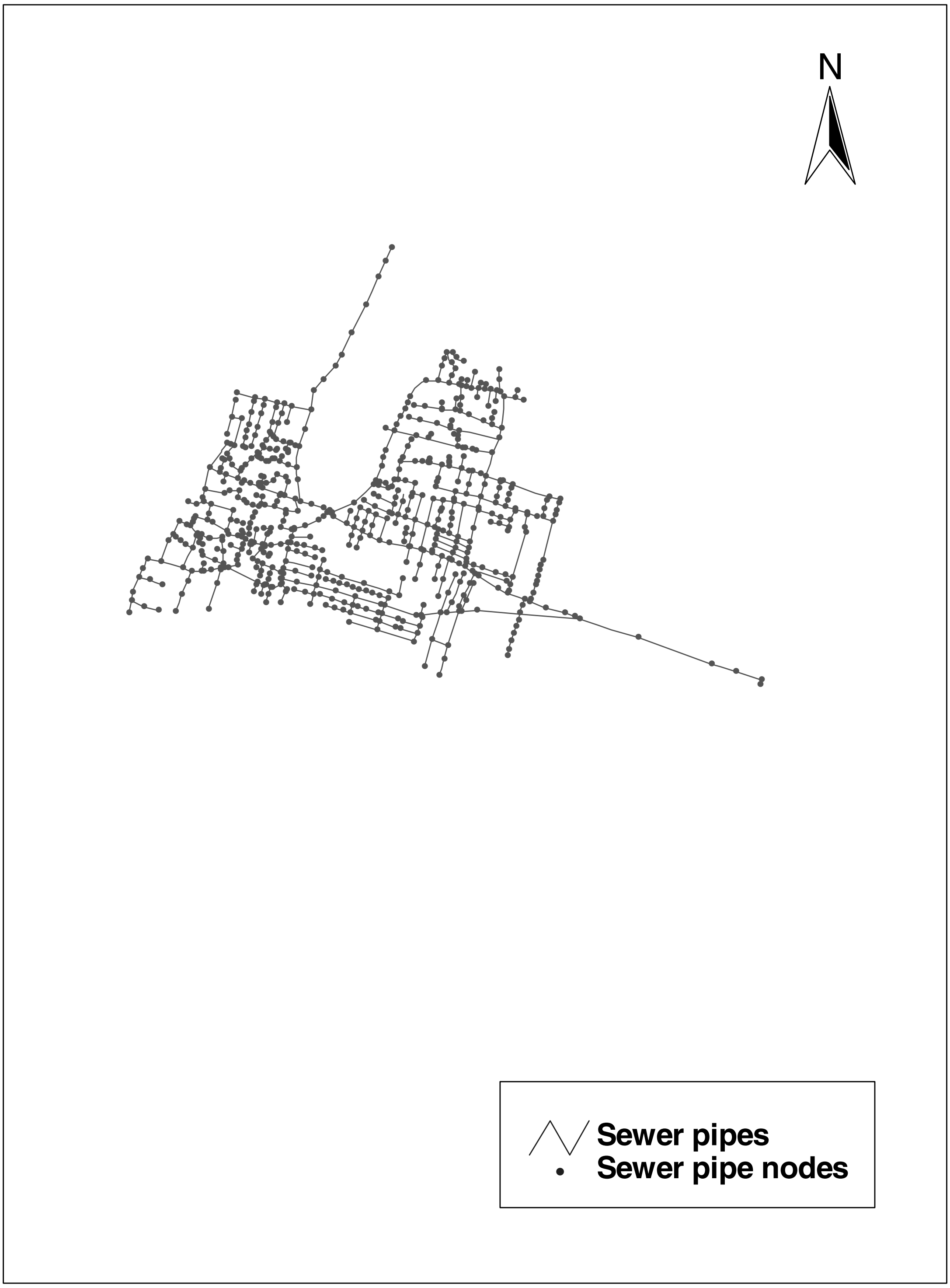

Figure 6.3. Sewer network of Guntur (Zone VIII)

6.4.4.3 Canal/Drain network

The canal/open drain network is shown in Figure 6.4. Most of the data related to the open drains was collected by visual inspection. Data collected included: type of drain (lined or unlined); age; length; width; and depth. It was observed that most of the drains were in bad condition and that the drain water was not flowing freely at many places. In some areas, the open drain is feeding nearby water bodies, making them foul water bodies. There are also several locations where drinking water pipes pass through the open drain.

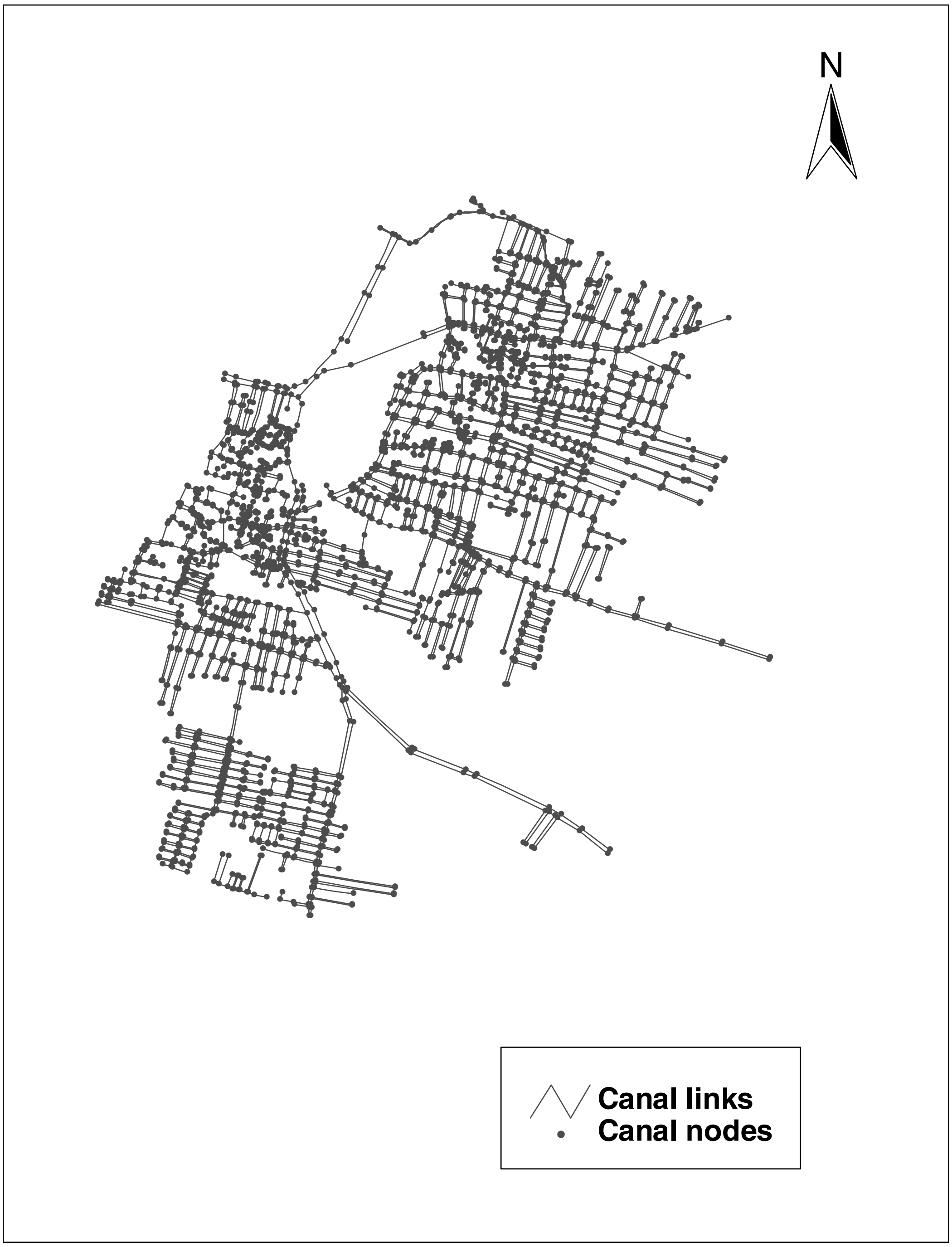

Figure 6.4. Canal/open drain network of Guntur (Zone VIII)

6.4.4.4 Surface foul water bodies

The foul water body polygon network is shown in Figure 6.5. There are several depressions around the city, of which four are polluted. Data collected for the foul water bodies included: their location; size (perimeter); and depth. The depth of water in the foul water bodies ranges from 9 to 14 m and the area varies from 1055 to 13266 m^2. Water supply pipelines pass near and in some cases below these water bodies.

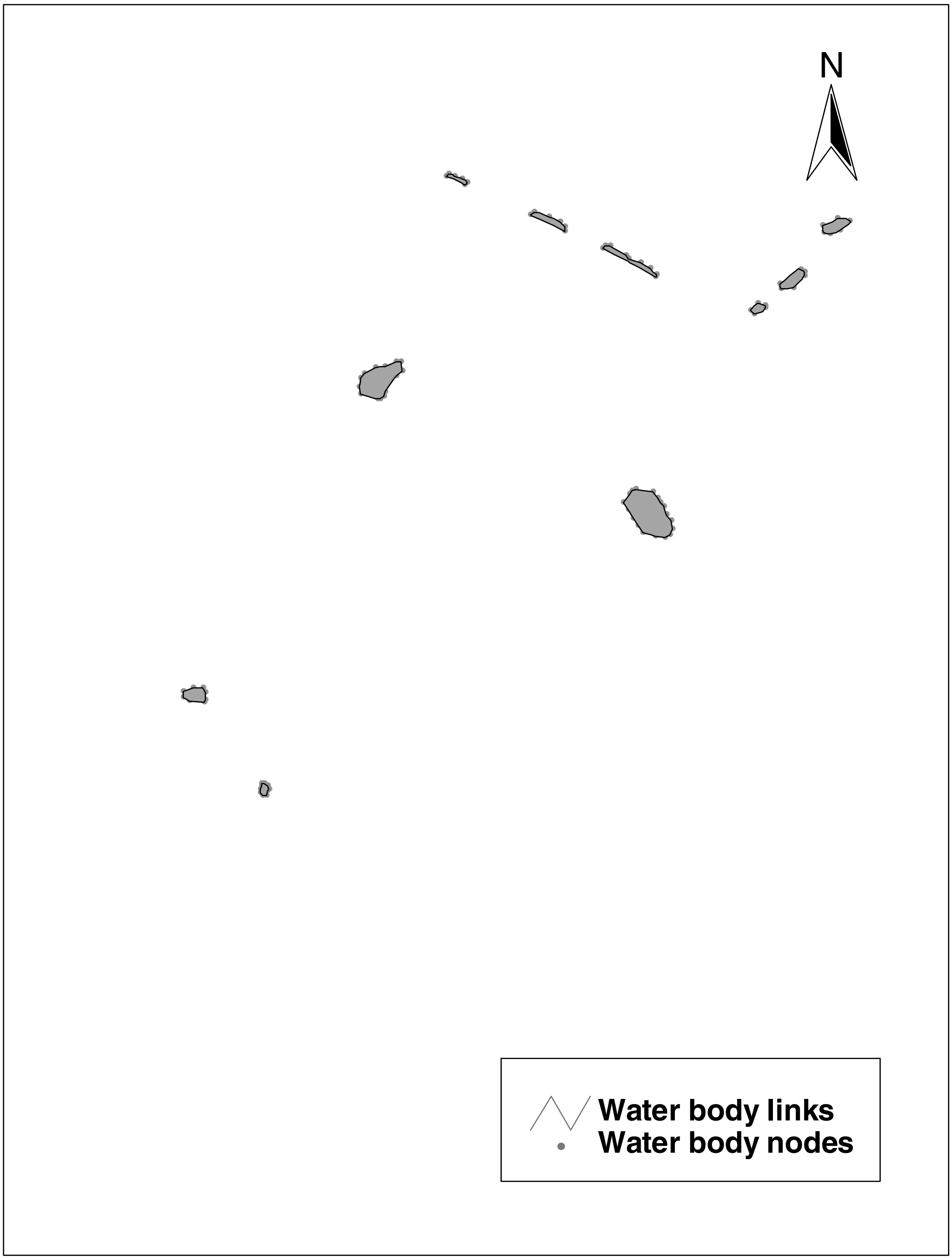

Figure 6.5. Foul water body polygon network of Guntur (Zone VIII)

6.4.5 Data preparation

As described in Section 5.5 of Chapter 5, the data preparation stage includes the preparation of various data/layers:

- Thematic layers
- Network database
- Derived layers.

6.4.5.1 Thematic layers

The first step in data preparation is thematic layers preparation. The following thematic layers of Guntur study area were prepared using the field data collected.

- Base map: infrastructure and contour maps
- Environmental maps: soil, groundwater, and pressure maps.

<u>Base map</u>

This map was prepared from a Survey of India (SOI) toposheet with a scale of 1:50,000. The SOI toposheet was obtained from the Guntur Municipal Corporation. ArcView GIS tools were used and the map was prepared by digitizing, editing and projecting the coordinates to a polyconic projection system. The entire area was divided into major classes, e.g. settlement, vegetation, roads etc. The following themes were added to generate the base map.

- Elevation contour map - The contour map (Figure 6.6) was prepared from reduced level data obtained by levelling survey. The elevation level in the study area varies from 18.5 m to 25 m.
- Land use/land cover map - The land use/land cover map (Figure 6.7) was prepared using IRS ID/LISS III & PAN merged data, scale 1:25,000. The major land-use classes that are found in the study area are shown in Table 6.1.
- Ward map - The ward map (Figure 6.8) of zone VIII was prepared from the data obtained from the Guntur Municipality. The study area consists of 10 wards.

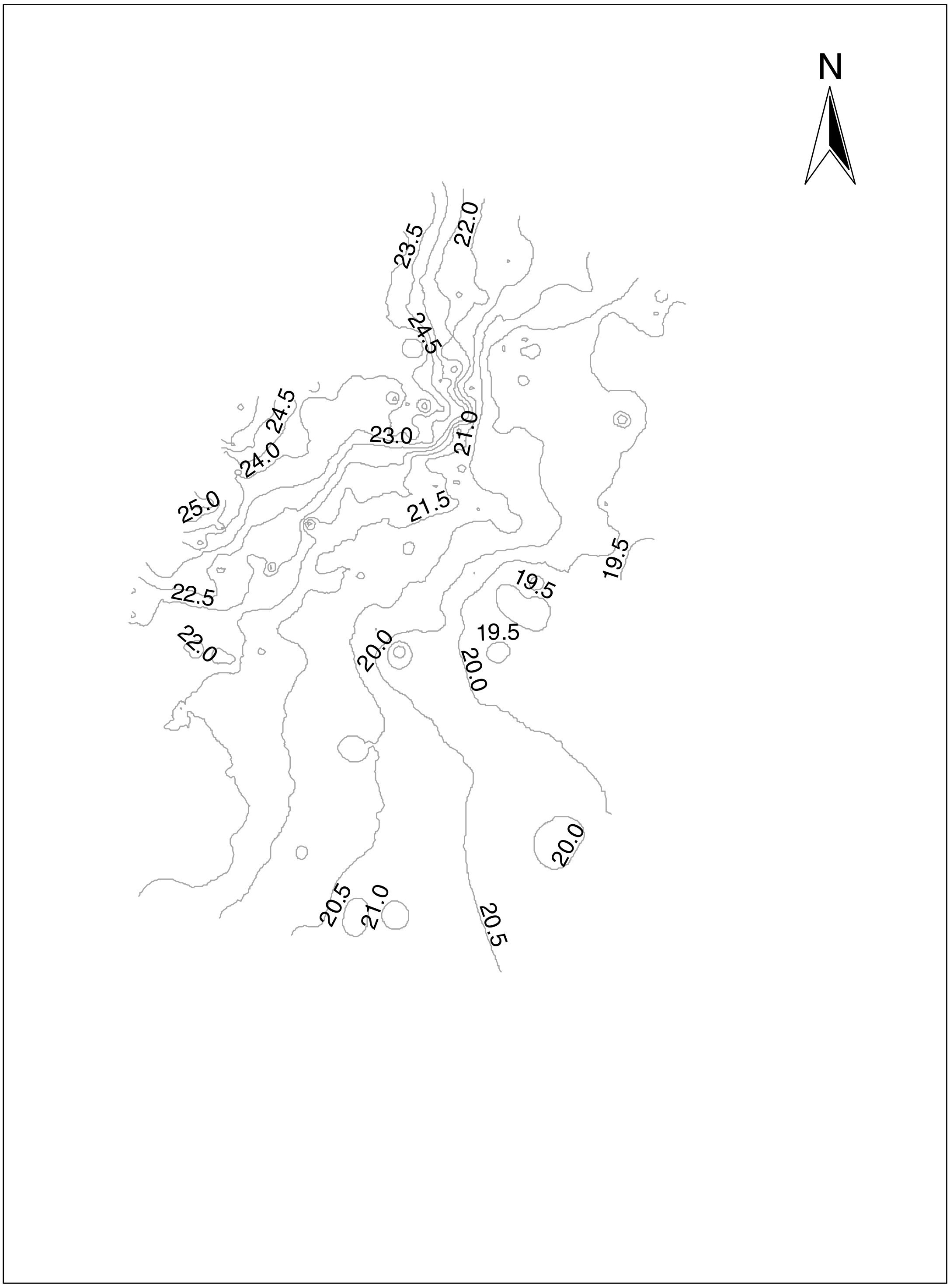

Figure 6.6. Contour map of Guntur (Zone VIII)

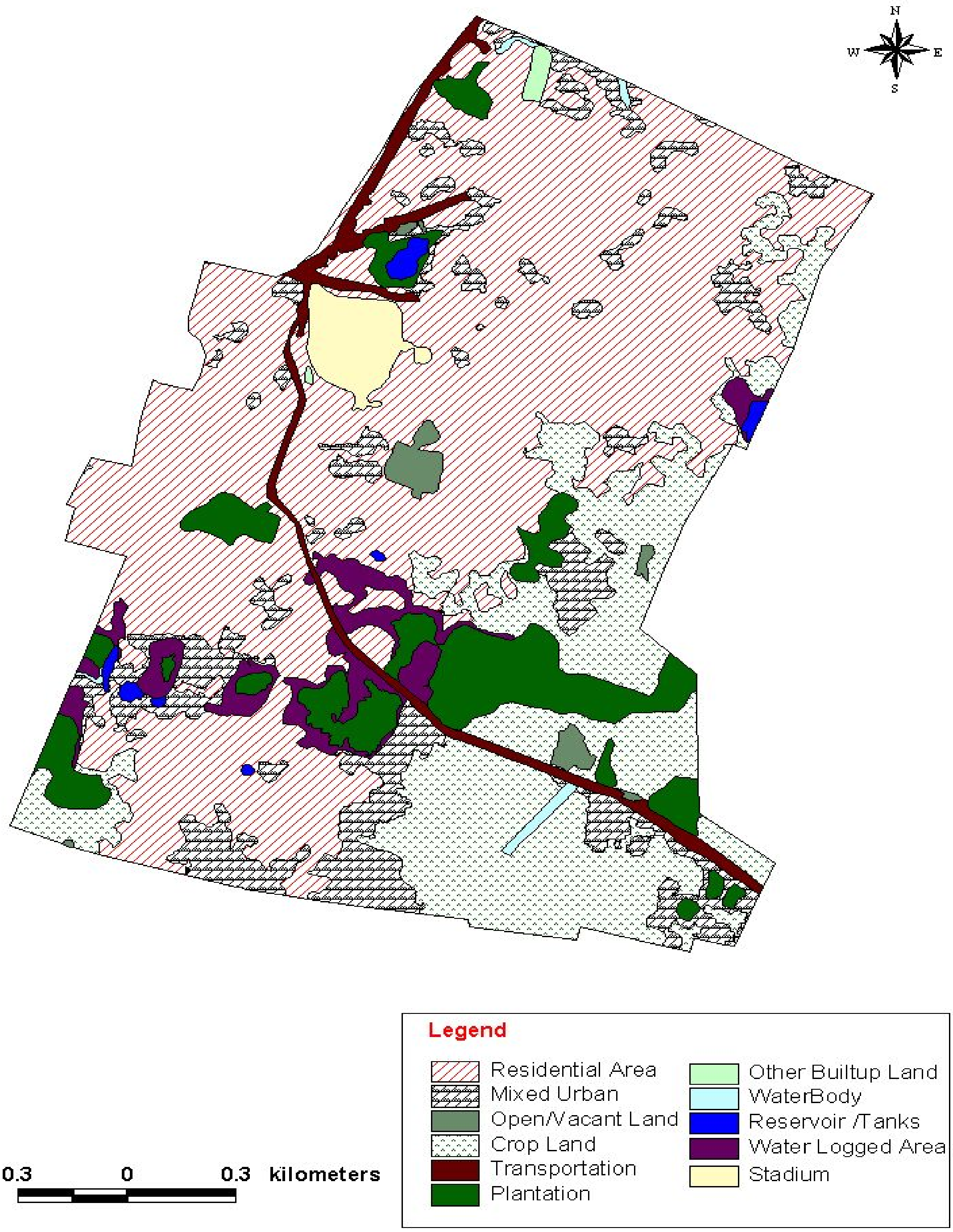

Figure 6.7. Land use/land cover map of Guntur (Zone VIII)

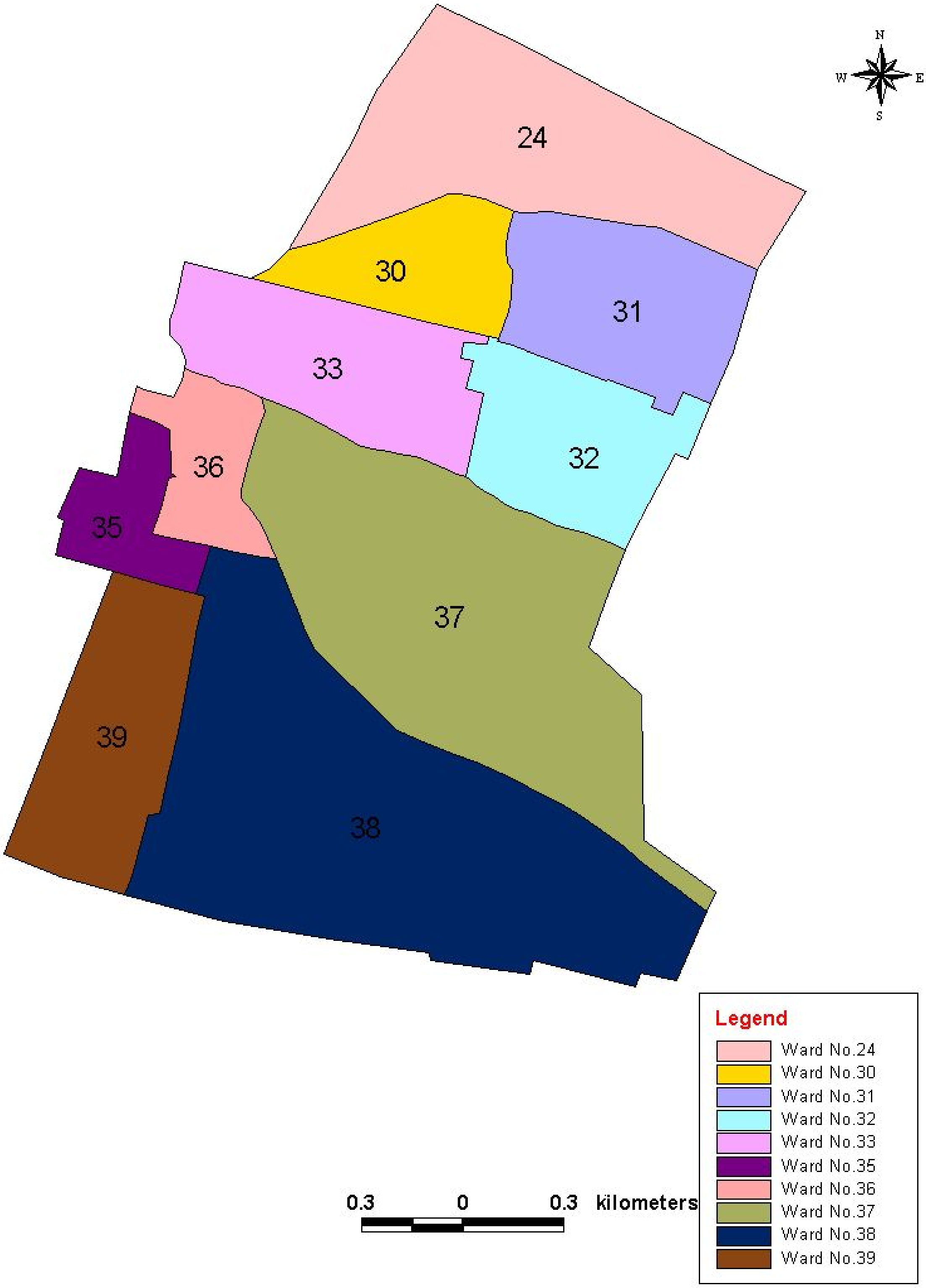

Figure 6.8. The ward map of Guntur (Zone VIII)

Table 6.1. Major land use classes found in Guntur (Zone VIII)	
Land use category	Area (km^2)
Residential area	2.11
Mixed urban	0.45
Open/vacant land	0.04
Crop land	0.77
Transportation	0.11
Plantation	0.33
Other built-up land	0.01
Stadium	0.07
Waterlogged area	0.14
Water bodies	0.03

Environmental maps

As discussed in Section 5.5.2 of Chapter 5, environmental maps are created from soil maps, groundwater maps and pressure zone maps. For the case study the following observations were made:

- The groundwater depth in Guntur is low (much lower than the water distribution pipes), and hence a groundwater zone map was not required.
- In the Guntur study area the soil is homogenous and is fully covered by black cotton soil. Hence there is no need for a soil zone map.
- Field study indicated that the pressures in the water distribution in Guntur study are low. Hence a pressure zone map is not required.

6.4.5.2 Construction of network database

Data preparation includes the construction of network data required for the contaminant ingress and pipe condition assessment models. Note the details of all the attributes required to run these models are given in Chapters 2 and 3.

The following GIS network maps were prepared for the study area:

1. Water distribution system network
2. Sewer system
3. Canals/open drainage network
4. Surface foul water body.

The steps involved in preparation of the network maps for IRA-WDS are as follows (see also Section 5.5.2 of Book 4):

1. Creation of appropriate shape-files: These are GIS files that contain the spatial information of all objects considered by IRA-WDS

2. Input of additional model data: These files contain specific characteristics of the objects generated in the shape-files.

In order to implement the above steps for the study area network maps, the following was performed (refer to Chapter 2 of Book 4 for more information):

- Maps converted from AUTOCAD to GIS format
- Nodes created for each of the networks (junctions and locations where there is a change in the characteristics of a link).
- Unique identification (IDs) assigned to all elements/links and nodes
- Shape-files generated containing key attribute data (IDs, elevation, length, diameter, material, etc.)
- Additional attribute data added to shape-files using the spreadsheets ('Data requirement Ingress Model.xls' for Contaminant Ingress Model and 'Data requirement PCA Model.xls' for Pipe Condition Assessment Model) enclosed with IRA-WDS.

<u>Water distribution network</u>

Figure 6.9 shows the water distribution network model for zone VIII (study area). Tables 6.2 and 6.3 show the attributes included in the link and nodal shape-files for the water distribution system from the data collected for the contamination ingress model. Table 6.4 and 6.5 show the attributes included in the link and nodal shape-files for the pipe condition assessment model.

Figure 6.9. Water distribution network model for zone VIII of Guntur

Table 6.2. Attributes included in the link shape-files for water distribution system for contaminant ingress model		
Data Name	**Data Type**	**Descriptions**
Pipe ID	Integer	Unique ID for each pipe
Start node ID	Integer	Node ID at pipe's starting point
End node ID	Integer	Node ID at pipe's ending point

Table 6.3 Attributes included in the node shape-files for water distribution system for contaminant ingress model		
Attribute	**Data Type**	**Description**
Node ID	Integer	Unique ID
Node coordinate (x)	Float	Unit in metres
Node coordinate (y)	Float	Unit in m
Node coordinate (z)	Float	Unit in m
Bury depth	Float	Unit in m
Elevation	Float	Unit in m

Table 6.4. Attributes included in the link shape-files for water distribution system for pipe condition assessment model		
Data Name	**Data Type**	**Descriptions**
Pipe ID	Integer	Unique ID for each pipe
Start node ID	Integer	Node ID at pipe's starting point
End node ID	Integer	Node ID at pipe's ending point
Pipe diameter	Float	In mm
Pipe material	Char	CI=cast iron; PVC=polyvinyl chloride; RCC=reinforced concrete; ASB or AC=asbestos cement
Pipe length	Float	In metres
Year of installation	Integer	Unit in year
Traffic loading	Integer	0=very busy; 1=busy; 2=normal; 3=quiet; 4=very quiet
Complaint frequency	Float	In times/year
Break frequency	Float	In times/year
Pipe location	Integer	0=very hard; 1=hard; 2=grassed; 3=open land; 4=water body

Table 6.5. Attributes included in the node shape-files for water distribution system for pipe condition assessment model		
Attribute	**Data Type**	**Description**
Node ID	Integer	Unique ID
Node coordinate (x)	Float	In metres
Node coordinate (y)	Float	In metres
Node coordinate (z)	Float	In metres
Bury depth	Float	In metres
Elevation	Float	In metres
Joint type	Char	CID, Clamped, Collar, FW, lead
Number of connected pipes	Integer	Number of pipes at a joint

Sewer network

Figure 6.10 shows the sewer network model for zone VIII (study area). Tables 6.6 and 6.7 show link and nodal shape-files for the sewer network from the data collected, for the contaminant ingress model

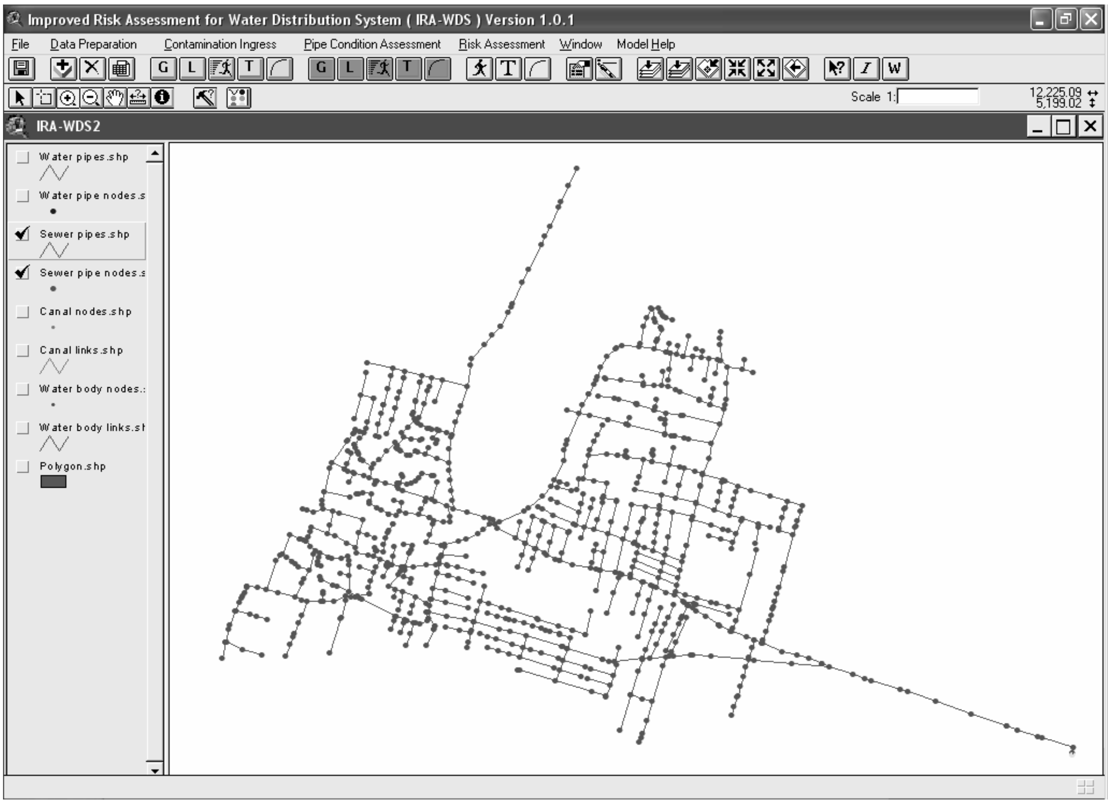

Figure 6.10. Sewer network model for zone VIII of Guntur

Table 6.6. Attributes included in the link shape-files for sewer system		
Attribute	**Data Type**	**Description**
Pipe ID	Integer	Unique ID for each pipe
Start node ID	Integer	Node ID at pipe's starting point
End node ID	Integer	Node ID at pipe's end point
Pipe diameter	Float	In mm
Pipe material	Char	Such as SWP, RCC.
Pipe length	Float	In metres
Pipe age (year installed)	Integer	Unit in year
Road loading above pipe	Integer	0=very quiet; 1=quiet; 2=normal; 3=quiet busy; 4=busy; 5=very busy. (prefer to give some numerical value for each category)
Pipe location	Integer	0=main road-urban; 1=main road-suburban/rural; 2=light road; 3=footpath; 4=others (prefer to indicate the type of area)
Sewer use/purpose	Integer	0=combined; 1=foul; 2=surface water;
Slope	Float	
Soil condition	Integer	0=non-aggressive; 1= slightly aggressive; 2=moderately aggressive; 3=highly aggressive; 4=very highly aggressive

Table 6.7. Attributes included in the node shape-files for sewer system		
Data Name	**Data Type**	**Descriptions**
Node ID	Integer	Unique ID for each node
Node coordinate (x)	Float	In metres
Node coordinate (y)	Float	In metres
Node coordinate (z)	Float	In metres
Bury depth	Float	In metres
Elevation	Float	In metres

Canal/open drain network

Figure 6.11 shows the canal/open drain network model for zone VIII (study area). Tables 6.8 and 6.9 show the link and nodal shape-files for the canal/open drain network from the data collected, for contaminant ingress model.

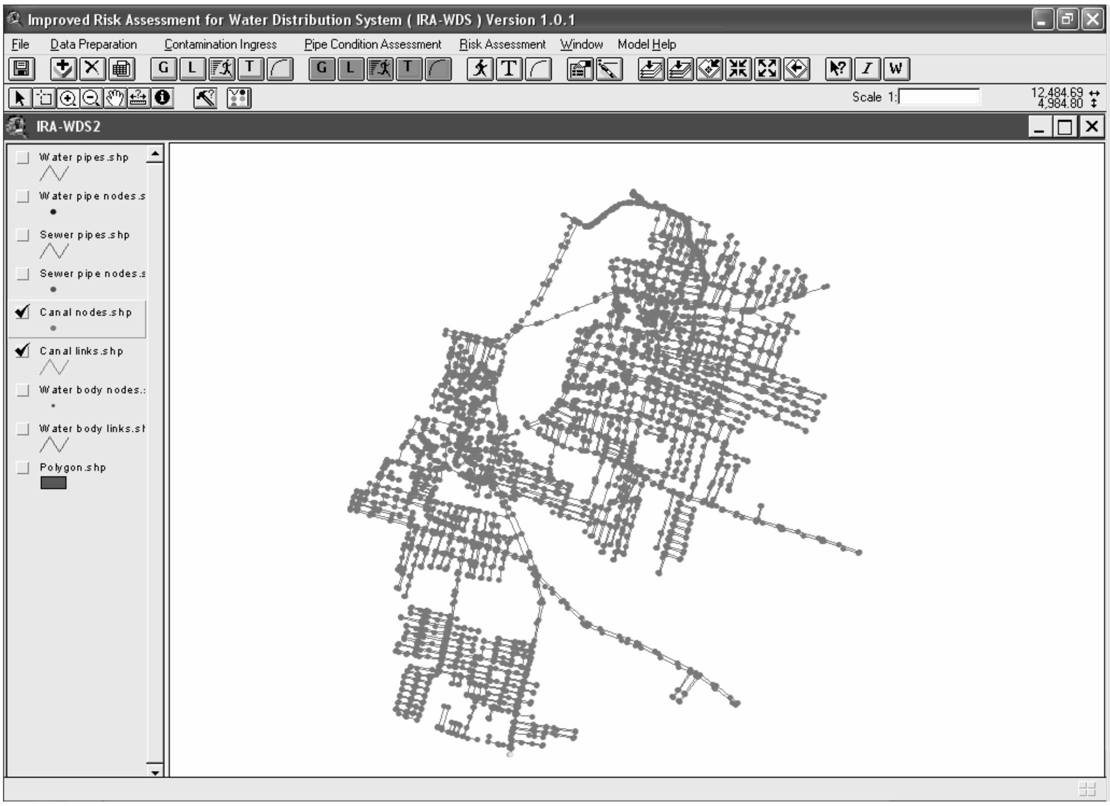

Figure 6.11. Canal/open drain network model for zone VIII of Guntur

Table 6.8. Attributes included in the link shape files for canal/open drain system			
No.	**Attribute**	**Data Type**	**Description**
1	Drainage canal ID	Integer	Unique ID for each link
2	Start point ID	Integer	Node ID at starting point of link
3	Endpoint ID	Integer	Node ID at ending point of link
4	Type of cross-section	Char	Circular, rectangular, triangular, trapezoidal, etc.
5	Cross-section	Float	Width, depth, angle, etc.
6	Length of canals	Float	In metres
7	Slope	Float	
8	Bed protection	Boolean	1=bed lining; 0=unlining
9	Soil condition	Integer	0=non-aggressive; 1= slightly aggressive; 2=moderately aggressive; 3=highly aggressive; 4=very highly aggressive

Table 6.9. Attributes included in the node shape files for canal/open drain system			
No.	**Attribute**	**Data Type**	**Description**
1	Canal node ID	Integer	Unique ID for each node
2	Canal node coordinate (x)	Float	In metres
3	Canal node coordinate (y)	Float	In metres
4	Canal node coordinate (z)	Float	In metres
5	Water depth	Float	In metres

Surface foul water bodies network

Surface foul water bodies are represented as polygon networks. Figure 6.12 shows the foul water bodies network model for zone VIII (study area). Tables 6.10 and 6.11 show the link and nodal shape-files for the foul water body networks from the data collected, for use in the contaminant ingress model.

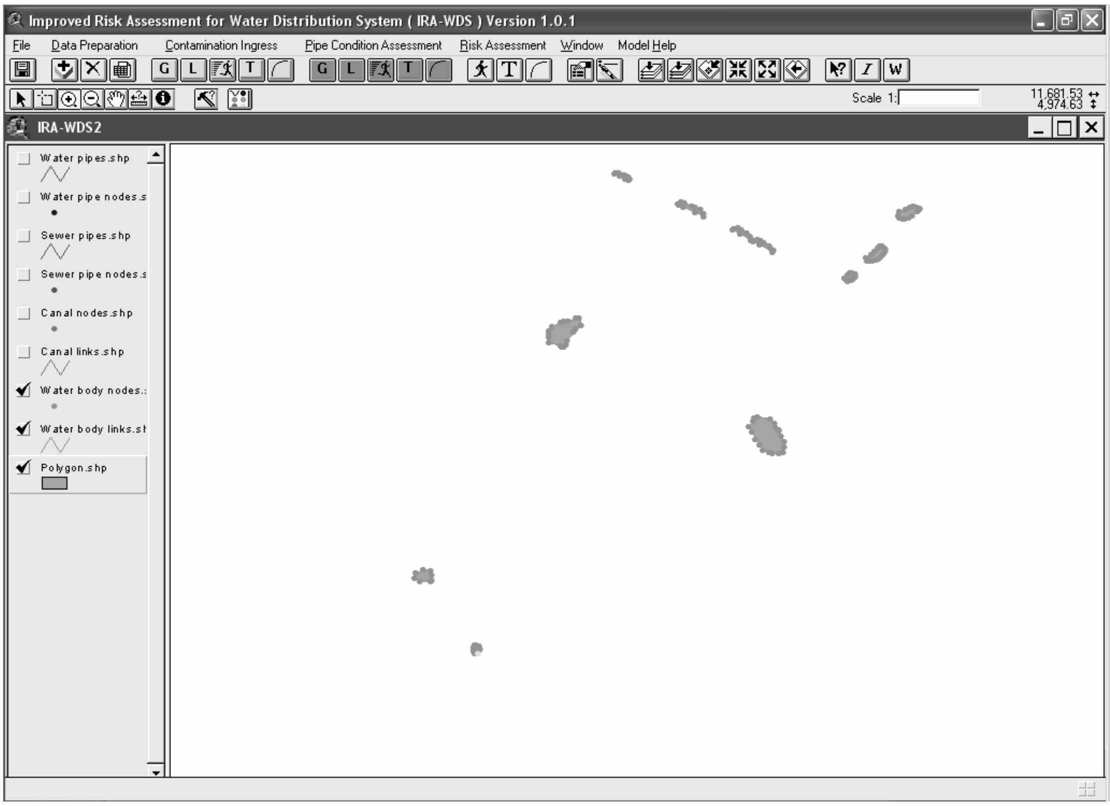

Figure 6.12. Surface foul water bodies network model for zone VIII of Guntur

Table 6.10. Attributes included in the link shape-files for surface foul water bodies			
No.	**Attribute**	**Data Type**	**Description**
1	link ID	Integer	Unique ID for each link
2	Start node ID	Integer	Node ID at starting point of link
3	End node ID	Integer	Node ID at ending point of link
4	Water depth	Float	In metres
5	Slope of water body bed	Float	Distance/elevation

Table 6.11. Attributes included in the node shape files for foul water bodies.			
No.	**Attribute**	**Data Type**	**Description**
1	Node ID	Integer	Unique ID for each node
2	Node coordinate (x)	Float	In metres
3	Node coordinate (y)	Float	In metres
4	Node coordinate (z)	Float	In metres

6.5 Model Application

Using the data collected, the maps, database and shape-files generated, the contaminant ingress, pipe condition assessment and risk assessment models were run using IRA-WDS. Details on how to execute these models through IRA-WDS are given in Chapters 4, 5 and 6 of Book 4. Below is a brief summary of the outputs obtained.

6.5.1 Contaminant ingress model

Figures 6.13 and 6.14 and Table 6.12 show the results obtained from the contaminant ingress model for the study area. The SPCZ shown in Figure 6.13 indicates that some water distribution pipes are within the contaminant zone of the pollution sources (sewers, canal/open drains and foul water bodies). A hazard map that is derived from SPCZ and contaminant concentration at upstream and downstream of SPCZ is given in Figure 6.14. Thus these outputs give an indication of the sections of water pipes that are in danger of being contaminated and highlights the risk areas within water distribution system due to pollution sources.

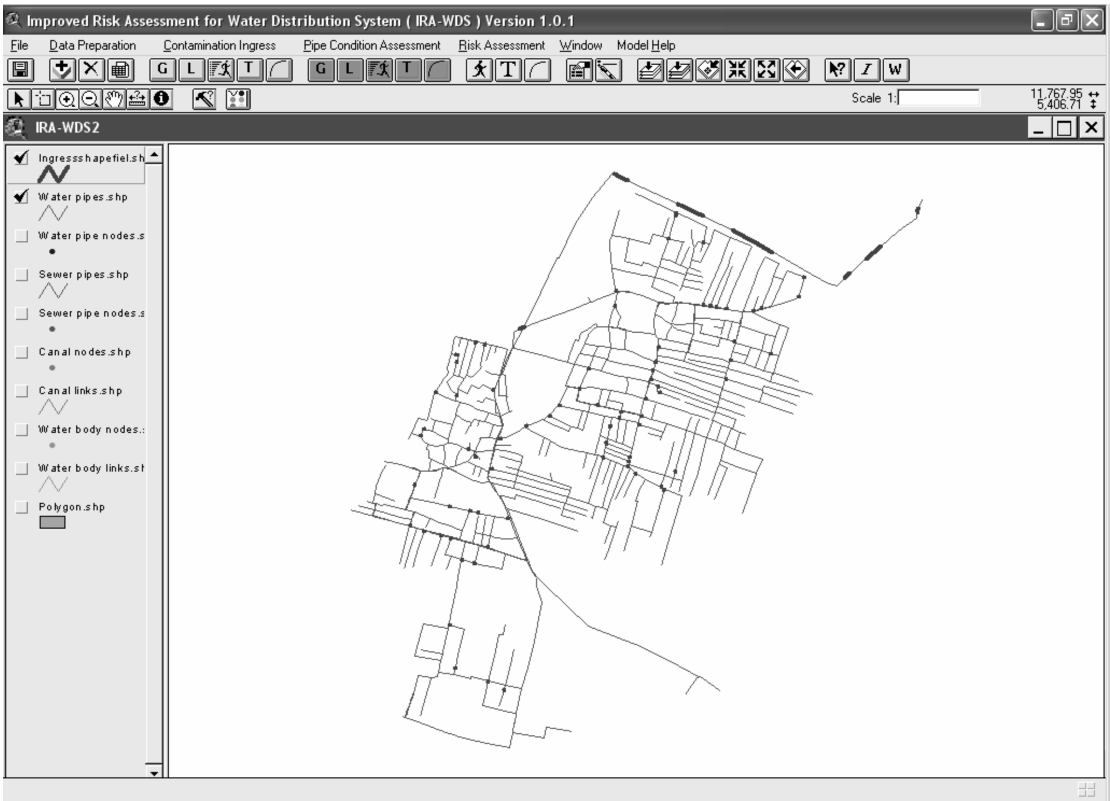

Figure 6.13. SPCZ map for Guntur (Zone VIII)

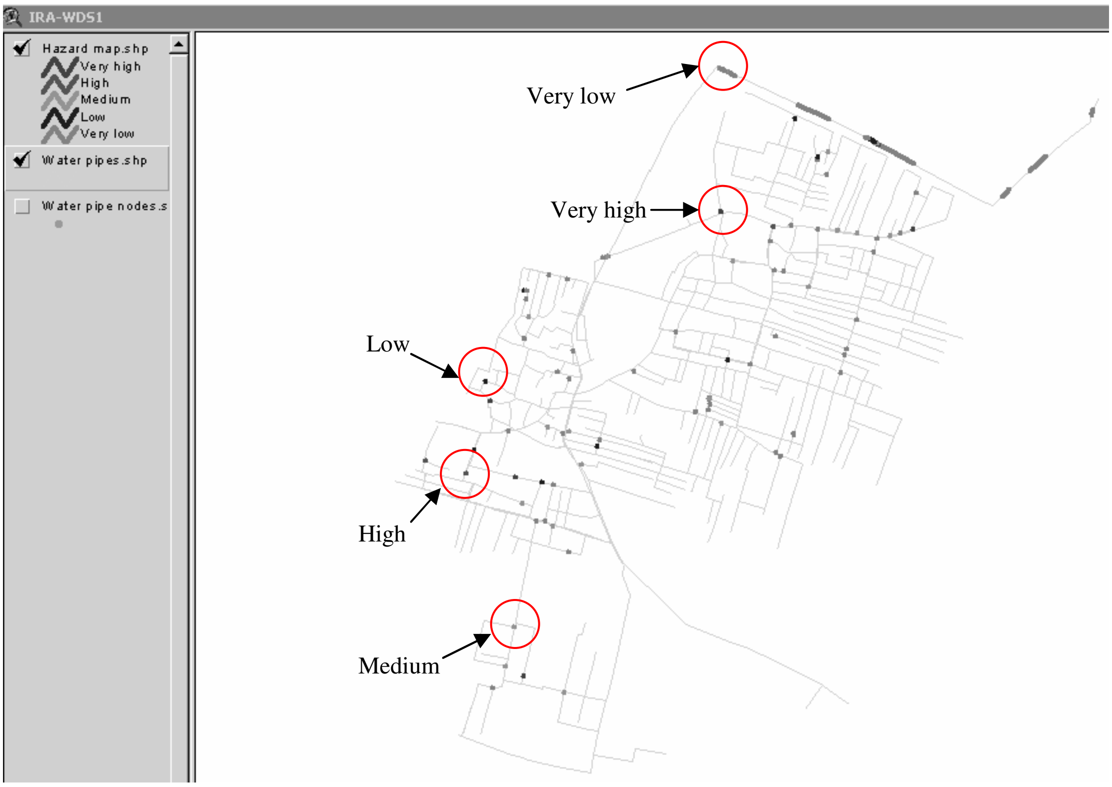

Figure 6.14. Hazard map for Guntur (Zone VIII)

Table 6.12. Results obtained from the contaminant ingress model for Guntur (Zone VIII)

Pipe ID	Start pollution point			End pollution point			Start C/C_o	End C/C_o	Pollution sources
	X	Y	Z	X	Y	Z			
305	12717.77	4545.922	24.50268	12717.58	4545.966	24.50225	0.028168	0.002896	Sewer 228
305	12743.89	4540.023	24.56024	12738.08	4541.334	24.54745	0.028168	0.128344	Sewer 809
303	12743.95	4506.873	24.47796	12745.82	4513.557	24.49958	0.009858	1	Sewer 811
313	12949.24	4146.949	21.21824	12951.1	4147.349	21.2079	1.14E-06	1.3E-07	Canal 1
823	12936.75	4117.176	21.42281	12937.86	4117.172	21.44787	3.4E-07	1	Canal 4
395	12932.87	4093.07	21.11469	12931.81	4093.229	21.10199	0.00014	8.75E-05	Canal 6
397	12908.37	4001.869	21.14883	12909.64	4001.574	21.14137	1.25E-05	9E-08	Canal 10
403	12901.88	3967.267	20.97322	12902.84	3967.049	20.96998	0.000172	1.31E-06	Canal 11
412	12957.66	3874.648	20.43584	12958.37	3874.517	20.43235	3.36E-05	0.000127	Canal 15
288	12815.99	4401.565	23.00558	12815.83	4401.658	23.0077	0	1.1E-07	Canal 33
285	12742.89	4351.888	22.5018	12742.95	4352.129	22.50285	3E-08	4E-08	Canal 36
300	12755.67	4440.881	24.194	12755.81	4441.425	24.194	5.82E-05	0.000104	Canal 37
202	12846.43	4221.799	21.85554	12846.31	4221.378	21.86952	2E-08	0.000126	Canal 44
229	12833.27	4091.534	21.15412	12833.05	4090.918	21.15261	2E-07	7E-08	Canal 53
263	12684.32	4110.998	22.03195	12684.3	4111.65	22.03903	0	1.1E-07	Canal 56
271	12607.54	4119.167	23.6308	12607.71	4119.558	23.64173	0.000129	0.004953	Canal 57
240	12832.75	4062.247	21.70734	12833.12	4062.112	21.70574	2.29E-05	7.55E-06	Canal 65
272	12611.61	4000.205	22.06734	12611.5	3999.812	22.07219	4.5E-07	2.49E-06	Canal 84
159	12514.88	3839.469	21.36859	12515.22	3840.397	21.36522	0.000376	7.01E-05	Canal 95
136	12513.03	3840.152	21.00388	12513.37	3841.08	21.01054	1.4E-07	1.97E-06	Canal 95
169	12627.01	3846.049	21.09016	12625.44	3846.37	21.09291	4.15E-05	1.31E-06	Canal 99

The hazard to water distribution pipes resulting from pollution sources is classified into five groups ranging from very high to very low, as shown in Figure 6.14. The percentage of water distribution pipes falling in each group is given in Table 6.13. It is seen that over 50 per cent of water distribution pipes are under very low hazard. As few as 11.4 per cent of water distribution pipes (57 pipes) are classified as under very high to high hazards. It is necessary to investigate the vulnerability of these pipes and, if these are vulnerable to hazards, immediate actions are required for these 57 pipes to avoid potential water quality deterioration that may cause related disease outbreaks. The possible remedial actions are to replace and rehabilitate water distribution pipes (if vulnerable to hazards) and clear up and reinforce pollution sources which are responsible for hazard. Thus the hazard map aids engineers to prioritize a maintenance programme for risk mitigation in order to meet tight budget constraints.

Table 6.13. Hazard group classification

Groups	**Number of pipes**	**Percentage (%)**
Very high	34	4.10
High	23	2.75
Medium	80	9.56
Low	54	6.45
Very low	309	36.92

6.5.2 Pipe condition assessment model

6.5.2.1 Inputs for model

Water pipe indicators Among the 20 water pipe indicators for the pipe condition assessment model (shown in Sections 3.1 and 3.3 of Chapter 3), only nine indicators were used (due to availability) for the Guntur study area. These are listed in Table 6.14 and Figure 6.15.

Table 6.14. Pipe condition assessment indicators used for the study		
Indicators	**Weightings**	**Balance factors**
First level indicators		
Diameter	0.3	1
Length	0.2	1
Material	0.5	1
Joint method	0.4	1
Number of connections	0.6	1
Bury depth	0.3	1
Traffic density	0.7	1
Pipe age	0.7	1
Surface permeability	0.3	1
Second level indicators		
Pipe indicators	0.4	2
Installation indicators	0.6	2
Corrosion indicators	0.5	2
Strength indicators	0.5	2
Breakage	1.0	2
Third level indicators		
Physical indicators	0.6	3
Environmental indicators	0.4	3

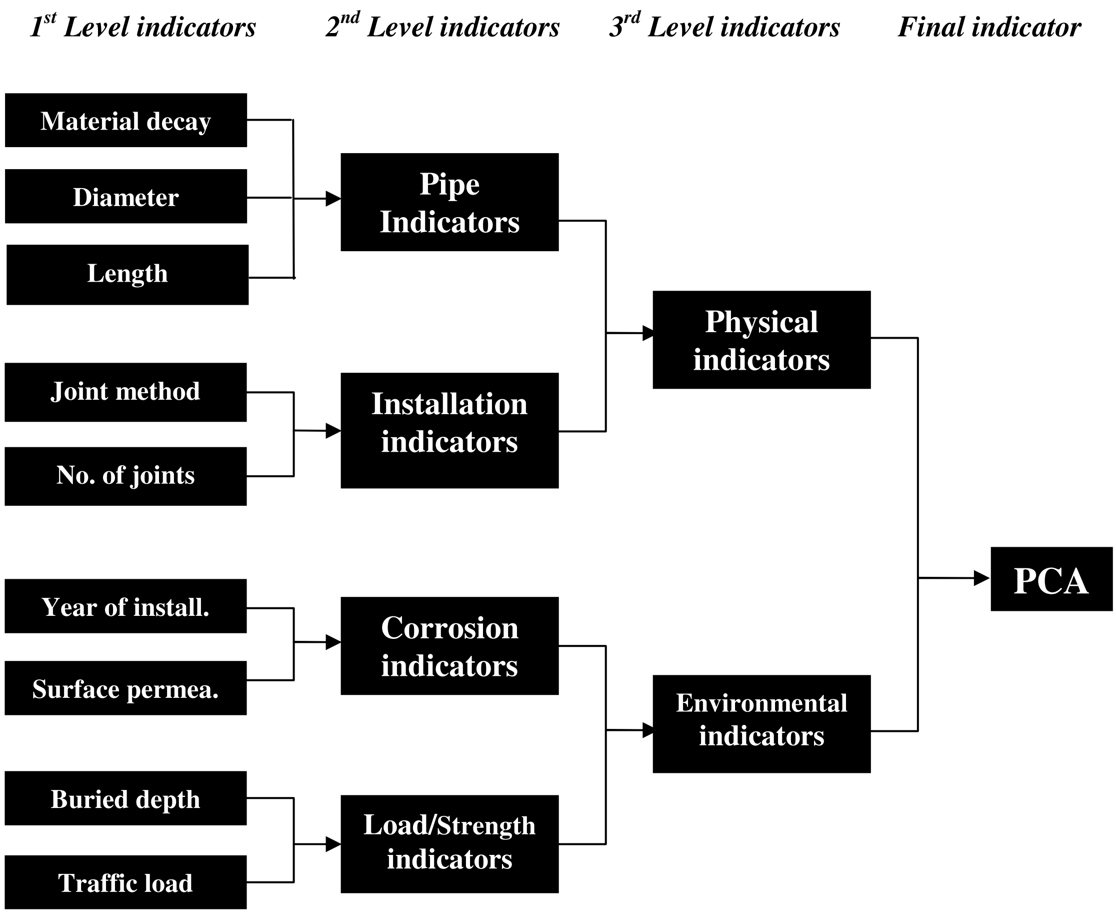

Figure 6.15. Composite structure of pipe condition assessment indicators for case study area

Weighting and balance factors

- For the case study, the weightings for pipe indicators were obtained from interviews with experienced engineers in the field. The engineers were asked to respond to the questionnaires shown in Appendix D, to give their opinion on the relative importance of each indicator. The analytical hierarchy process (AHP – see Section 3.4.4 of Chapter 3) was then used to derive the weights for each indicator in each group. The weights used for Guntur are shown in Column 2 of Table 6.14.

- For the case study, the balance factors used were established using engineering judgement. As explained in Section 3.4.3, balance factors indicate the degree of compromise among the pipe indicators in the same group. The balance factors used in the Guntur study are shown in Column 3 of Table 6.14.

Membership functions There are three fuzzy indicators used in the pipe condition assessment model for the Guntur study area, i.e. pipe material corrosion index, traffic load and surface permeability. The membership functions used are shown in Figure 6.16.

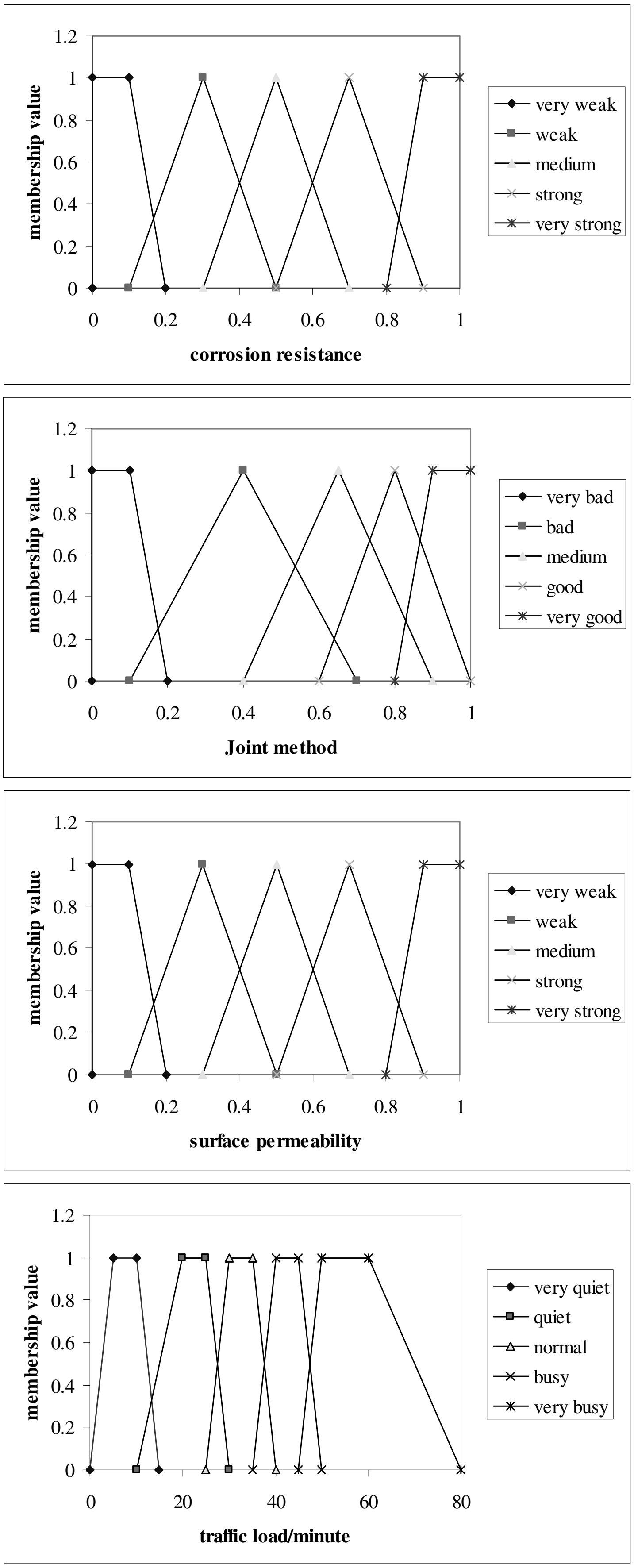

Figure 6.16. Membership functions used for the study

6.5.2.2 Model output

The output from the pipe condition assessment model gives details of the pipe condition index for each pipe and a respective pipe condition group. Typical outputs from the pipe condition assessment model are shown in Table 6.15. It can be noted from Table 6.16 that the pipe conditions for the case study area are divided into five groups described as very bad to very good (see Figure 6.17). Table 6.16 shows the number of pipes falling into each pipe condition group.

Table 6.15. Typical output from the pipe condition assessment model for Guntur (Zone VIII)

Pipe ID	Pipe condition index	Pipe condition groups
779	0.043009	1
598	0.123034	1
674	0.127655	1
791	0.157856	2
470	0.157925	2
594	0.160561	2
722	0.160912	2
683	0.161229	2
652	0.165564	2
464	0.168525	2
675	0.172551	2
593	0.173336	2
468	0.177353	2
474	0.178039	2
473	0.179092	2
649	0.179634	2
588	0.182802	2
656	0.183607	2
734	0.183849	2
785	0.184558	2
795	0.18582	2
361	0.186374	2
467	0.187123	2
650	0.188046	2

Table 6.16. Water pipe condition groups		
Pipe condition groups	**Number of pipes**	**Percentage (%)**
Very bad	2	0.24
Bad	44	5.26
Medium	394	47.07
Good	389	46.48
Very good	8	0.95

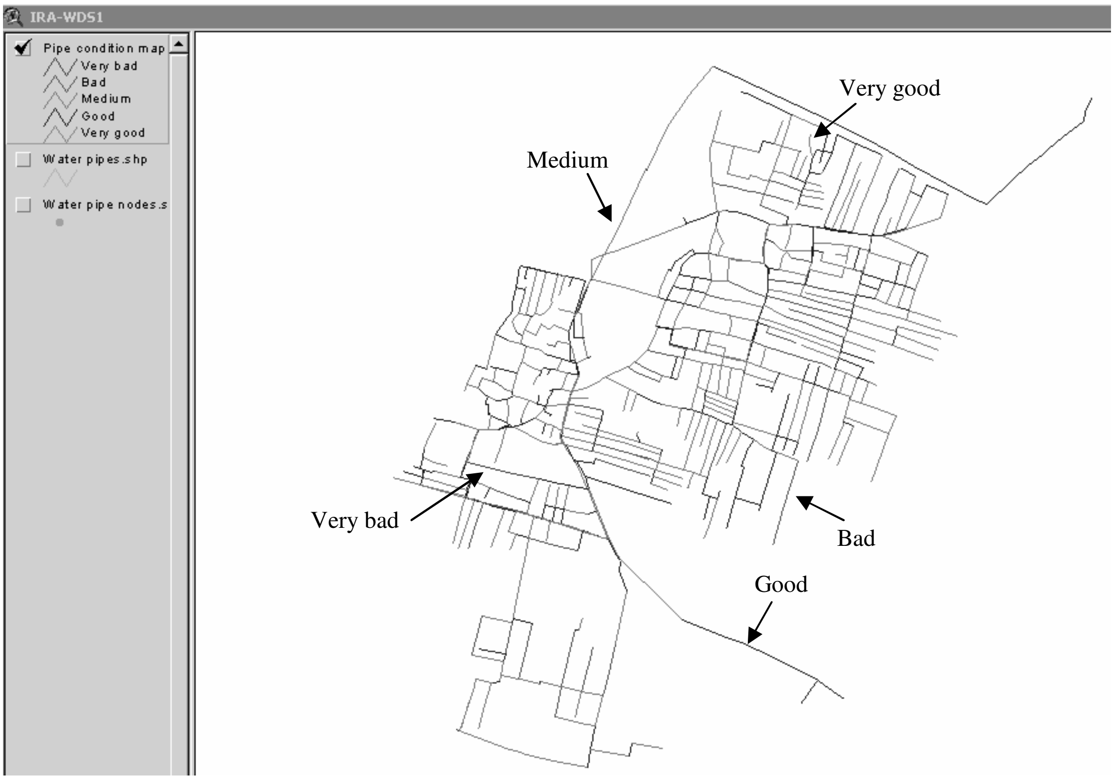

Figure 6.17. Results obtained from the pipe condition assessment model for Guntur (Zone VIII)

Table 6.16 shows that about 94 per cent of the pipes are classified as medium to very good. The percentage of pipes that are classified as bad to very bad is only 5.5 per cent. There is a negligible percentage of pipes (0.24 per cent) that are marked as very bad, indicating that there is no alarming situation for the pipe rehabilitation. On the other hand, almost half of the pipes are classified as very good to good. The results indicate that although the current situation is not bad because 50 per cent of the pipes subjected to medium risk, of these 5.26 per cent are bad and only 0.24 per cent are marked very bad indicating that the authorities need to be prepared for a rehabilitation programme.

There is often a limited budget for a water municipality to rehabilitate its water distribution system. Therefore, there is a need to prioritize the limited budget for the rehabilitation of the worst pipe. The results from this model will enable decision-makers to prioritize their investments in terms of rehabilitation. For example, the model predicts that currently two pipes are in very bad condition. These pipes need to be rehabilitated immediately; otherwise there will be a risk to health because of contaminant intrusion. Both are RCC pipes of 100 mm diameter and are over 20 years old. Due to the weak strength of RCC pipe, lining or slip lining is not appropriate. Therefore replacement of these two pipes is recommended. The results also indicate that 44 pipes are in bad condition. The municipal authority can prepare rehabilitation programme for these pipes. This may include:

- Lining 20 AC pipes: these AC pipes are less than 15 years old, but due to the traffic and soil condition, these pipes deteriorate very fast. Lining would reduce internal deterioration especially chemical attack.
- Replace 14 RCC pipes: these RCC pipes are older than 20 years with smaller diameter and weak in physical strength. Therefore replacement of these pipes is appropriate.
- Slip lining 10 CI pipes: this would improve the physical strength and hydraulic capacity of these pipes.

6.5.3 Risk assessment model

6.5.3.1 Model outputs

Weightings

For the case study area, the weightings for the risk factors were obtained from interviews with experienced engineers in the field. The engineers were asked to respond to the questionnaires shown in Appendix E, to give their opinion on the relative pipe condition in relation to contamination. Table 6.17 shows the risk factors obtained.

Table 6.17. Risk factors for risk assessment

Risk factors	Weightings
Section of pipe in contaminant zone and contaminant concentration (hazard)	0.4
Pipe condition (vulnerability)	0.6

6.5.3.2 Model outputs

The output from applying the risk assessment model to the case study are shown in Figure 6.18 and Table 6.18. The risk of contaminant intrusion for the case study area is divided into five groups, i.e. very high, high medium, low and very low (as shown in the risk map of Figure 6.18). Table 6.19 shows the number of pipes falling into each risk group and it is observed that a majority of water pipes (52.2 per cent) are in medium to low risk areas. However, 7.6 per cent of water pipes are in high risk areas and need action to mitigate against the risk of intrusion of contaminated water.

The risk is an interaction between the hazard of pollution sources and the vulnerability of water distribution system. Table 6.20 selects a few pipes from the risk map given in Figure 6.18 to show the derivation of risk from hazard and vulnerability. From the contaminant ingress model, pipe no. 98 has a very high hazard ranking (grade 1) due to its proximity to canal no. 248 and results in a high contaminant concentration. From the pipe condition assessment model, the pipe no. 98 is also assigned a high vulnerability (grade 2) as it is a small diameter AC pipe with a number of service connections and joints. In addition, it is located under a busy road which increases its traffic loadings. The combination of the very high hazard and the high vulnerability of pipe no. 98 gives a high risk for contaminant intrusion. In a similar way, other pipes are assigned risk grades based on the hazard and vulnerability derived from contaminant ingress model and pipe condition assessment model respectively.

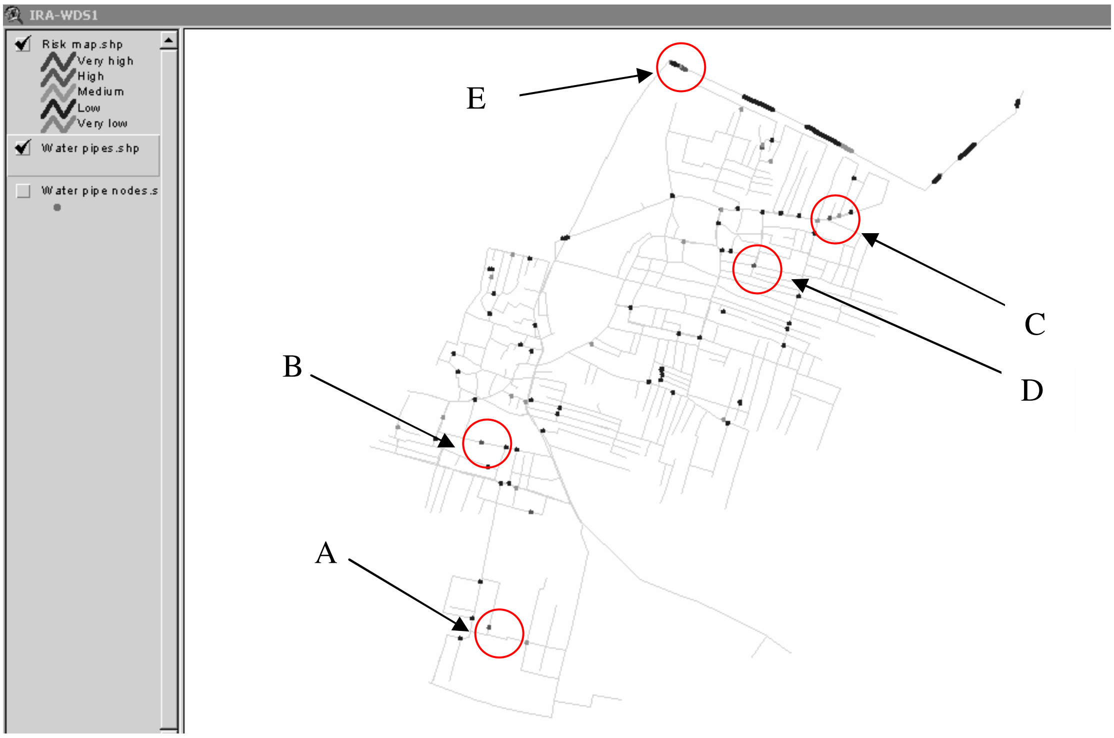

Figure 6.18. Results obtained from the risk assessment model for Guntur (Zone VIII)

Table 6.18. Typical output from the risk assessment model for Guntur (Zone VIII)		
Pipe ID	**Risk Index**	**Risk groups**
779	0.483939	3
674	0.526132	3
791	0.541186	3
594	0.542534	3
683	0.542867	3
675	0.548511	3
686	0.602601	4
466	0.603477	4
604	0.603488	4
544	0.604466	4
740	0.604844	4
360	0.60511	4
357	0.606963	4
440	0.60763	4
525	0.607685	4
601	0.608237	4
602	0.608401	4
820	0.608807	4
673	0.609064	4
682	0.609359	4
592	0.611511	4
493	0.611668	4
796	0.611992	4
769	0.612234	4
732	0.612291	4
766	0.612311	4
487	0.612323	4
669	0.612385	4
358	0.612472	4
451	0.612513	4
449	0.612549	4

Table 6.19. Risk assessment groups		
Risk group	**Number of pipes**	**Percentage (%)**
Very high	2	0.23
High	62	7.40
Medium	82	9.80
Low	347	41.50
Very low	7	0.84

Table 6.20. A comparison among risk, hazard and vulnerability			
Pipe ID	**Hazard**	**Vulnerability**	**Risk**
98	1	2	1
576	3	1	2
395	4	2	3
508	5	4	4
765	5	4	5

The main factors that contribute to the 7.6 per cent of pipes subjected to high and very high risk are the open drains in the study areas and pipes with many joints and connections (high hazard with high vulnerability). Also, high risk is observed in areas where there are surface foul water bodies coupled with poor condition pipes (high hazard with medium vulnerability). From the risk map in Figure 6.18, several recommendations can be made to reduce the risk of contaminant intrusion. These include:

- Replace/rehabilitate one AC pipe which is found to be in bad condition and has very high susceptibility to contaminant intrusion (e.g. risk area A).
- Undertake a leakage detection and repair programme in areas that have pipes with many joints and connections (e.g. risk area B);
- Inspect open drains and reline where necessary (e.g. risk area C);
- Provide protection to water pipes in areas where they are close to the open drains (risk areas D);
- De-water and fill foul water bodies in the north-east (e.g. risk area E).

6.6 Concluding Remarks

One of the major benefits of using the developed methodology in the form of IRA-WDS is that it is possible for the decision-makers to gauge the impacts of the above recommendations on the risk index. This can be achieved by simply modifying the database appropriately and re-running the model.

It should be noted that the outputs from this model can than be coupled with a water network quality model (EPANET (Rossman 1994)) to show the movement of contamination within the distribution system. This will enable the decision-makers to identify areas and consumers most at risk to contaminated water. This can be achieved by first adding dummy input pollutant nodes to areas where the risk assessment model shows a high risk of contamination. Then by adding pollutant loads at these nodes it is possible to simulate their propagation in the network to identify areas and consumers most at risk. An example of such an application to the case study area is shown in Appendix F.