GIS Mapping of the Observed Trend in Kolkata's Air Quality with Special Emphasis on Airborne Bacterial Load and their Resistance to Common Antibiotics

A Thesis Submitted

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RECOMMENDATION CERTIFICATE

It is hereby certified that this thesis title "**GIS Mapping of the Observed Trend in Kolkata's Air Quality with Special Emphasis on Airborne Bacterial Load and their Resistance to Common Antibiotics**" is prepared and submitted for the partial fulfilment of the continuous assessment of Master of Technology in Environmental Biotechnology course of Jadavpur University by Moumita saha, a student of said course for session 2017-2019 under the joint supervision and guidance of Dr. Subarna Bhattacharya, Assistant Professor, School of Environmental Studies, Jadavpur University and Dr. Biswajit Thakur, Assistant Professor, Department of Civil Engineering, Meghnad Saha Institute of Technology.

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CERTIFICATE OF APPROVAL*

This is certify that this thesis is hereby approved as an original work conducted and presented in a manner satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is implied that by this approval the undersigned do not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn therein, but approve the thesis only for the purpose for which it is submitted.

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<u>Declaration</u>

This **Thesis** titled "**GIS Mapping of the Observed Trend in Kolkata's Air Quality with Special Emphasis on Airborne Bacterial Load and their Resistance to Common Antibiotics"** is prepared and submitted for the partial fulfilment of the continuous assessment of **Master of Technology in Environmental Biotechnology** course of Jadavpur University for the session 2017-2019. It is declared that no part of thesis of the said work has been presented or published elsewhere.

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EXECUTIVE SUMMARY

Throughout the world, air pollution is a major concern in every level. The worldwide epidemiological study on the effect of air pollution had expressed that gaseous pollutants and particulate matter had enough potential to cause several health effect like respiratory, cardiovascular diseases and cardiopulmonary mortality. Also air pollution level of cities is led to increases due to rapid urbanisation and industrialisation. The population growth of mega cities, number of motor vehicles, and use of motor fuels with poor environmental performance, poor land use pattern increases and finally air pollution level is increases. The United Nation Environment Programme has estimated that the globally 1.1 billion people breathe in unhealthy air. As per the World Health Organisation (WHO) in every year urban air pollution is responsible for approximately 800,000 deaths and 4.6 million people lose their lives. In developing countries air pollution is associated with increased risk of acute respiratory infections (ARI) which is principle cause of infant and child mortality. GIS is used as a platform for spatio-temporal analysis between GIS database and standalone modelling tools. Air data generally very complex to model due to correlation between several parameters. The significant differences between the results reveals that the proper air quality management requires sensitive air quality evaluation. New mapping approaches supported by a geographic information system (GIS), combined with spatial data analysis and mathematical modelling that can be integrated into the standard user interface. Many environmental data analyses have been coupled with GIS in the past decades to simulate environmental processes. Also GIS has become an essential tool for providing boundary conditions to environmental models. However, the recent development of spatial data management harnessing a spatial database heralds a new era for integrating ecological modelling and GIS.

Chapter 1 is the introduction that includes discussion of the air pollution, their source and classification of such pollution. It also include the details of bio-aerosol and their collection procedure especially airborne bacteria.

Chapter 2 includes literature review. It represents general studies of air pollution, general studies of GIS technology, mathematical modelling of air pollution, and studies of human health effect due to air pollution. And also studies of antibiotic resistance profiling of airborne bacteria.

This thesis problem is defined and the objectives and scope of study are stated in Chapter 3. The problem title is “GIS Mapping of the Observed Trend in Kolkata’s Air Quality with Special

Emphasis on Airborne Bacterial Load and their Resistance to Common Antibiotics" and the problem objectives are:

1. To prepare the air quality maps for the city of Kolkata based on AQI calculated for different locations of the city based on the measurements carried out by West Bengal Pollution Control Board (WBPCB) over last five years (May 2014-May 2018).
2. To observe and evaluate the changing trend of air quality of Kolkata from the mentioned AQI maps for different months.
3. To evaluate the microbial load in the ambient air by sampling and measuring the airborne bacterial counts in different parts of Kolkata.
4. Preliminary identification of the sampled bacteria in the ambient air of Kolkata and measurement of zone of inhibition produced by antibiotics.
5. To evaluate the correlation between different air quality parameter and the airborne bacterial load with the meteorological parameters.

In chapter 4, the study program and methodology for analysis and for computation for air quality parameters and AQI analysis is presented. Detailed procedure for calculation are presented and flowchart are provided whenever required.

The results of the present study are presented in tabular, graphical and also contour mapping format wherever applicable in chapter 5. The necessary discussion also provided in this chapter. The current study has been carried out in limited scope and time. So future scope of study for the subject has been suggested to carry forward the current network.

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Chapter 1

Introduction

1. Introduction

Throughout the world, air pollution is a major concern in every level. The worldwide epidemiological study on the effect of air pollution had expressed that gaseous pollutants and particulate matter had enough potential to cause several health effect like respiratory, cardiovascular diseases and cardiopulmonary mortality (D.W. Dockery and P. J. koken). Now-a-day, all over the world a systematic monitoring programme especially in urban cities are urgently needed as the level of air pollution is increasing rapidly in many areas of mega cities of the developing countries (UNEP.1999). Also air pollution level of cities is led to increases due to rapid urbanisation and industrialisation. The population growth of mega cities, number of motor vehicles, use of motor fuels with poor environmental performance, poor land use pattern increases and finally air pollution level is increases (Ghosh et. al. 2004). Exposure to air pollution, especially particulate pollution (PM_{10}) (particulate matter which passes through a size selective impacter inlet with a 50% efficiency cut-off at 10μm aerodynamic diameter) is now an almost inescapable part of an urban life throughout the world. Dust from paved and unpaved roads, construction and demolition, and unclad ground sites are important contributors to PM10 (Chow and Watson, 2002). Urban air pollution problem are provoked by meteorological and topographical factors which often bulk pollutants in cities and confine proper dispersion and dilution. Ambient particulate matters also have adverse effect on environment including change in cloud formation, scattering solar radiation and visibility impairment (Karar and Gupta, 2005). Toxicological studies show that the health effect of particles are fully dependent on their chemical composition (Mugica et. al., 2002).

Air pollution is a major threat to human health. The United Nation Environment Programme has estimated that the globally 1.1 billion people breathe in unhealthy air (UNEP, 2002). A per the World Health Organisation (WHO) in every year urban air pollution is responsible for approximately 800,000 deaths and 4.6 million people lose their lives. In developing countries air pollution is associated with increased risk of acute respiratory infections (ARI) which is principle cause of infant and child mortality (Bendahmane, 1997). Studies exhibit that the presence of ultrafine particles due to automobile traffic and exposure to it in the urban atmosphere can have negative health impacts that can further be taken as the basis for epidemiologic study (Albuquerque, 2012). Various research work had been done on the spatial and temporal variation of urban air pollution in various cities like Kolkata, Delhi, Lucknow, Haryana, Chennai, Mumbai (Gupta and Karar, 2008).

GIS is used as a platform for spatio-temporal analysis between GIS database and standalone modelling tools. Air data generally very complex to model due to correlation between several parameters. The significant differences between the results reveals that the proper air quality management requires sensitive air quality evaluation (S.J. Song, 2008). Urban environmental management addresses problems are distributed spatially as well as dynamically. Two basic method addressing these dimensions are databases and Geographical information System (GIS) and on other hand Dynamic Simulation Models. Suitable monitoring systems are urgently needed to minimize the damage caused by atmospheric pollution which can rapidly and reliably detect and quantify the sources of pollution for monitoring by regulating bodies in order to minimize the further deterioration of the current pollution levels. New mapping approaches supported by a geographic information system (GIS), combined with spatial data analysis and mathematical modelling that can be integrated into the standard user interface. Many environmental data analyses have been coupled with GIS in the past decades to simulate environmental processes (Longley et. al., 2001). The four dimensional (3D space and time) nature of the distribution of environmental pollution, the two-dimensional concept of digital mapping in GIS should be extended to include temporal variations of three-dimensional spatial data (Goodchild et. al., 1996). Also GIS has become an essential tool for providing boundary conditions to environmental models. However, the recent development of spatial data management harnessing a spatial database heralds a new era for integrating ecological modelling and GIS (Fedra, 1998).

1.1 Air Pollution

According to the air (Prevention and Control of Pollution) Act, 1981' *"Air pollution is the presence of any solid, liquid or gaseous substances in the atmosphere in such concentration as may be or tend to be injurious to human beings or other living creatures or plants or property or environment."*

1.2 Sources of air pollution

Air pollution can be either natural or may be the results of various activities of man like industrial operations. The industrial contaminant can be either by-products of external combustion like smoke, dust or sulphur di-oxide and by-products of internal combustion like the reactions in petrol and diesel engines. The emission can be either primary pollutants or secondary pollutants. The various sources of pollutants can also be broadly grouped under either stationary sources or mobile sources. All these are explained in details in below:

Table 1.1: Air contaminants

No.	Group	Examples
1	Natural contaminant	Natural fog, pollen grains, bacteria and products of volcanic eruptions.
2.	Aerosols (Particulates)	Dust, smog, mist, fog and fumes.
3.	Gases and vapours	Sulphur compounds (SO_2, NO_2, H_2S, mercaptance), nitrogen compounds (NO,NO_2, NH_3), oxygen compounds, halogen compounds (HF, HCL), organic compounds and radioactive compounds (radioactive gases).

In above, some of these contaminants undergo chemical reactions when they enters in atmosphere. And resulting in the end product formed are more dangerous than the original contaminant. For example, in the presence of sunlight hydrocarbons react with nitrogen dioxide to form smog.

1.3 Classification of air pollutants

Air pollution can also be broadly classified into two general groups like primary air pollutants and secondary air pollutants.

1.3.1 Primary air pollutants

Primary air pollutants are those substances which are emitted directly into atmosphere from combustion of fuel and several industrial operations. The main primary pollutants are harmful in high enough concentrations.

Examples of primary pollutants are:

1. Finer particles (less than 100µ in diameters)
2. Coarse particles (greater than 100µ in diameter)
3. Sulphur compounds
4. Oxides of nitrogen
5. Carbon monoxide
6. Halogen compounds
7. Organic compounds

8. Radioactive compounds

Finer aerosols include particles of metal, carbon, tar, resin, pollen, bacteria etc.

1.3.2 Secondary air pollutants

Secondary air pollutants are those which are produced in the air by the interaction among two or more primary pollutants, or by reaction with normal atmospheric constituents, with or without photo activation.

Examples of secondary pollutants are:

1. Ozone
2. Formaldehyde
3. PAN (Peroxy Acetyl Nitrate)
4. Photochemical smog
5. Formation of acid mists (H_2SO_4) due to reaction of sulphur dioxide and dissolved oxygen, when water droplets are present in the atmosphere (Rao & Rao et. al., 2007).

Table 1.2 National ambient air quality standards, India

NATIONAL AMBIENT AIR QUALITY STANDARDS (2009)

Pollutants (µg/m³)	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area (Notified by GOI)
Sulphur Dioxide (SO_2)	Annual * 24 Hours **	50 80	20 80
Nitrogen Dioxide (NO_2)	Annual * 24 Hours **	40 80	30 80
Particulate Matter, Size less than 10 µm (PM_{10})	Annual * 24 Hours **	60 100	60 100
Particulate Matter, Size less than 2.5µm ($PM_{2.5}$)	Annual * 24 Hours **	40 60	40 60
Ozone (O_3)	8 Hours * 1 Hour **	100 180	100 180

Source: Central pollution Control Board (CPCB), 2009

*Annual Arithmetic mean of minimum 104 measurements in a year taken twice a Week 24 hourly at uniform Interval.
** 24 hourly/8 hourly or 1 hourly monitored values as applicable shall be complied with 98 % of the time in a Year. However, 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

1.4 Air pollution criteria

Air pollution criteria is used internationally as an air pollutants which have been regulated as an air quality indicators. The regulation or criteria are totally depends on the health and environmental effects. Generally air pollution criteria are widely distributed across the country (Australian Government, 2015).

1.5 Particles as air pollutants

Air quality parameters fall into two broad categories mainly particulate matter, which may be liquid or solid and gaseous matter. Federal criteria documents identify particulates as any scattered matter, solid or liquid, in which the individual aggregates are larger than a single small molecules (about 0.002 μm in diameter) but smaller than about 500μm. Particulates may be classified and discussed according to their physical, chemical, or biological characteristics. Physical characteristics include size, mode of formation, setting properties and optical qualities. Chemical characteristic include organic or inorganic composition and biological characteristic relate to their classification as bacteria, viruses, spores, pollens etc.

1.5.1 Physical characteristics

- **Size:** The most important physical properties of a particulate is size. Particulate larger than 50μm can be seen with an unaided eye but smaller than 0.005μm may be observed through an electronic microscope. Particles smaller than 1 μm do not tend to settle out rapidly. Metallurgical fumes, cement dust, fly ash, carbon black and sulphuric acid mist all fall into the 0.01 to 100 μm range.
- **Mode of formation:** Particles are classified based on their mode of formation as dust, smoke, fumes, fly ash, mists, or spray. The first four are in solid form while the lasts ones are in liquid form. Dust, small, solid particles are formed by the break of larger masses through crushing, grinding, blasting process or may come from coal, cement or grains. They settles under influence of gravity.
- **Settling properties:** Settling characteristics are one of the most important properties of particulates, though settling is the major natural self-cleansing process for removal of particulates from the atmosphere. Particulates can generally be classified as suspended or settleable. Suspended particulates size vary in from less than 1 μm to approximately 20 μm. They remain suspended in the atmosphere for long periods of time. Settleable

particles are larger and heavier and settle out close to their sources. They are generally greater than 10 µm in size.

- **Optical qualities:** Reduction in visibility in one of the most obvious effects of air pollution and the scattering of light by particulate matter is responsible for that reduction. Particles in the range of visible light (0.38 to 0.76 µm) are the most effective in visibility reduction (Peavy et. al., 1985).

1.5.2 Chemical characteristics of air particulates

There is a great variation in the chemical composition of the particulates found in the atmosphere. Atmosphere particulates contain both organic and inorganic components (Peavy et. al., 1985). The major components are listed as follows:

- **Sulphates:** Sulphates are derived from sulphur dioxide oxidation in the atmosphere because of sulphur dioxide is oxidised slowly.
- **Nitrates:** Nitrates are formed mainly from oxidation of nitrogen oxides like NO and NO_2 to nitrate. NO_2 oxidizes much more rapidly than SO_2.
- **Ammonium salts:** They are formed when atmospheric ammonia undergoes neutralization reactions with sulphuric and nitric acids.
- **Chlorides:** The main sources are sea spray and de-icing salt during winter and also from ammonia neutralization of HCl gas from incineration and power stations. Harrison et. al., 1997).

1.5.3 Biological Characteristics of Airborne Particulates

The biological particles in the atmosphere consist of protozoa, bacteria, viruses, fungi, spores, pollens, and algae. Micro-organisms generally survive for a short time in the atmosphere as they lack nutrients and ultraviolet rays from the sun. Since, certain bacteria and fungi form spores that can survive for long periods, any spores and pollens are adapted for aerial dispersion and are found at elevations above 300m (1000 ft). Especially the blue-green algae have been found at altitudes up to 2000m (6600 ft) (Peavy et. al., 1985).

1.5.4 Classification of Particulates According to Size

It is convenient to classify particles by their aerodynamic properties because of three reasons viz.:

a) These properties govern the transport and removal of particles from the air.
b) They also govern their deposition within the respiratory system.
c) They are associated with the chemical composition and sources of particles.

Particles are sampled and described on the basis of their aerodynamic diameter, usually called simply the particle size.

- **Coarse Particulate Matter (PM_{10})** is less than 10 micrometres in diameter. Its sources are mainly agriculture dust, road dust, river beds, construction sites, mining operations, and other similar activities etc. Most people in Alaska experience PM_{10} as dust.
- **Coarse Particulate Matter ($PM_{2.5}$)** is less than 2.5 micrometres in diameter. $PM_{2.5}$ is a product of combustion, mainly caused by burning fuels. Examples of $PM_{2.5}$ sources include power plants, vehicles, wood burning stoves, and wild land fires etc. State of Alaska (2015).

1.5.5 Bio aerosol

A bio-aerosol is a mixture of airborne particles that contain living organisms or were released from living organisms. These particles are very small and range in size from less than 1 µm to 100 µm. Bio-aerosols react to air currents and move quickly or slowly depending on the environment. Bio-aerosols are impacted by gravity but due to their size, air density and air currents play a large role in their movement. The intact cellular component has been given the name, Primary Biological Aerosol (PBA), which consists of virus particles, bacteria, fungal spores and plant pollen. Primary Biological Aerosol (PBA) can range in size from 10 nm (small virus particles) to 100 µm. The atmospheric lifetime of PBA particles range from a near indefinite time frame for some of the smallest virus particles to a few hours for the larger pollen particles (Wathes and Cox, 1995).

1.5.5.1 Classification of bio-aerosol

Air often contains tiny organisms such as fungi, bacteria, mycotoxins, and viruses. It is currently thought that the majority of these airborne microorganisms are not in a viable state while in the atmosphere. However, current research has shown that certain groups of bacteria are capable of performing basic metabolic activity within cloud water. Groups of the small organisms clump up and enhance survival while airborne. Due to evaporation of water, bacterial cells usually die when they become airborne but under high humid conditions bio-aerosol levels are increased. Fungal cells such as spores, molds, and yeast can be active at low humidity levels and high or low temperatures.

- **Fungi:** The number of different fungal species existing on Earth is assumed to be in the range of 1–1.5 million. Some 80000 to 120000 have been described till date (Hawksworth, 2003; Levetin, 2004; Webster and Weber, 2007), but only about 40 000 are well-characterized (Rossman, 1994). Species in the biological kingdom of Fungi

(Eumycota) can be grouped into the four divisions (phyla) Ascomycota (AM), Basidiomycota (BM), Chytridiomycota (CM), and Zygomycota (ZM) (Webster andWeber, 2007). Most of the fungal species found in the biosphere and atmosphere belong to AM and BM (Gregory and Sreeramulu, 1958; Chatterjee and Hargreave,1974; Calderon et al., 1995; Decco et al., 1998; Newsonet al., 2000; Kendrick, 2001;Troutt and Levetin, 2001;Helbling et al., 2002; Boreson et al., 2004; Hasnain et al., 2004; Fang et al., 2005; Hasnain et al., 2005; Zoppas et al.,2006; Butinar et al., 2007). CM and ZM are less frequently detected in the atmosphere. Fungi are able to survive harsh environmental conditions, and viable forms have been found in deserts, hot biomass burning plumes, hailstones, sub glacial ice of Arctic glaciers, glacial melt water, soils of snow-capped tundra, and deep sea sediments (Novozhilova and Popova, 1969; Mandrioli et al., 1973; Ma et al., 2000; Schadt et al., 2003; Boreson et al.,2004; Hasnain et al., 2004; Mims and Mims, 2004; Butinaret al., 2007; de Garcia et al., 2007). Fungi can be pleomorphic, i.e. they can exist in two or more forms (morphs). Many well-known species of AM and BM occur in two morphs: a sexually reproducing form called the teleomorph (perfect state) and an asexually reproducing form termed the anamorph (imperfect state) (Elbert et. al., 2007).

- **Bacteria:** Bacteria are abundant in the atmosphere, where they often represent a major portion of the organic aerosols. Potential pathogens of plants and livestock are commonly dispersed through the atmosphere. Airborne bacteria can have important effects on human health as pathogens trigger the allergic asthma and seasonal allergies. Despite their importance, the diversity and biogeography of airborne microorganisms remain poorly understood. Scientists have long known that bacteria are ubiquitous in the atmosphere. Bacterial concentrations typically range from 104 to 106 cells m_{-3} (28). Airborne bacteria can have important effects on human health and the productivity of managed and natural ecosystems. For example bacteria can cause allergic asthma and seasonal allergies (Brodie et. al., 2007).
- **Viruses:** A virus is a small infectious agent that replicates only inside the living cells of other organisms. Viruses can infect all types of life forms, from animals and plants to microorganisms, including bacteria and archaea. Dmitri Ivanovsky's 1892 article described a non-bacterial pathogen infecting tobacco plants, and the discovery of the tobacco mosaic virus by Martinus Beijerinck in 1898 for the first time, Since then about 5,000 viruses have been described in detail. Although there are millions of different

types of viruses found in almost every ecosystem on Earth and they are the most abundant type of biological entity (Koonin et. al., 2006).

1.5.5.2 Collection technique of bio-aerosol

Many techniques are used to collect bio-aerosols such as collection plates, electrostatic collectors, and impactors, although some methods are experimental in nature. Another way to collect or detect bio-aerosols is by using a mass spectrometer.

- **Single stage impactors:** To collect aerosols falling within a specific size range, impactors can be designed for a variety of size cuts, depositing material onto slides, agar plates, or tape. The spore trap samples at 10 LPM, has a wind vane to always sample in the direction of wind flow. Collected particles are impacted onto a vertical glass slide greased with petroleum. Variations such as the 7-day recording volumetric spore trap (Burkard Air Sampling CO.) have been designed for continuous sampling using a slowly rotating drum that deposits impacted material onto a coated plastic tape. The airborne bacteria sampler (ABS) can sample at rates up to 700 LPM, allowing for large samples to be collected in a short sampling time. Biological material is impacted and deposited onto an agar lined Petri dish, allowing cultures to develop.
- **Cascade impactors:** Similar to single-stage impactors in collection methods, cascade impactors have multiple size cuts, allowing size resolution of sampled bio-aerosols. Separating biological material by aerodynamic diameter is useful due to size ranges being dominated by specific types of organisms (bacteria exist range from 1 µm to 20 µm, and pollen from 10 um to 100 um). The Andersen line of cascade impactors (Thermo Electron Corporation) are most widely used, available in two and size-stage versions.
- **Impingers:** Instead of collecting onto a greased substrate or agar plate, impingers have been developed to impact bio-aerosols into a liquid, such as deionized water or phosphate buffer solution (PBS). Collection efficiencies of impingers are shown to be generally higher than similar single stage impacter designs. Commercially available impingers include the AGI-30 (Ace Glass Inc.) and Bio sampler (SKC, Inc).

1.6 Mapping of air quality index using GIS tool

Mapping the air quality parameters using the Decision Support system like GIS can be very useful for taking quick decisions as a graphical representation would be easy to facilitate policy makers in taking a decision. A spatial Decision Support System (SDSS) is a computer based system designed to assist the decision system. This type of system will include spatial data relevant to the decision, analytical tools to process the data to process the data for decision makers and display the functions. GIS has an advantage of handling attribute data in conjunction with spatial features which was totally impossible with manual cartographic analysis (Berktay et. al., 2010).

1.7 Air quality in Kolkata

The air quality scenario of Kolkata, the capital city of the state of West Bengal, is not very encouraging. Kolkata is the 3rd most polluted city in terms of nitrogen oxide levels and 12th most polluted city in terms of PM10 levels according to the statement given by Ministry of Environment and Forests in 2010. But Kolkata has also been a leader in generating valuable evidences on the tiniest fraction of particulates, the key pollutant of concern in Indian cities that has helped the Central Pollution Control Board to define the air quality standards for PM2.5. The West Bengal State Pollution Control Board has found that particles as small as 3.3 μm are 74 percent of the PM10. An even tinier fraction, smaller than 1.1 μm, is 57.5 percent of the total PM10. Such tiny particles that come largely from vehicles and combustion sources are very toxic and go deep inside the lungs and pose a serious public health threat. The new national air quality standard has further changed the air quality status of the locations in Kolkata. Dunlop Bridge and Behala Chowrasta that were earlier classified as moderate pollution zones for particulate pollution are now bracketed as high pollution locations. For NOX seven out of nine locations are now classified as "critically polluted". Kolkata needs urgent action to reduce the toxic risk and protect public health.

1.8 Air quality indexing

The Air Quality Indices are widely used in reporting daily air quality. It tells how clean or polluted the surrounding ambient air is, and what associated health effects might be a concern as its consequence. Generally, the higher the index value, the greater is the level of air pollution as well as the consequent health concern. Air quality indexing helps scientists, policy-makers as well as general public to understand what local air quality means to receptors health.

1.8.1 Air quality index is used in present study

In the present study, Air Quality Index (AQI) for ambient air of Kolkata is calculated based on the methodology suggested by United States Environmental Protection Agency (USEPA).

The mathematical expression (a segmented linear function) used to calculate the AQI for a particular pollutant is given in Equation (1) as shown below:

$$I_p = \frac{(I_{Hi} - I_{L0})(L_p - BP_{l0})}{(BP_{Hi} - BP_{L0})} + I_{l0} \qquad \ldots \text{ Equation 1.1}$$

Where,

I_P = the index for pollutant p

C_P = the rounded concentration of pollutant p

BP_{Hi} = the breakpoint that is greater than or equal to Cp

BP_{Lo} = the breakpoint that is less than or equal to Cp

I_{Hi} = The AQI value corresponding to BP_{Hi}

I_{Lo} = The AQI value corresponding to BP_{Lo}

1.8.2 Air quality categories

AQI Category	PM2.5 (ug/m3)	PM10 (ug/m3)	Health Impact
Good (0-50)	0-30	0-50	Minimal
Satisfactory (51-100)	31-60	51-100	Minor Breathing discomfort to sensitive people.
Moderately polluted (101-200)	61-90	101-250	Breathing discomfort to asthma patents, elderly and children.
Poor (201-300)	91-120	251-350	Breathing discomfort to all
Very poor (301-400)	121-250	351-430	Respiratory illness on prolonged exposure.
Severe (401-500)	250+	430+	Health impact even on light physical work. Serious impact on people with heart/lung disease.

Source: West Bengal Pollution Control board (WBPCB)

1.9 Sources of air pollution in Kolkata

Several factors cause air pollution in Kolkata and among them the main factor is transportation where the abundance of poorly-maintained vehicles, use of petrol fuel, and poor controlling are making transportation the major air polluting sector. Additionally, there are three thermal power plants operating in and around Kolkata, and some small-scale industries which also affects the air quality. An analysis of different sources of air pollution in Kolkata has revealed that motor vehicles are the leading contributor to air pollution (51.4%) which is followed by industry (24.5%) and dust particles (21.1%), respectively (Table 3).

Table 1.3: Sources of air pollution emissions in Kolkata

Source type RPM	**Source type RPM**	**Source type RPM**	**Source type RPM**	**Source type RPM**	**Source type RPM**	**Source type RPM**	**Source type RPM**	**Source type RPM**
Motor Vehicles	16,115	95,452	0	111,567	7.4	44.0	0	51.4
Industry	6,571	34,208	12,378	53,157	3.0	15.8	5.7	24.5
Road Dust	45,881	0	0	45,881	21.1	0	0	21.1
Area sources	6573	0	0	6573	3.0	0	0	3.0
Grand total	75,140	129,378	12,378	217,178	34.5	59.8	5.7	100.0

Source: Compiled by Researcher from WBPCB, 2005

The vehicular pollution in Kolkata is attributed to a large number of automobiles plying daily over only 6% available road space, causing congestion which reduces the average vehicular speed and also results in heavy vehicular emission. The number of vehicles has a growth of about 2.00 times, numbering to 1.20 million in 2011 from 0.73 million in 1996. The vehicular population in Kolkata has increased at an annual growth rate of 4%. Private cars have increased from 0.26 million in 2000 to 0.65 million in 2011, which indicates a 2.5 times increase. The heavy concentration of private motor vehicles has been one of the key reasons for congestion, increased travel times, pollution, and accidents. In terms of available surface road length, Kolkata has the least coverage, with about 1416 km, whereas the vehicular density is one of the highest, nearing 823/km.

Chapter 2

Literature Review

2. Current researches on air quality indexing and airborne bacteria

From various natural and anthropogenic sources variety of air pollutants are emitted in to the atmosphere of which particulate matters, sulphur of oxides and nitrogen of oxides having individual significant role and increasing impact on urban air quality, therefore represent the overall air quality in term as Air Quality Index (AQI) which is introduced by Environmental Protection Agency (EPA) in USA to measure the pollution level due to major air pollution (Sharma et.al. 2000, 2003b).

The air consists of solid and liquid particulate matters referred as aerosols. Apart from organic and inorganic constituents of aerosol, it can have also microorganisms commonly termed as bio-aerosol. The origins of bio-aerosol can be natural, biogenic or anthropogenic. Bio-aerosol includes micro-organism viz. bacteria, fungi and viruses, its biological activities or components can cause allergies, intoxications or infections to humans and animals.

This chapter provides a detailed review of existing literatures on various studies on mapping of air quality index with the aid of GIS technology, monitoring of airborne bacteria in various location of city Kolkata, identification of bacterial colonies and antibiotics susceptibility.

2.1 Studies of air pollution

Aliyev Anvar Abbas et. al., (2018) examined that the existence, life and health of people depends on the condition and quality of the atmosphere, the main sources of life on Earth. Its natural balance is disturbed mainly due to the release of anthropogenic gases (90%), dust and aerosols caused by stationary and non-stationary sources. One of the pressing problems worrying the whole world over the past decades is related to the damage posed to the environment by vehicles as the main non-stationary source at current time.

Lelieveld et. al., (2002) uncovered that air pollution layers from the surface to an altitude of 15 kilometers. In the boundary layer, air pollution standards are exceeded throughout the region, caused by West and East European pollution from the north. Aerosol particles also reduce solar radiation penetration to the surface, which can suppress precipitation. In the middle troposphere, Asian and to a lesser extent North American pollution is transported from the west. Additional Asian pollution from the east, transported from the monsoon in the upper troposphere, crosses the Mediterranean tropopause, which pollutes the lower stratosphere at middle latitudes.

Madhav G. Badami (2005) examined that the rapid growth in motor vehicle activity and other industrializing in India and other low-income countries is contributing to high levels of urban air pollution, among other adverse socioeconomic, environmental, health, and welfare impacts. In this paper first discusses the local, regional, and global impacts associated with air pollutant emissions resulting from motor vehicle activity, and the technological, behavioural and institutional factors have contributed to these emissions in India. After that this paper discusses some implementation issues related to various policy measures that have been undertaken and the challenges of the policy context. Finally the paper represents insights and lessons based on the recent Indian experience for better understanding and more effectively addressing the transport air pollution problem in India and similar countries in a way that is sensitive to their needs, capabilities, and constraints.

Guttikunda et. al., (2014) evaluate that the global burden of disease study estimated 695,000 premature deaths in 2010 due to continued exposure to outdoor particulate matter and ozone pollution for India. By 2030, the expected growth in many of the sectors (industries, residential, transportation, power generation, and construction) will result in an increase in pollution related health impacts for most cities. The available information on urban air pollution, their sources, and the potential of various interventions to control pollution, should help us propose a cleaner path to 2030. In this paper, we present an overview of the emission sources and control options for better air quality in Indian cities, with a particular focus on interventions like urban public transportation facilities; travel demand management; emission regulations for power plants; clean technology for brick kilns; management of road dust; and waste management to control open waste burning. Also included is a broader discussion on key institutional measures, like public awareness and scientific studies, necessary for building an effective air quality management plan in Indian cities.

Chowdhury et. al., (2007) examined fine particle organic carbon in Delhi, Mumbai, Kolkata, and Chandigarh is speciatedto quantify sources contributing to fine particle pollution. Gas chromatography/ mass-spectrometry of 29 particle-phase organic compounds, includingn-alkanes, polycyclicaromatic hydrocarbons (PAHs), hopanes, steranes, and levoglucosan along with quantification of silicon, aluminium, and elemental carbon are used in a molecular-markerbased source apportionment model to quantify the primary source contributions to the PM2.5mass concentrations for four seasons in three sites and for the summer in Chandigarh. Five primary sources are identified and quantified viz. diesel engine exhaust, gasoline engine exhaust, road dust, coal combustion, and biomass combustion. Important trends in the seasonal and spatial patterns of the impact of these five sources are observed. On average, primary emissions from fossil fuel combustion (coal, diesel, and gasoline) are responsible for about 25–33% of PM2.5mass in Delhi, 21–36% in Mumbai, 37–57% in Kolkata, and 28% in Chandigarh. These figures can be compared to the biomass combustion contributions to ambient PM2.5of 7–20% for Delhi, 7–20% for Mumbai, 13–18% for Kolkata, and 8% for Chandigarh. These measurements provide important information about the seasonal and spatial distribution of fine particle phase organic compounds in Indian cities as well as quantifying source contributions leading to the fine particle air pollution in those cities.

Gurjar et. al., (2016) examined more than half of the world's population lives in urban areas. It is estimated that by 2030 there will be 41 megacities and most of them will be located in developing countries. The megacities in India (Delhi, Mumbai, and Kolkata) collectively have >46 million inhabitants. Increasing population and prosperity results in rapid growth of the already large consumption of energy and other resources, which contributes to air pollution, among other problems. Megacity pollution outflow plumes contain high levels of criteria pollutants (e.g. Particulate matter, SO_2, NO_x), greenhouse gases, ozone precursors and aerosols; which can affect the atmosphere not only on a local scale but also on regional and global scales. In the current study, emissions and concentration trends of criteria and other air pollutants (polycyclic aromatic hydrocarbons, carbon monoxide and greenhouse gases) were examined in the three Indian megacities. Further, various policies and control strategies adopted by Indian Government are also discussed to improve air quality. Decreasing trends of SO_2 was observed in all three megacities due to decrease in the sulphur content in coal and diesel. However, increasing trend for NO_x was found in these megacities due to increase in number of vehicles registered and high flash point of CNG engines, which leads to higher NO_x emission. In terms of SPM and PM_{10}, highest emissions have been found at Kolkata, whereas highest ambient concentrations were recorded in Delhi. For Mumbai and Kolkata fluctuating trends of SPM concentrations were observed between 1991 and 1998 and stable afterwards till 2005; whereas for Delhi, fluctuating trend was observed for the entire study period. However, several steps have been taken to control air pollution in India but there is a need to focus on control of non-exhaust emissions including municipal solid waste and biomass burning in the megacities and surrounding areas.

2.2 Studies of GIS technology on air pollution

Chattopadhyay S. et. al., (2010) evaluate that the different gaseous pollutants viz. SO_2, NO_2 and RSPM of pre monsoon and post monsoon distribution and investigate the seasonal variation of ambient air quality of Burdwan town by using GIS technology, Digital Elevation Model (DEM) and Inverse Distance Interpolation Technique (IDINT). As a result due to gaseous pollutants shows the significant seasonal variation.

Maantay et. al., (2009) developed new procedure to loosely integrate an air dispersion model, AREMOD, and ArcGIS to encourage air dispersion from stationary sources for $PM_{2.5}$, PM_{10}, NO_x, SO_x and CO by using different technology viz. GIS, Air dispersion model, Proximity analysis and loose coupling. Provides a relatively simple and possible method for health purpose to take advantages of both method air dispersion modelling and GIS by avoiding need for intensive programming and substantial GIS approach and advantages over proximity analysis and geostatistical method for environmental health research.

Fischer et. al. (2006) by using "Ripley's k" with GIS and spatial analysis method which identify statistically significant areas of clusters and also the scales at which those clusters are exist. And it also examine the spatial point pattern of industrial toxic substances and the problem of non-point sources with an analysis of the street network.

Matejicek L. et. al. (2005) wide range of data collected by ERDAS Imagine, LIDAR etc. monitoring systems and by mathematical and physical modelling can be managed in GIS in the frame of spatial models which further manage all the data together with GIS model outputs to carry out risk assessment analysis and map composition for air quality.

Lim et. al. (2005) development of the prototype software IMPAQT (Integrated Modular Programme for Air Quality Tools) by using a countrywide transportation model, and an advanced atmospheric dispersion model and GIS to carry out urban air quality assessments and to test traffic scenarios. By this software identify the high concentration of pollutants in residential or commercial areas and also predict travel impacts on present or future transportation systems. Determination of existing travel demands on the current transport network and predict the future traffic flows for transportation planning.

Marquez et. al. (1999) developed a framework and identifies the relationship between various components such as land use transport environment module, GIS database and also air shed model. Also evaluate the effect on the city due to air quality which identifies the relationship between various components.

Sengupta et. al. (1997) provide a summary of the basic road traffic emission model and also focuses on the design and implementation of the computer application with the emphasis on the component used and GIS technology.

Briggs et. al. (1997) for mapping traffic related air pollutant NO_2 GIS regression based approach is used that containing data on monitored sir pollution levels, land cover, road network, traffic volume, altitude assessed predicted pollution levels. As a result provide pollution map by estimation of NO_2 concentration.

2.3 Mathematical modelling of air pollution

Briggs et. al., (1997) the study revealed stepwise multiple regression analysis was retuen using the two compounds factor viz. $Tvol_{300}$ and $Land_{300}$, together with altitude, topex, sitex and sampler height against modelled mean NO_2 concentration:

$$Mean\ NO_2 = 11.83 + (0.00398\ Tvol_{300}) + (0.268 Land_{300}) - (0.0355 RS_{Alt}) + (6.777 Sampht)$$

The above equation is applicable for traffic related air pollution mapping for NO_2 which compute the predicted pollution level at all unmeasured sites.

Wong et. al. (1994) for compute the air pollution concentration

$$Z(X_0) = \sum_{i=0}^{n} \lambda i_{Z(Xi)0} \text{ And } \sum \lambda i = 1$$

Where λi represent the weights assigned to each neighbouring values and sum of the weights is one. Estimation of air pollutant concentrations viz. O_3, PM_{10} by using four different interpolation methods like 1) spatial averaging 2) nearest neighbour, 3) inverse distance weighting and 4) Kriging.

Jerrett et. al., (2005) developed model that can be expressed mathematically in the form of:

$$hij\ (t) = h0(t)\eta j \exp(\beta' xijs)$$

This is developed and used Cox proportional hazards regression for analysis of association between air pollution and mortality.

Crabbe et. al., (2000) revealed that modelled personal exposure of air pollutants for purpose of characterization of human exposure and those assessment techniques.

$$E_p = \sum_{x} e\ (x, t)$$

$$e_{(x,t)} = \frac{\int_{t0}^{t1} C_{(x,t)}}{t_1 - t_0}$$

Where,

x = home, work, and other locations identified in GIS

t = time spent at each location identified from the environmental factor

e = the exposure of air quality at that location either measured or modelled

c = concentration of air quality at that point, Ep = total personal exposure

Chelani et. al., (2010) the oak Ridge air quality index is given by:

$$ORAQI = 5.7 \times \left(\sum_{i=0}^{s} I_i\right)_{1.37}$$

Where, I_i = concentration of pollutants ÷ Standard level of pollutant

The Oak Ridge Air Quality Index (ORAQI) based on 24 hourly average concentrations of air pollutants. This index is based on the premise that the effect on environmental quality varies inversely in relation to the pollutant concentration.

Joshi et. al., (2010) the following equation is derive to Air Quality Index (AQI) under consideration:

$$\text{AQI} = {}^{1}\!/_{4}\ [\frac{RSPM}{sRSPM} + \frac{SPM}{sSPM} + \frac{SO_2}{sSO_2} + \frac{NO_2}{sNO_2}]\times 100$$

Where sRSPM, sSPM, sSO_2 and sNO_2 are represent the ambient air quality as per the CPCB of India and RSPM, SPM, SO_2 and NO_2 are represent the actual values of pollutants obtained on sampling.

2.4 Studies of human health effect due to air pollution

Kampa et. al., (2008) examined that hazardous chemicals escape to the environment by a number of natural and/or anthropogenic activities and may cause adverse effects on human health and the environment. Increased combustion of fossil fuels in the last century is responsible for the progressive change in the atmospheric composition. Air pollutants, such as carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxides (NOx), volatile organic compounds (VOCs), ozone (O_3), heavy metals, and respirable particulate matter (PM2.5 and PM10), differ in their chemical composition, reaction properties, emission, time of disintegration and ability to diffuse in long or short distances. Air pollution has both acute and chronic effects on human health, affecting a number of different systems and organs. It ranges from minor upper respiratory irritation to chronic respiratory and heart disease, lung cancer, acute respiratory infections in children and chronic bronchitis in adults, aggravating pre-existing heart and lung disease, or asthmatic attacks. In addition, short- and long-term exposures have also been linked with premature mortality and reduced life expectancy. These effects of air pollutants on human health and their mechanism of action are briefly discussed.

Kurt et. al., (2017) described that air pollution continues to be a major public health concern affecting nine out of ten individuals living in urban areas worldwide. Exposure to air pollution is the ninth leading risk factor for cardiopulmonary mortality. The aim of this review is to examine the current literature for the most recent updates on health effects of specific air pollutants and their impact on asthma, chronic obstructive pulmonary disease (COPD), lung cancer and respiratory infection.

Kim et. al., (2016) examined environmental air pollution encompasses various particulate matters (PMs). The increased ambient PM from industrialization and urbanization is highly associated with morbidity and mortality worldwide, presenting one of the most severe environmental pollution problems. This article focuses on the correlation between PM and skin diseases, along with related immunological mechanisms. Recent epidemiological studies on the cutaneous impacts of PM showed that PM affects the development and exacerbation of skin diseases. PM induces oxidative stress via production of reactive oxygen species and secretion of pro-inflammatory cytokines such as TNF-α, IL-1α, and IL-8. In addition, the increased production of ROS such as superoxide and hydroxyl radical by PM exposure increases MMPs including MMP-1, MMP-2, and MMP-9, resulting in the degradation of collagen. These processes lead to the increased inflammatory skin diseases and skin aging. In addition, environmental cigarette smoke, which is well known as an oxidizing agent, is closely related with androgenetic alopecia (AGA). Also, ultrafine particles (UFPs) including black carbon and polycyclic aromatic hydrocarbons (PAHs) enhance the incidence of skin cancer. Overall, increased PM levels are highly associated with the development of various skin diseases via the regulation of oxidative stress and inflammatory cytokines. Therefore, anti-oxidant and anti-inflammatory drugs may be useful for treating PM-induced skin diseases.

Franklin et. al., (2015) examined an escalating body of epidemiologic and clinical research provides compelling evidence that exposure to fine particulate matter air pollution contributes to the development of cardiovascular disease and the triggering of acute cardiac events. There are 3 potential mediating pathways that have been implicated, including “systemic spillover,” autonomic imbalance, and circulating particulate matter constituents. Further support that the increased morbidity and mortality attributed to air pollution comes from studies demonstrating the adverse cardiovascular effects of even brief periods of exposure to secondhand smoke. Accordingly, persons with known or suspected cardiovascular disease, the elderly, diabetic patients, pregnant women, and those with pulmonary disease should be counseled to limit leisure-time outdoor activities when air pollution is high. Recognizing the insidious and pervasive nature of air pollution, and the associated odds ratios and population attributable fractions for this widely underappreciated chemical trigger of acute cardiovascular events, may serve to maximize the potential for cardiovascular risk reduction by addressing at least a portion of the 10%-25% incidence of coronary disease that is unexplained by traditional risk factors.

Munnuccio et. al., (2015) evaluated air pollution is a complex and ubiquitous mixture of pollutants including particulate matter, chemical substances and biological materials. There is growing awareness of the adverse effects on health of air pollution following both acute and chronic exposure, with a rapidly expanding body of evidence linking air pollution with an increased risk of respiratory (e.g., asthma, chronic obstructive pulmonary disease, lung cancer) and cardiovascular disease (e.g., myocardial infarction, heart failure, cerebrovascular accidents). Elderly subjects, pregnant women, infants and people with prior diseases appear especially susceptible to the deleterious effects of ambient air pollution. The main diseases associated with exposure to air pollutants will be summarized in this narrative review.

2.5 Studies of antimicrobial properties

Jailin Hu et. al., (2018) examined information is currently limited regarding the distribution of antibiotic resistance genes (ARGs) in smog and their correlations with airborne bacteria. This study characterized the diversity and abundance of ARGs in the particulate matters (PMs) of severe smog based on publicly available metagenomic data, and revealed the occurrence of 205 airborne ARG subtypes, including 31 dominant ones encoding resistance to 11 antibiotic types. Among the detectable ARGs, tetracycline, β-lactam and aminoglycoside resistance genes had the highest abundance, and smog and soil had similar composition characteristics of ARGs. During the smog event, the total abundance of airborne ARGs ranged from 4.90 to 38.07 ppm in $PM_{2.5}$ samples, and from 7.61 to 38.49 ppm in PM_{10} samples, which were 1.6–7.7 times and 2.1–5.1 times of those in the non-smog day, respectively. The airborne ARGs showed complicated co-occurrence patterns, which were heavily influenced by the interaction of bacterial community, and physicochemical and meteorological factors. *Lactobacillus* and sulfonamide resistance gene *sul*1 were determined as keystones in the co-occurrence network of microbial taxa and airborne ARGs. The results may help to understand the distribution patternsof ARGs in smog for the potential health risk evaluation.

Boron et. al., (2016) examined this study assessed the antimicrobial resistance of airborne *Staphylococcus* spp. strains isolated from healthcare facilities in southern Poland. A total of 55 isolates, belonging to 10 coagulase-negative staphylococci (CoNS) species, isolated from 10 healthcare facilities (including hospitals and outpatient units) were included in the analysis. The most frequently identified species were *Staphylococcus saprophyticus* and *Staphylococcus warneri*, which belong to normal human skin flora, but can also be the cause of common and even severe nosocomial infections. Disk diffusion tests showed that the bacterial strains were most frequently resistant to erythromycin and tetracycline and only 18% of strains were susceptible to all tested antimicrobials. Polymerase chain reaction amplification of specific gene regions was used to determine the presence of the Macrolide–Lincosamide–Streptogramin resistance mechanisms in CoNS. The molecular analysis, conducted using specific primer pairs, identified the *msrA1* gene, encoding active efflux pumps in bacterial cells, as the most frequent resistance gene. As many as seven antibiotic resistance genes were found in one isolate, whereas the most common number of resistance genes per isolate was five ($n = 17$). It may be concluded that drug resistance was widely spread among the tested strains, but the resulting antimicrobial resistance profile indicates that in the case of infection, the use of antibiotics from the basic antibiogram group will be effective in therapy. However, before administering treatment, determination of the specific antimicrobial resistance should be conducted, particularly in the case of hospitalized patients.

Jorgrnsen et. al., (2009) examined an important task of the clinical microbiology laboratory is the performance of antimicrobial susceptibility testing of significant bacterial isolates. The goals of testing are to detect possible drug resistance in common pathogens and to assure susceptibility to drugs of choice for particular infections. The most widely used testing methods include broth micro dilution or rapid automated instrument methods that use commercially marketed materials and devices. Manual methods that provide flexibility and possible cost savings include the disk diffusion and gradient diffusion methods. Each method has strengths and weaknesses, including organisms that may be accurately tested by the method. Some methods provide quantitative results (eg, minimum inhibitory concentration), and all provide qualitative assessments using the categories susceptible, intermediate, or resistant. In general, current testing methods provide accurate detection of common antimicrobial resistance mechanisms. However, newer or emerging mechanisms of resistance require constant vigilance regarding the ability of each test method to accurately detect resistance.

Chapter 3

Research Problem

3. Title of the Study

GIS Mapping of the Observed Trend in Kolkata's Air Quality with Special Emphasis on Airborne Bacterial Load and their Resistance to Common Antibiotics

3.1 Location of Study

The study has been carried out in Kolkata. It is the capital of Indian state of West Bengal. The city is bounded with Hooghly River spread along 80 kilometres which divide it from Howrah district. The city has savannah tropical with monsoon season. Average relative humidity (RH) is 66% and 69% in winter and summer. Mean monthly temperature is from 20-31ºC and maximum temperature often exceed 42ºC. The pre-monsoon and monsoon season are dominated by strong south-westerly wind with greatest air ventilation potential (UNEP/WHO, 1992). City is located in a coastal area and influenced by sea based disturbances, it has an average wind speed around 7km/hour throughout the year. But now-a-days air pollution is major concern of Kolkata.

3.2 Objective of Study

The principle objective of the study is to develop the Air Quality Index (AQI) maps of Kolkata using Geographic Information System (GIS) technology and observe the variation over last five years. Special emphasis are given on the current scenario of bacterial load in airborne particulates, also represented through GIS maps, and their resistance to common antibiotics. The detailed objectives are listed below:

1. To prepare the air quality maps for the city of Kolkata based on AQI calculated for different locations of the city based on the measurements carried out by West Bengal Pollution Control Board (WBPCB) over last five years (May 2014-May 2018).
2. To observe and evaluate the changing trend of air quality of Kolkata from the mentioned AQI maps for different months.
3. To evaluate the microbial load in the ambient air by sampling and measuring the airborne bacterial counts in different parts of Kolkata.
4. Preliminary identification of the sampled bacteria in the ambient air of Kolkata and measurement of zone of inhibition produced by antibiotics.

5. To evaluate the correlation between different air quality parameter and the airborne bacterial load with the meteorological parameters.

3.3 Scope of Study

The spatial range of this study has been limited to the geographical boundary of Kolkata city. The sampling has been done at in front of Jadavpur University Gate no. 3, near Jadavpur 8B bus stand, Shyambazar, Rabindra Bharati University Dunlop, Gariahat, Baishnabghata, Beliaghata, Rajarhat, Salt Lake and Paribesh Bhawan. The study has been carried out for a period of eight month starting from 18^{th} August 2018 to 20^{th} February 2019. The details of study program are discussed in next chapter.

3.4 Brief Methodology

The details of the methodology followed during the study along with the test equipment and materials are provided in the next chapter. The steps followed are listed briefly as follows:

1. Collection of air quality data from www.wbpcb.gov.in.
2. Organizing those data in excel sheets corresponding to each location for further analysis.
3. Generation of air quality maps using Geographic Information System (GIS) technology for Air Quality Index.
4. Microbial pollutants have been collected in Kolkata city once in every location during the monitoring period using Andersen Cascade Impacter.
5. Quantification and identification has been done in laboratory by culturing on appropriate media and measurement of zone of inhibition produced by common antibiotics.
6. The meteorological data were collected in sampling days from www.freemeteo.in.
7. For statistical calculations, using standard MS-EXCEL were used.

Chapter 4

Research Methodology

4. The Study Program

The study has been conducted in Kolkata (22°32´N 88º22'E), the capital city of West Bengal in India. According to census report of India (2011), Kolkata had 4.5 million population which makes it third most populated metropolitan area in India. The first population count for Kolkata (4.5 million) under the Kolkata Municipal Corporation (KMC) and second count (14.1) is for the Kolkata Metropolitan Authority (KMA), which includes the suburbs and city (KMC). Instantaneous and unplanned urbanisation, and insensitive vehicular density on badly endeavored road space and higher use of petrol fuel rapidly increased the air pollution in Kolkata (Ghose et. al., 2004). The air pollution in Kolkata terrible during winter season, when the pollution ranges higher than other time. In addition, the worst polluted traffic intersection increases the city's pollution level during busy schedule.

The city is bounded with Hooghly River spread along 80 kilometres which divide it from Howrah district. The city has savannah tropical with monsoon season. Average relative humidity (RH) is 66% and 69% in winter and summer. Mean monthly temperature is from 20-31ºC and maximum temperature often exceed 42ºC. The pre-monsoon and monsoon season are dominated by strong south-westerly wind with greatest air ventilation potential (UNEP/WHO, 1992). City is located in a coastal area and influenced by sea based disturbances, it has an average wind speed around 7km/hour throughout the year. The study starts with the collection of secondary data that includes 16 monitoring locations for air quality assessment. The study area involves city of Kolkata. The air quality monitoring location of study area are shown in Figure 4.1.

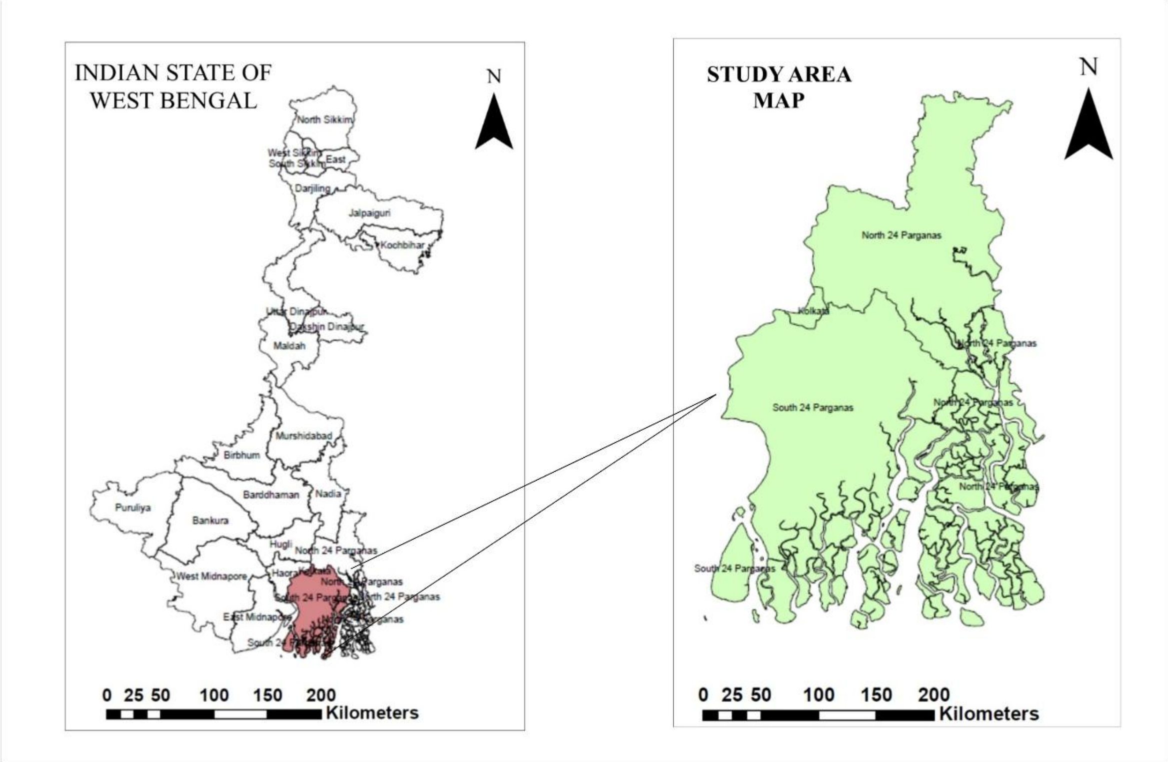

Figure 4.1: Maps showing the area having 16 monitoring locations under study

Figure 4.2: Study Location

The methodology of this study is elaborated here. The sampling frequency was done once in every location. Standard laboratory scale study was performed following existing literature. The last five years AQI data are collected from www.wbpcb.gov.in . And the microbial sampling location was selected on the basis of AQI locations. Different meteorological data was observed on the sampling days to analyse their correlation with the parameter collected from www.wbpcb.gov.in . The meteorological logical data are collected from www.freemeteo.in . Six meteorological parameters viz. minimum temperature, relative temperature, dew point, relative humidity, wind speed and pressure are observed and presented on sampling days.

Table 4.1: Experimental Program of the Study

Type of Study	Sub Type	Experiment	No. of Sampling Location
Study of Air Pollutants		Observation of ambient NOx, Sox, PM10, PM2.5 from www.wbpcb.gov.in	16
Study of Air Quality Index (AQI)	Mapping	Developed contour mapping through ArcGIS	16
Study of air Borne bacteria	Quantification study	Bacterial load in ambient air through two stage Andersen Cascade Impacter	10
	Characterization Study	Gram staining of the bacteria in the ambient air through Two stage Andersen Cascade Impacter	10
	Mapping	Developed contour map for bacterial load through ArcGIS	10
Study of Antimicrobial Susceptibility		Antibiotic susceptibility profiling of bacterial load in ambient air	10

4.1 Collection of Geographical coordinates for Geo-referencing in ArcGIS

This is the most important initial step to start a GIS based study. The first thing done is finding out the exact real time coordinate system for analysis of air quality monitoring sites based on their geographical location. In this present study Google Earth Pro program is utilized for collection of respective latitude and longitude data of the monitoring locations. The figure shown below explain how it is done:

Figure 4.3: Areas showing the monitoring locations in Google Earth Pro for detection of coordinates

The red arrow markings are denote the sampling location, whereas red highlighted rectangular box denoted the latitude and longitude coordinates. This thing is repeated all the 16 locations.

4.1.1 Generation of data attribute table with Microsoft excel

After collection of all the coordinates, all the data are transferred into spreadsheet along with location ID and the monitoring station names. The table also contains present year airborne microbial concentration for the respective 10 locations. Respective 16 locations chemical parameters each divided in separate files for generation of separate maps. A sample data sheet for generation of contour map is shown below.

Table 4.2: Data attribute table for integration and generation of contour maps in ArcGIS

ID	LOCATION	Latitude	Longitude	AQI
1	Baishnabghata	22.47111	88.39222	181.3333333
2	Behala	22.48694	88.31306	321.25
3	Dunlop	22.65389	88.37694	205.6666667

4	Minto park	22.54167	88.35417	178.5555556
5	Moulali	22.55944	88.36389	245.5555556
6	Paribesh Bhawan	22.56138	88.40861	192.625
7	Saltlake	22.59167	88.41722	166.1111111
8	Shymbazar	22.59805	88.36861	288.6666667
9	Ultadanga	22.59472	88.38667	217.5555556

In the similar way for 2014-2018 year such attribute tables are generated along with air quality parameters and AQI values that has been collected as explained earlier.

4.1.2 Generation of contour maps using ArcMap 10.3

After aggregation of required data and their integration in the ArcMap program, contour maps are generated for the selected region under study area. In cartography, a contour line (often just called a **"contour"**) joins points of equal elevation above mean sea level (MSL). A contour map is a map illustrated with contour lines, for example topographic map. In air quality studies airborne bacteria concentration studies maps are prepared. Various thematic maps (contour maps in our case) using spatial interpolation technique through inverse distance weighted (IDW) method. This contouring method has been applied in the present study to separate the area wise distribution of air pollutants. This method uses a selected set of monitoring points for estimating the output grid cell value. It calculates the cell value by using a linearly weighted combination of a set of a monitoring points and it control the significance of known points upon the interpolated values based to their distance from the output points, thereby generating a surface profile. In this way air quality maps for air quality index (AQI) has been generated as per the methodology mentioned in below flowchart.

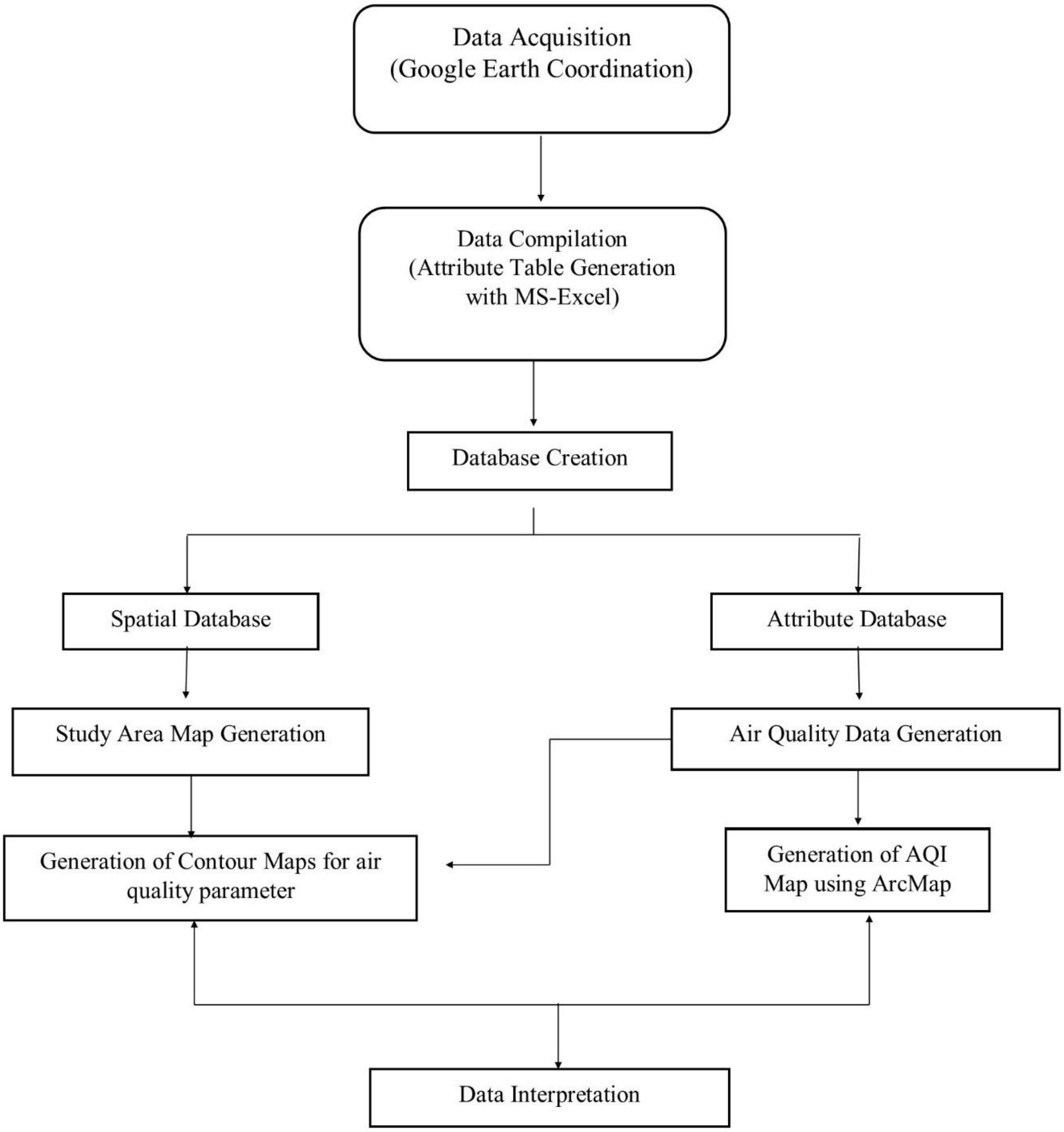

Figure 4.4: Flowchart of the methodology adopted

4.1.3 Interpretation of air quality maps

Once the maps generated it needs to be interpreted to derive a meaningful conclusion. All the AQI maps have some points of concentration which denotes areas having high concentration of pollutants and need to be taken care of treatment to purify the air. Determination of the type of restrictive pollutant in a particular area over a period of time and henceforward helps to lay a focus on the source of pollutants and subsequently develop methods to displace them as much as possible. This will be elaborated further in details in next chapter.

4.2 Use of statistical tools for air quality and meteorological data study

4.2.1 Generation of correlation matrix

In order to find the relationships between 4 air quality parameters and their influence on meteorological parameter, a study through calculation of correlation are made.

Correlation coefficients are used in statistics to measure how strong a relationship in between two variables. The correlation values range from a value -1 to +1, whereas:

I. +1 indicates that a very strong positive relationship built in two variables. It also means that for every positive increase in one variable there is a fixed proportion of positive increase in other variable.
II. -1 indicates that a very strong positive relationship built in two variables. It also means that for every positive increase in one variable there is a decrease of fixed proportion

This correlation analysis established how the different parameter of air are inter related with each other and it influence the overall meteorological parameters. All these multiple correlation analysis is done using MS-Excel. Detailed discussion on this will be presented further in next chapter.

4.3 Sampling and Monitoring of Air Pollutants

Air microbial pollutants was monitored in the laboratory scale during entire study period of eight month starting from 18th August 2018 to 20th February 2019 in different location of Kolkata, India. The sampling was done once in every location for duration of fifteen minutes using the standard methodology. Thermo specific two stage viable, Andersen Cascade Impactor was used to measure the concentration of air microbial pollutants. The operating flow rate of this machine is 28.3 lpm (1CFM). It is a primary standard calibration device.

Figure 4.5: Sampling days in monitoring location

Note: A: Beliaghata area; B: Paribesh Bhawan; C: Gariahat more; D: Rajarhat

4.4 Quantification and characterization of bacterial load

4.4.1 Quantification of airborne bacteria in ambient air

The air-borne bacteria collected on the petri dish through Anderson Cascade Impacter during the air pollution study were further analysed to quantify the bacteria present in that size fraction of particulates. The study was carried out at ten sampling locations viz. in front of Jadavpur University Gate no. 3, near Jadavpur 8B bus stand, Shyambazar, Dunlop (Rabindra Bharati University), Gariahat, Baishnabghata, Beliaghata, Rajarhat, Salt Lake and Paribesh Bhawan.

Andersen Cascade Impacter is widely used to measure the bacterial concentration and particle size distribution of aerobic bacteria in ambient air. It is constructed with multi-orifice aluminium stages that are held together by clamps and it is used as a standard for counting the microbial particles in aerosol. Particles can be collected on a bacteriological agar and incubated for identification and counting. The sampler is a primary standard calibrated to make all the physical characteristics viz. size, shape and density are aerodynamically in sized, so that it can be directly related to human lung deposition. Each impacter stage has 200 holes, 1.5 mm diameter in the first stage and 0.4 mm in the second. Collection plates were prepared with appropriate amount of selected agar by aseptically pipetting into each Petri dishes. Air sampled enters into cascade and the inlet cone through the succeeding orifice stage with continuously higher velocities from upper to lower stage. Selectively smaller particles are initially impacted onto the agar plates.

Luria Bertani media petri plates were used for estimating the bacterial load. Two petri plates were placed into the both stages Andersen Cascade Impacter and then run the sampler for 15 minutes. After sampling petri plates were incubated for 24 hour at 37ºC. After 24 hour total number of growing colonies was counted (Pastuszka et al., 2000). The bacterial count is converted to concentration (CFU/m^3) value using equation as given below:

$$C = \frac{1000P}{RT}$$

Where C = Bacterial Concentration in CFU/m^3, P = no. of bacterial colony, R = air sampling rate, T = Exposure time in minutes.

Table 4.2: Media Composition of Luria Bertani (pH 7.0±2)

Ingredients	Concentration (gm/100 ml)
Tryptone	1
Yeast Extract	0.5
NaCl	1
Agar	1.5-2

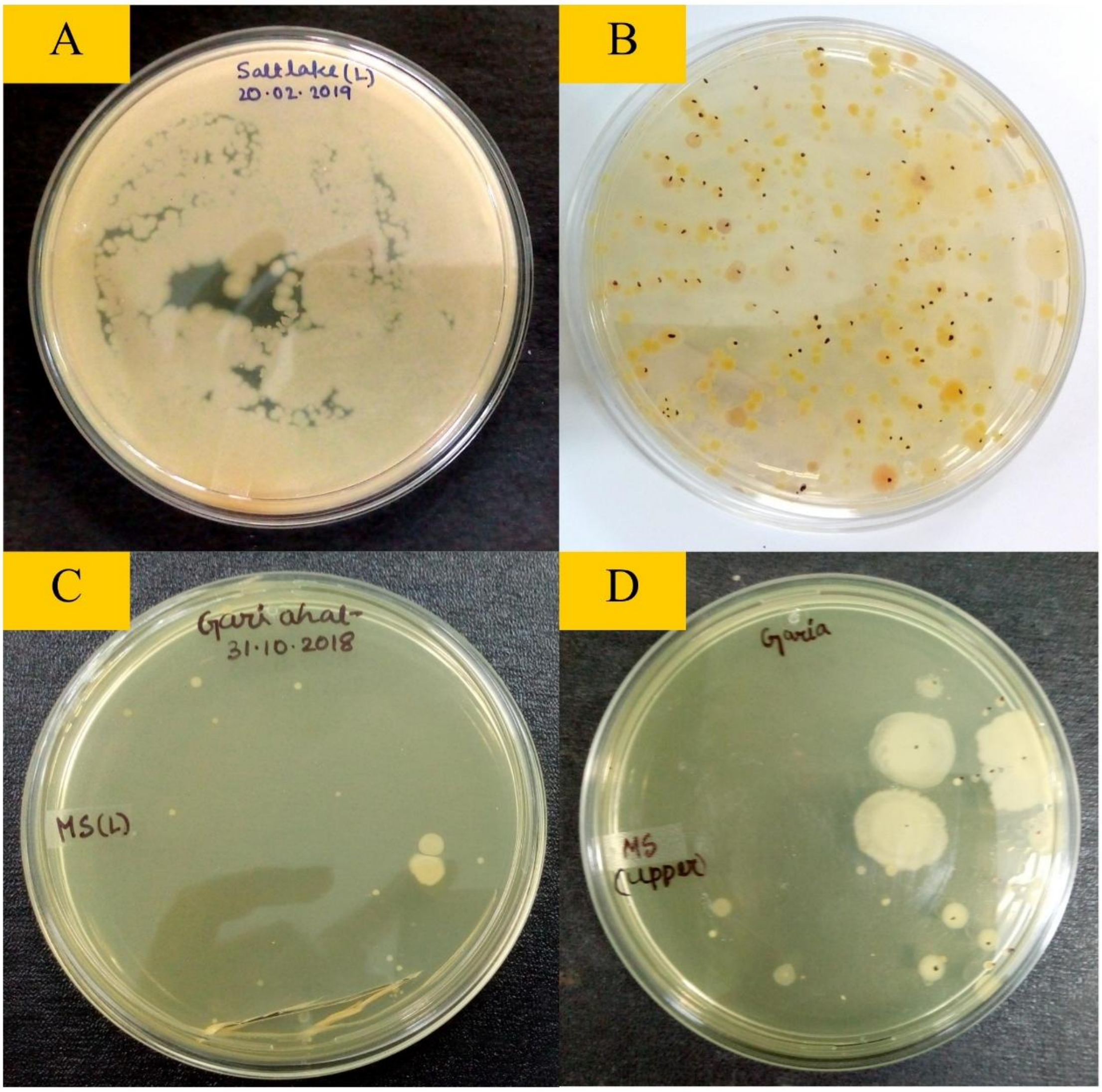

Figure 4.6: Bacterial load in sampling days in monitoring location

Note: A: Saltlake; B: Jadavpur University gate no. 3; C: Gariahat; D: Baishnabghata

4.4.2. Characterisation of Air borne Bacteria

Characterisation of air borne bacteria were carried out to perform initially laboratory scale identification of air borne bacteria sampled during this study period. The bacteria present in air sample through the two stage Andersen Cascade Impacter were utilized in the identification study. Gram staining was performed for identification studies. The test methodology are elaborated in the subsequent sections.

4.4.2.1 Gram Staining

Gram staining method is always a first step of bacterial identification. Gram stain characteristics differentiate in morphologic structure and chemical composition of bacterial cell wall by detecting peptidoglycan (90% of cell wall), which present in a thick layer in gram positive bacteria while gram negative bacteria have walls with thin layer of peptidoglycan (10% of cell wall), and high lipid content. The performance of gram stain requires four basic steps that include applying a primary stain (crystal violet) to a heat fixed smear, followed by addition of a mordant (Gram's Iodine) and rapid decolourization with alcohol, acetone or mixture of alcohol and acetone, lastly apply counterstaining of saffranin (Dmitriev, 2004). In aqueous solution of crystal violet dissociates with $\mathrm{CV}^{+}$and Cl^{-} ions which penetrate through the cell wall and membrane of both gram positive and gram negative bacteria cells. Due to differences in the thickness of peptidoglycan layer in between gram positive and gram negative bacteria, gram positive bacteria maintain crystal violet stain during decolourisation process, while gram negative bacteria loss the crystal violet stain and instead stain by the saffranin in the final staining process (Cappuccino and Sherman, 2014).

Bacterial smear was prepared by bacterial inoculation in a slide and it was heat fixed. The slide was then flooded with crystal violet for one minute and then excess dye was washed off through distilled water. The smear then flooded with gram's iodine for one minute. The slide washed with alcohol to stop decolourisation. The slide was counterstain with 0.25% saffranin for one minute and excess stain was washed off with distilled water. The slide was examined under Bright Field Microscope (Make: Leica, Model: Leica-DM750+Lcc50HD+LASEZ) after adding immersion oil in 1000 ×magnification. Bacterial morphology was observed. Materials and reagents required for Gram staining are listed in table 4.2:

Table 4.3 Materials and Reagents required for Gram staining

Materials	Reagents
Clean glass slides Inoculating loop Bunsen Burner Bibulous paper Microscope Lens paper and lens cleaner Immersion oil Distilled water Cultures of organism	Primary stain - Crystal Violet Mordant - Grams Iodine De-colorizer - Ethyl Alcohol Secondary Stain - Safranin

4.5 Antibiotic Susceptibility Profiling of Bacterial Load

The performance of antimicrobial susceptibility testing is important by the clinical microbiology laboratory to ensure the susceptibility of chosen antimicrobial agents, or discover resistance in individual bacterial isolates. Empirical therapy is effective for some bacterial pathogens because of their resistance mechanisms have not been observed viz. penicillin susceptibility of *Streptococcus pyogenes*.

Susceptibility of air borne microbes to antibiotics was determined by disc diffusion method on Luria Bertani agar (Bauer et. al., 1966) and recommendation of Clinical and Laboratory Standard Institute (CLSI, 2006). The test is performed by applying bacterial inoculum of approximately 1-2×10^8 CFU/mL to the surface of the large (150 mm diameter) Luria Bertani agar medium.

The advantages of disk diffusion method are the test simplicity that does not require any special equipment and flexibility in selection of disks for testing. It is least costly of all susceptibility methods (approximately $2.50–$5 per test for materials). On the other hand the disadvantage of the disk diffusion methods are lack of mechanisation or automation of the test. The disk test has been standardized for testing streptococci, *Haemophilus influenza* and *N. meningitides* through used of specialized media, incubation condition and specific zone size interpretive criteria.

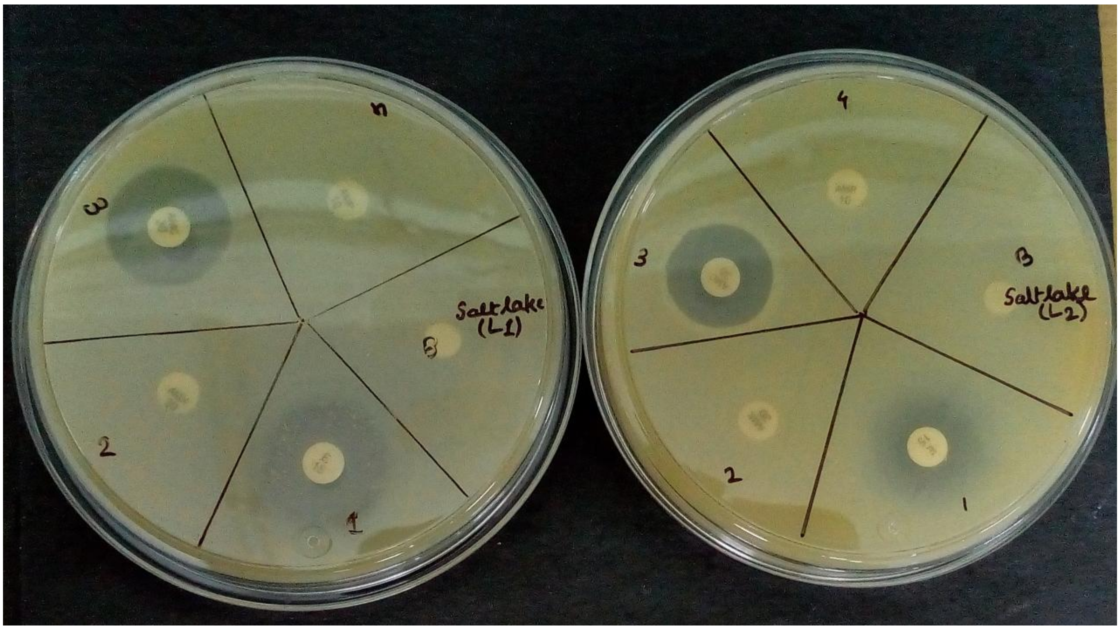

Figure 4.4: A disk diffusion test of airborne bacteria

Take about 1ml of Luria Bertani broth and inoculate the bacteria to be tested. After the preparation of inoculum, prepare Luria Bertani agar (LB) and sterilize it by autoclaving. Put the media in petri plate. Leave it for 15-20 minutes to solidify. Collected 0.5ml suspension by micro pipette added by drop in the surface of Luria Bertani agar (LB). Then the spreader was streaked over the surface of Luria Bertani agar (LB) to obtain uniform inoculums. Antibiotic discs were then placed aseptically on the surface of Luria Bertani agar (LB) medium with the help of sterile forceps. Each disc was gently pressed down onto the medium to ensure complete contact with agar surface. The plates were inverted and incubated at 37 °C for 24 h. After incubation, the plates were examined and the diameter of the zones of inhibition (ZOI) was measured to the nearest whole millimetre. The diameter of zone of inhibition (ZOI) was related to the susceptibility of the isolate and ZOI of each antibiotics are illustrated using the criteria published by Clinical and Laboratory Standard Institute (CLSI, formerly the National Committee for Clinical Laboratory Standards or NCCLS). Media composition for antibiotic sensitivity are listed in table 4.2.

Antibiotics disc were collected from Himedia, Kolkata, India. The antibiotic tested were Erythromycin (15 mcg), Ampicillin (30 mcg), Amoxyclav (Amoxicillin / clavulanic) (30 mcg [20/10 mcg]) and Amoxicillin (10 mcg). The antimicrobials were chosen on the basis of their common use in treatment in Kolkata. The colonies grown in Luria Bertani agar medium was inoculated in Luria Bertani broth and inoculated at 37ºC for 16-24 h to determination of results.

4.5.1 Multiple Antibiotic Resistance (MAR) Index

Multiple Antibiotic Resistance (MAR) index is a very useful tool for identification of bacterial source tracking. This method helps in differentiating between human and nonhuman fecal sources. MAR indices of the present isolates, against the common antibiotics were calculated based on the following formula.

$$\text{MAR index for isolates} = {}^{a}/_{b}$$

a = Number of antibiotics to which the isolates is resistance

b = Number of antibiotic tested

This will be elaborated further in next chapter.

Chapter 5

Result and Discussion

5. Introduction

The present study involves quantification and characterization of biological fraction of air borne bacteria in the ambient air of Kolkata and also involved the collection of air quality data for 16 locations around Kolkata district. The bacterial load of ambient air is collected by measuring bacterial count in the collected particulates through two stage Andersen Cascade Impacter. The correlation of air pollutants and meteorological parameters is analysed from the results of simultaneous monitoring. Different meteorological parameters are also observed and recorded during the study period to analyse their correlation with the secondary air pollutants in the ambient air. The datasheet of different selected parameters has been prepared. Based on the datasheet Air Quality Index (AQI) is calculated which has been developed by United States Environmental Protection Agency (EPA). Further analysis using AQI will be presented in this chapter. Thematic maps (Contour maps) has been developed for more details analysis. The study has been carried out for a period of eight month starting from 18th August 2018 to 20th February 2019 in different location of Jadavpur University Gate no. 3, near Jadavpur 8B bus stand, Shyambazar, Dunlop (Rabindra Bharati University), Gariahat, Baishnabghata, Beliaghata, Rajarhat, Salt Lake and Paribesh Bhawan.

5.1 Generation of Geographic Information System techniques to study the air pollutants spread across the monitoring location using ArcGIS

With the help of data compiled for calculation of Air Quality Index (AQI) as shown above, an MS-Excel datasheet is created which serves as an attribute table for generation of contour map for air quality parameters and AQI index which is further help in more accurate interpretation of acutely polluted areas that needs to be treated. Also this study will create a scope to study the source of pollutants.

5.1.1 SO2 concentration in 2014 – 2018 (January) in Kolkata city

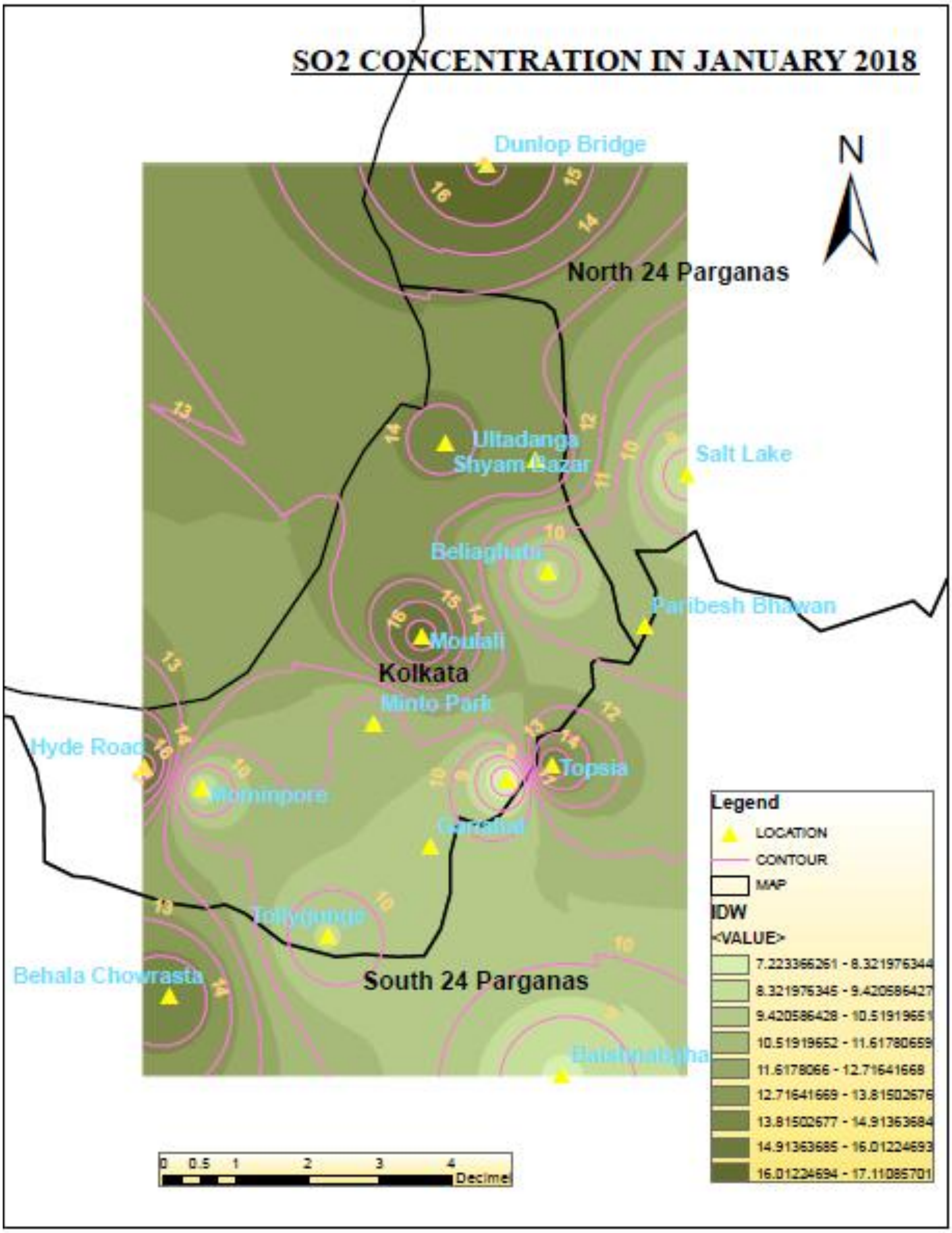

Figure 5.1: Contour map showing areas of high index of SO2 in January in Kolkata city

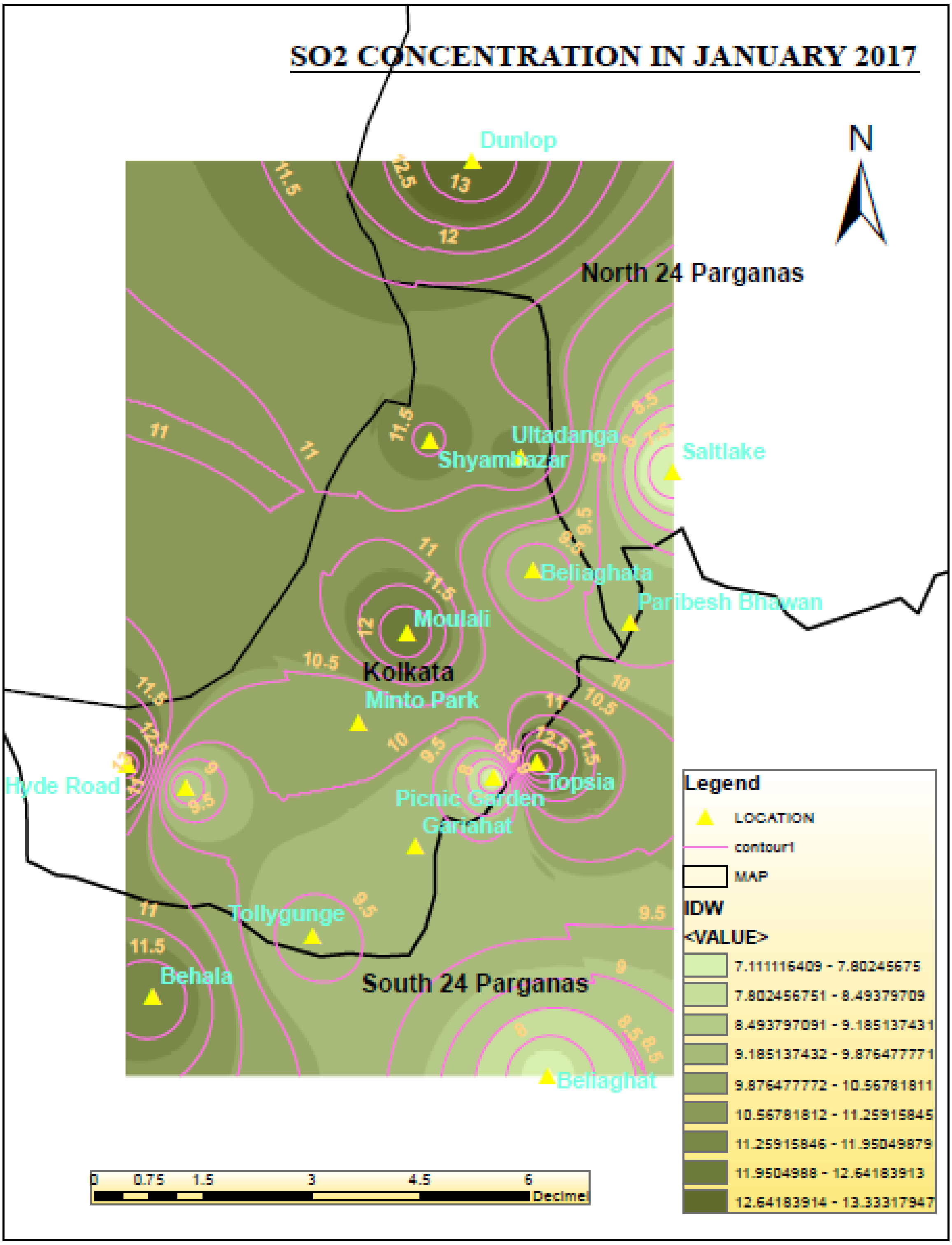

Figure 5.2: Contour map showing areas of high index of SO2 in January in Kolkata city

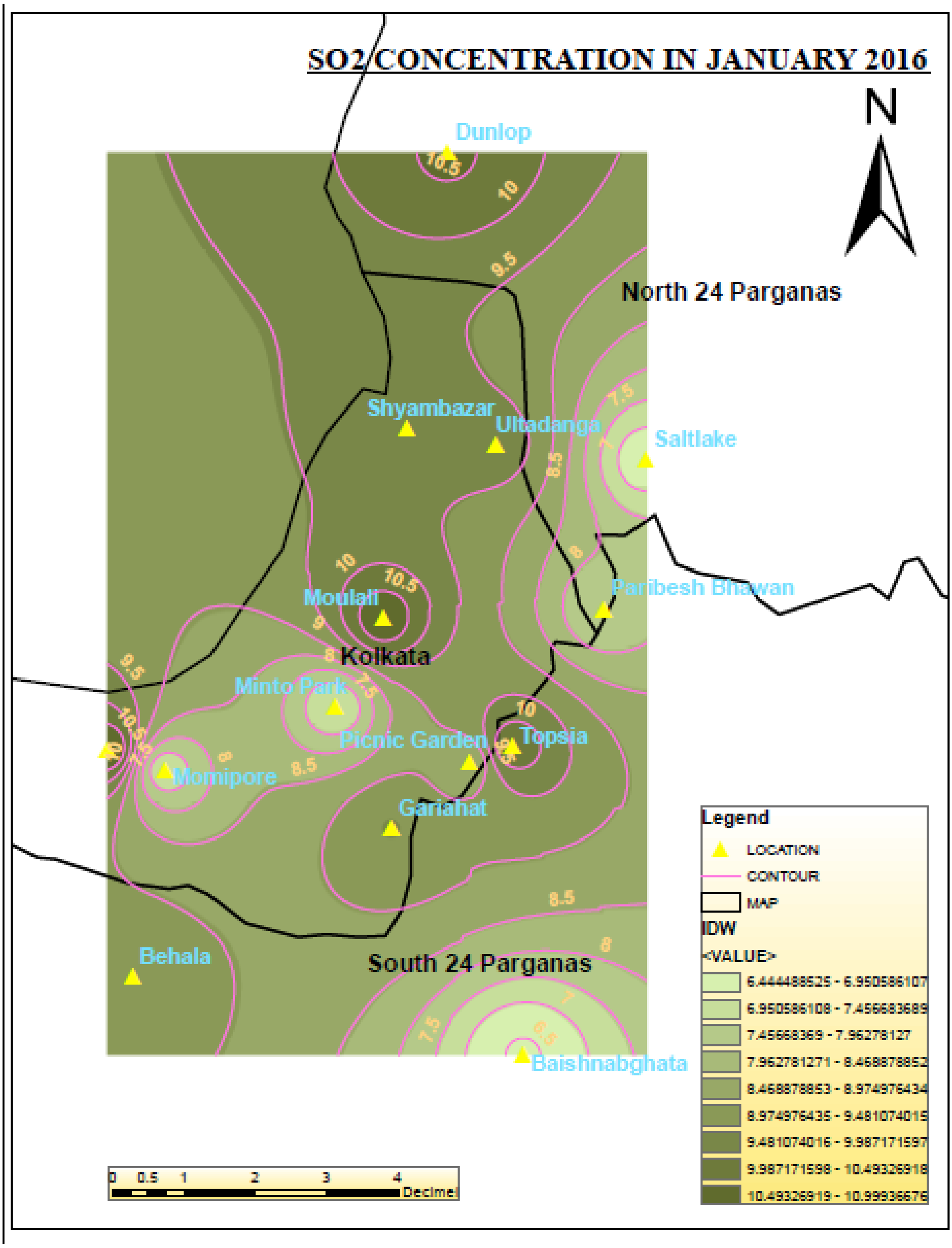

Figure 5.3: Contour map showing areas of high index of SO2 in January in Kolkata city

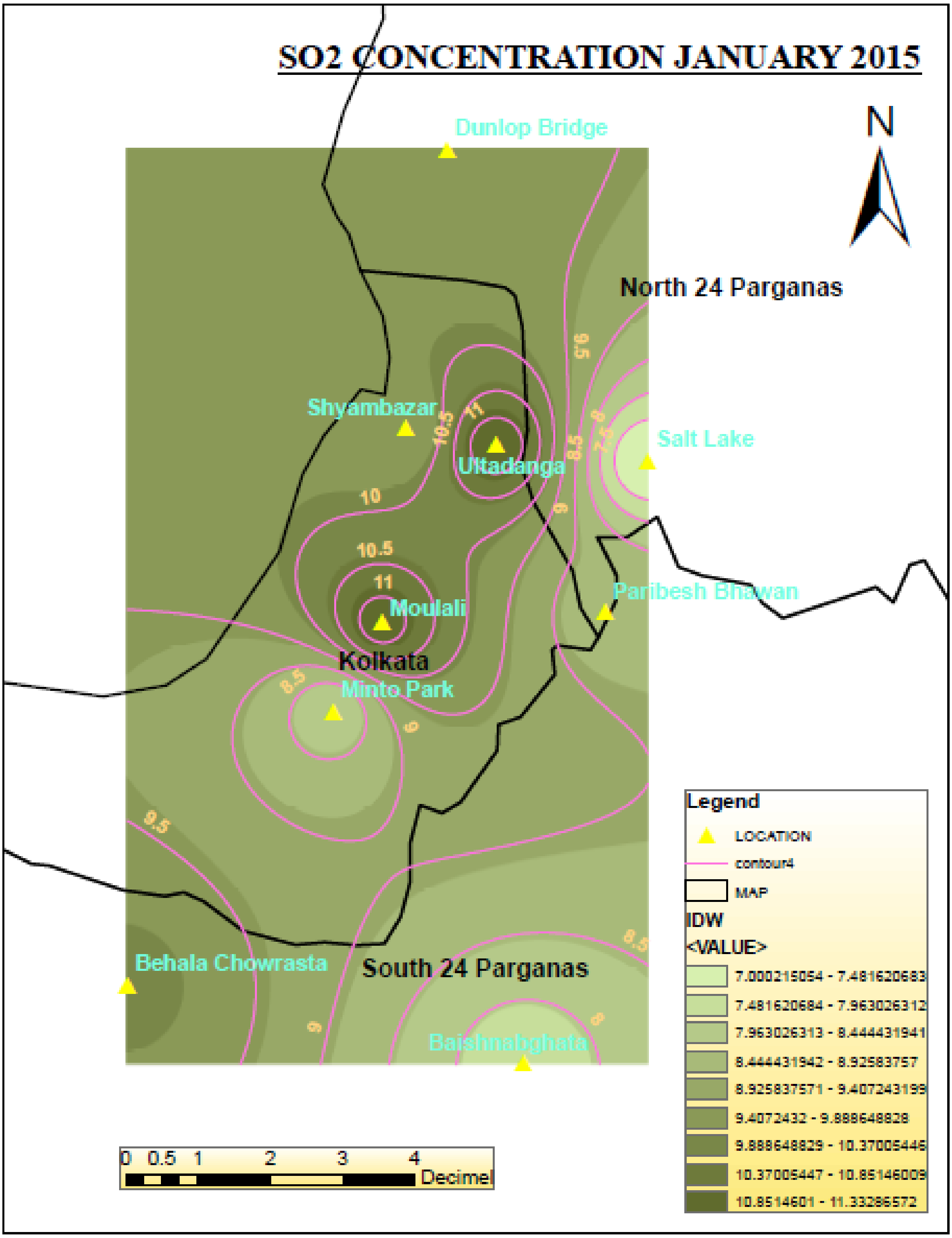

Figure 5.4: Contour map showing areas of high index of SO2 in January in Kolkata city

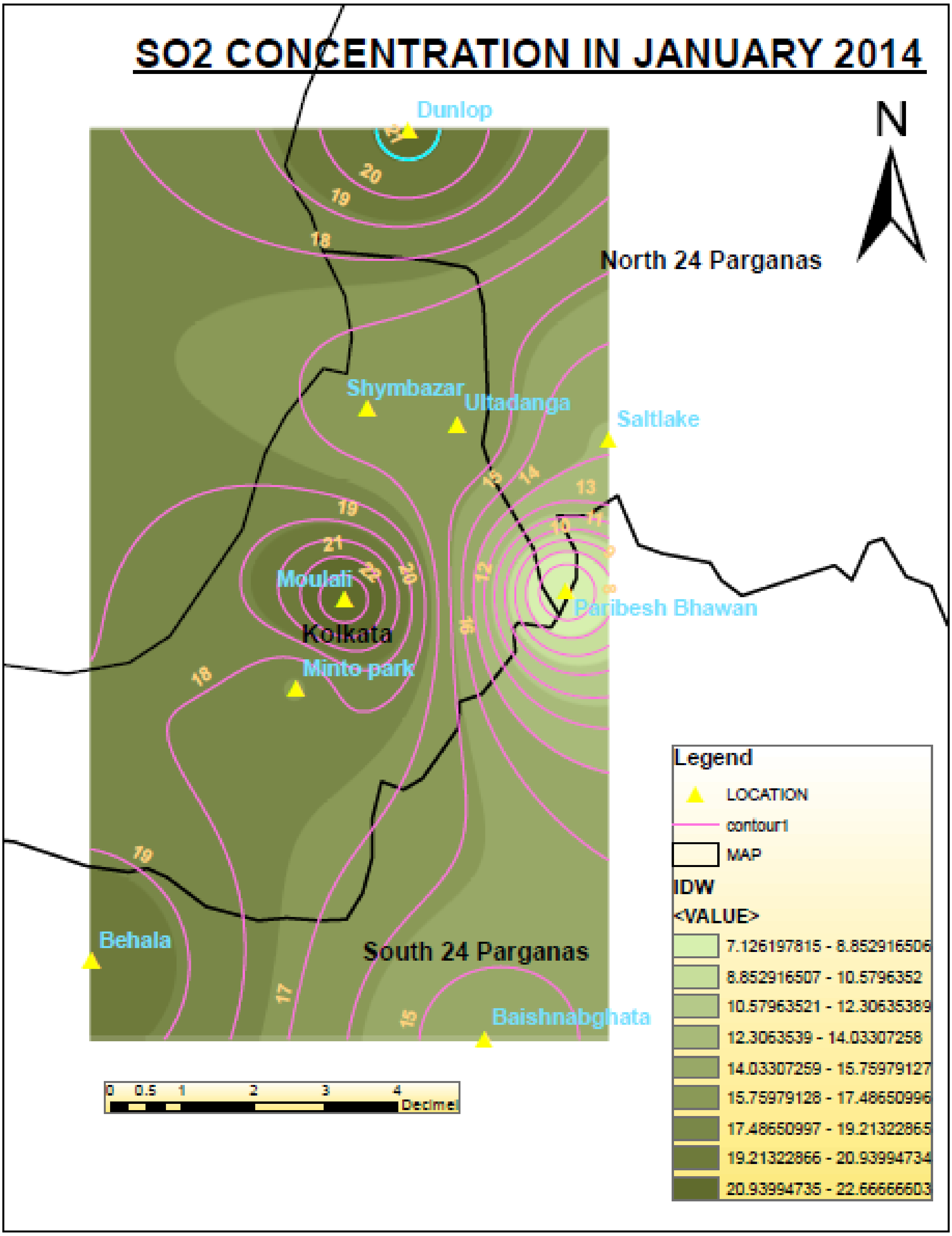

Figure 5.5: Contour map showing areas of high index of SO2 in January in Kolkata city

5.1.2 SO2 concentration in 2014 – 2018 (February) in Kolkata city

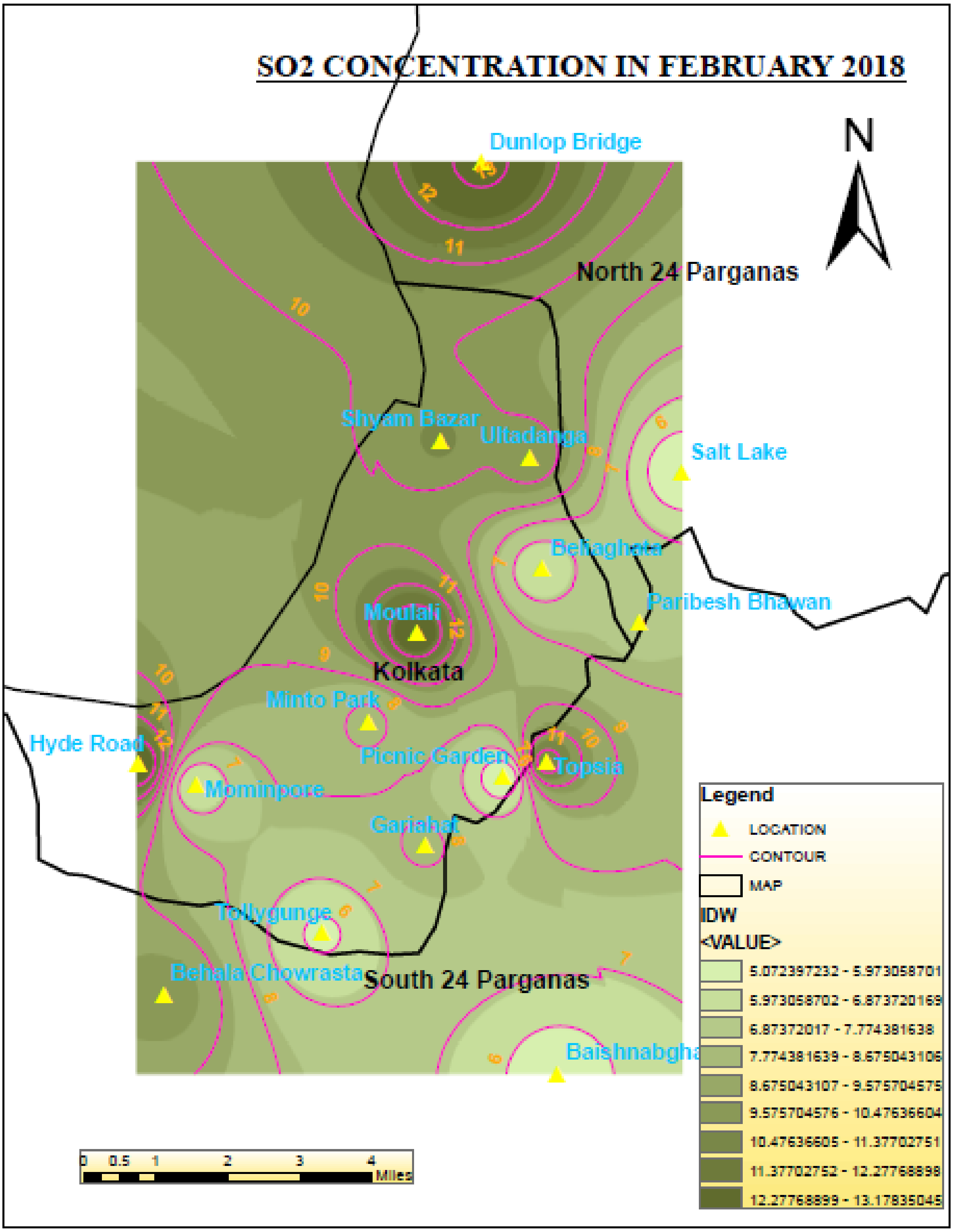

Figure 5.6: Contour map showing areas of high index of SO2 in February in Kolkata city

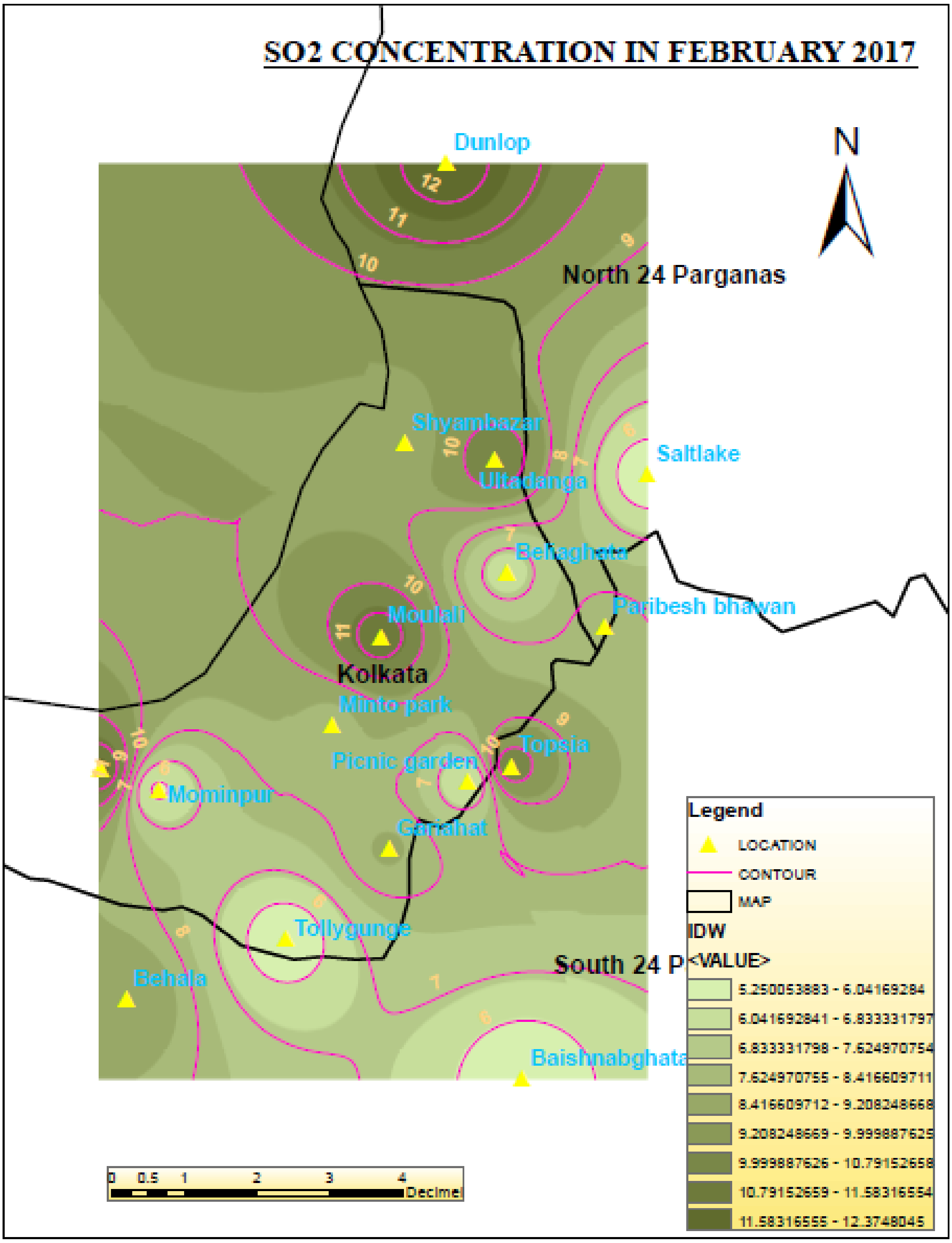

Figure 5.7: Contour map showing areas of high index of SO2 in February in Kolkata city

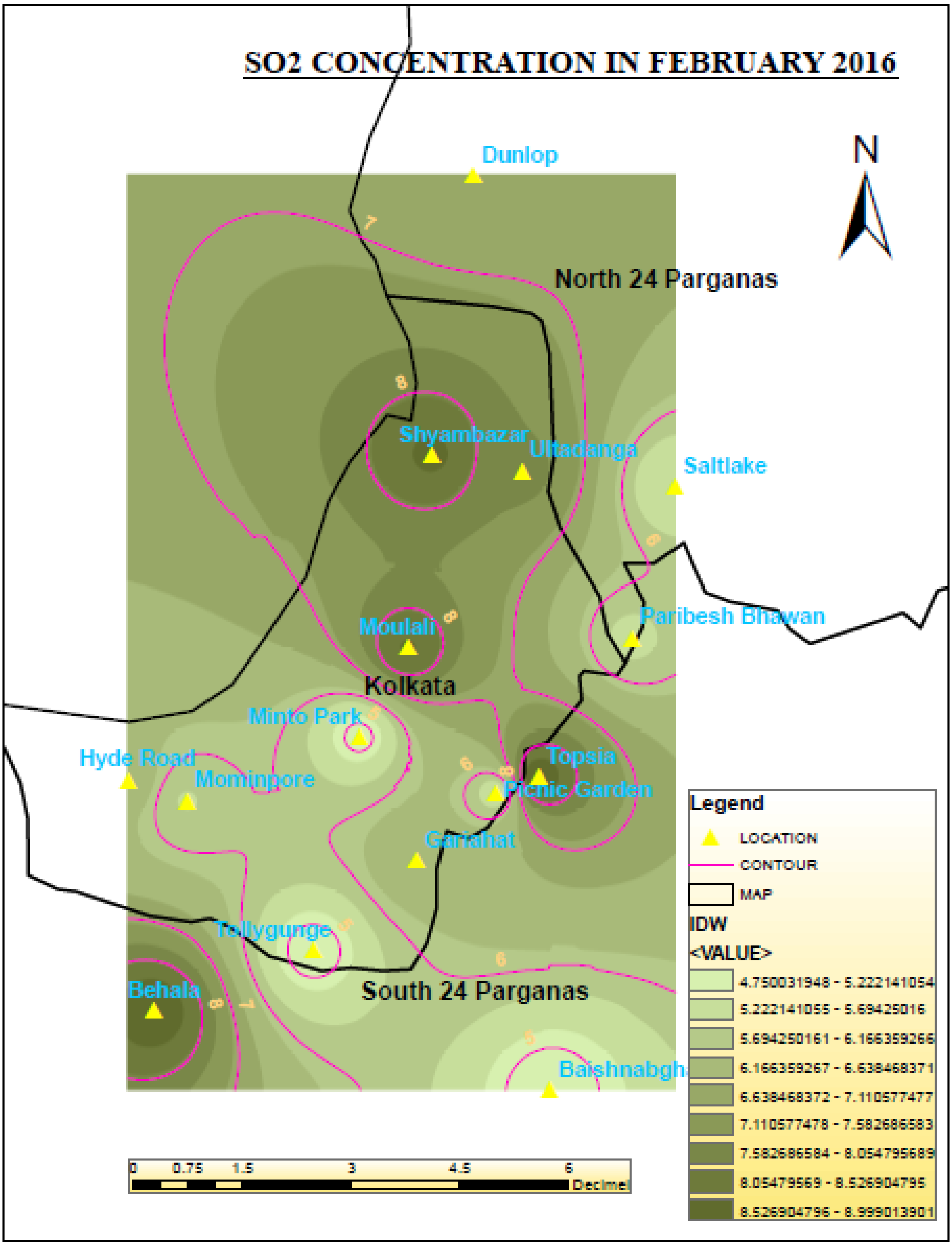

Figure 5.8: Contour map showing areas of high index of SO2 in February in Kolkata city

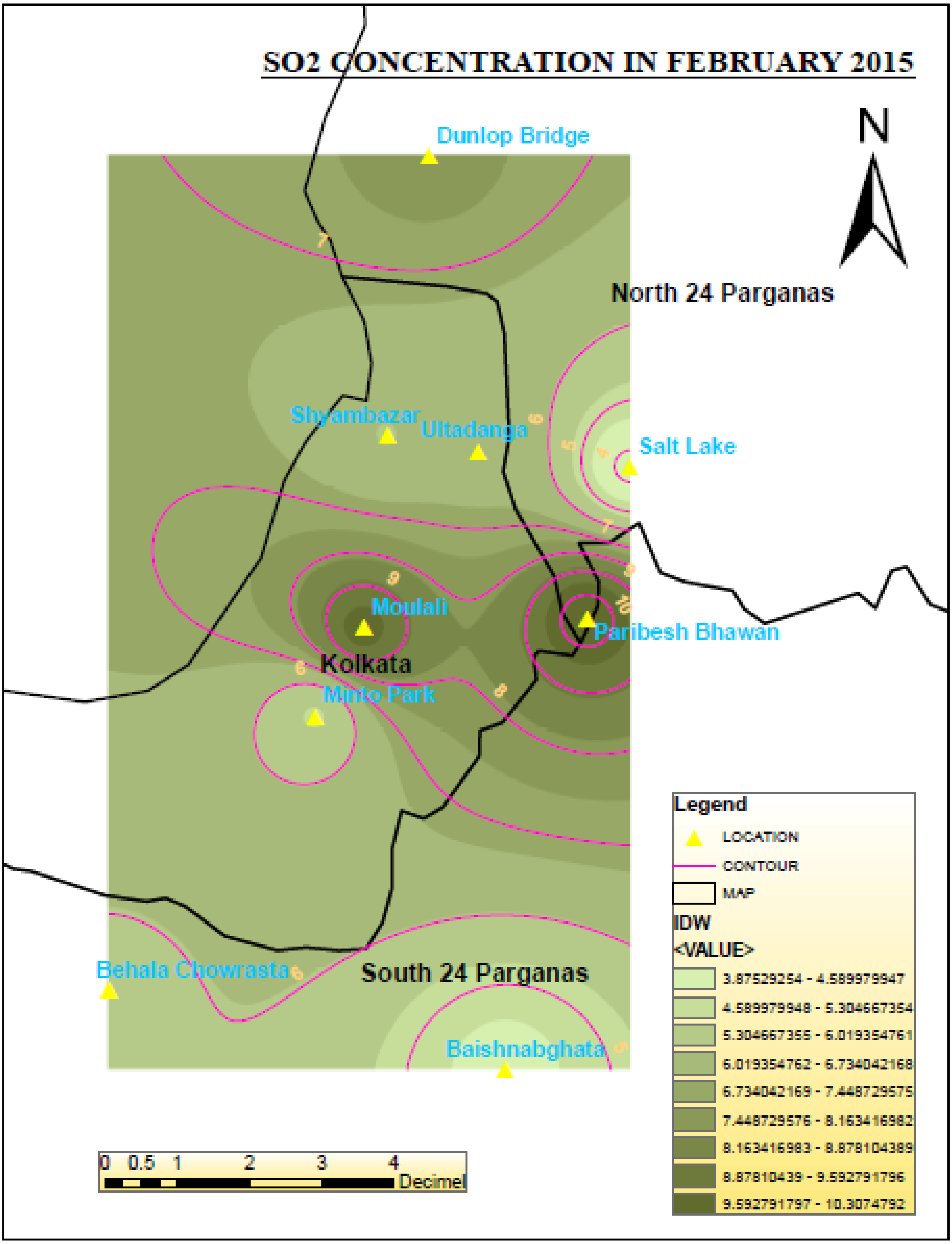

Figure 5.9: Contour map showing areas of high index of SO2 in February in Kolkata city

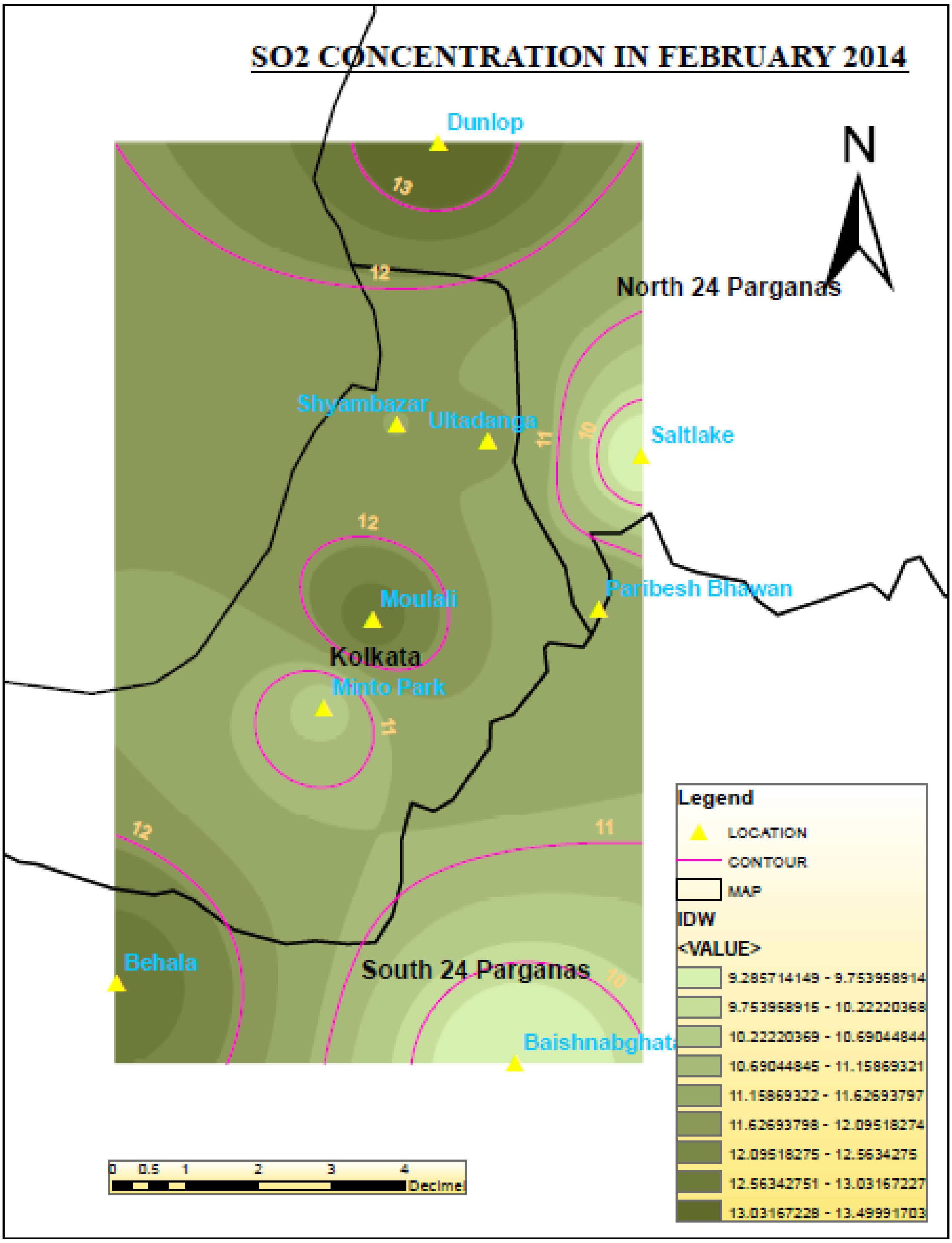

Figure 5.10: Contour map showing areas of high index of SO2 in February in Kolkata city

5.1.3 SO2 concentration in 2014 – 2018 (March) in Kolkata city

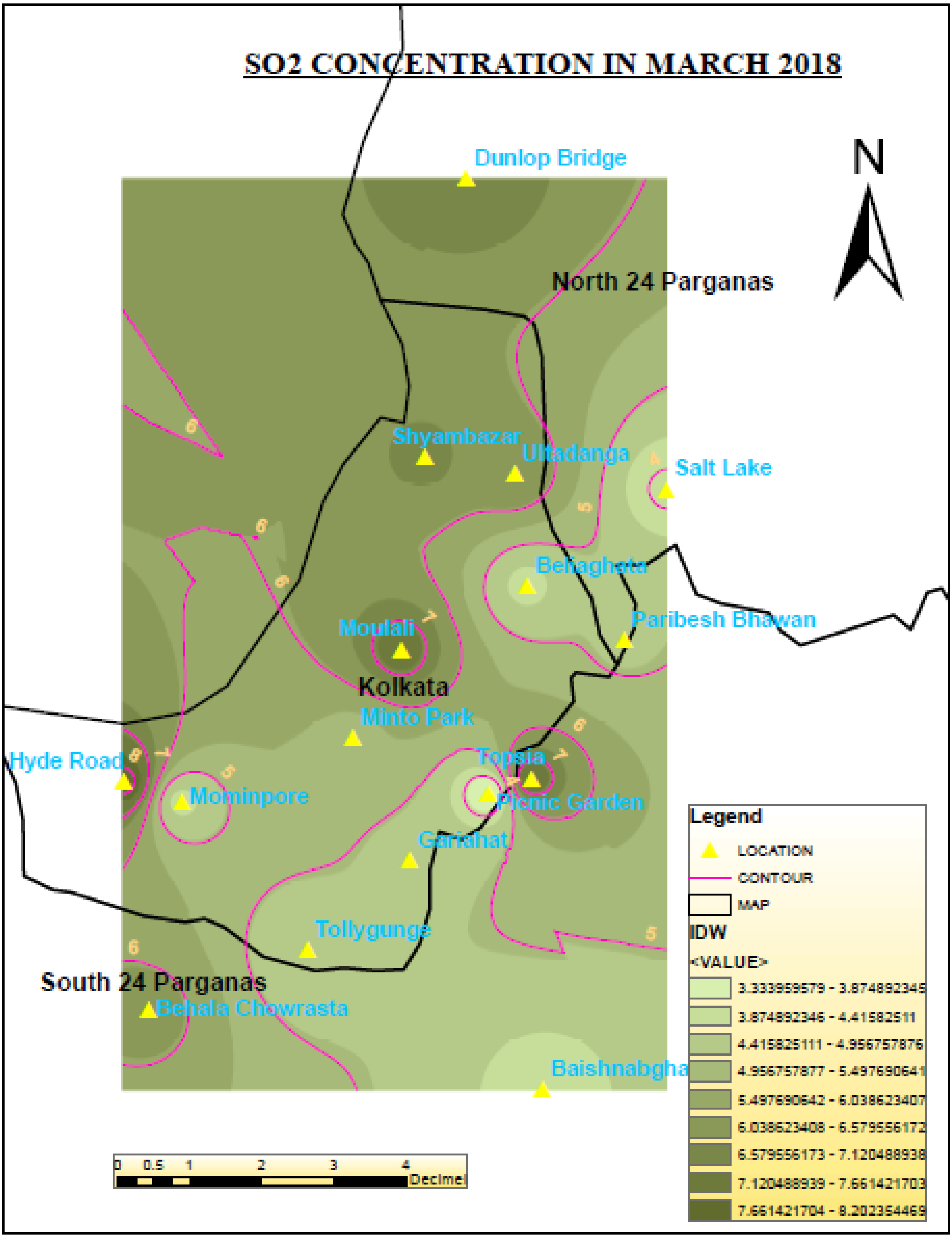

Figure 5.11: Contour map showing areas of high index of SO2 in March in Kolkata city

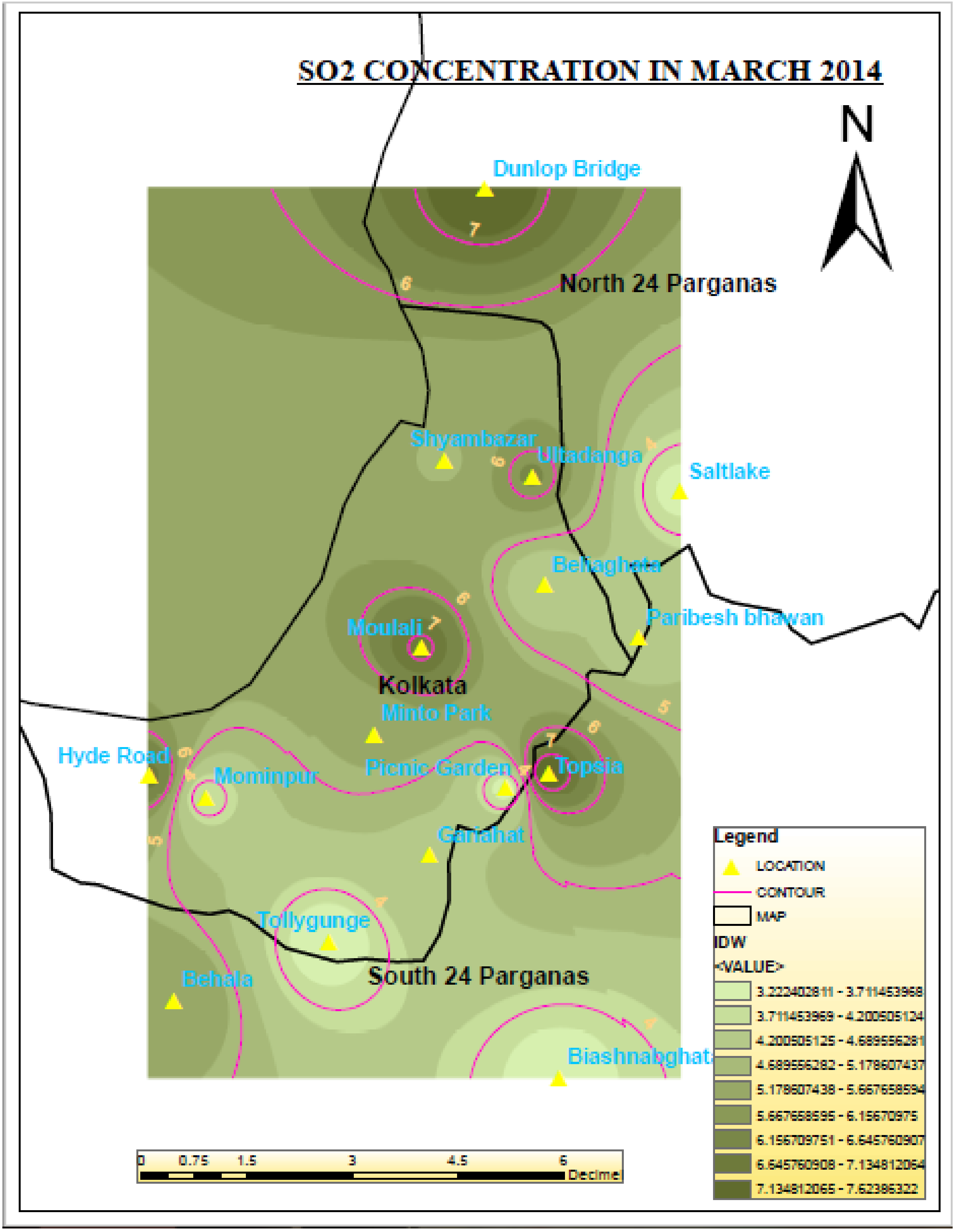

Figure 5.12: Contour map showing areas of high index of SO2 in March in Kolkata city

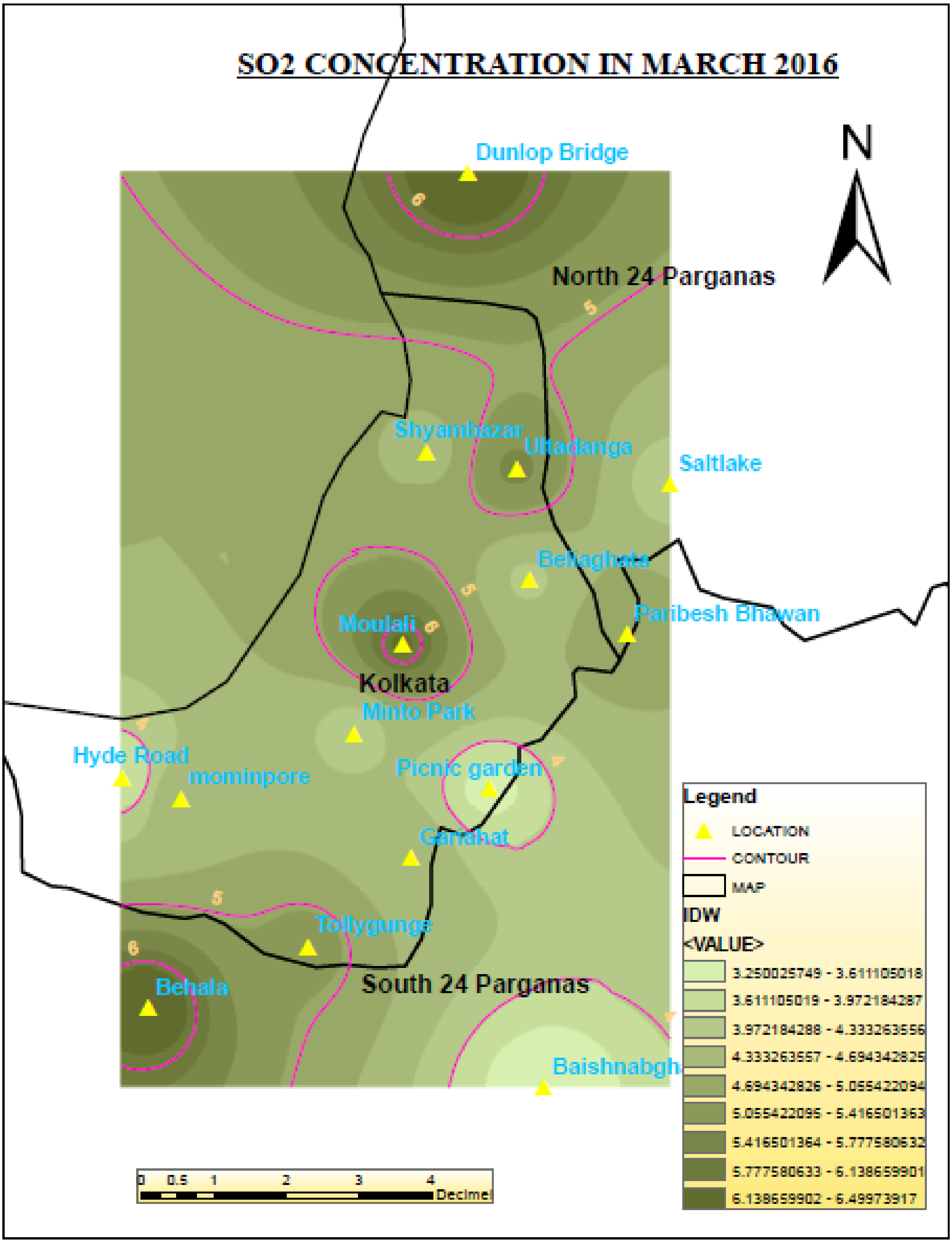

Figure 5.13: Contour map showing areas of high index of SO2 in March in Kolkata city

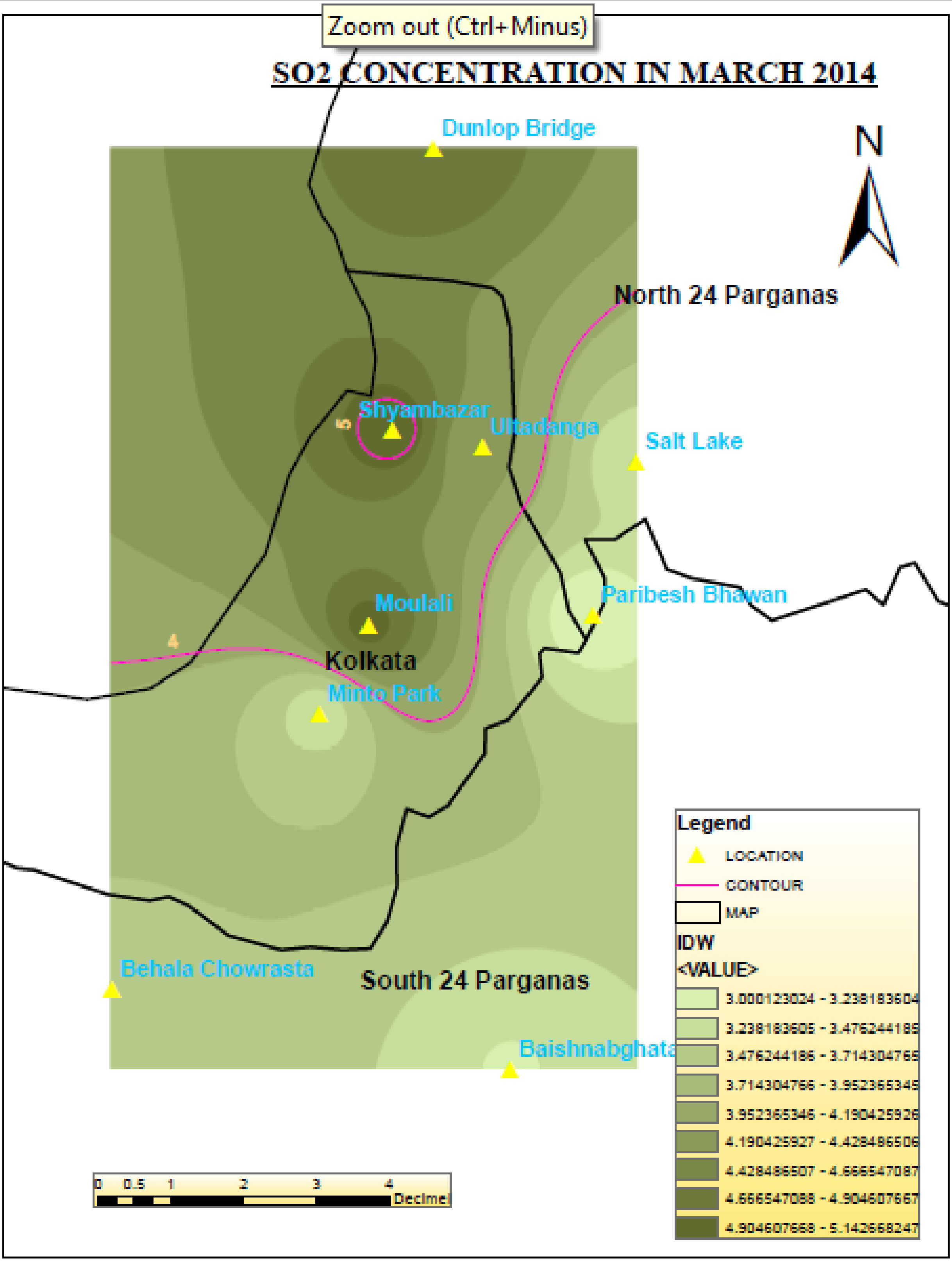

Figure 5.14: Contour map showing areas of high index of SO2 in March in Kolkata city

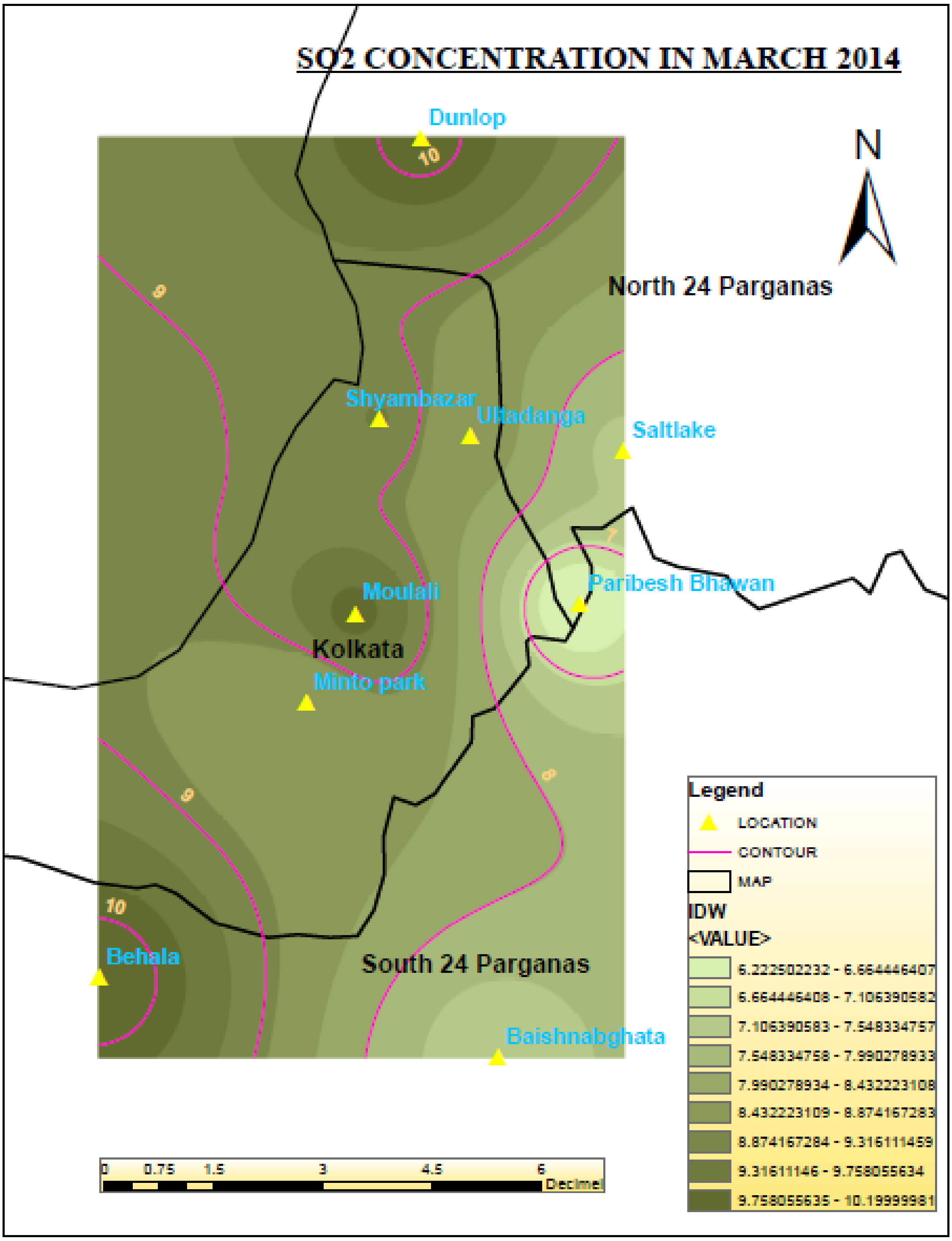

Figure 5.15: Contour map showing areas of high index of SO2 in March in Kolkata city

5.1.4 SO2 concentration in 2014 – 2018 (April) in Kolkata city

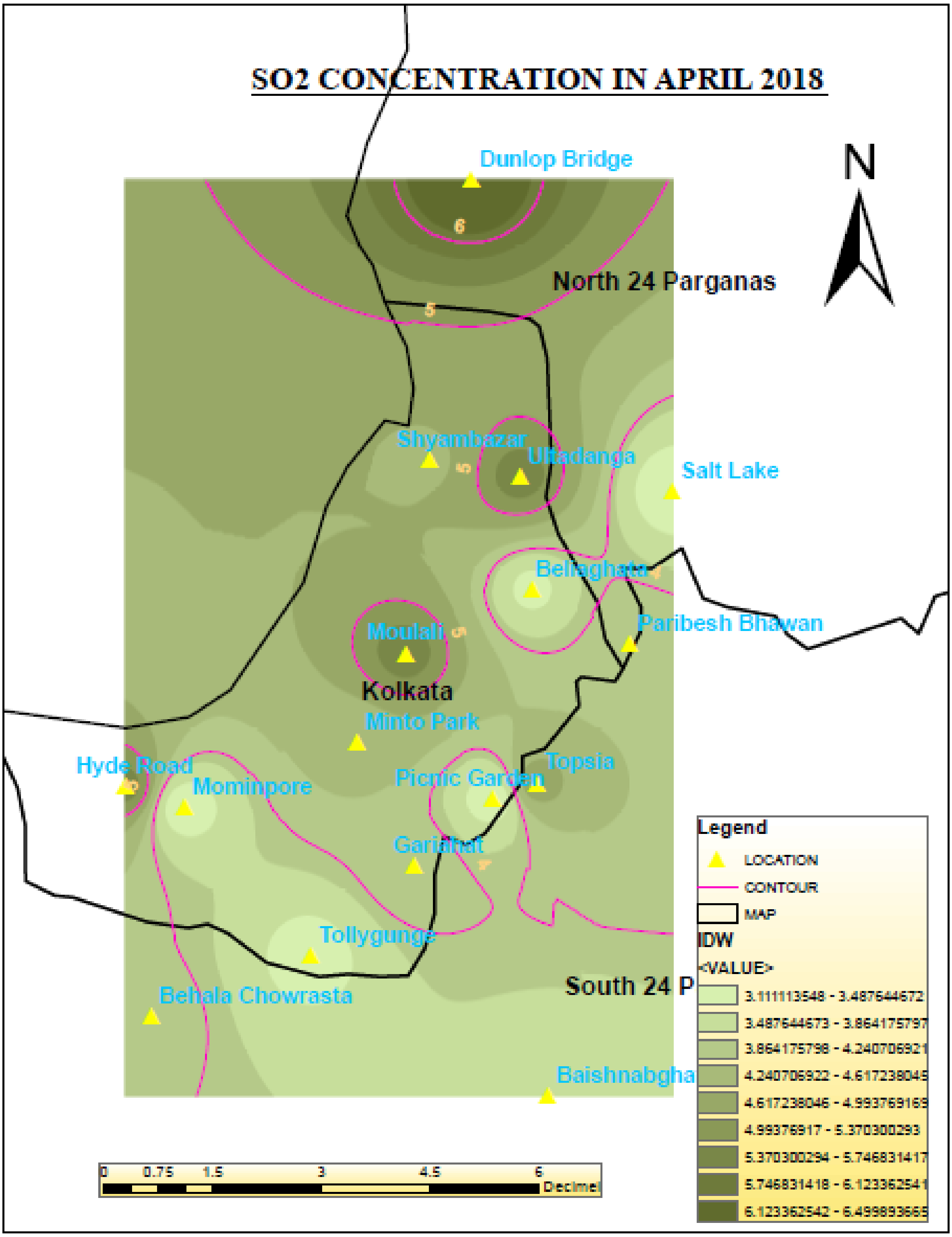

Figure 5.16: Contour map showing areas of high index of SO2 in April in Kolkata city

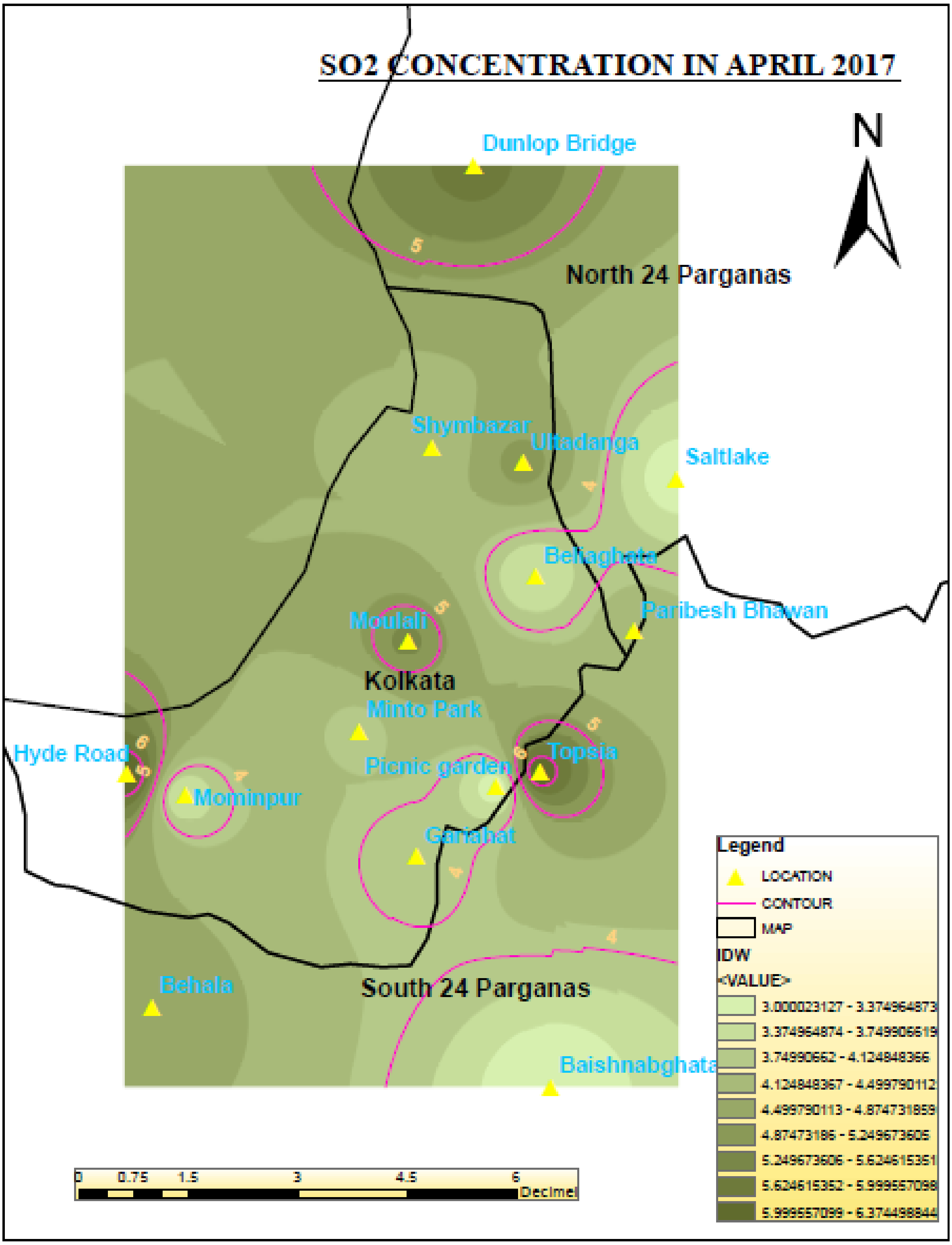

Figure 5.17: Contour map showing areas of high index of SO2 in April in Kolkata city

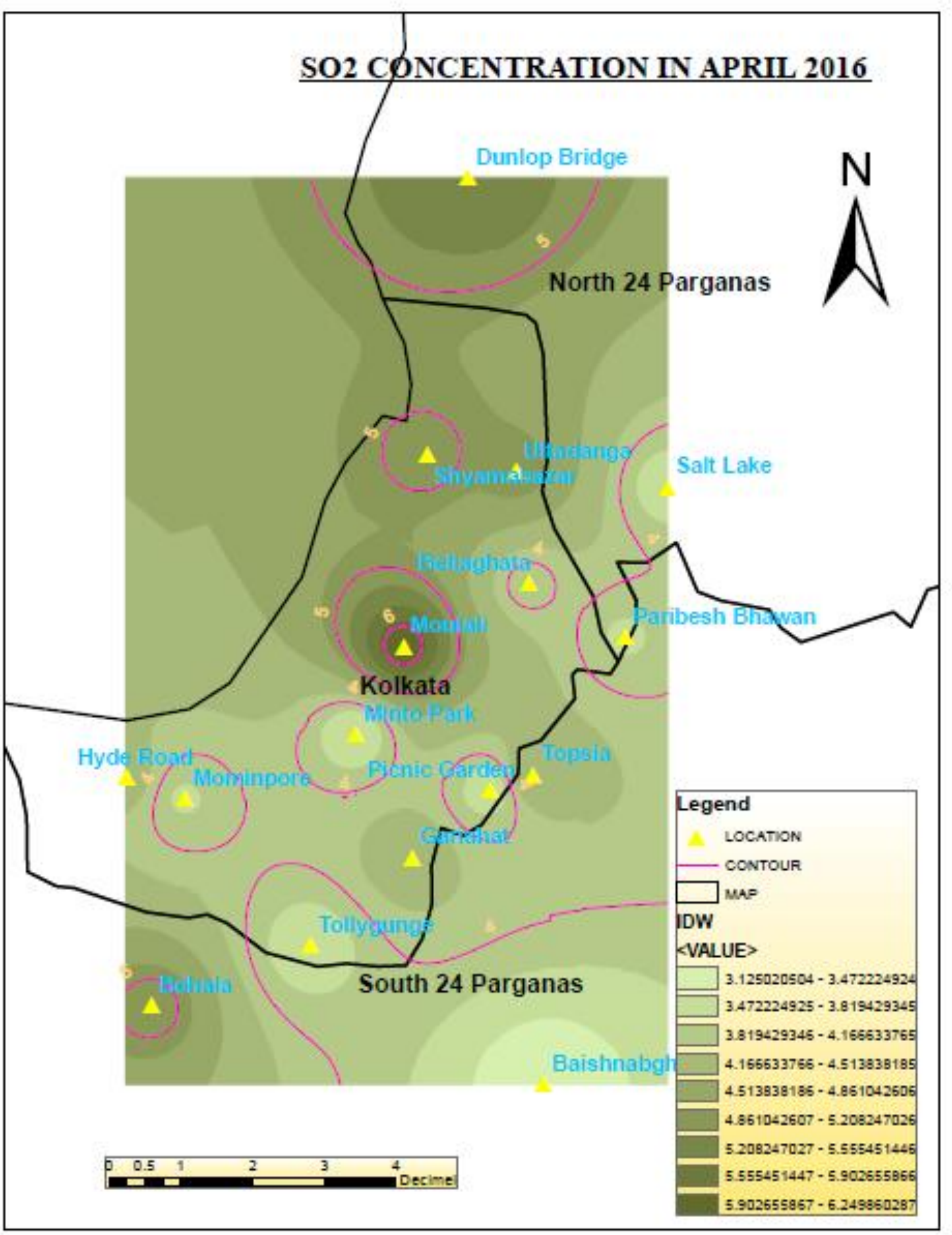

Figure 5.18: Contour map showing areas of high index of SO2 in April in Kolkata city

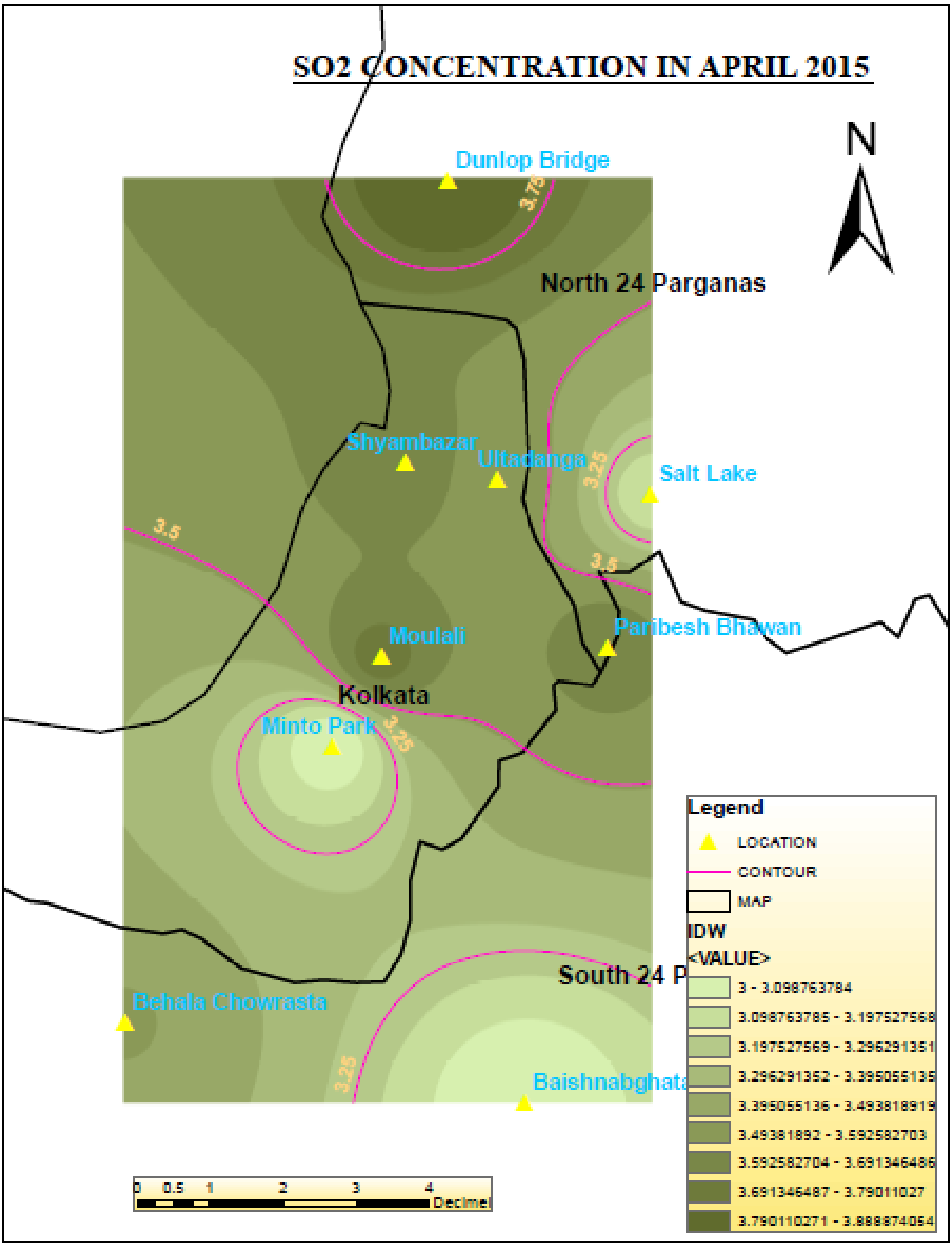

Figure 5.19: Contour map showing areas of high index of SO2 in April in Kolkata city

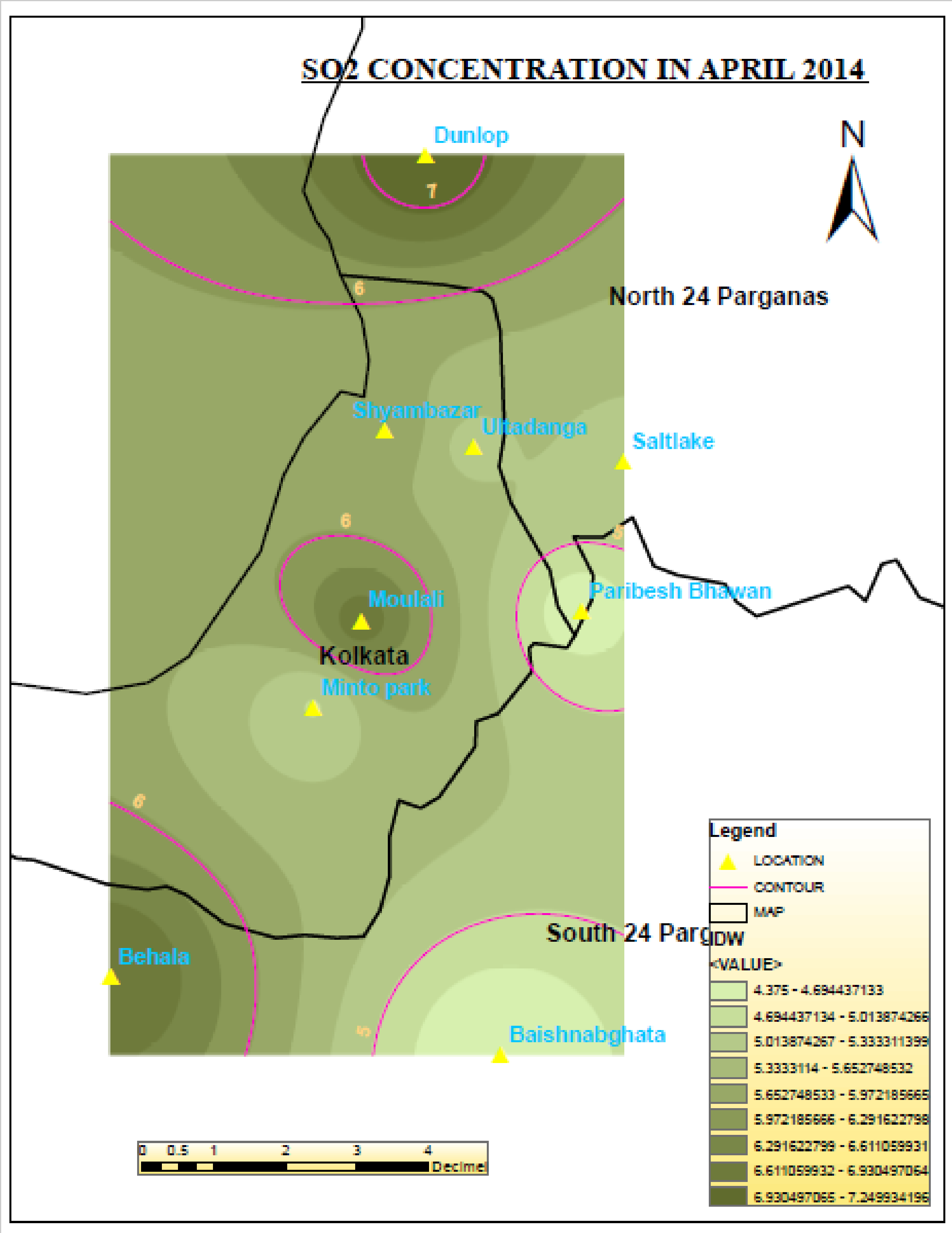

Figure 5.20: Contour map showing areas of high index of SO2 in April in Kolkata city

5.1.5 NO2 concentration in 2014 – 2018 (January) in Kolkata city

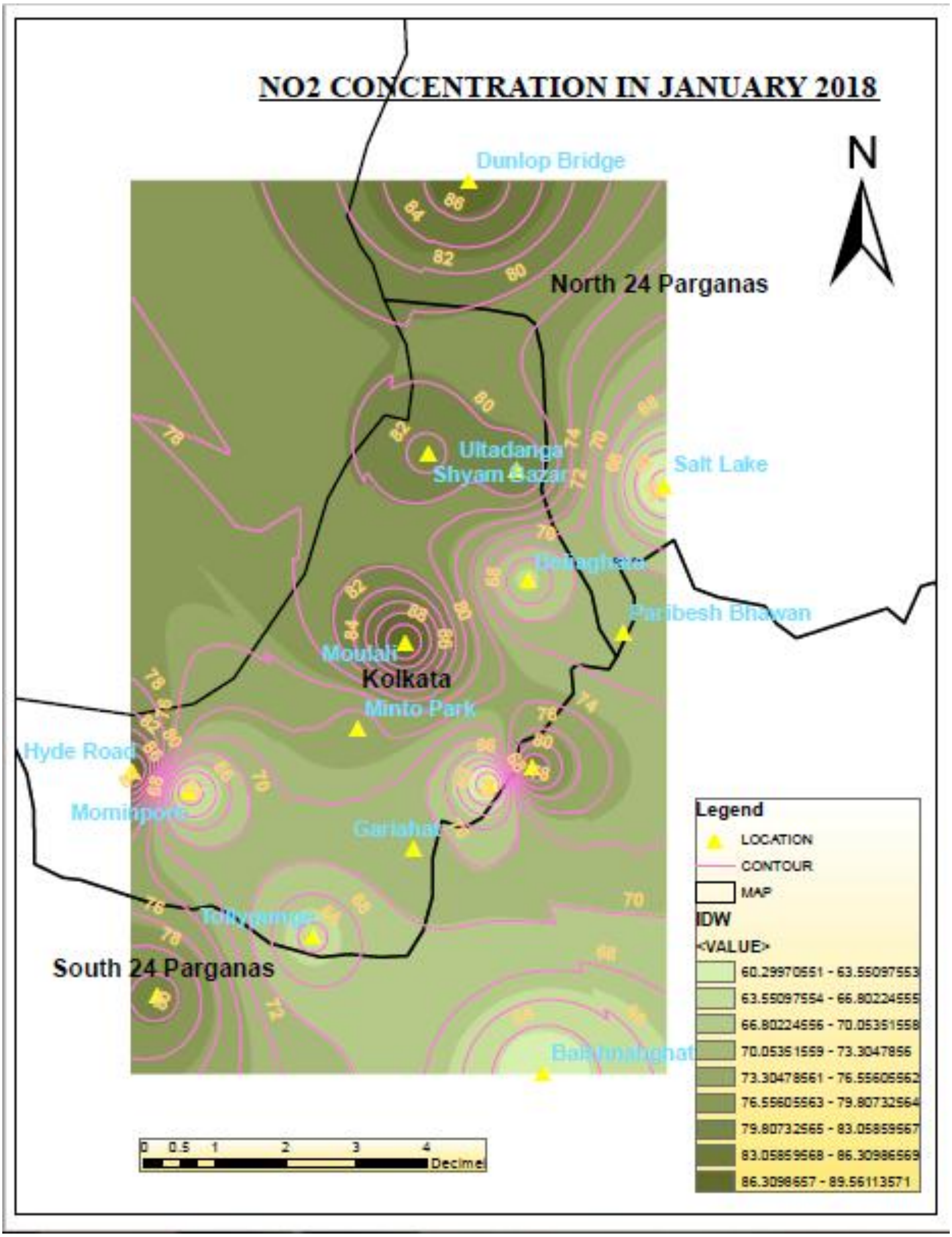

Figure 5.21: Contour map showing areas of high index of NO2 in January in Kolkata city

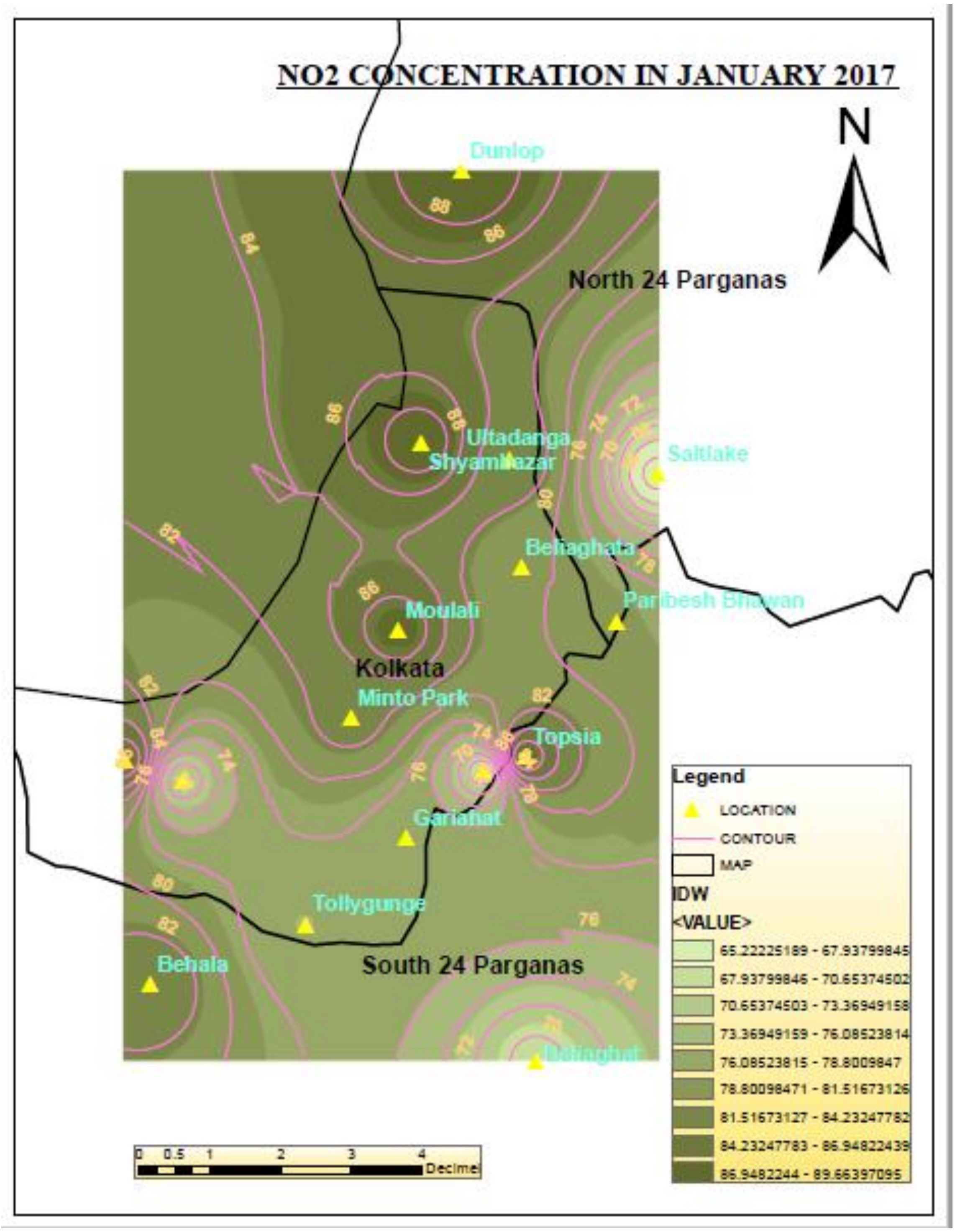

Figure 5.22: Contour map showing areas of high index of NO2 in January in Kolkata city

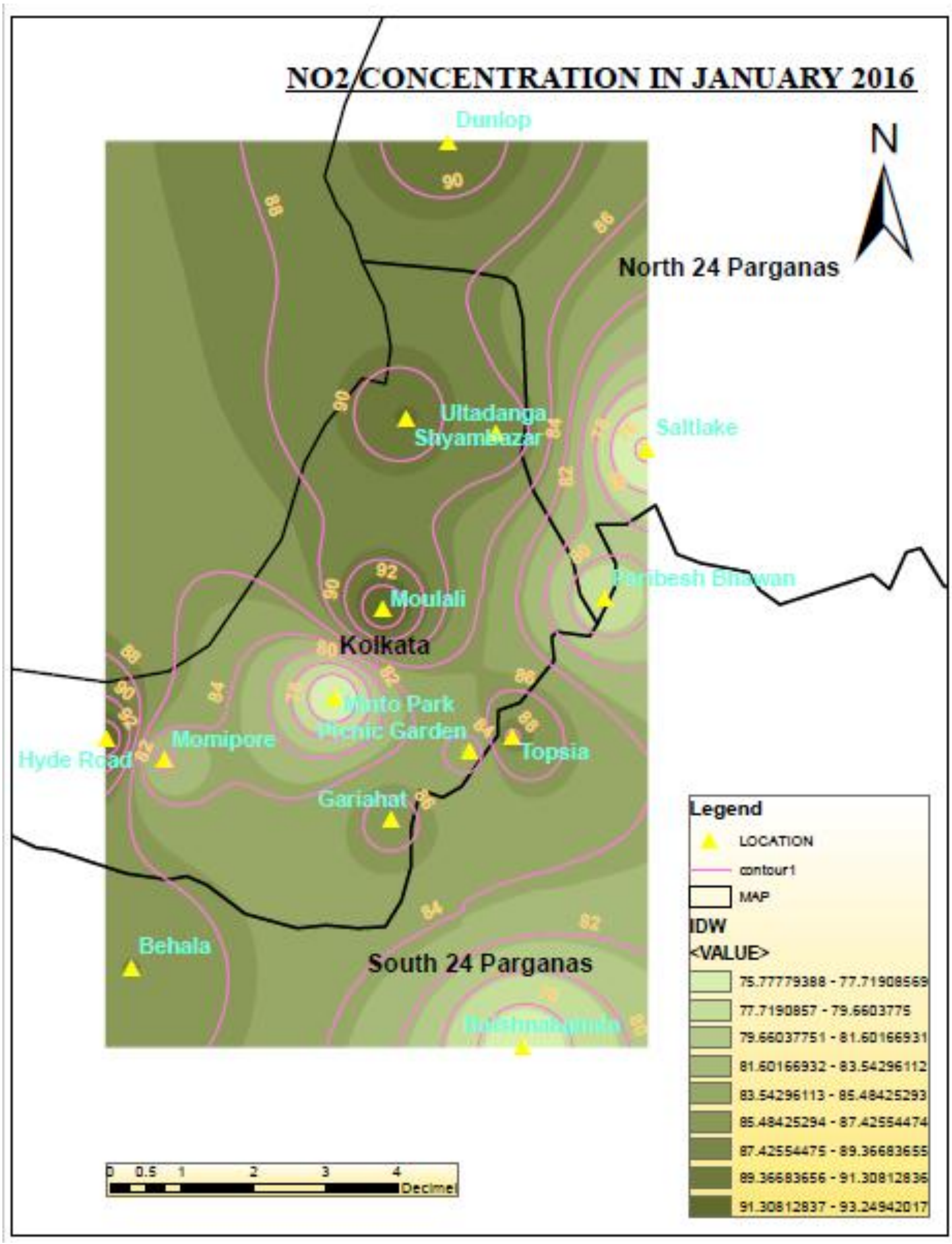

Figure 5.23: Contour map showing areas of high index of NO2 in January in Kolkata city

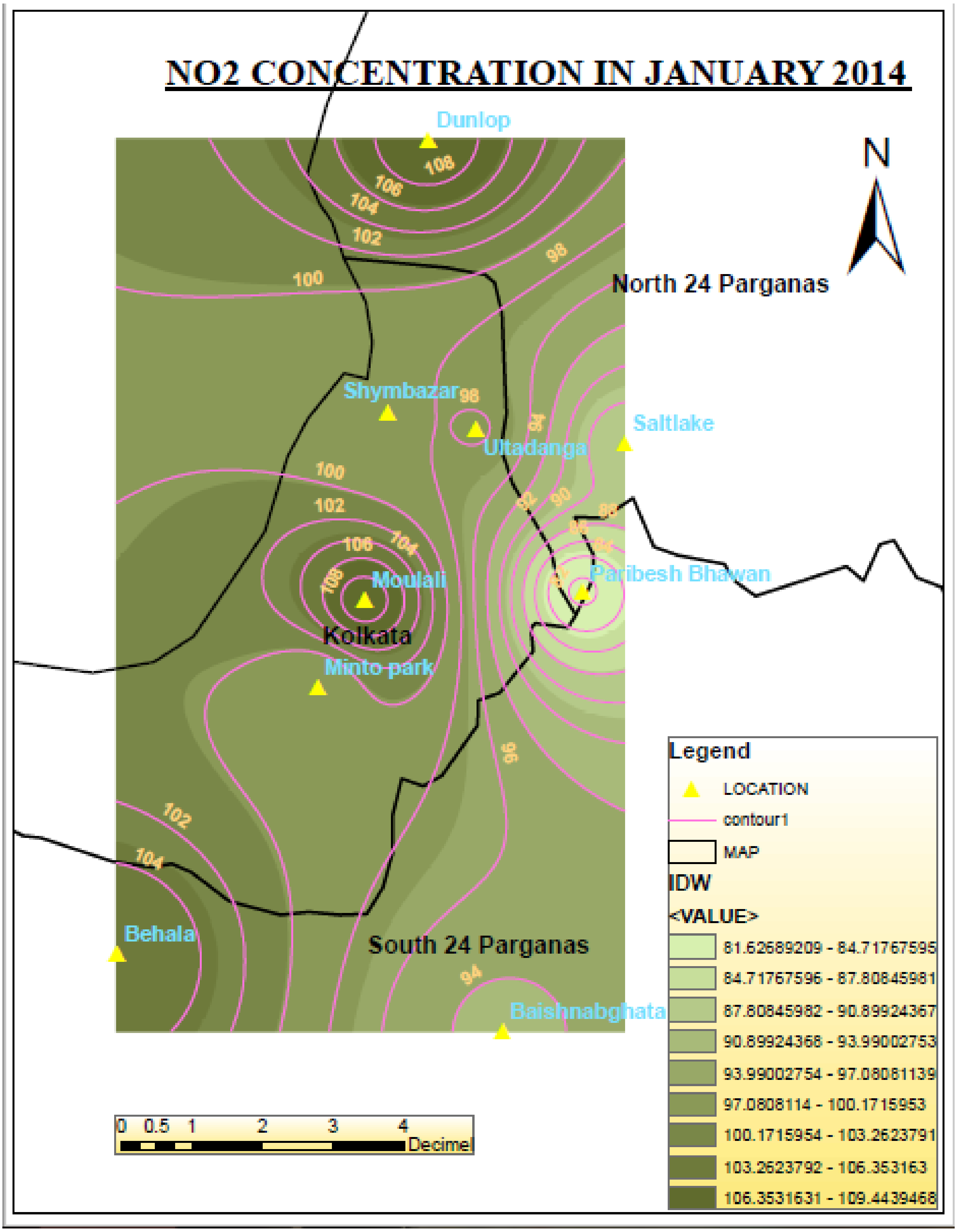

Figure 5.24: Contour map showing areas of high index of NO2 in January in Kolkata city

5.1.6 NO2 concentration in 2014 – 2018 (February) in Kolkata city

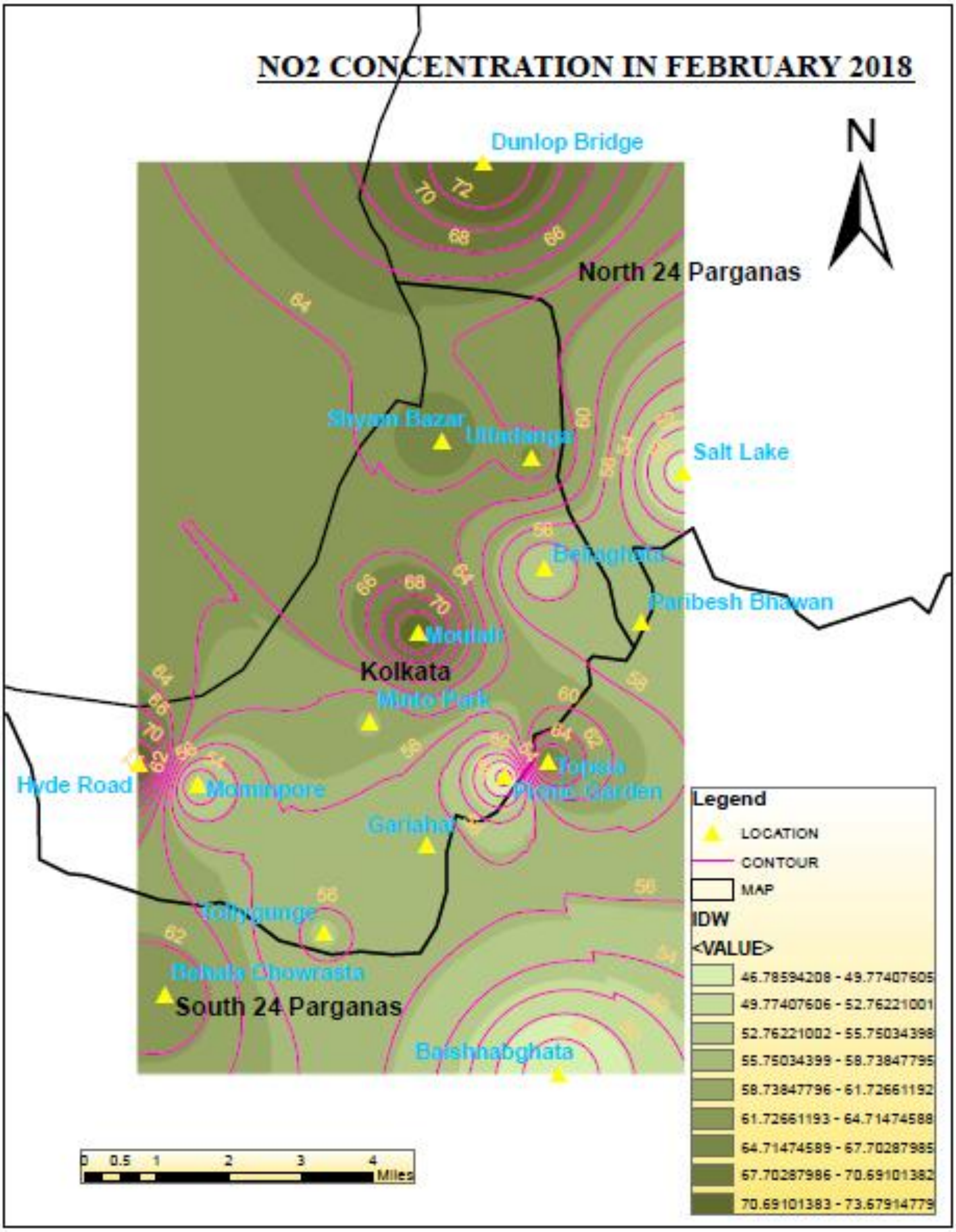

Figure 5.25: Contour map showing areas of high index of NO2 in February in Kolkata city

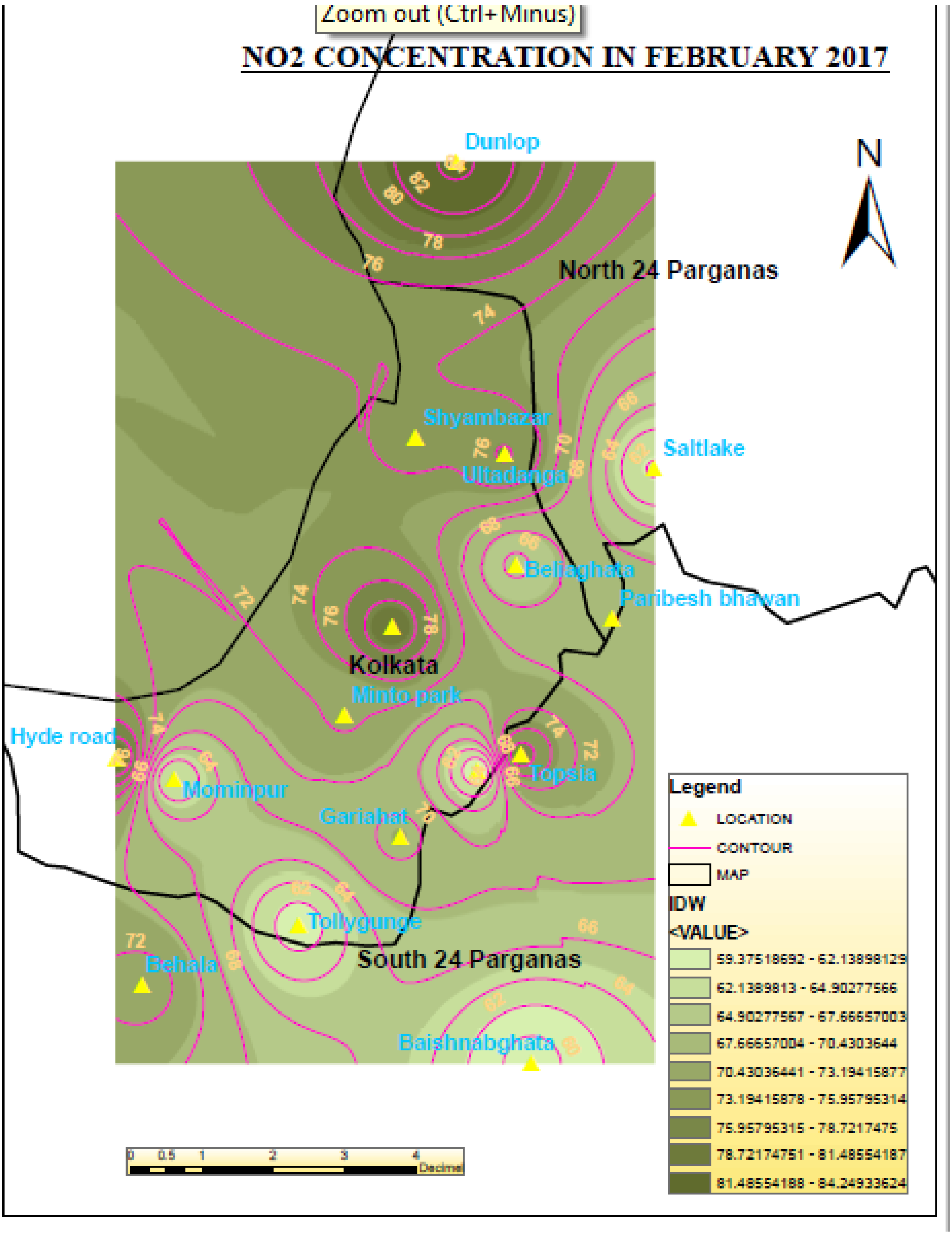

Figure 5.26: Contour map showing areas of high index of NO2 in February in Kolkata city

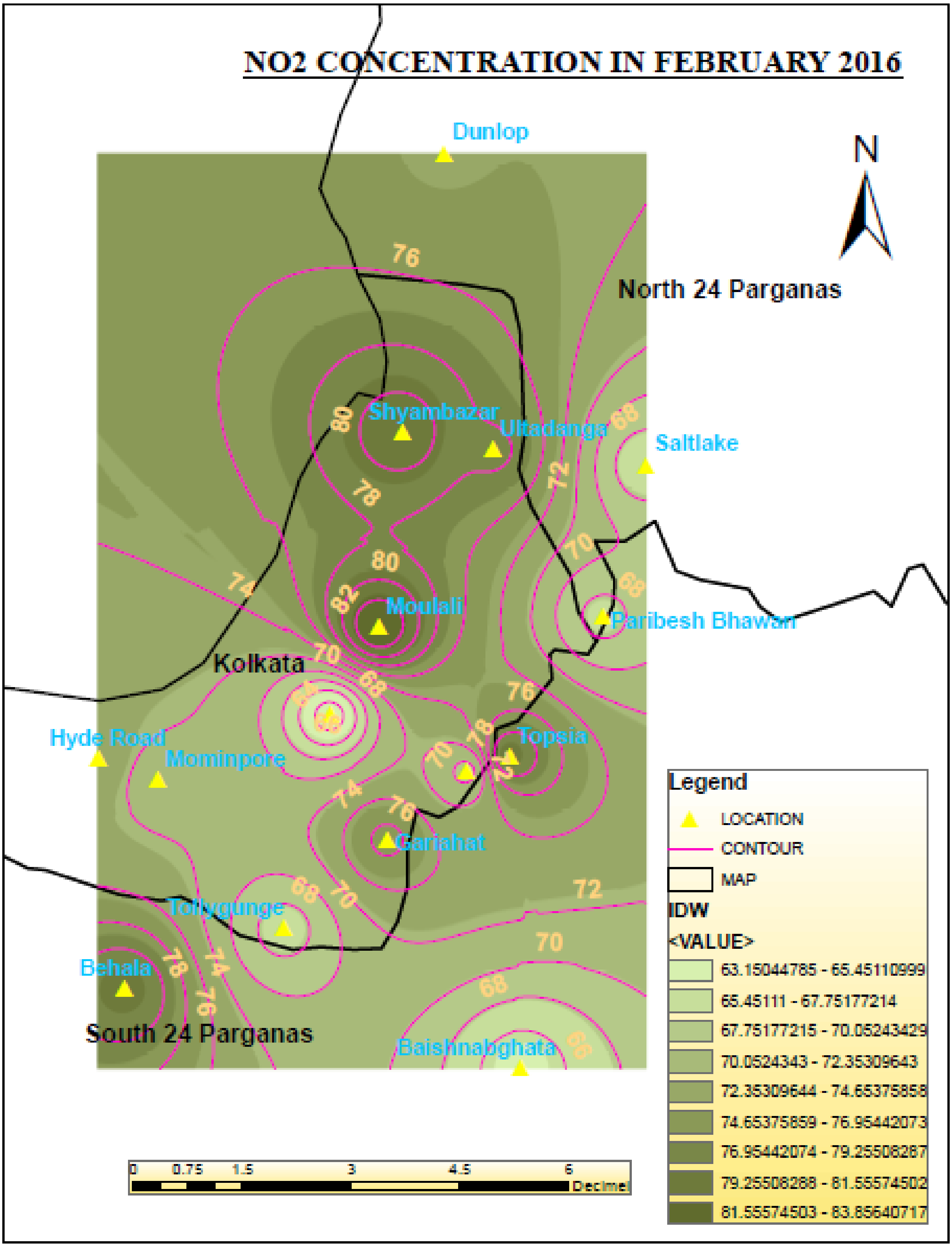

Figure 5.27: Contour map showing areas of high index of NO2 in February in Kolkata city

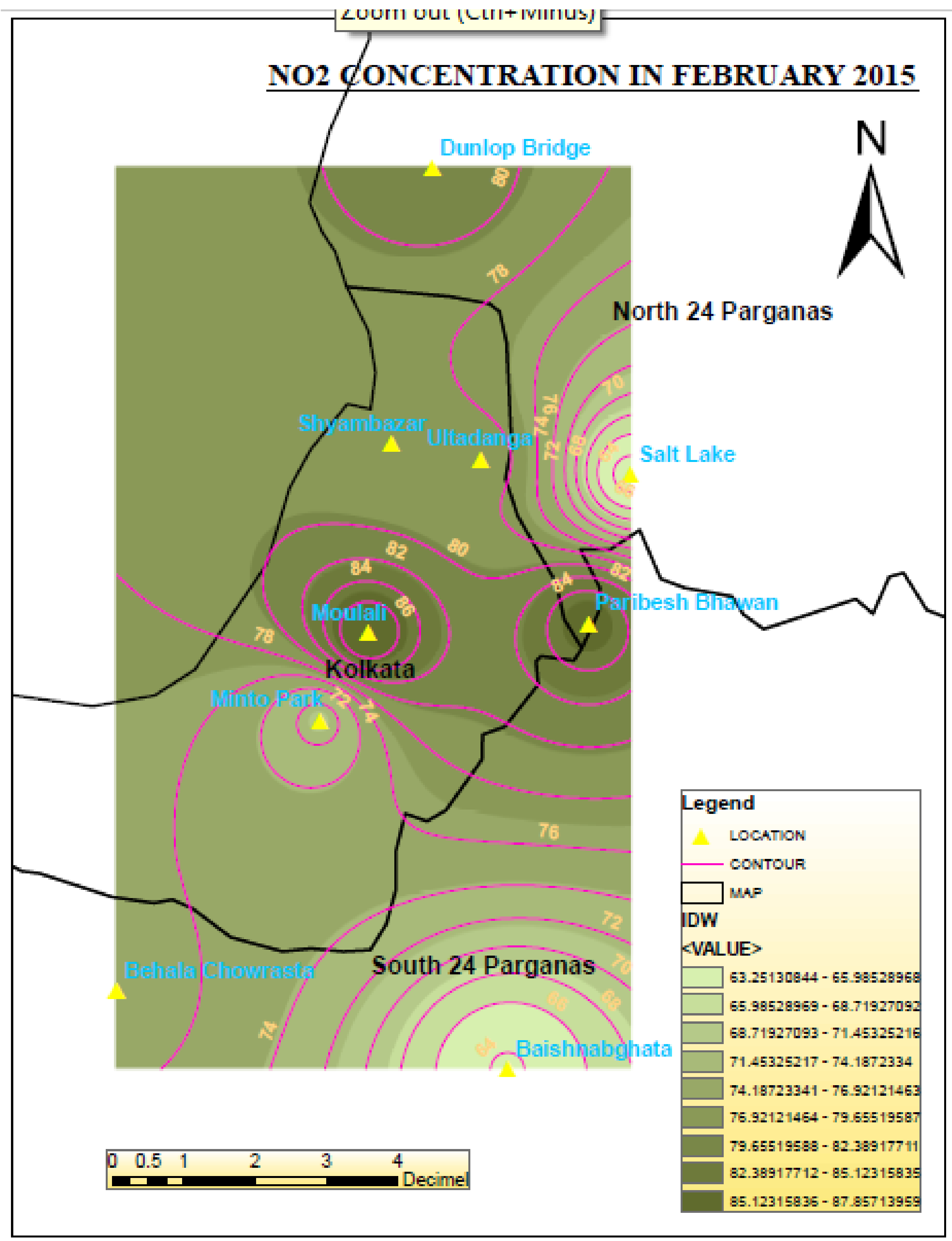

Figure 5.27: Contour map showing areas of high index of NO2 in February in Kolkata city

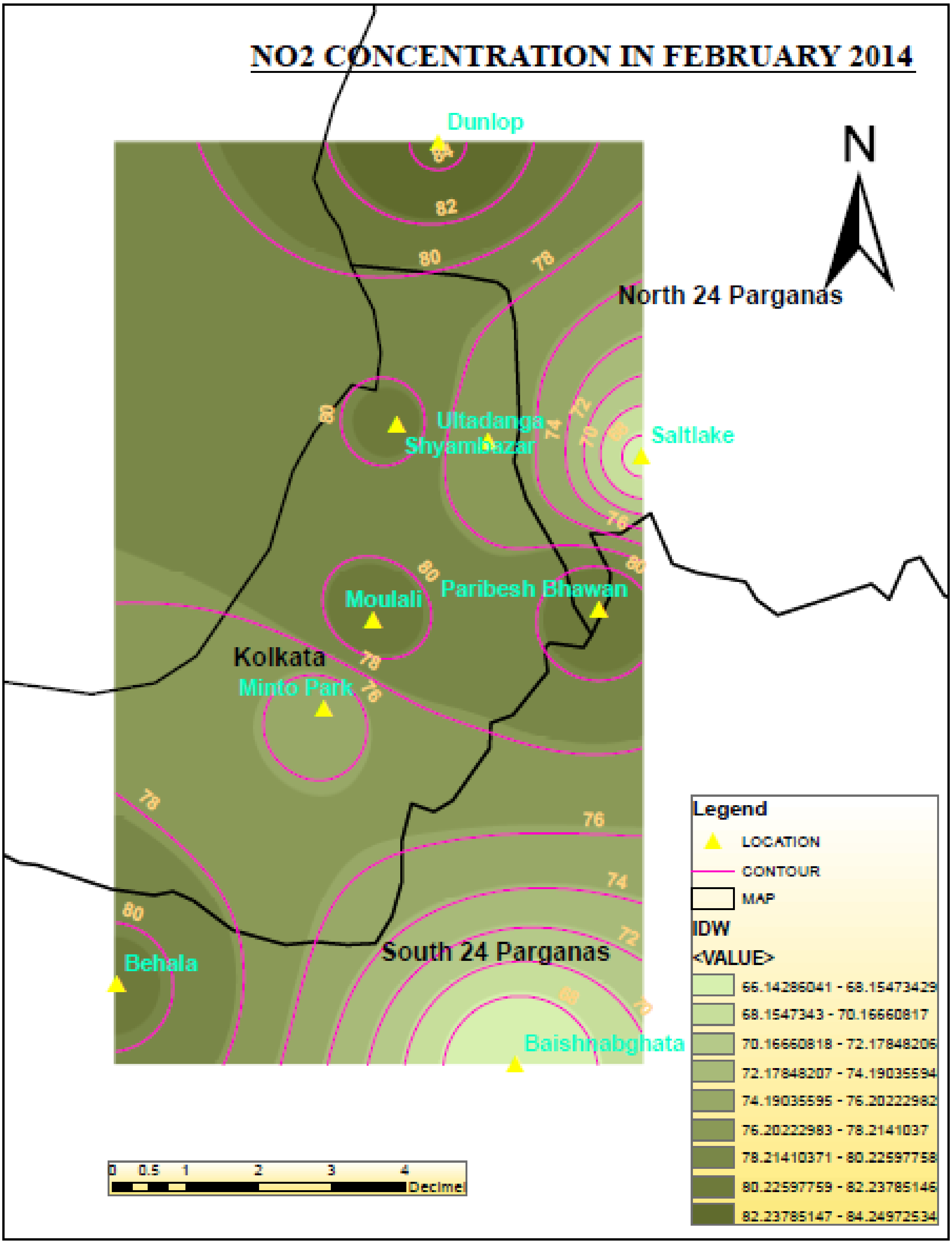

Figure 5.28: Contour map showing areas of high index of NO2 in February in Kolkata city

5.1.6 NO2 concentration in 2014 – 2018 (March) in Kolkata city

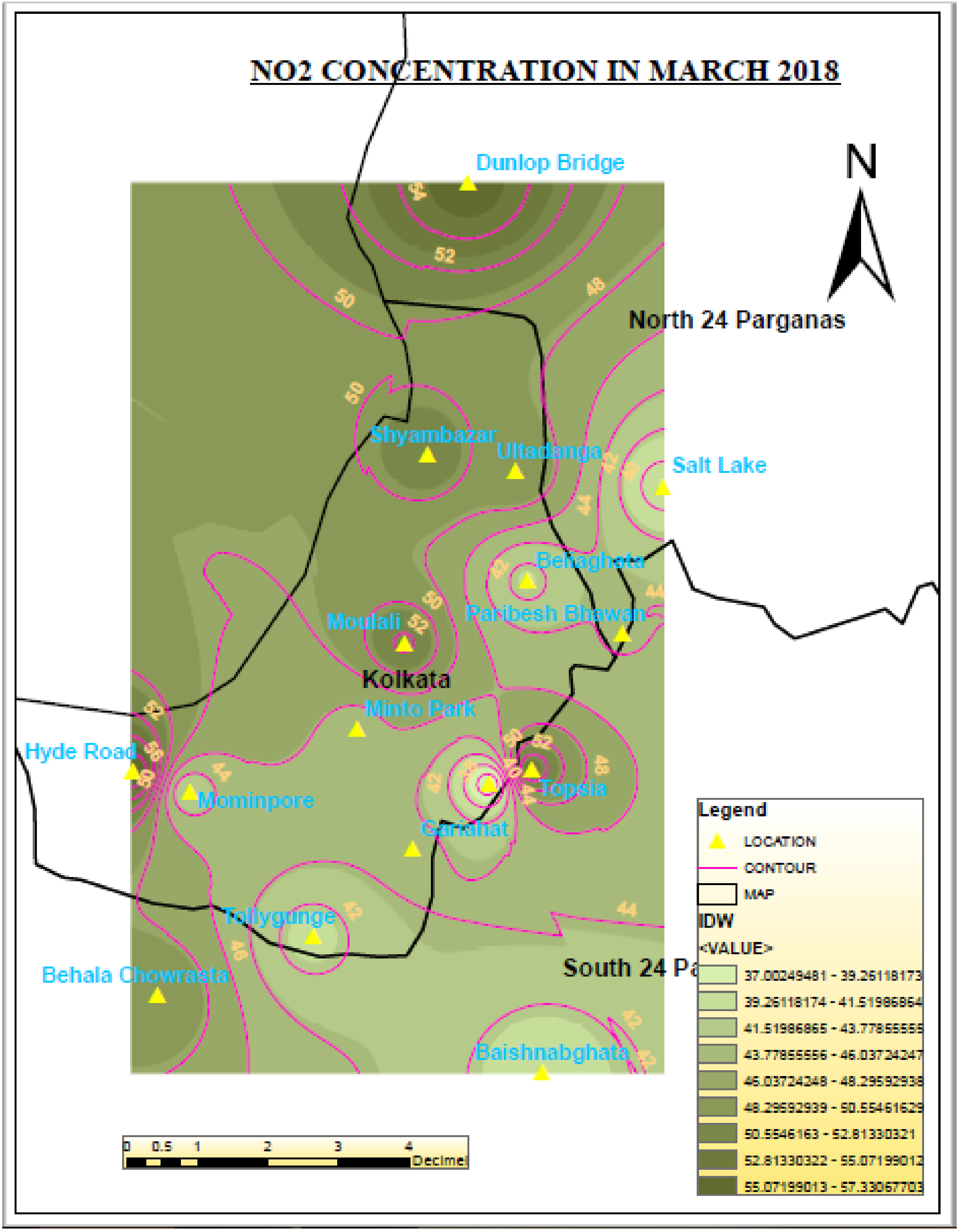

Figure 5.29: Contour map showing areas of high index of NO2 in March in Kolkata city

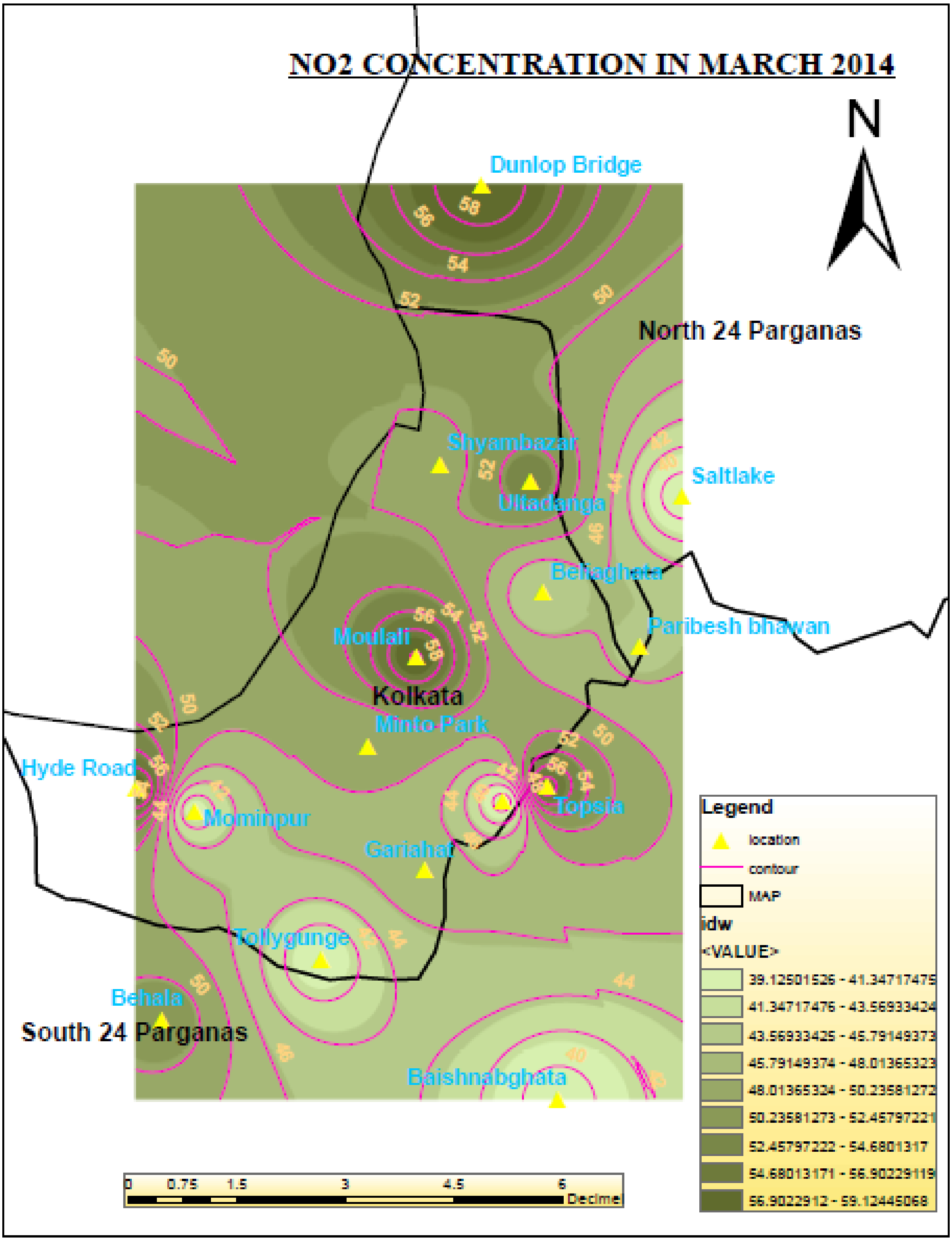

Figure 5.30: Contour map showing areas of high index of NO2 in March in Kolkata city

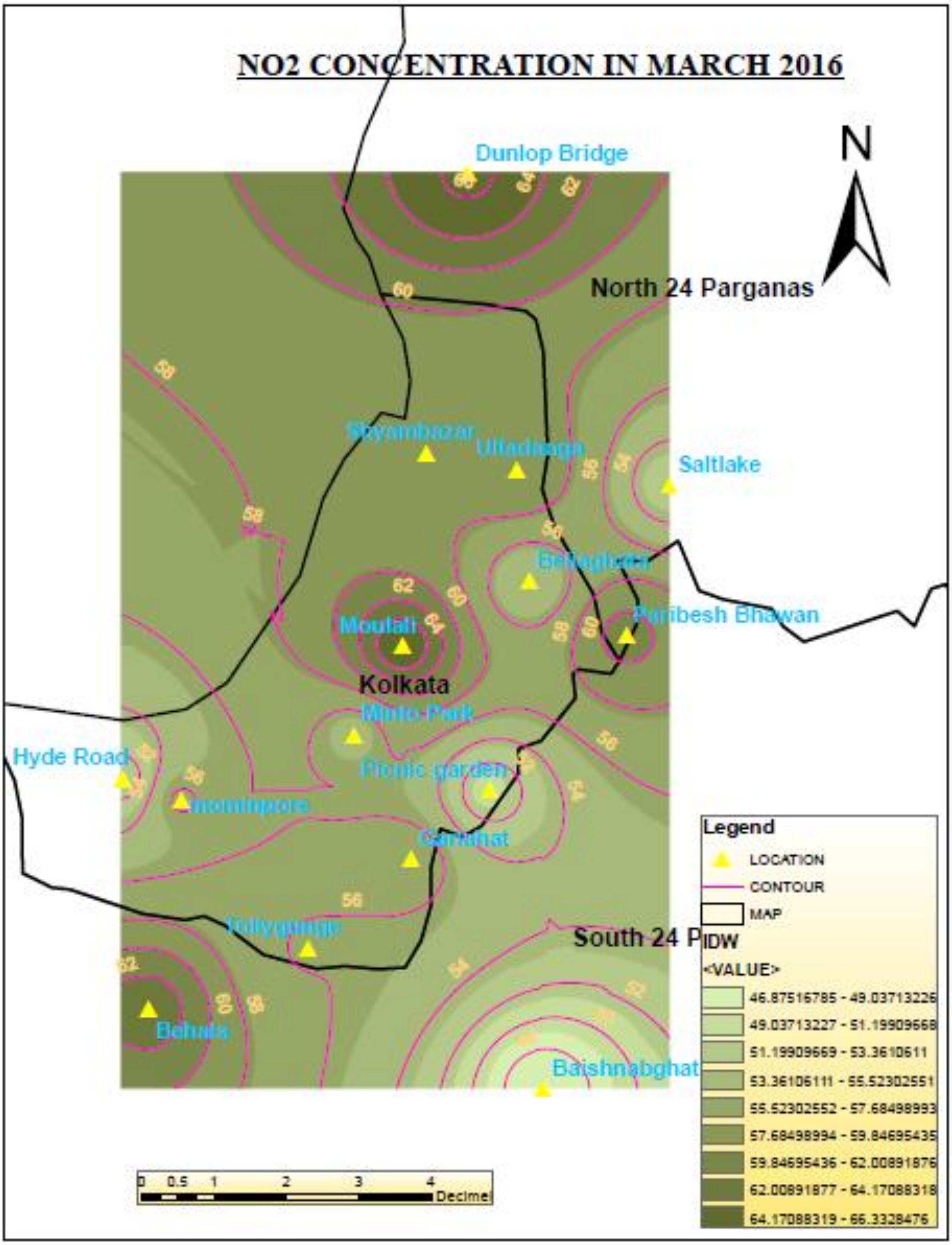

Figure 5.31: Contour map showing areas of high index of NO2 in March in Kolkata city

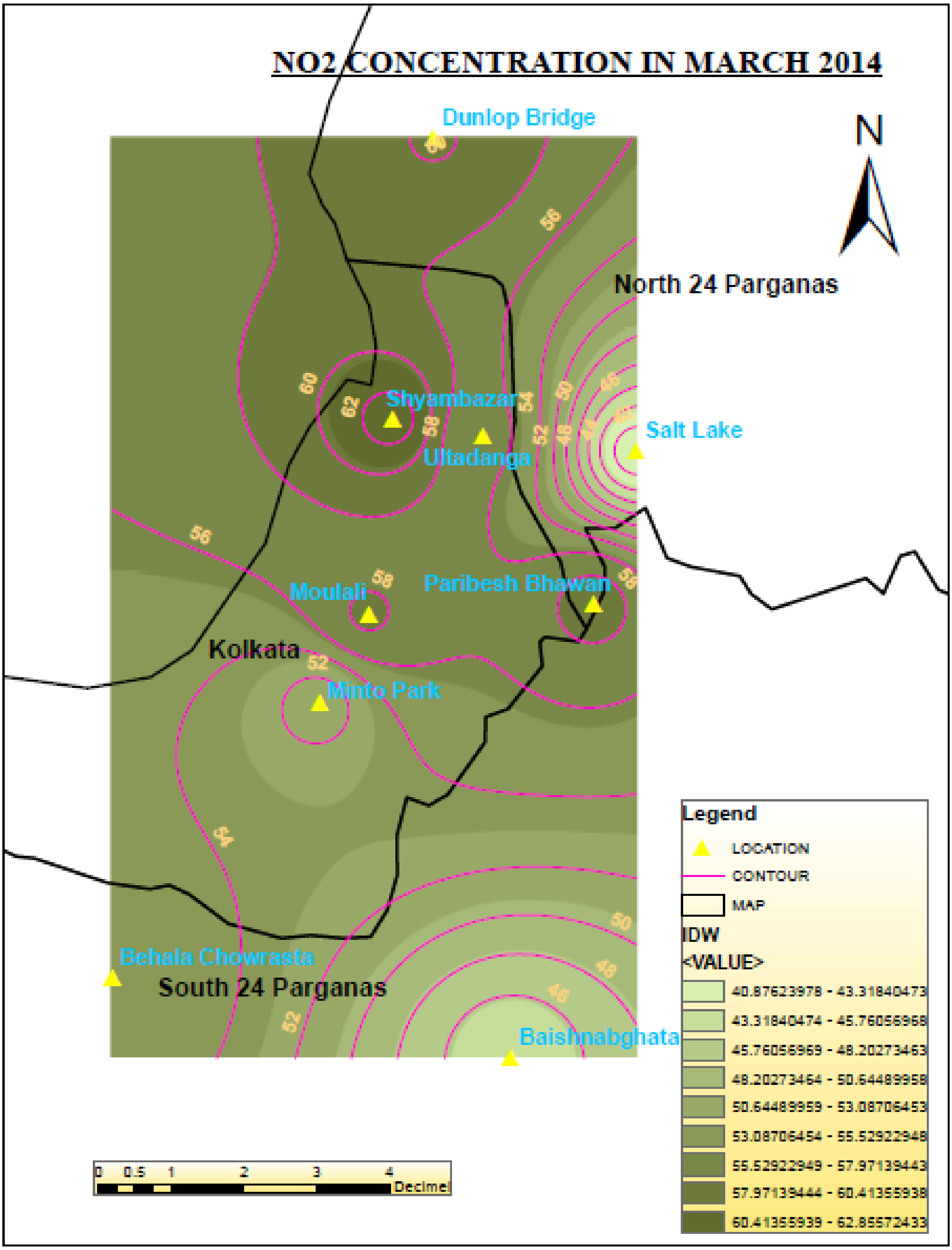

Figure 5.32: Contour map showing areas of high index of NO2 in March in Kolkata city

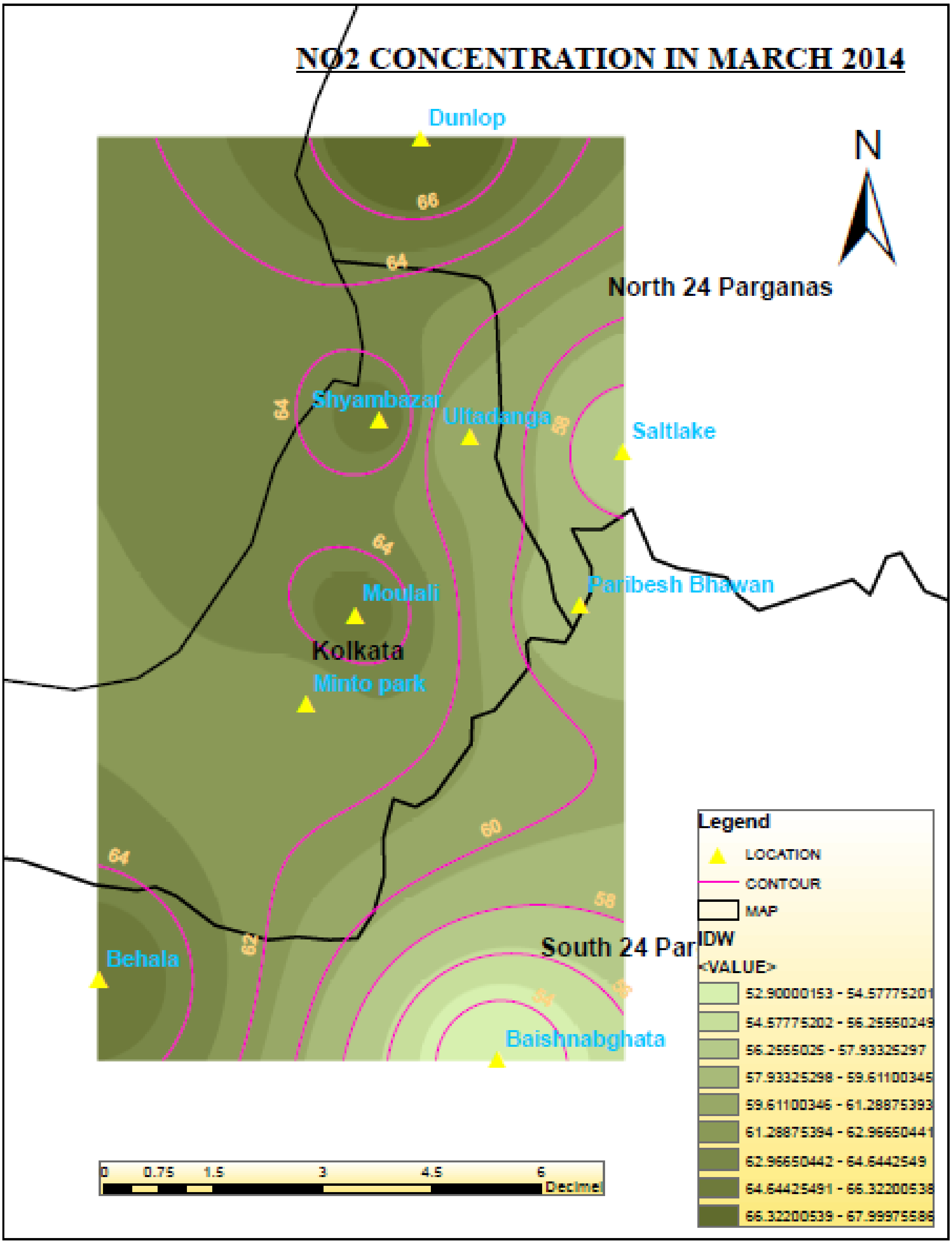

Figure 5.33: Contour map showing areas of high index of NO2 in March in Kolkata city

5.1.7 NO2 concentration in 2014 – 2018 (April) in Kolkata city

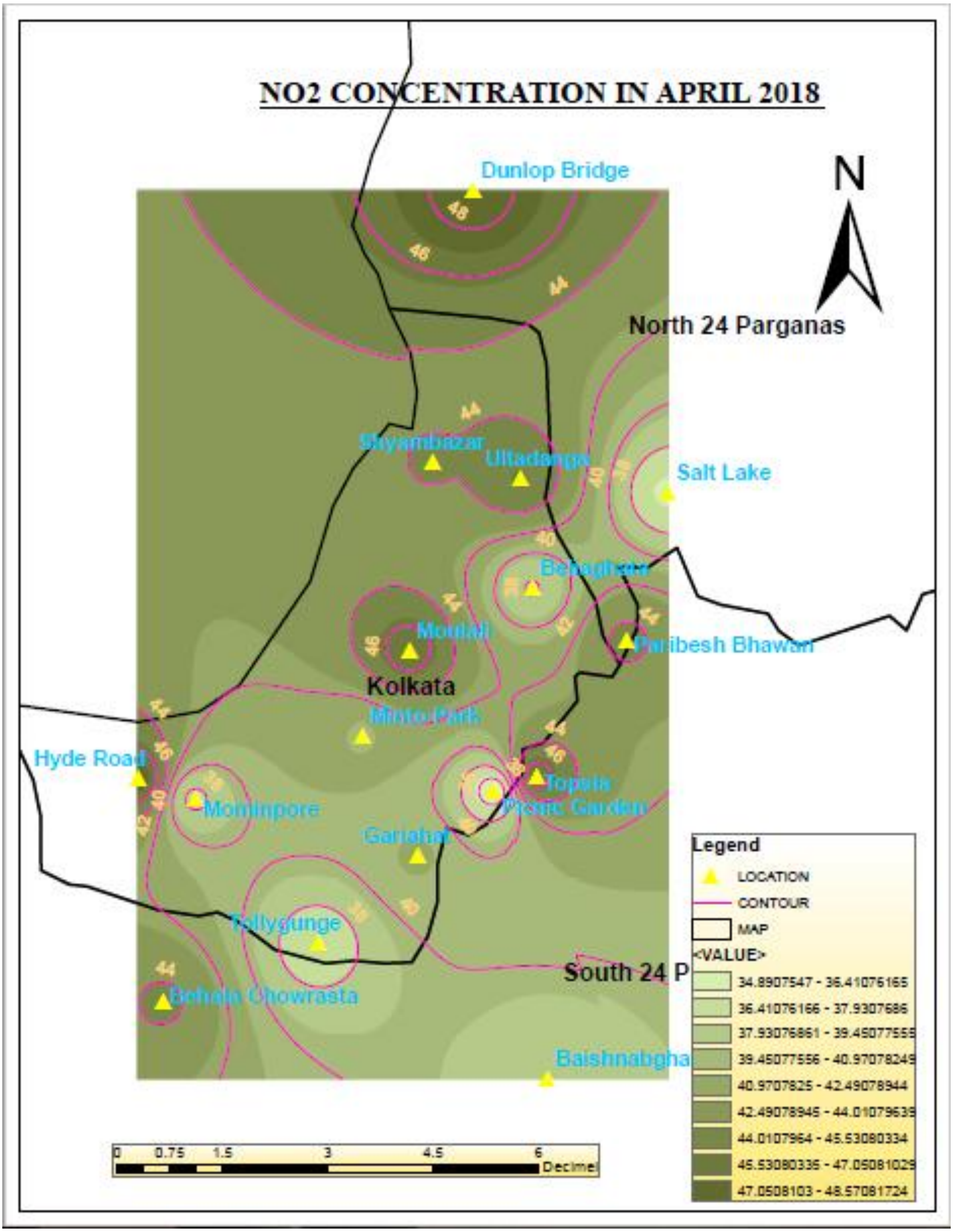

Figure 5.34: Contour map showing areas of high index of NO2 in April in Kolkata city

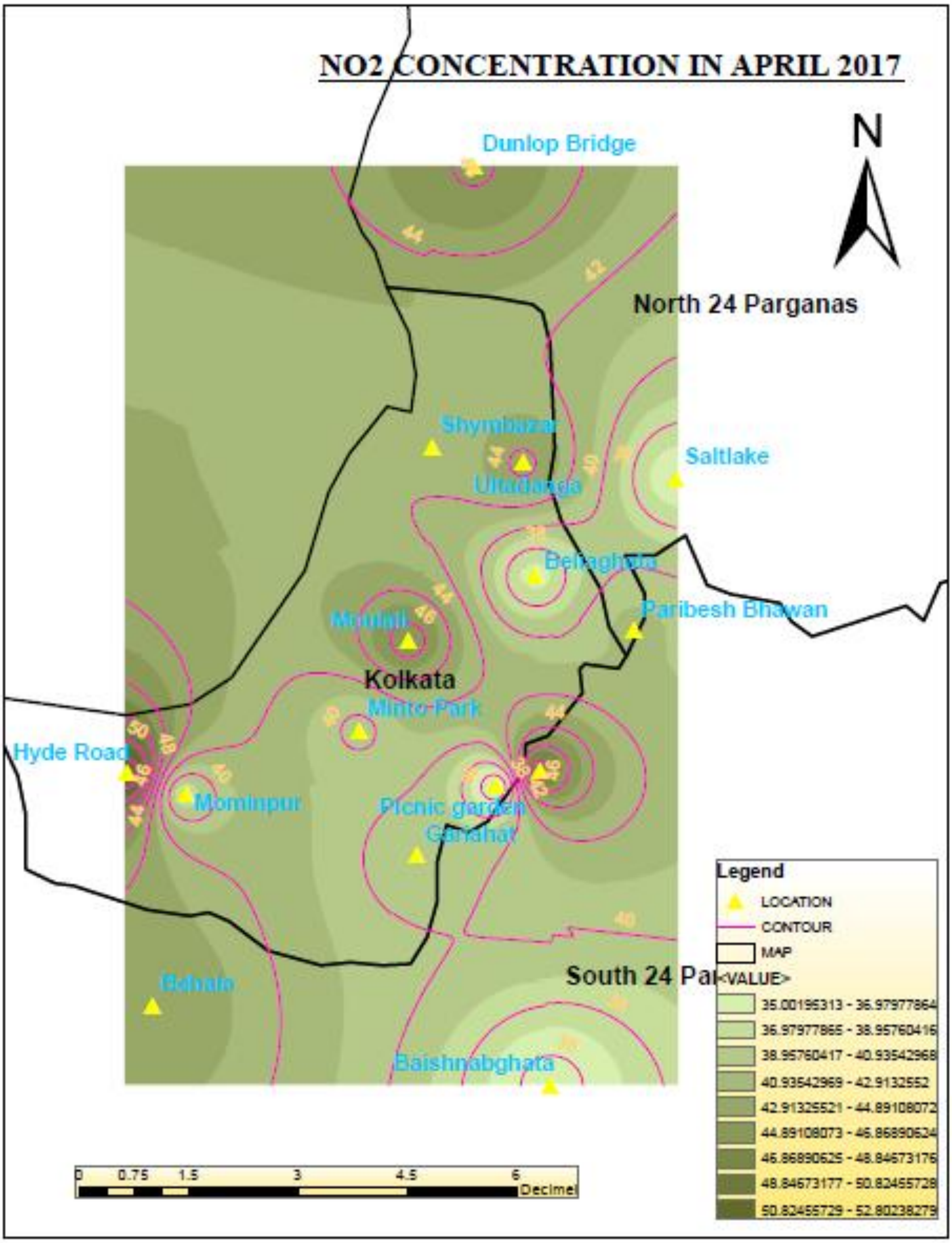

Figure 5.35: Contour map showing areas of high index of NO2 in April in Kolkata city

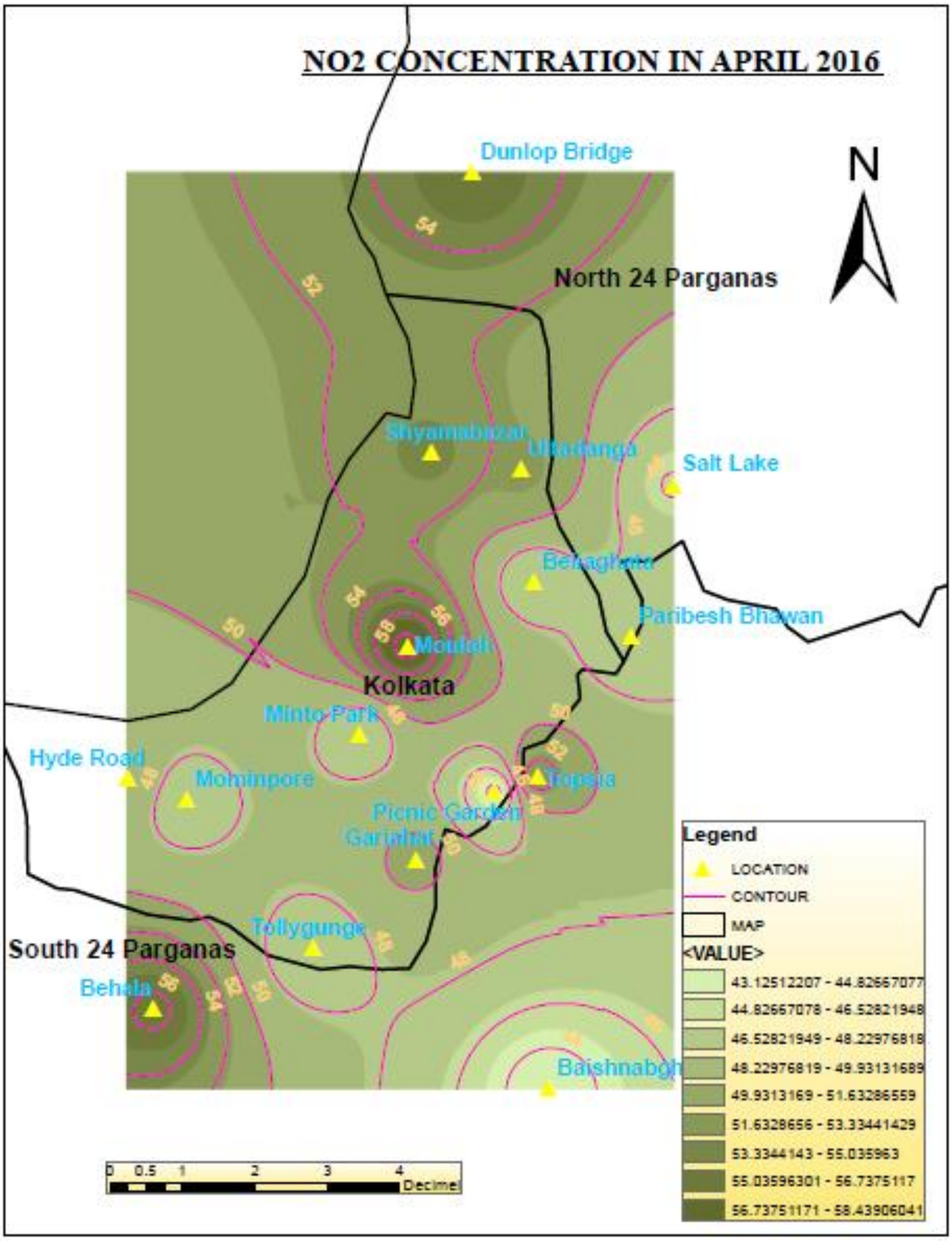

Figure 5.36: Contour map showing areas of high index of NO2 in April in Kolkata city

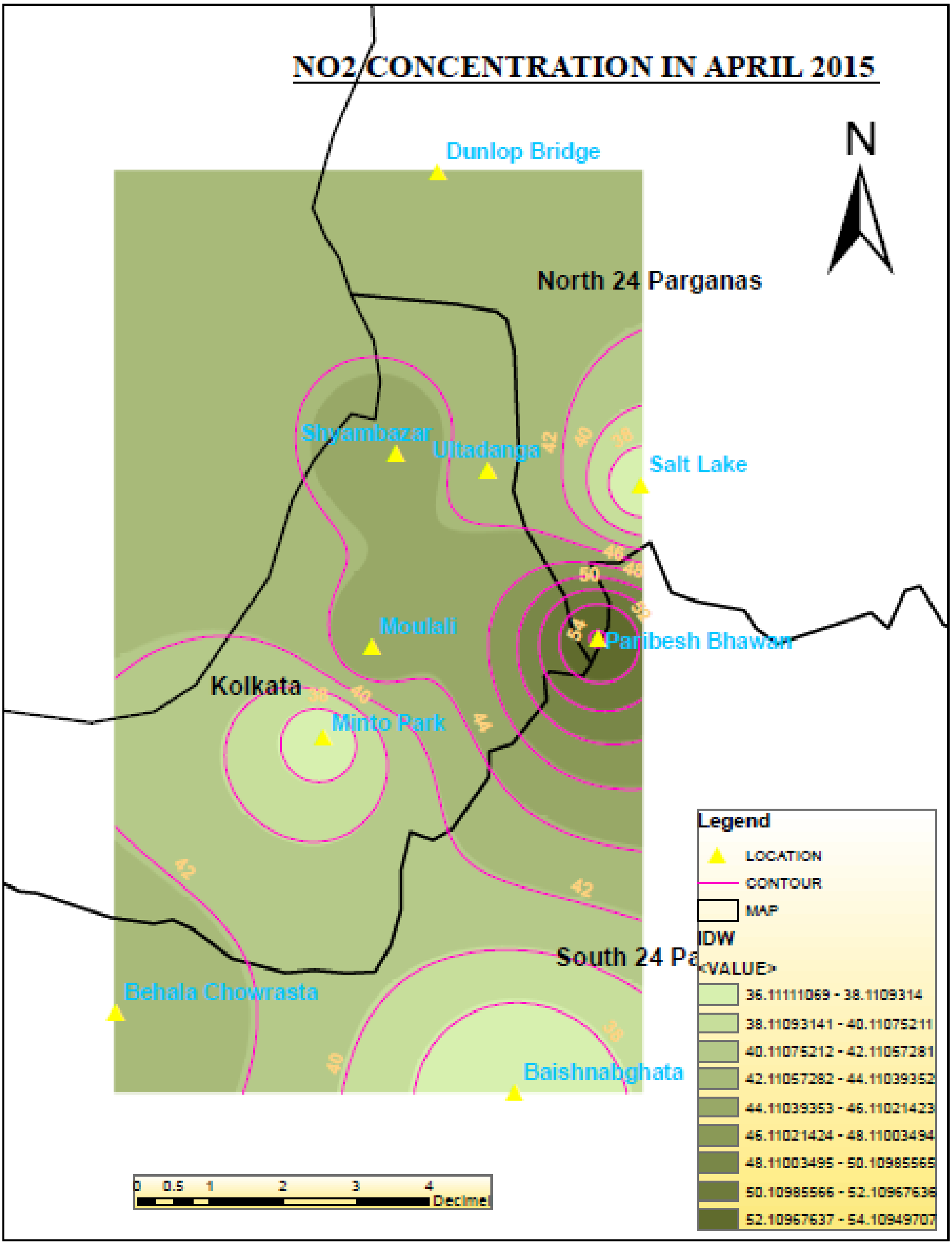

Figure 5.37: Contour map showing areas of high index of NO2 in April in Kolkata city

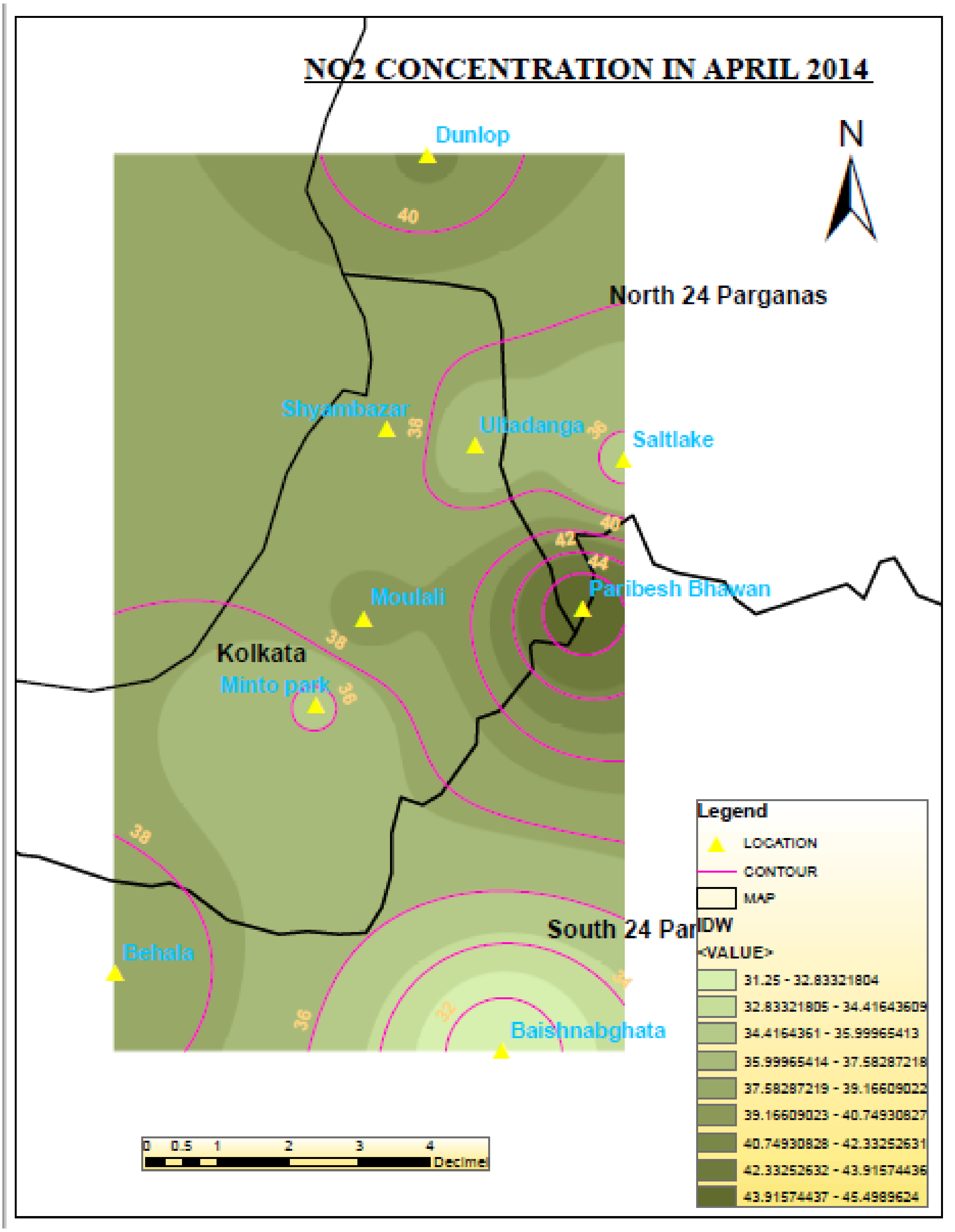

Figure 5.38: Contour map showing areas of high index of NO2 in April in Kolkata city

5.1.8 PM10 concentration in 2014 – 2018 (January) in Kolkata city

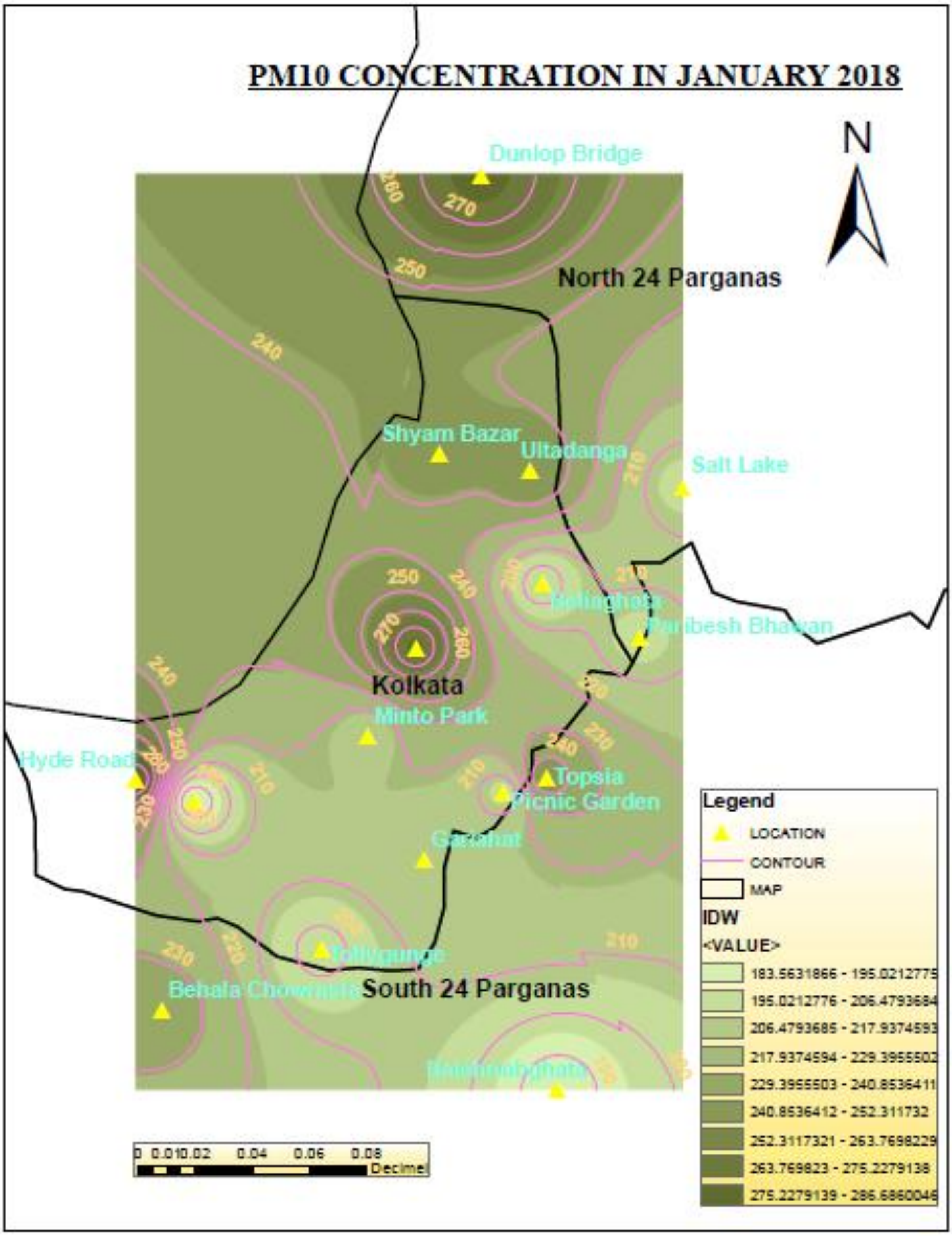

Figure 5.39: Contour map showing areas of high index of PM10 in January in Kolkata city

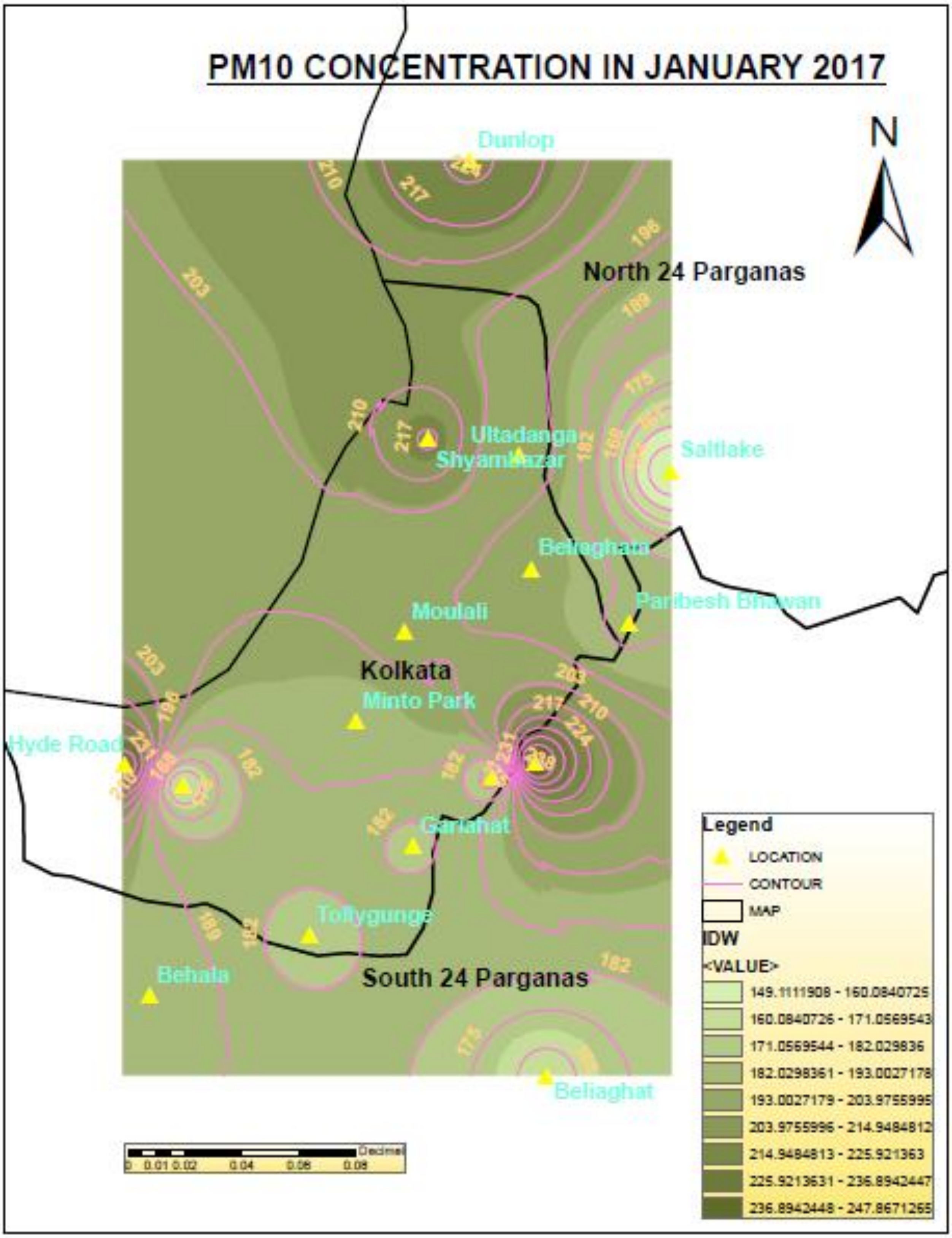

Figure 5.40: Contour map showing areas of high index of PM10 in January in Kolkata city

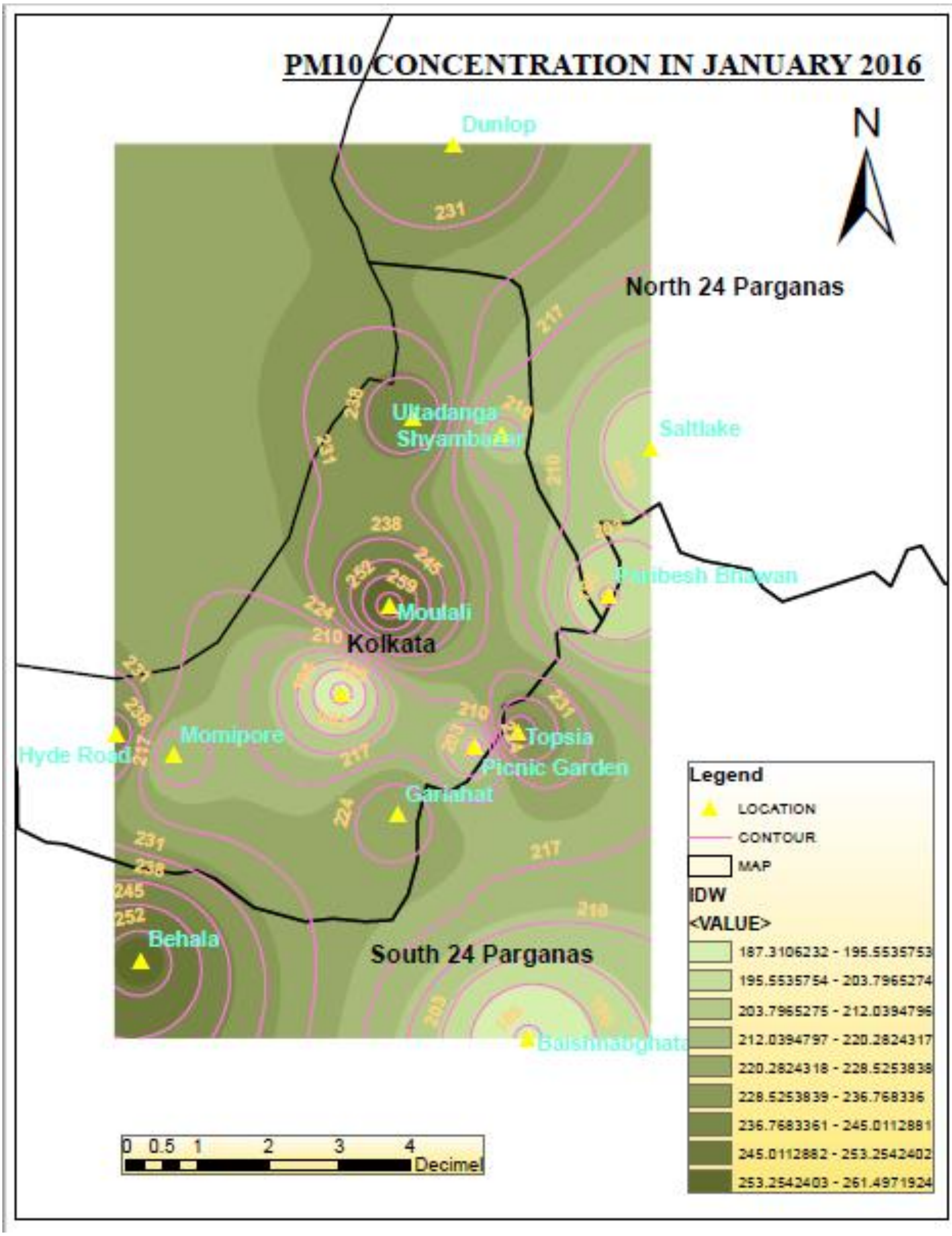

Figure 5.41: Contour map showing areas of high index of PM10 in January in Kolkata city

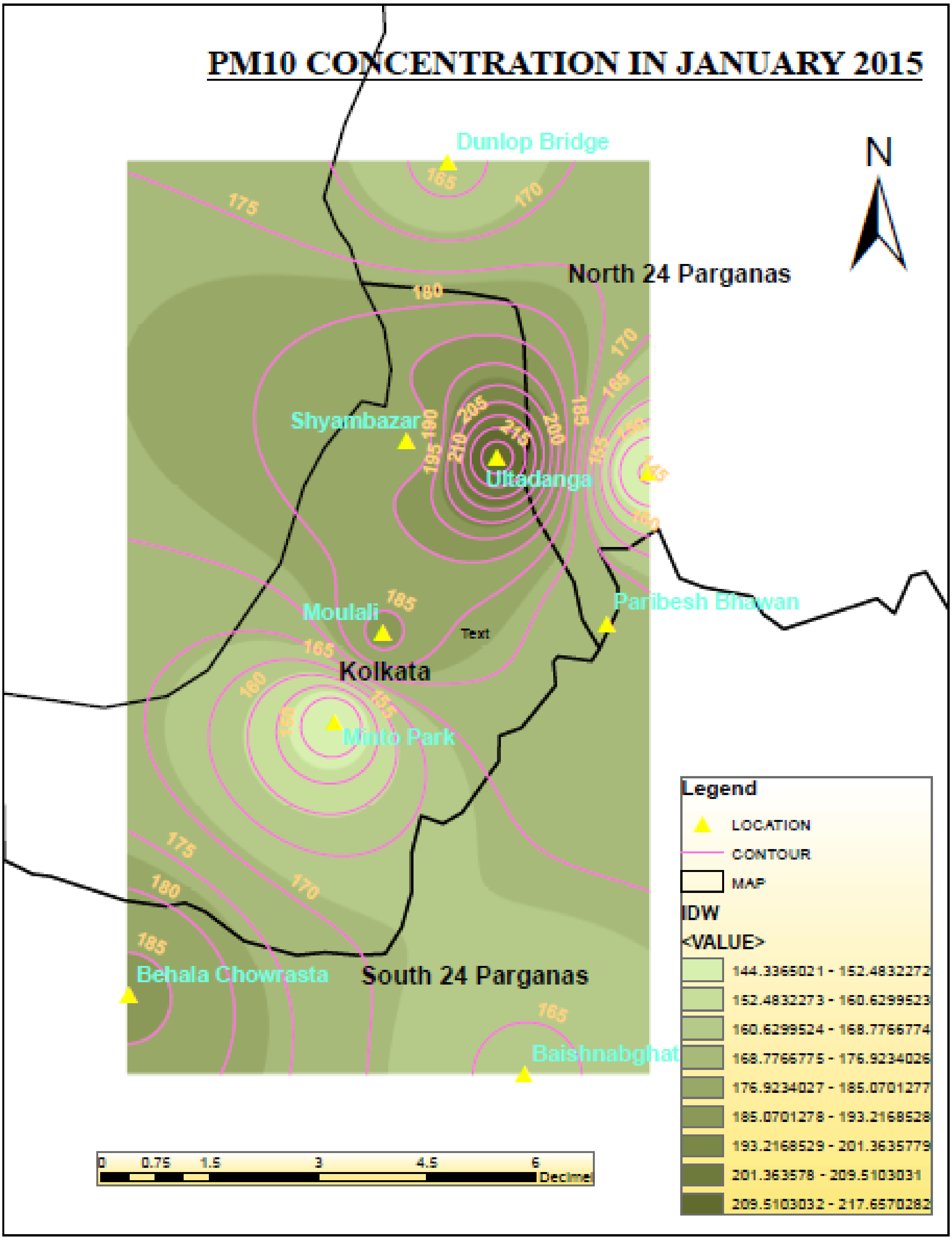

Figure 5.42: Contour map showing areas of high index of PM10 in January in Kolkata city

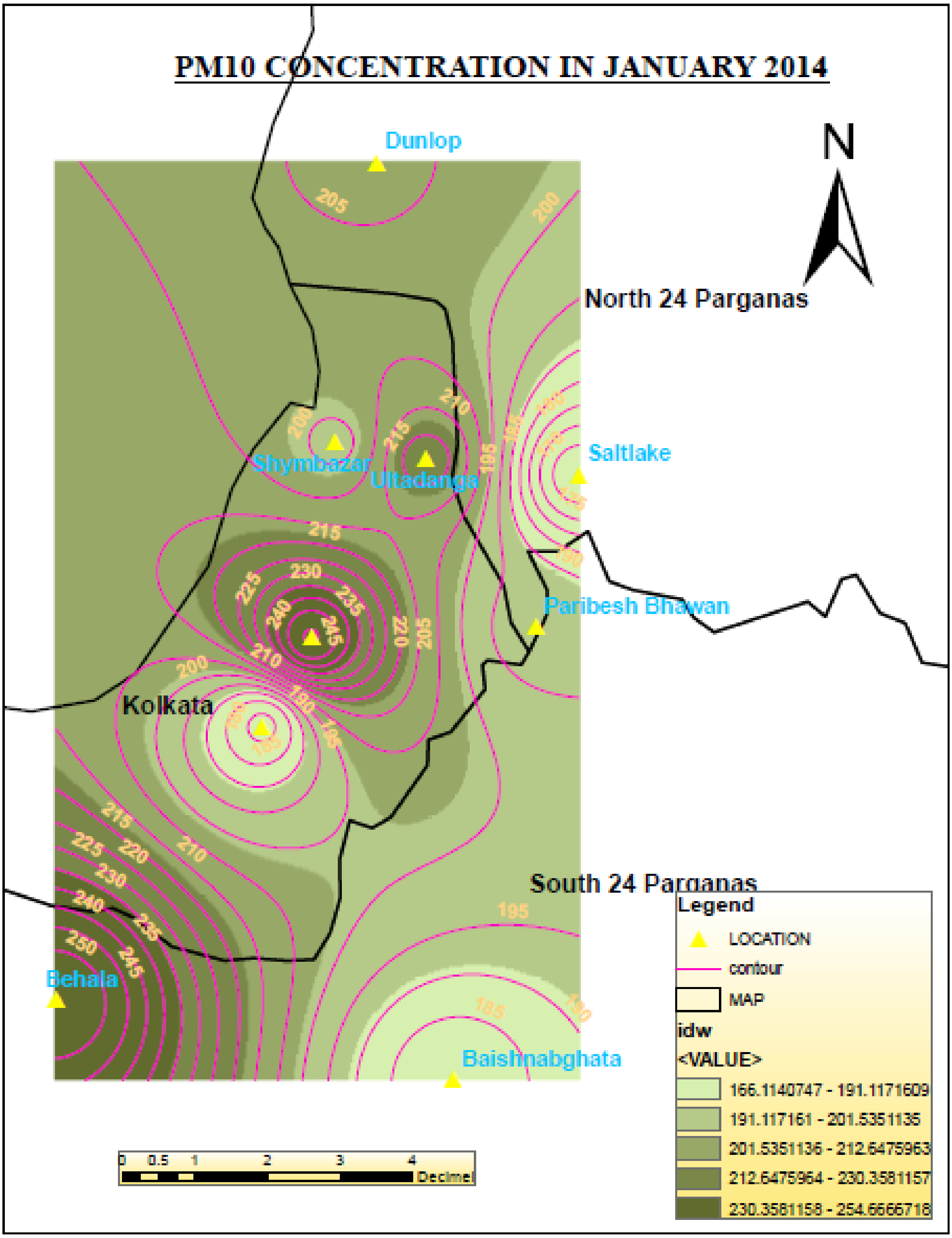

Figure 5.43: Contour map showing areas of high index of PM10 in January in Kolkata city

5.1.9 PM10 concentration in 2014 – 2018 (February) in Kolkata city

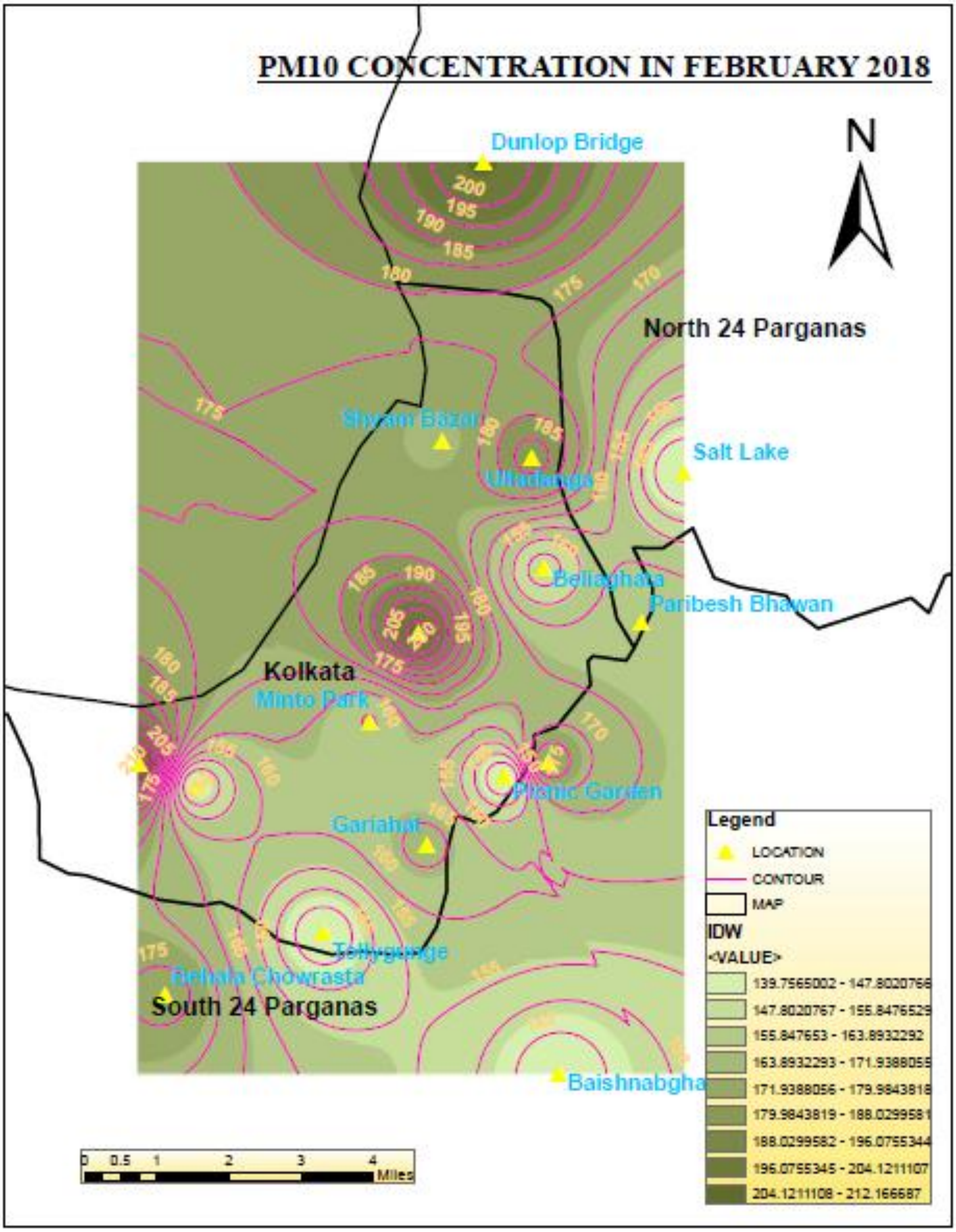

Figure 5.44: Contour map showing areas of high index of PM10 in February in Kolkata city

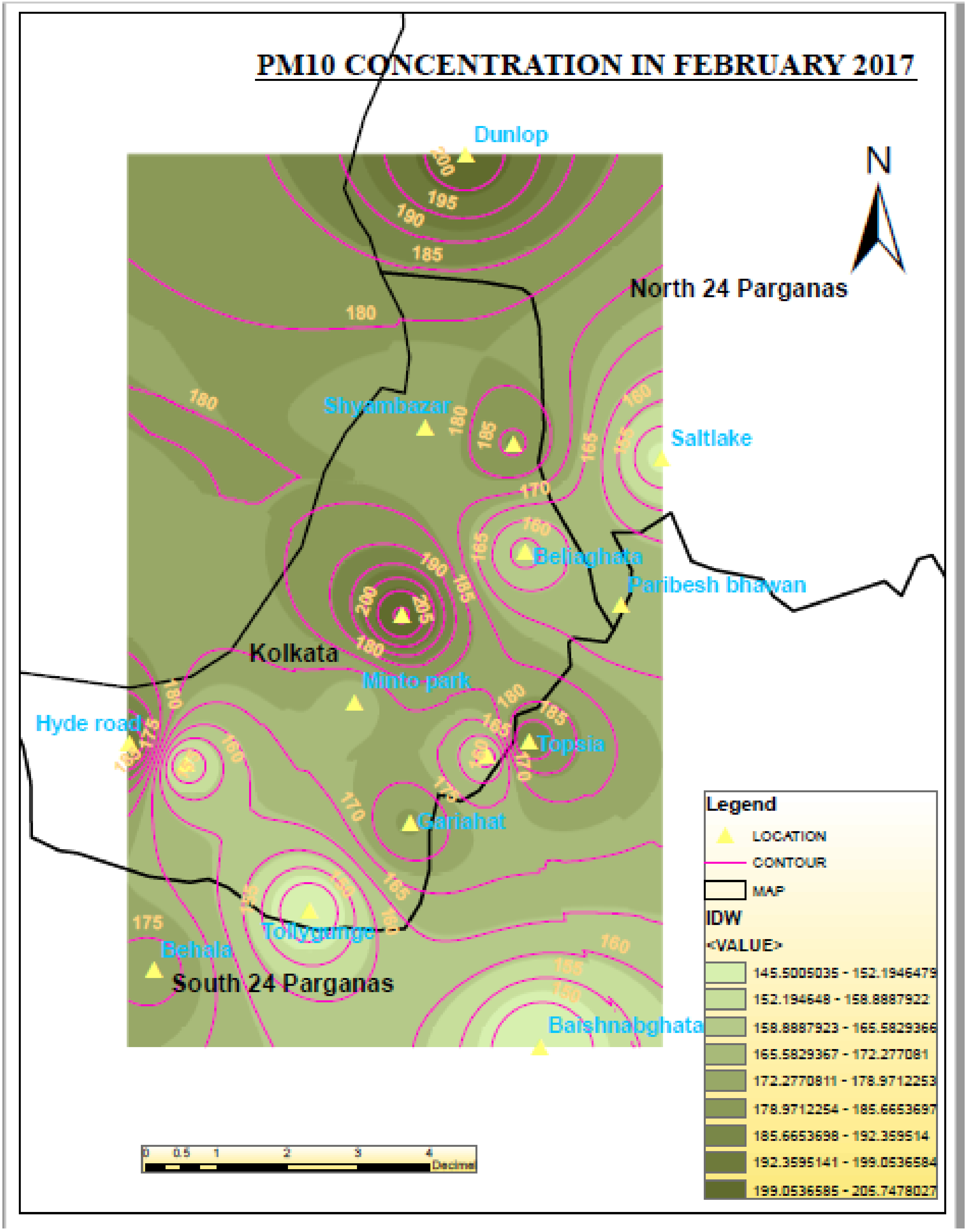

Figure 5.45: Contour map showing areas of high index of PM10 in February in Kolkata city

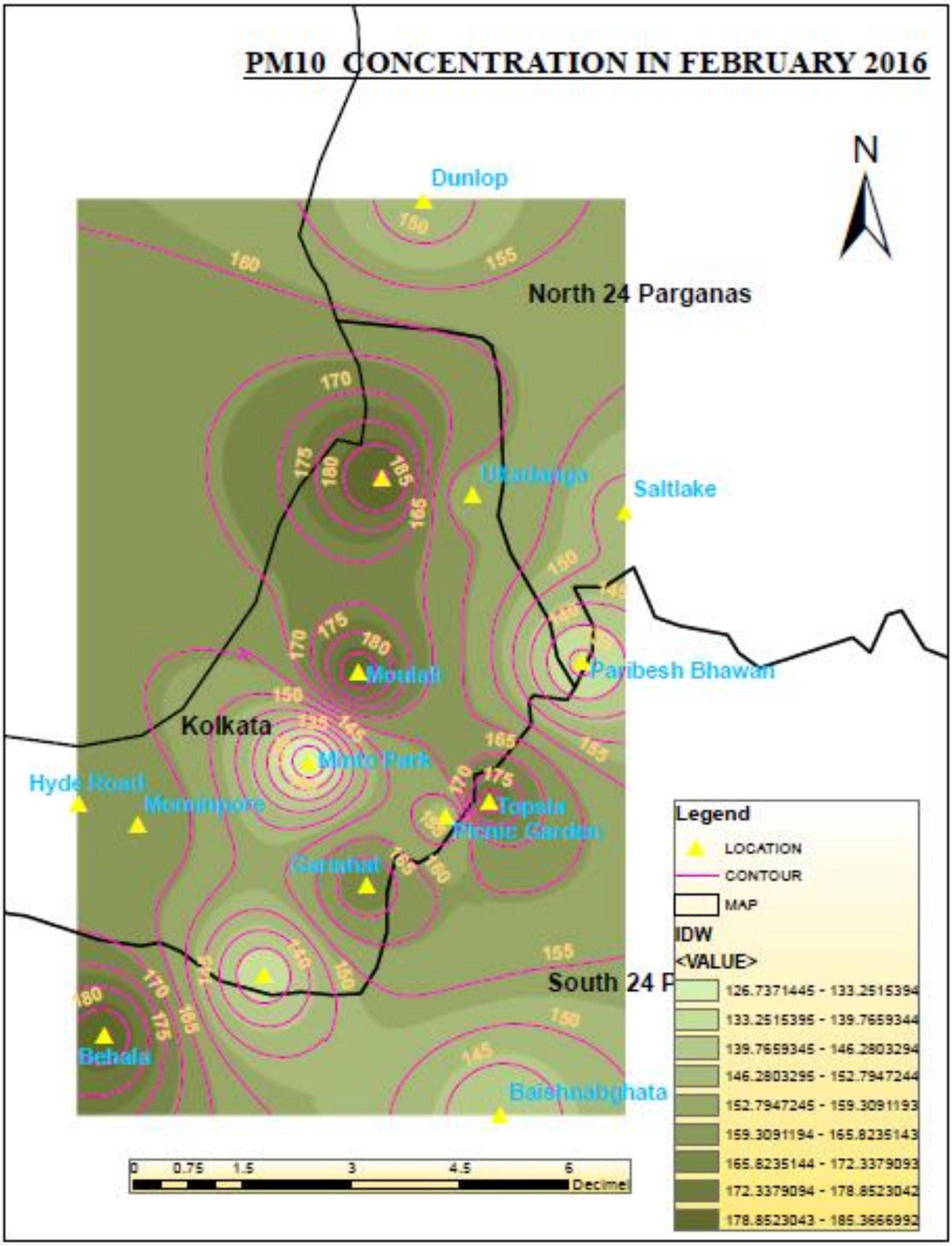

Figure 5.46: Contour map showing areas of high index of PM10 in February in Kolkata city

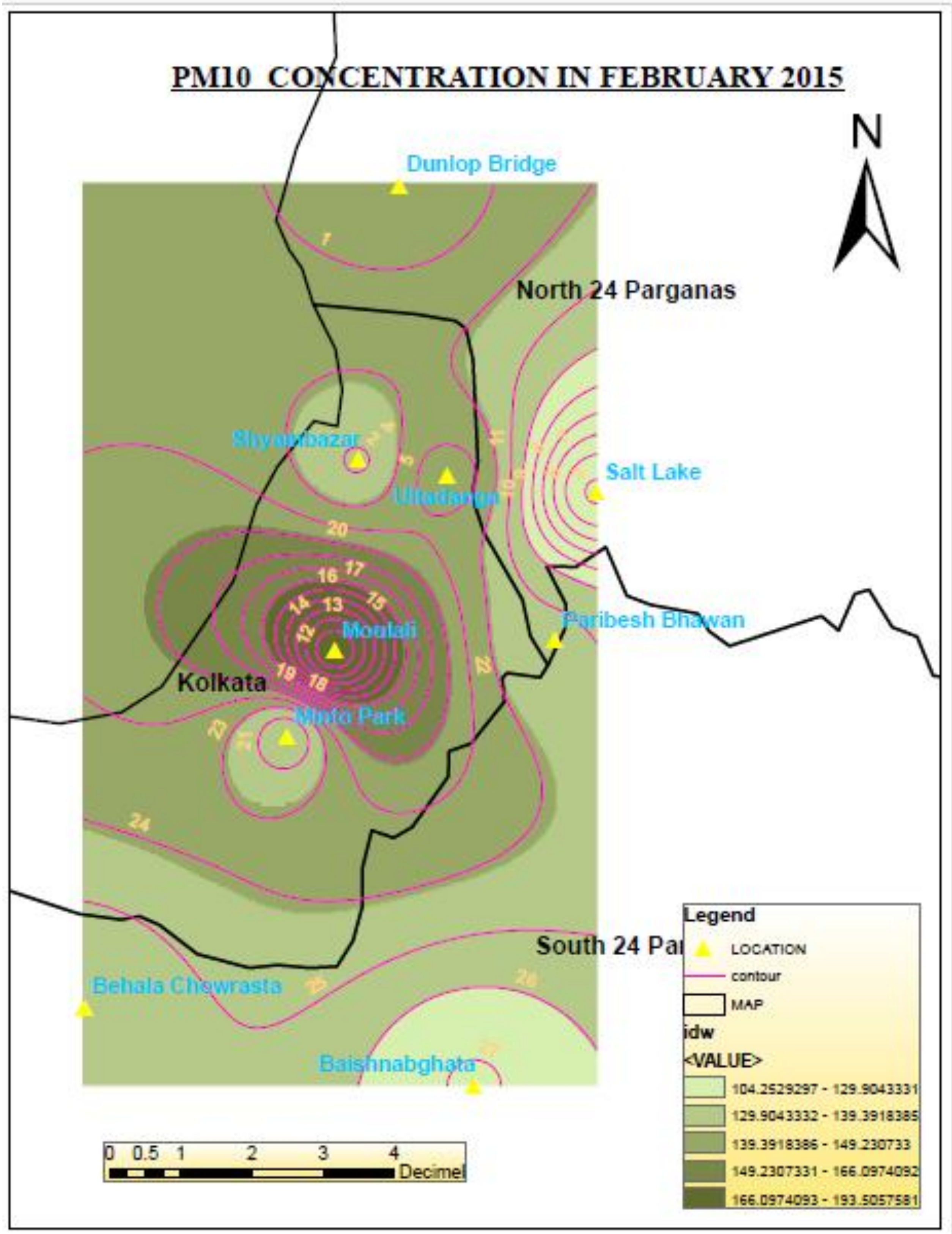

Figure 5.47: Contour map showing areas of high index of PM10 in February in Kolkata city

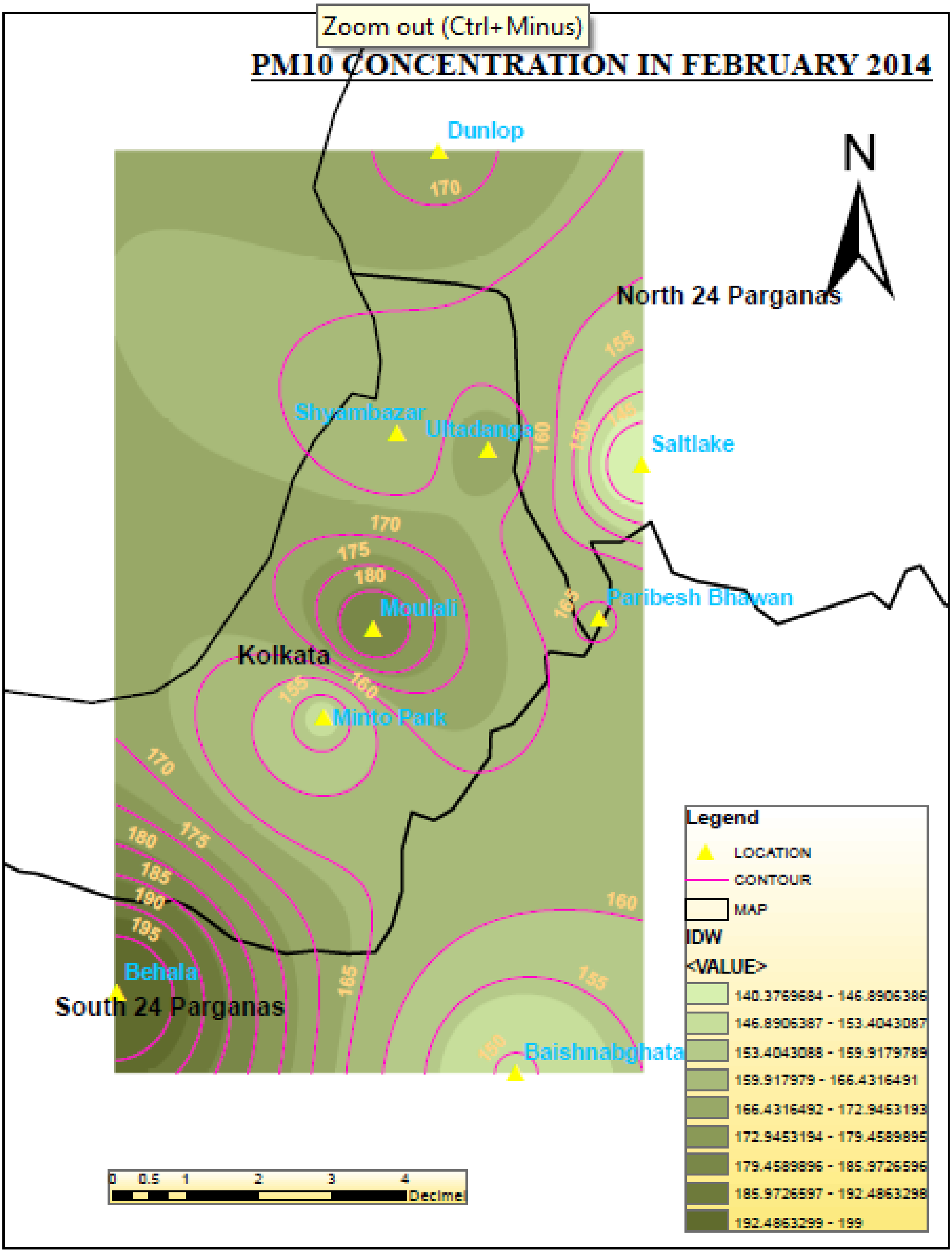

Figure 5.48: Contour map showing areas of high index of PM10 in February in Kolkata city

5.1.10 PM10 concentration in 2014 – 2018 (March) in Kolkata city

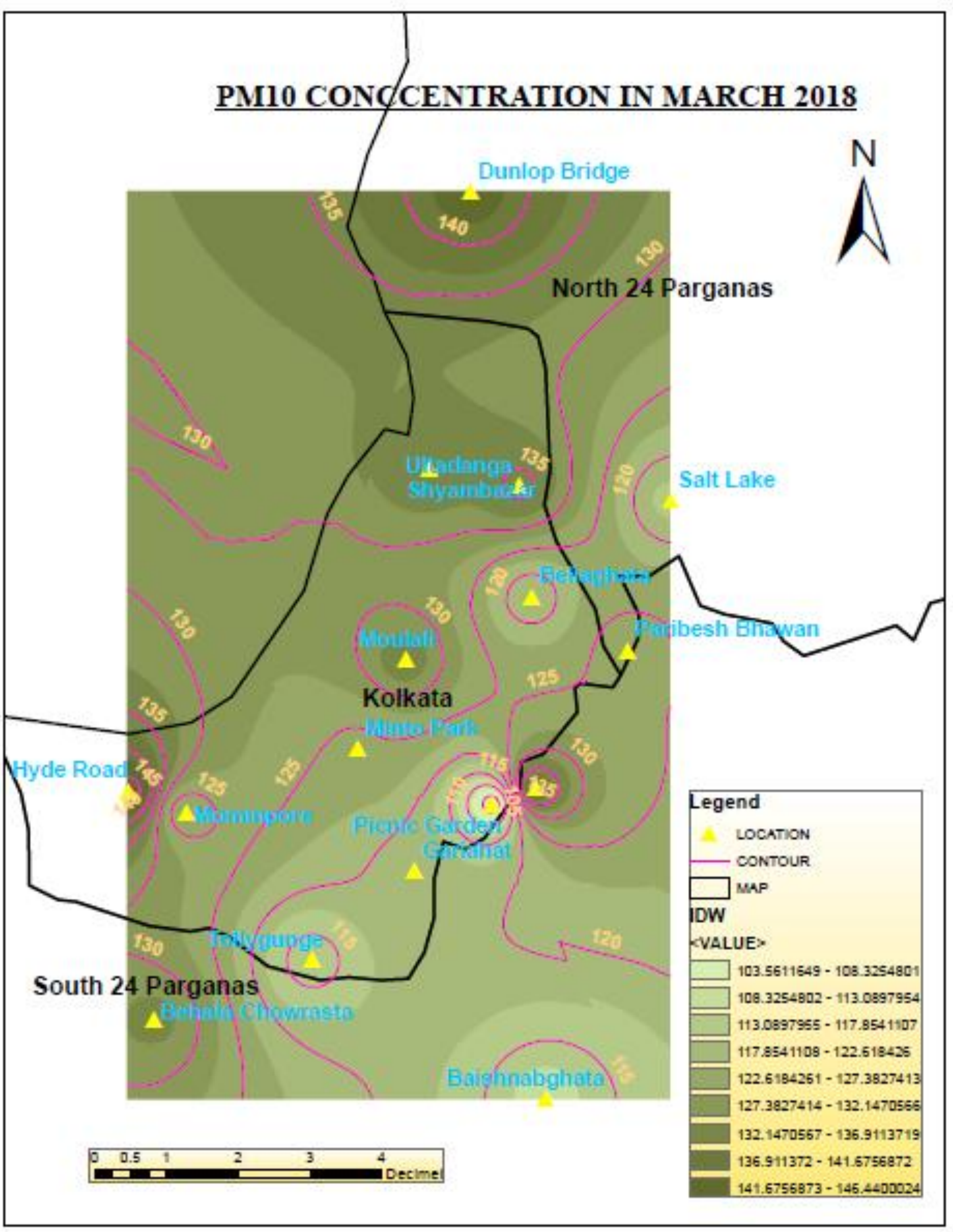

Figure 5.49: Contour map showing areas of high index of PM10 in March in Kolkata city

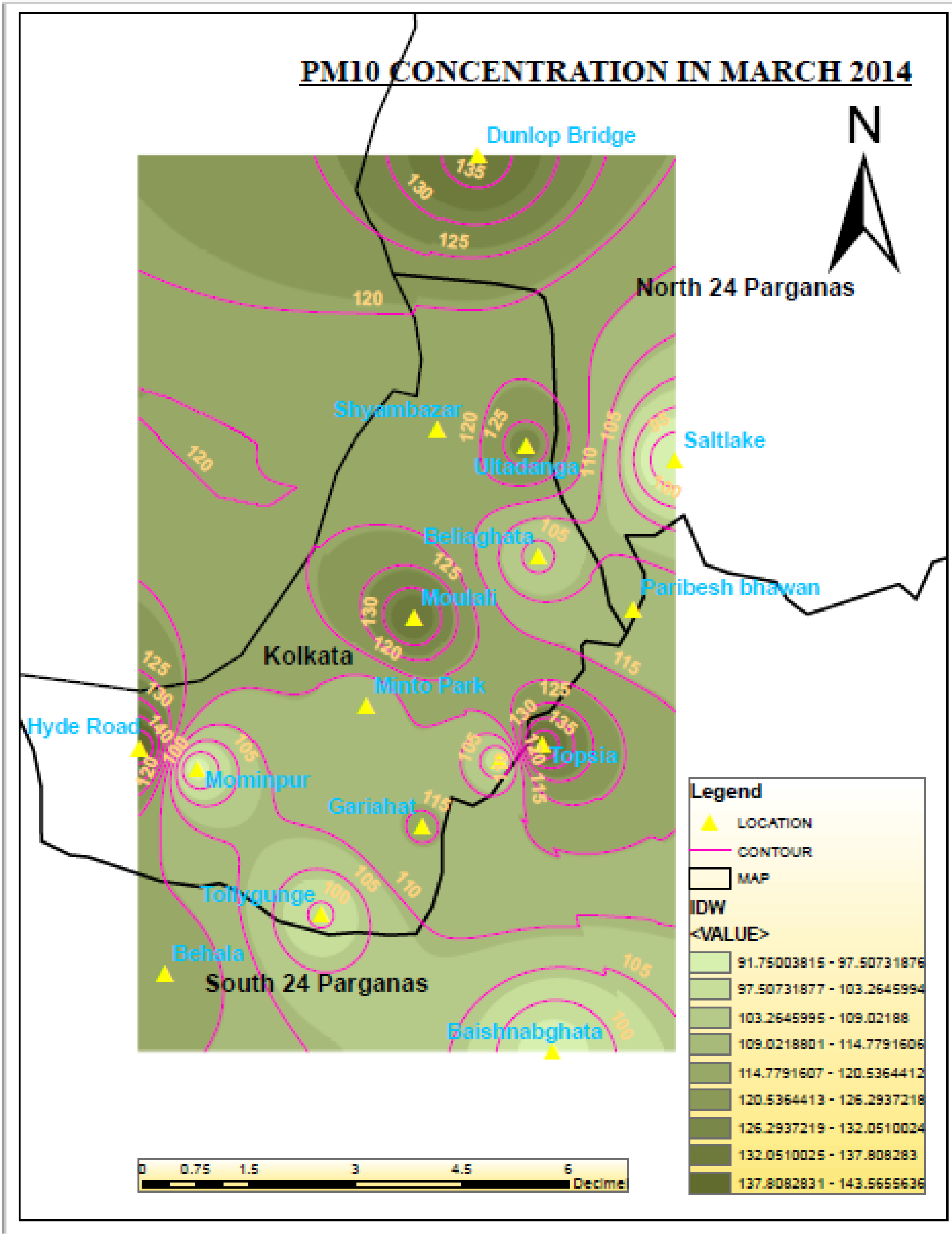

Figure 5.50: Contour map showing areas of high index of PM10 in March in Kolkata city

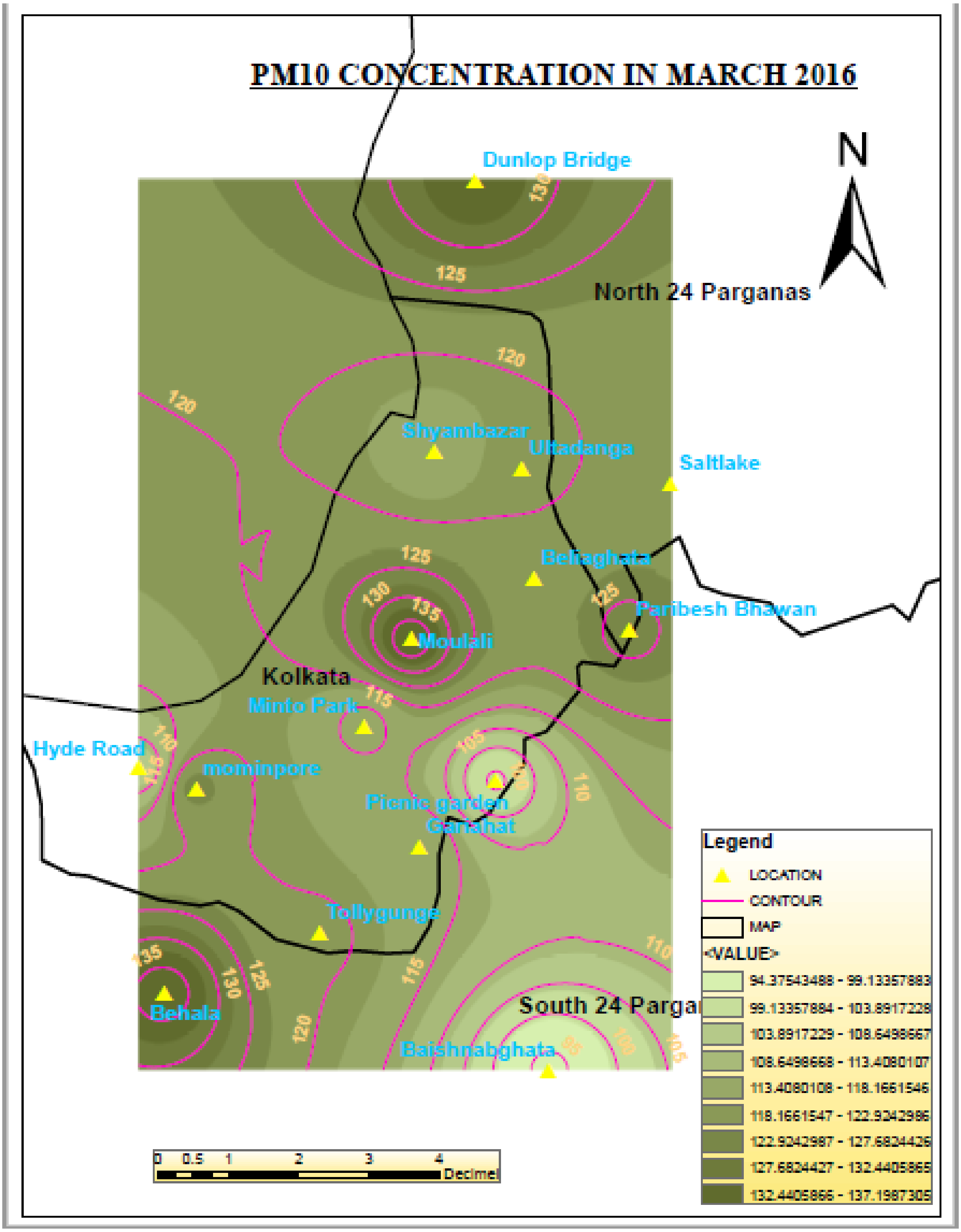

Figure 5.51: Contour map showing areas of high index of PM10 in March in Kolkata city

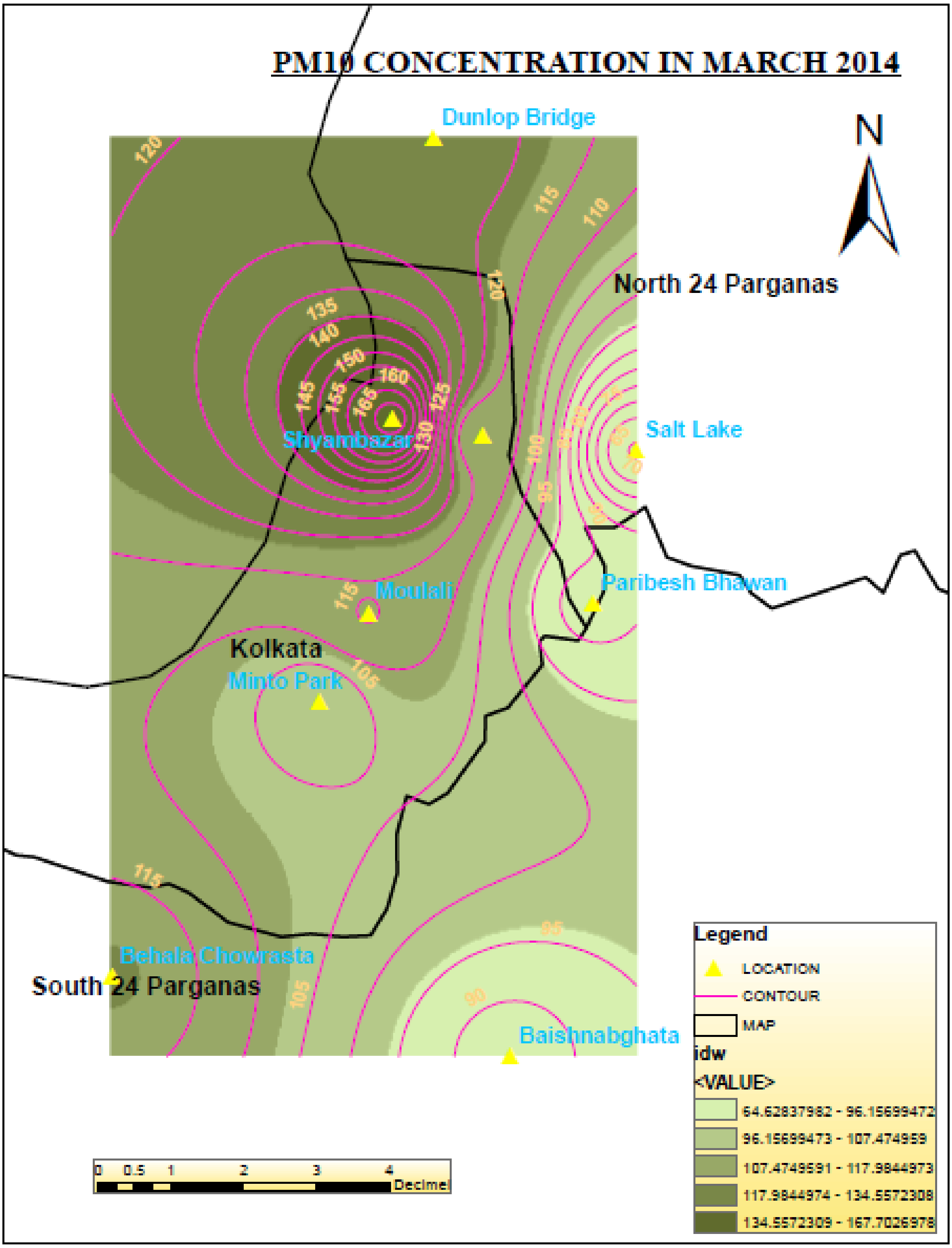

Figure 5.52: Contour map showing areas of high index of PM10 in March in Kolkata city

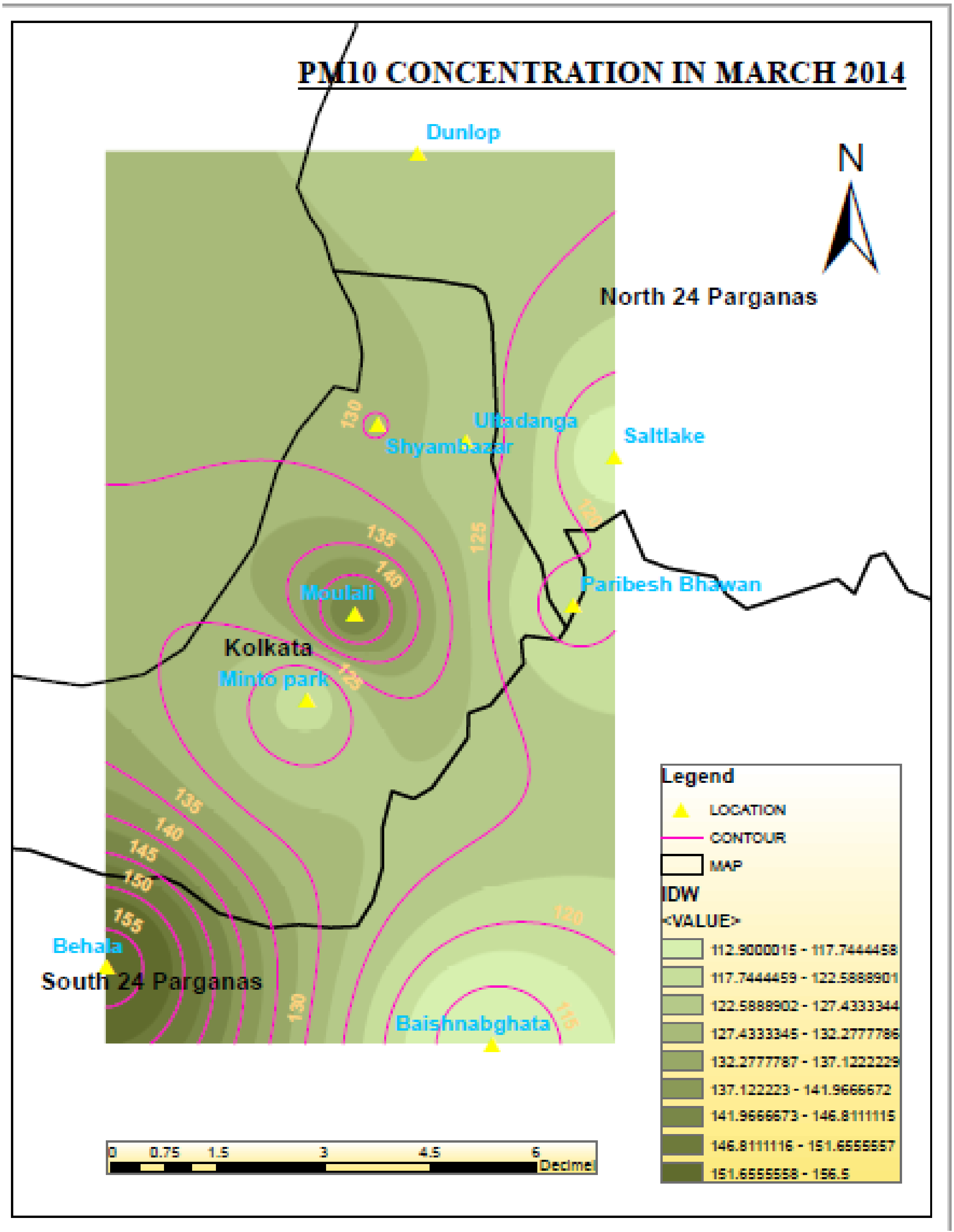

Figure 5.53: Contour map showing areas of high index of PM10 in March in Kolkata city

5.1.11 PM10 concentration in 2014 – 2018 (April) in Kolkata city

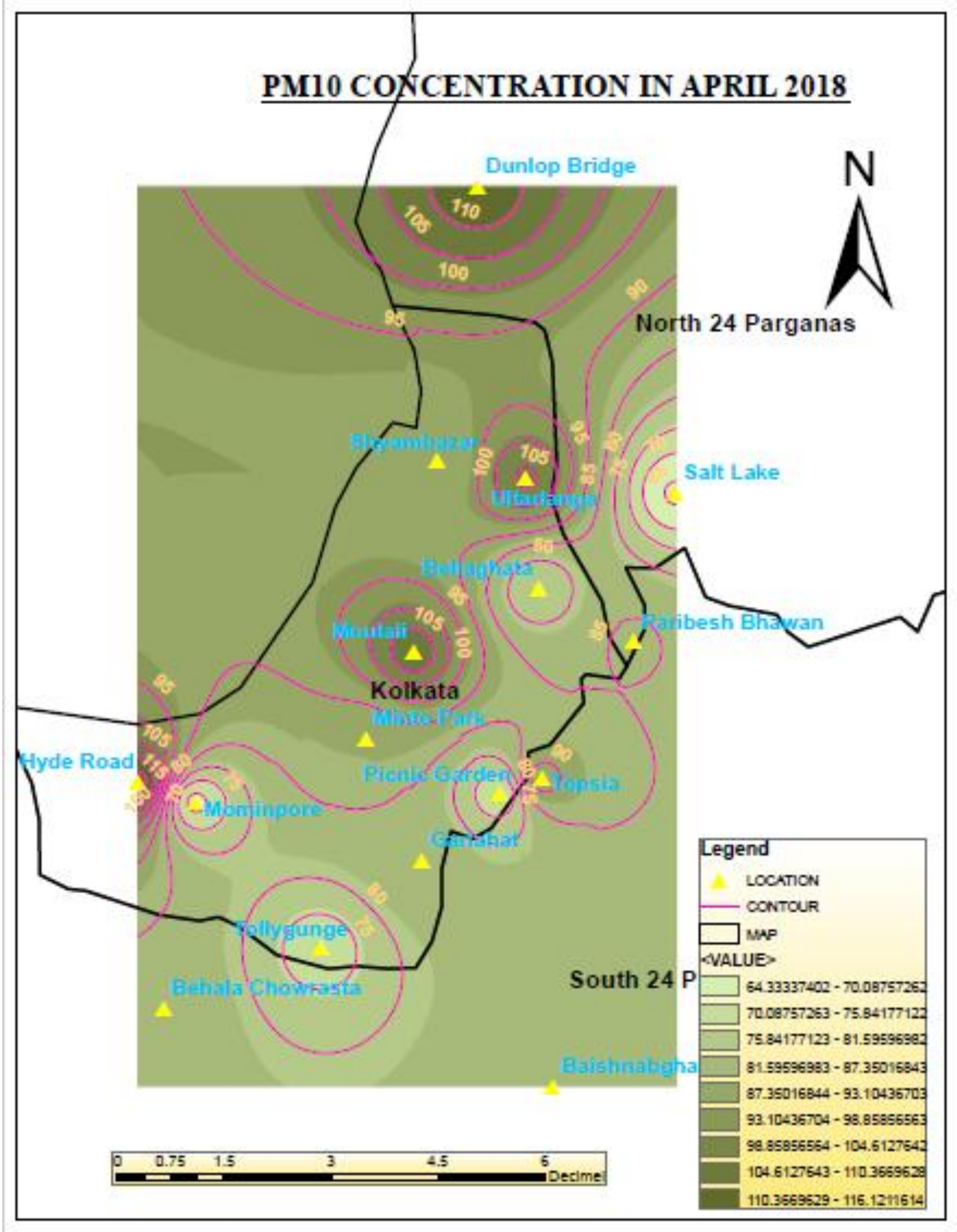

Figure 5.54: Contour map showing areas of high index of PM10 in April in Kolkata city

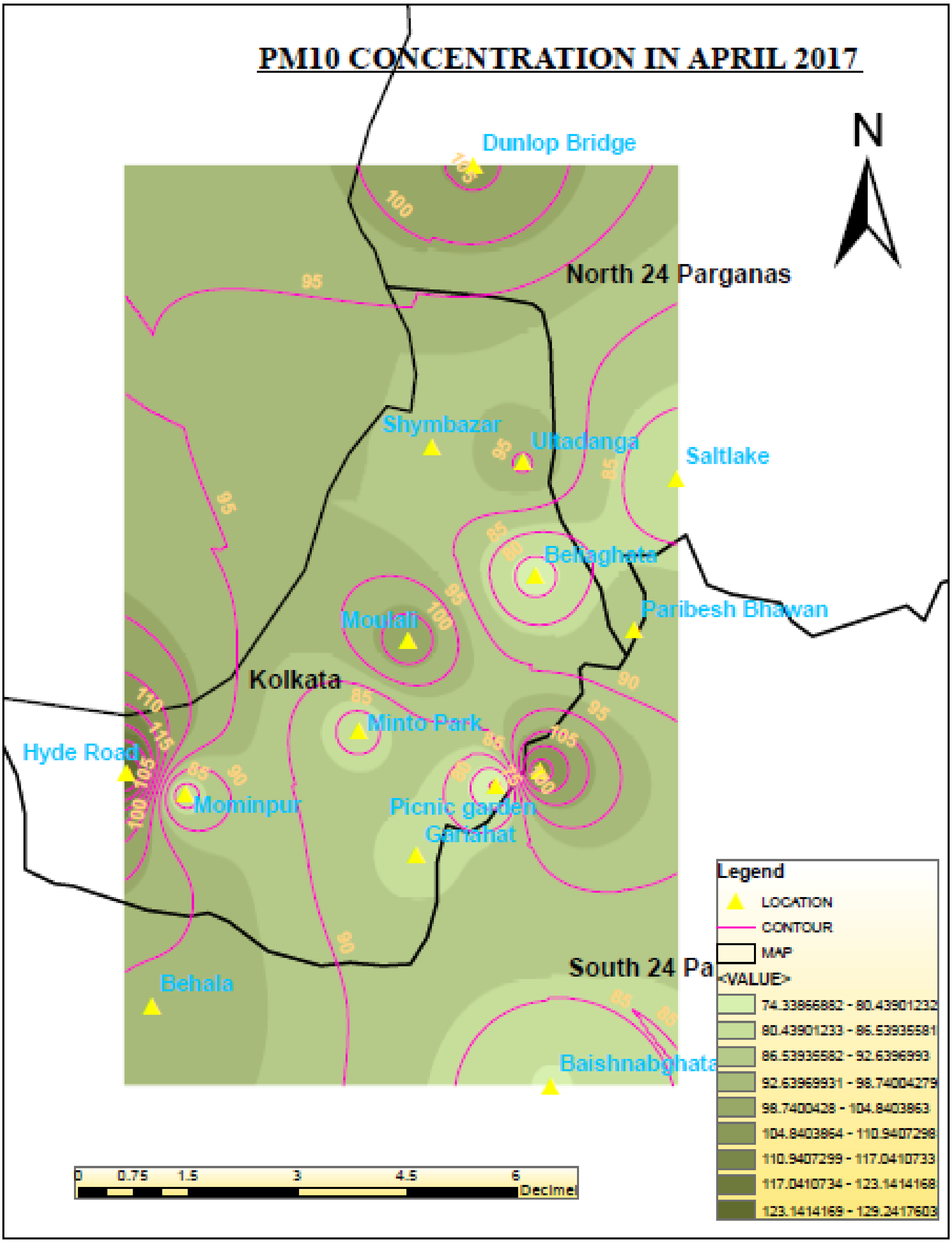

Figure 5.55: Contour map showing areas of high index of PM10 in April in Kolkata city

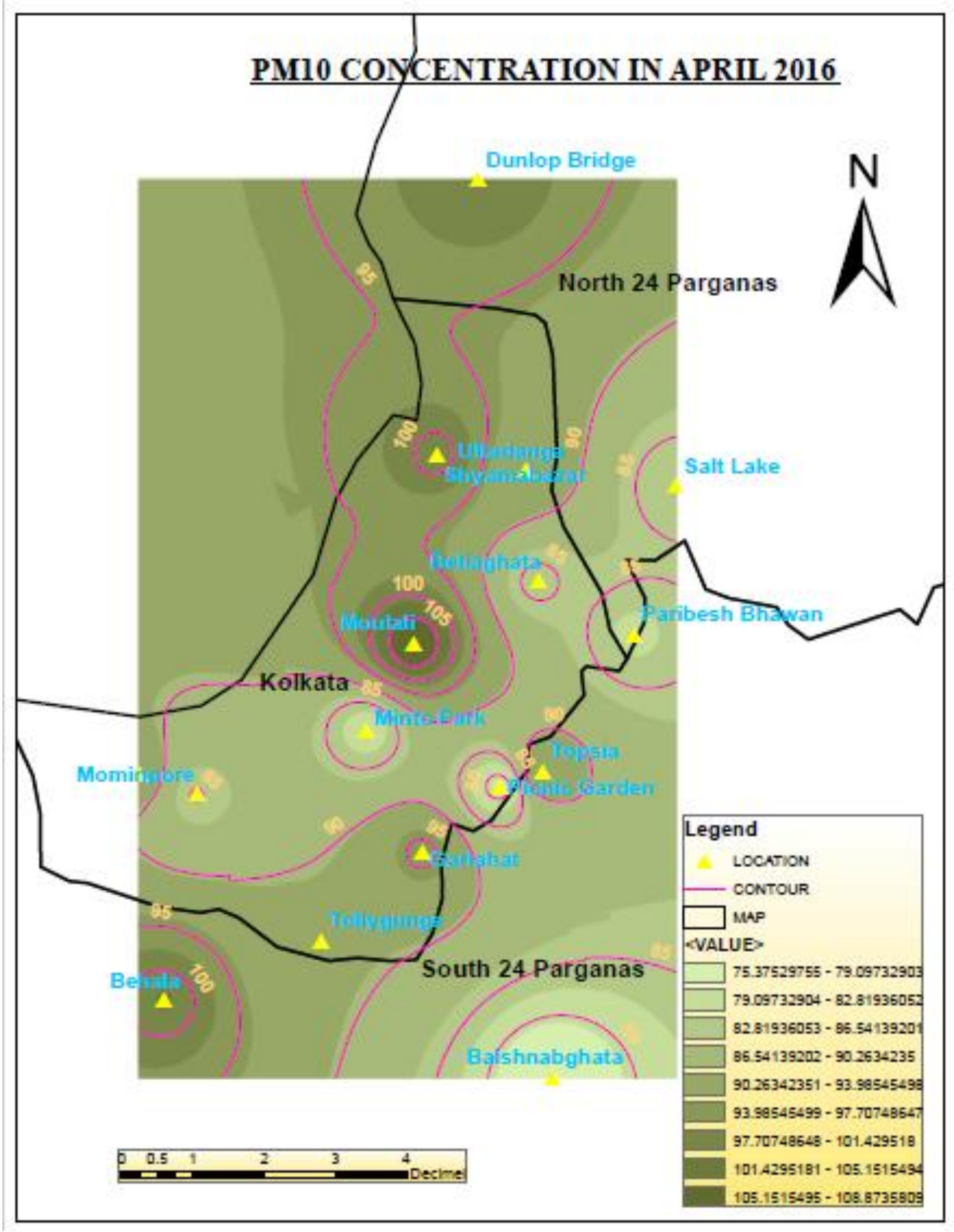

Figure 5.56: Contour map showing areas of high index of PM10 in April in Kolkata city

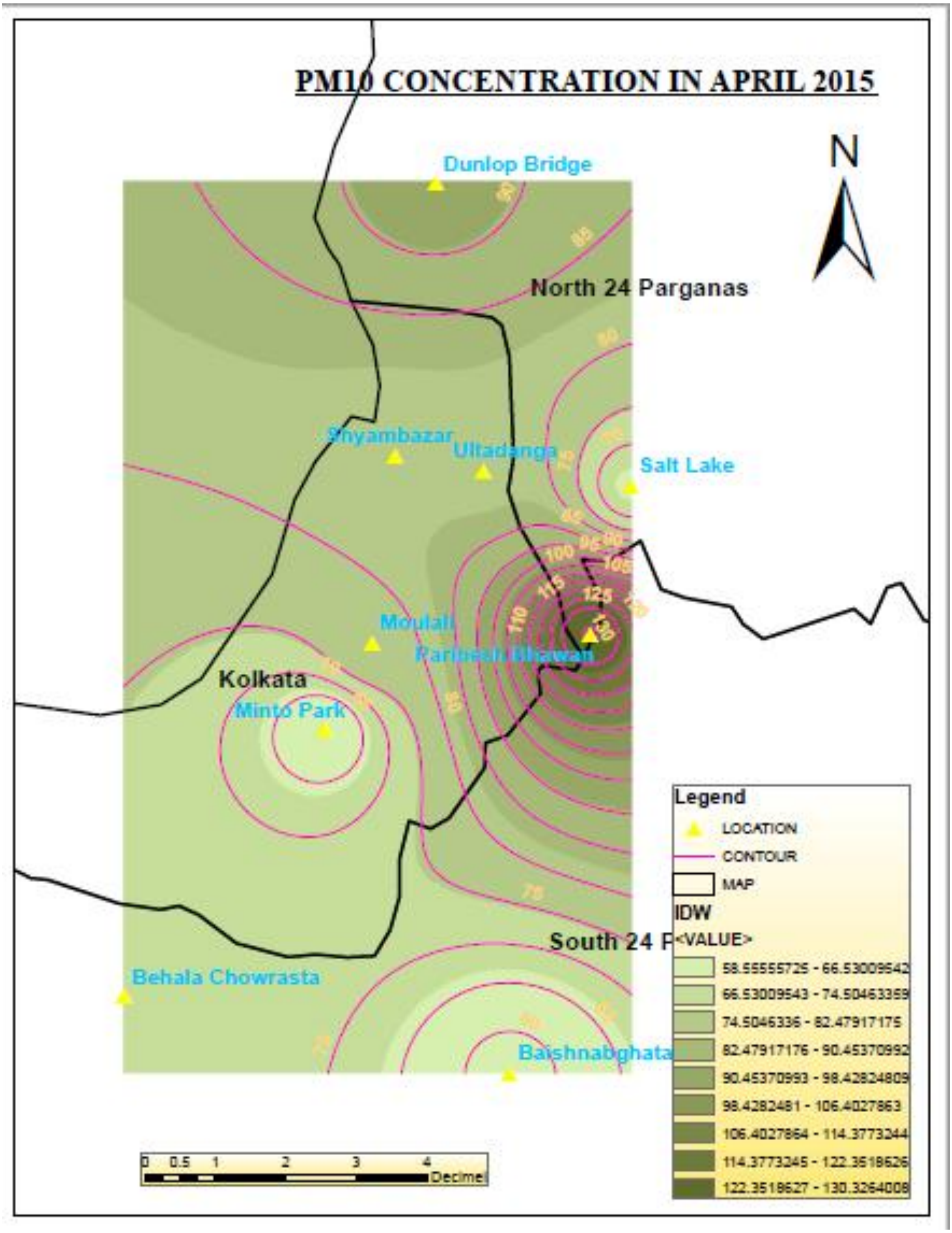

Figure 5.57: Contour map showing areas of high index of PM10 in April in Kolkata city

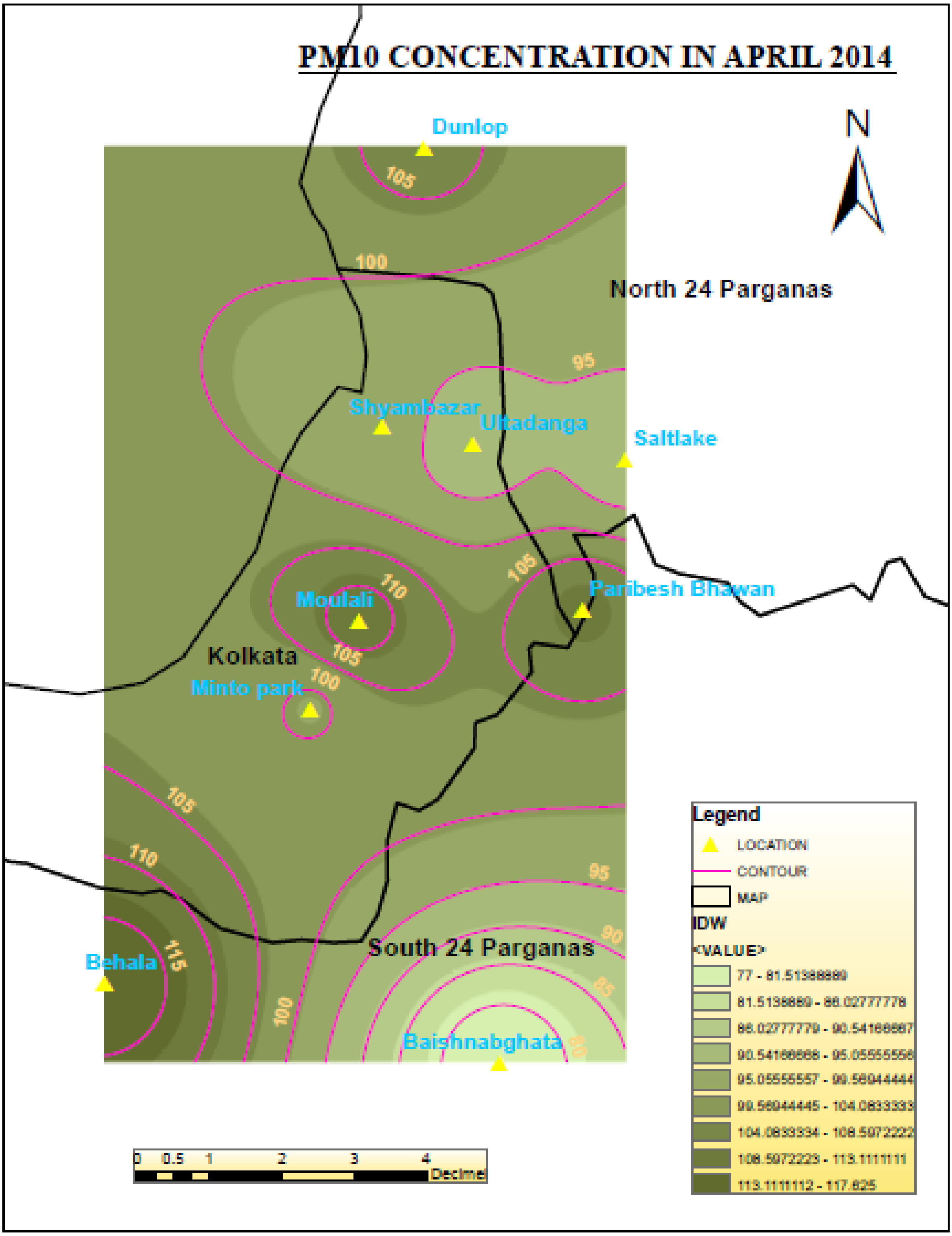

Figure 5.58: Contour map showing areas of high index of PM10 in April in Kolkata city

5.1.12 Air quality index (AQI) in Kolkata city over last five year 2014-2018 (January to May)

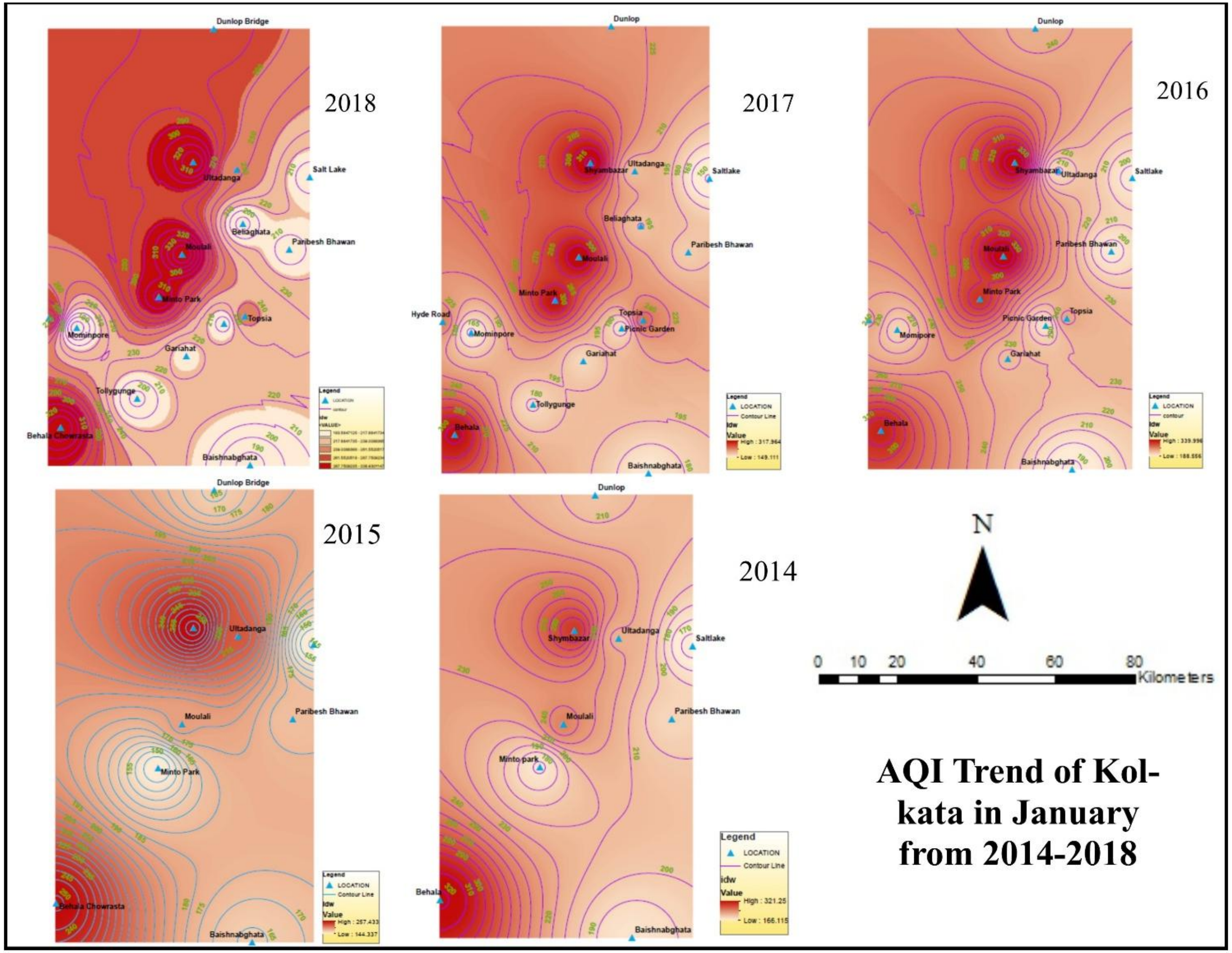

Figure 5.59: Contour map showing areas of high index of Air Quality Index (AQI) in January 2014-2018

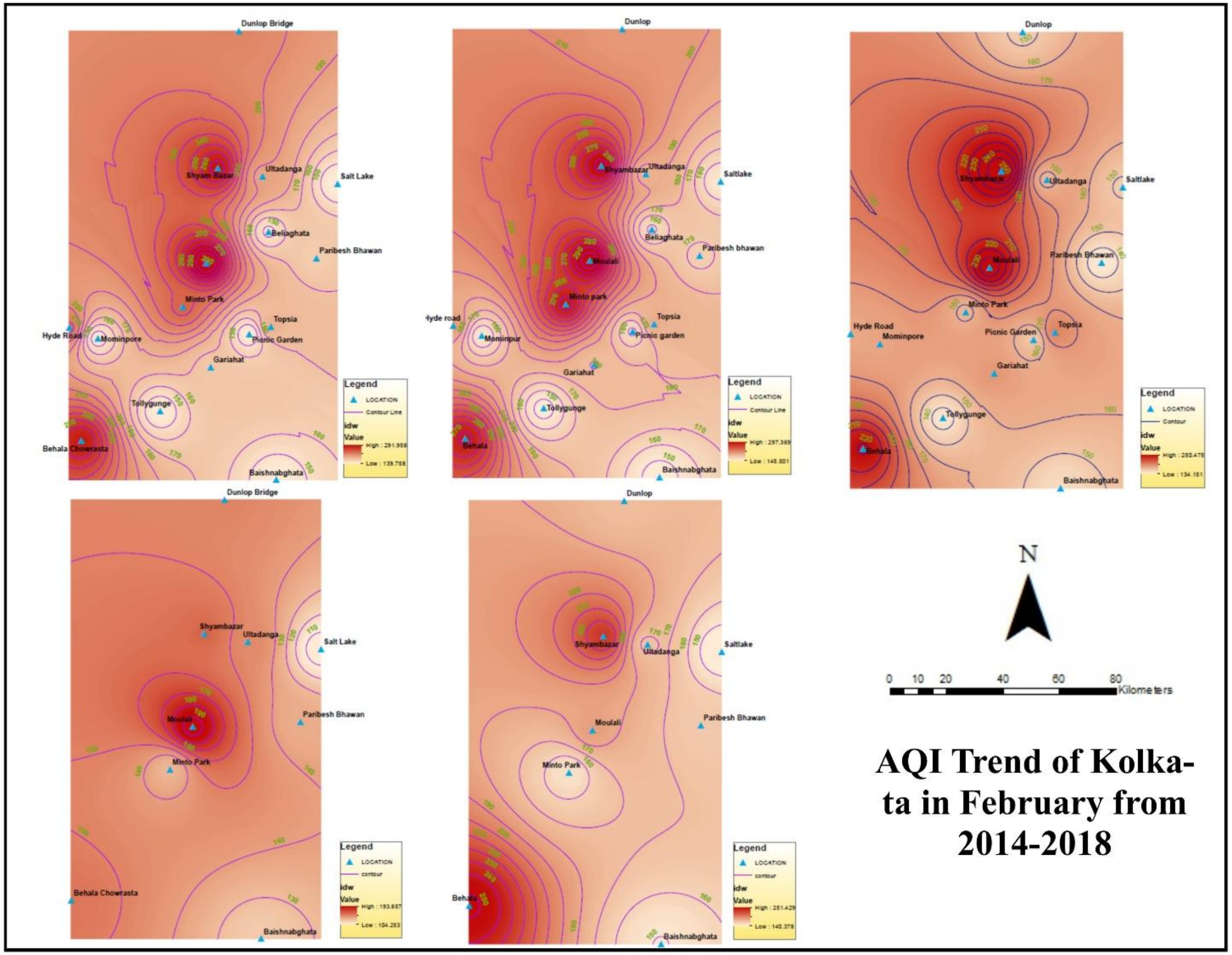

Figure 5.60: Contour map showing areas of high index of Air Quality Index (AQI) in February 2014-2018

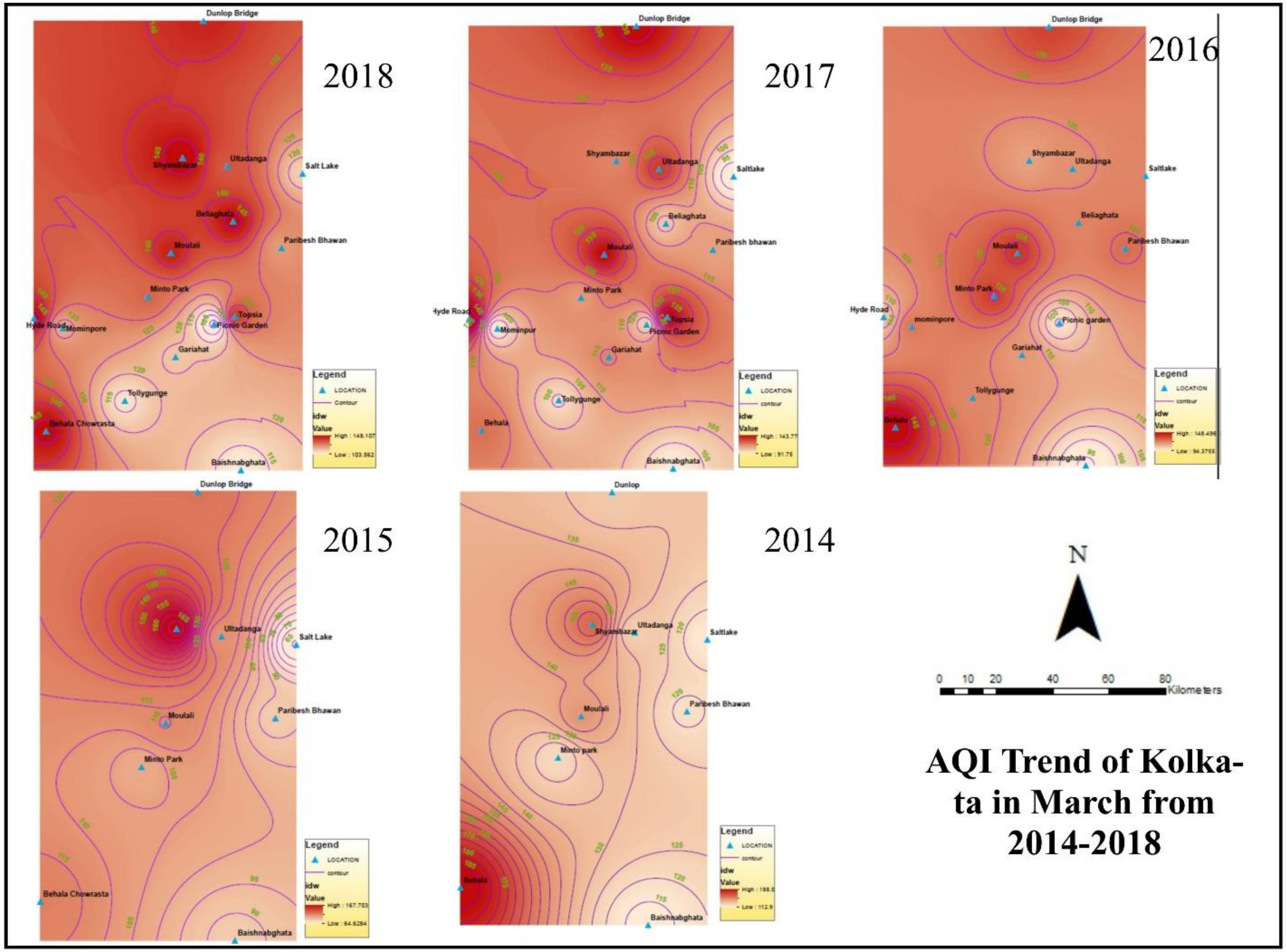

Figure 5.61: Contour map showing areas of high index of Air Quality Index (AQI) in March 2014-2018

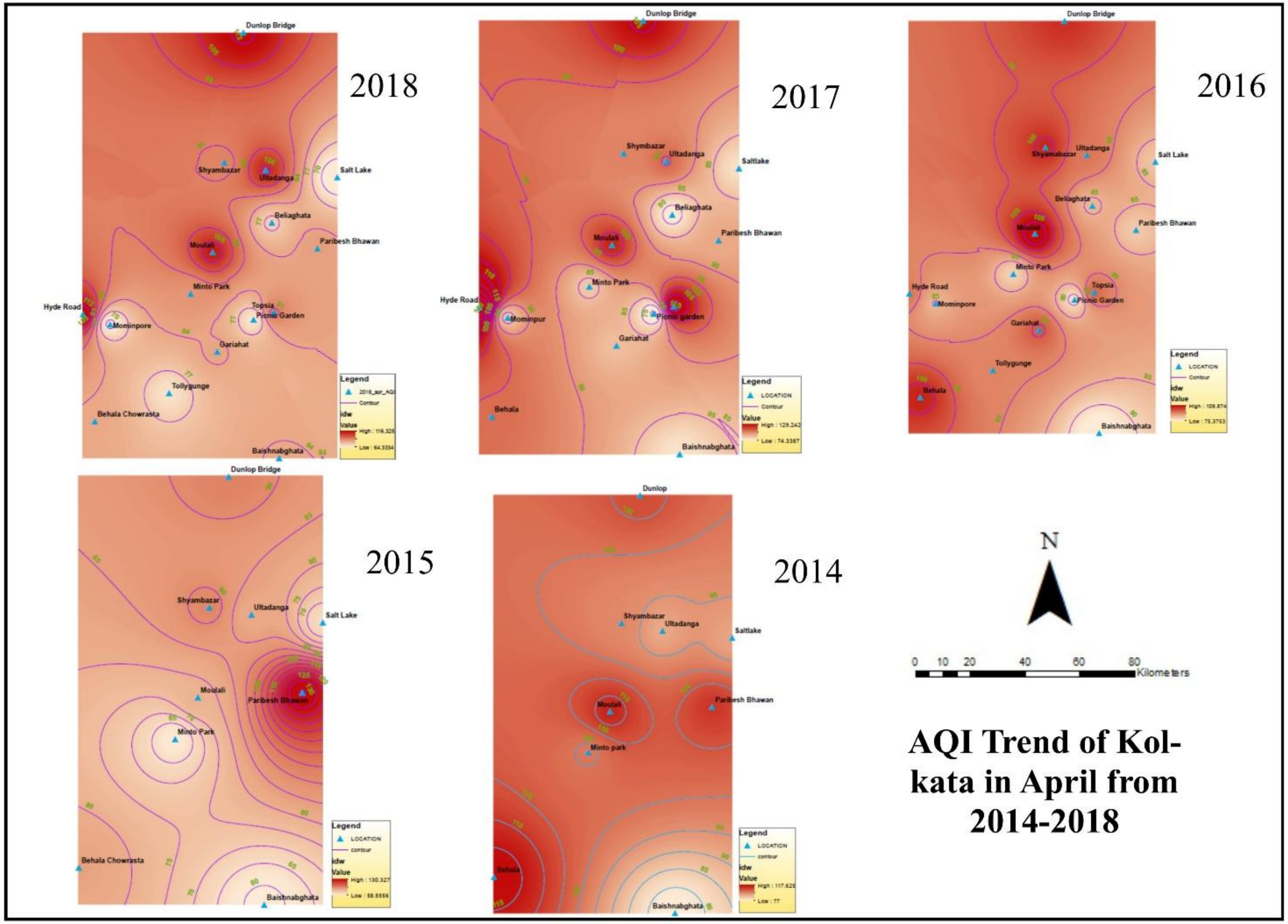

Figure 5.62: Contour map showing areas of high index of Air Quality Index (AQI) in April 2014-2018

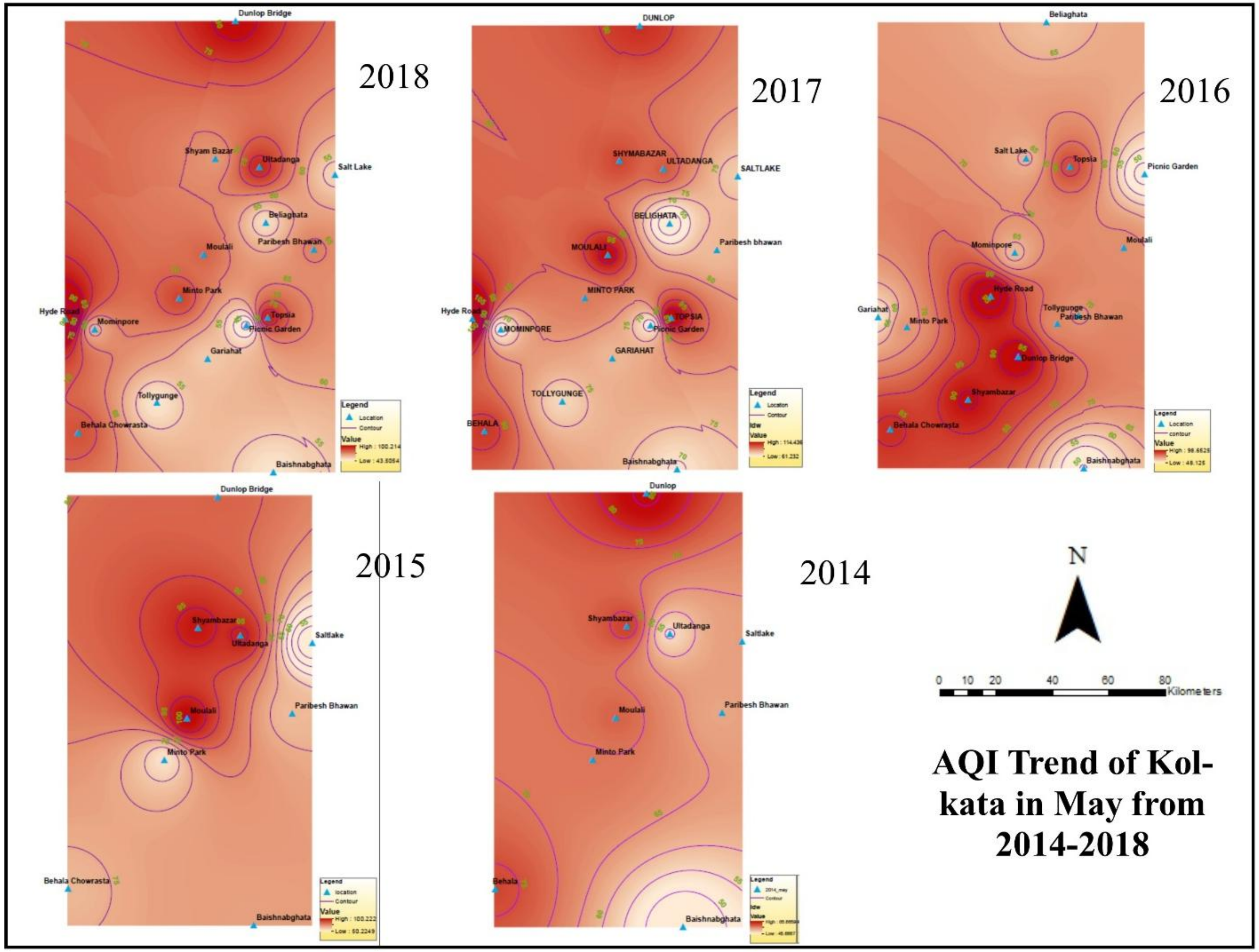

Figure 5.63: Contour map showing areas of high index of Air Quality Index (AQI) in January 2014-2018

5.1.1 Interpretation of the contour maps generated using ArcGIS for AQI

After drawing data from AQI index maps, it gives an overview of quality of air in a particular area. From the map it is to be noted that over the year north Kolkata poorly graded AQI index due to heavy concentration of air pollutants measured. So proper planning and implementation is required for treating the city's air to prevent further deterioration in the future.

5.2 Study of the air pollutants

Air microbial pollutants was monitored in the laboratory scale during entire study period of eight month starting from 18th August 2018 to 20th February 2019 in different location of Kolkata, India. The sampling was done for 15 minutes once in every sampling location using Andersen Cascade Impacter. The meteorological parameters also recorded during monitoring days on every monitoring location.

Two particulates parameters viz. Respirable Particulate Matter (RPM orPM_{10}), Fine Particulate Matter ($PM_{2.5}$) and two gaseous pollutants viz. Sulfur Di-Oxide (SO_2) and Nitrogen Di-Oxide (NO_2) are among the studied pollutants. The results are presented in table 5.1 and 5.2.

Table 5.1: Meteorological parameters recorded during the monitoring period

Location	Date	Time	Temperature (°C)	Relative Temperature (°C)	Wind speed (Km/h)	Relative Humidity (%)	Dew Point (°C)	Pressure (mb)
JU Gate No. 3	18.07.2018	11:20AM	32	42	17	75	27	998.0
Jadavpur 8B Bus Stand	09.08.2018	15:36 PM	30	40	11	89	28	1000.0
Shyambazar	16.08.2018	12:21 PM	31	44	15	89	29	1001.0
Dunlop	16.08.2018	14:35 PM	32	44	22	79	28	1000.0
Gariahat	31.10.2018	16:00 PM	30	33	15	62	22	1011.0
Baishnabghata	21.11.2018	11:00AM	28	29	7	58	19	1016.0
Beliaghata	19.02.2019	12:51 PM	30	30	7	43	16	1001.0
Rajarhat	20.02.2019	13:00 PM	31	31	11	43	17	1014.0
Salt Lake	20.02.2019	14:34 PM	33	33	11	36	16	1014.0
Paribesh Bhawan	20.02.2019	15:45 PM	33	33	7	34	15	1013.0

Table 5.2: Ambient concentration of different air pollutants during the monitoring period

Location	Date	Time	PM10	PM2.5	SO2	NO2
Shyambazar	16.08.18	12:21 PM	63	58	4	41
Dunlop	16.08.2018	2:35 PM	56	-	3	42
Gariahat	31.10.2018	4:00 PM	46	-	3	33
Baishnabghata	21.11.2018	11:00 PM	141	-	5	48
Beliaghata	19.02.2019	12:51 PM	125	-	6	54
Salt Lake	20.02.2019	14:34 PM	126	-	5	53
Paribesh Bhawan	20.02.2019	15:45 PM	136	-	7	57

5.2.1 Correlation of air pollutants with meteorological parameters

A multiple correlation is derived to evaluate the correlation between the different air pollutants and the recorded meteorological parameters though out the study period. The multiple correlation matrix is presented in table 5.3.

Table 5.3: Correlation matrix for air pollutants and meteorological parameters

	PM10	PM2.5	SO2	NO2	T	RT	WS	RH	DP	Pr
PM10	1									
PM2.5	-0.0376	1								
SO2	0.9572	0.0951	1							
NO2	0.9313	0.1215	0.9700	1						
T	-0.0169	0	0.0825	0.0929	1					
RT	-0.5225	0.4796	-0.4108	-0.3099	0.3353	1				
WS	-0.5570	0.1918	-0.4686	-0.2886	0.3017	0.7924	1			
RH	-0.5785	0.4643	-0.5227	-0.4336	-0.2464	0.8212	0.6197	1		
DP	-0.6267	0.4413	-0.5532	-0.4519	-0.0964	0.8949	0.7367	0.9830	1	
Pr	0.4574	-0.2785	0.3503	0.3067	-0.0777	-0.7658	-0.5295	-0.7085	-0.7445	1

Note: Particulate Matter (PM), Sulfur Di-Oxide (SO_2), Nitrogen Di-Oxide (NO_2), Temperature (T), Relative Temperature (RT), Wind Speed (WS), Relative Humidity (RH), Dew Point (DP), Pressure (Pr)

5.3 Quantification and characterization of bacterial load

Air borne bacteria was monitored by Andersen Cascade Impacter during the entire the study period of eight month starting from 18th August to 20th February 2019 in Kolkata. Both quantification and characterization studies were carried out. The results are elaborated in subsequent sections.

5.3.1 Quantification of airborne bacteria in ambient air

Airborne bacteria was collected through Andersen Cascade Impacter once in every location during the entire study period of eight month starting from 18th August 2018 to 20th February 2019 in Kolkata. The result is presented in the table 5.4, Figure 5.64 and Figure 5.65.

Table 5.4 Bacterial load in the ambient air through Two Stage Andersen sampler

ID	LOCATION	DATE	TIME	CONC (CFU/m3)	CONC (CFU/m3)	TOTAL CONC (CFU/m3)
				UPC	LPC	
1	JU Gate no. 3	18.07.2018	11:20 PM	19	5	24
2	8B Bus Stand	09.08.2018	3:36 PM	95	80	175
3	Shyambazar	16.08.18	12:21 PM	27	13	40
4	Dunlop	16.08.2018	2:35 PM	11	9	20
5	Gariahat	31.10.2018	4:00 PM	20	15	35
6	Baishnabghata	21.11.2018	11:00 PM	23	5	28
7	Beliaghata	19.02.2019	12:51 PM	38	219	257
8	Rajarhat	20.02.2019	1:00 PM	21	223	244
9	Saltlake	20.02.2020	2:34 PM	2	193	195
10	Paribesh Bhawan	20.02.2021	3:45 PM	13	241	254

Note: Upper Plate Count (UPC), Lower Plate Count (LPC)

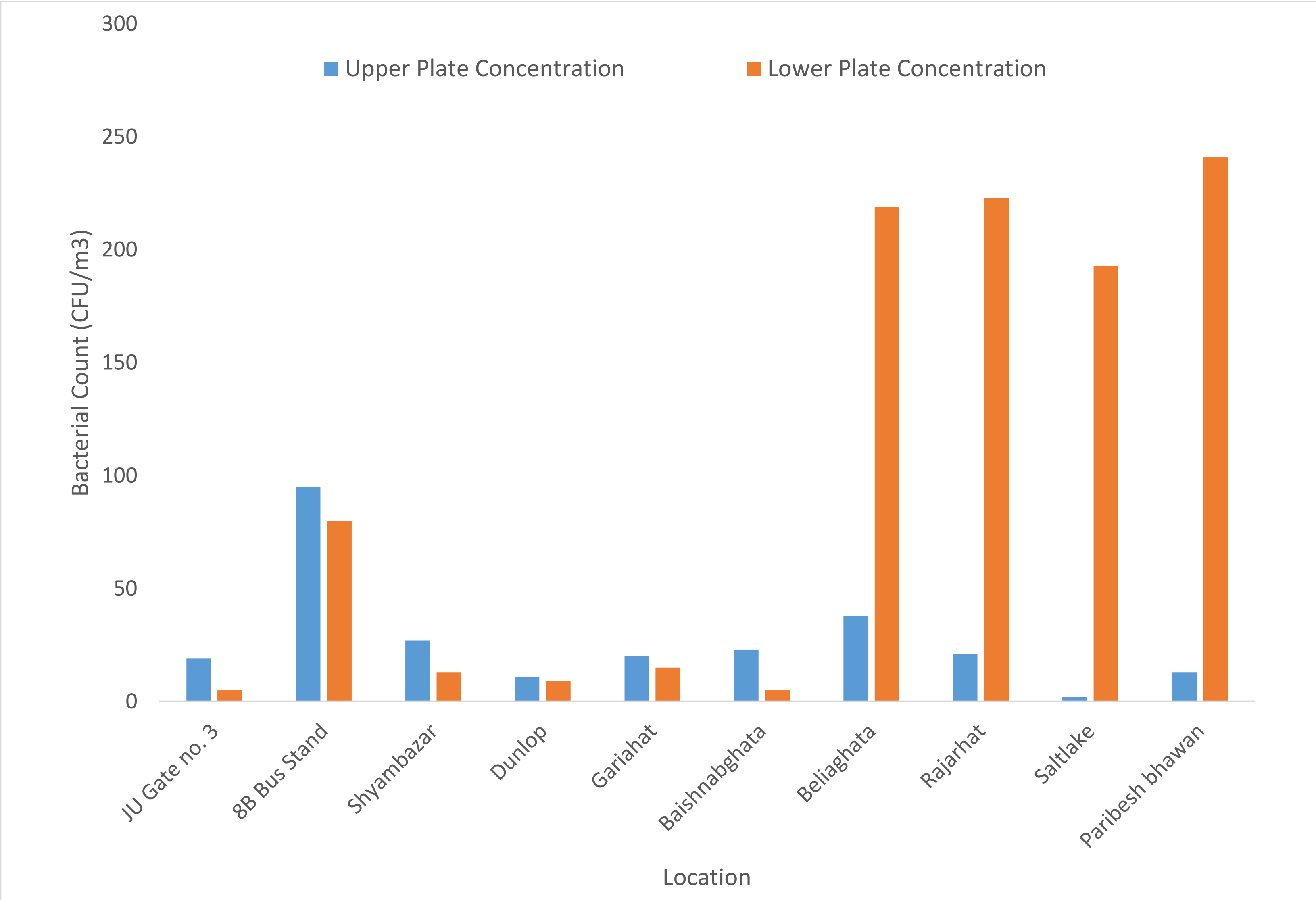

Figure 5.64: Variation of bacterial load in the ambient air during the monitoring period

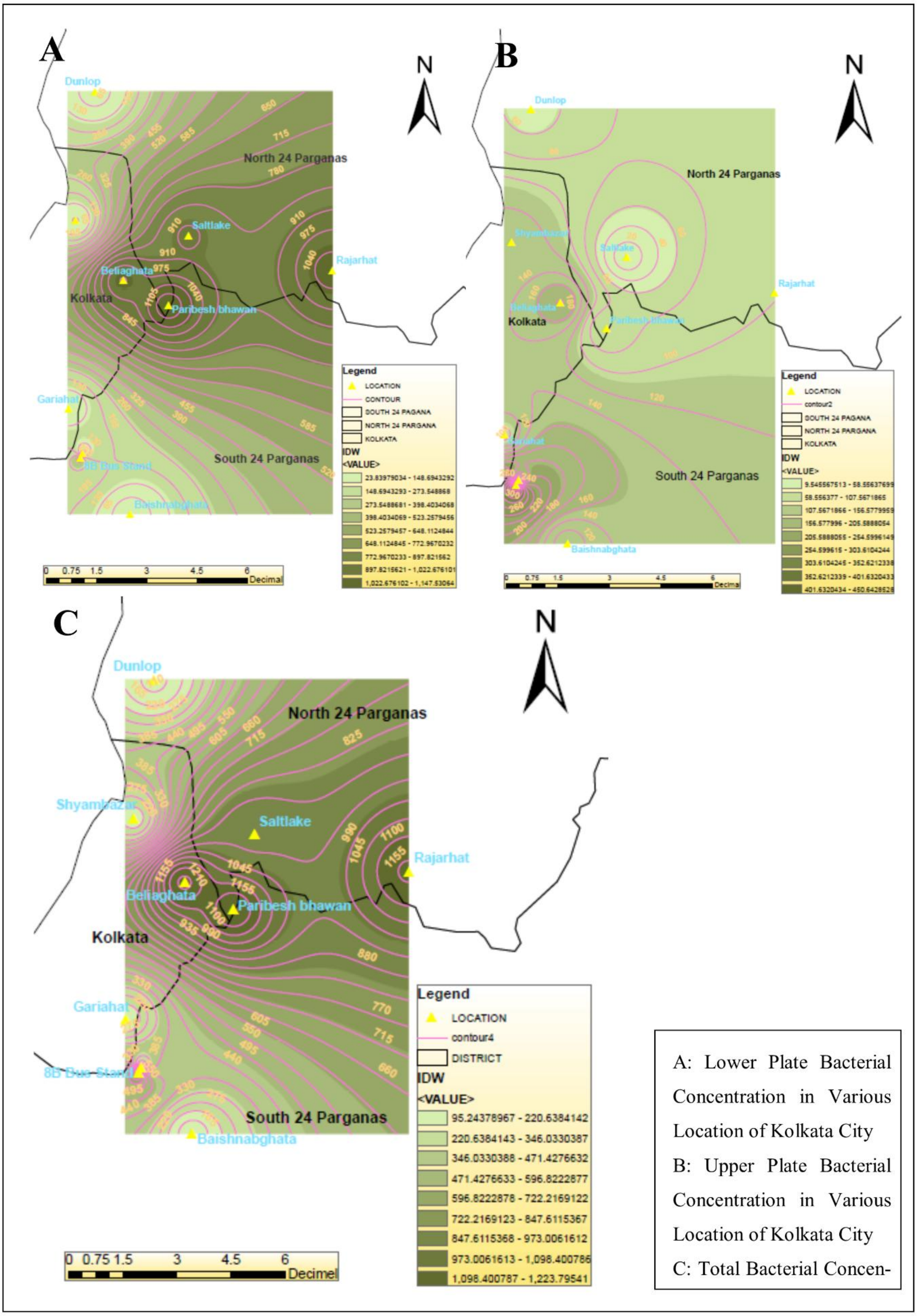

Figure 5.65: Map variation of bacterial load in the ambient air during the monitoring period

5.3.1.1 Interpretation of the contour maps generated using ArcGIS for airborne microbial concentration

After drawing data from airborne bacterial concentration in different monitoring location it gives an overview on that air microbial concentration is very high in winter monsoon than in summer monsoon. So proper planning and implementation is more required for treating the city's air to prevent further deterioration in the future.

5.3.2. Characterization of airborne bacteria

Characterization study of airborne bacteria were carried out to perform laboratory scale identification of sampled airborne bacteria during the entire study period. The bacteria present in air sample through the two stage Andersen Cascade Impacter were utilized in the identification study. Gram staining was performed for preliminary identification studies. These test is performed only for air borne bacteria sampled through the Andersen Cascade Sampler. The test result is elaborated in the subsequent section.

5.3.2.1 Gram staining

Gram staining method is always a first step of bacterial identification. Gram stain characteristics shows a basic differences between morphological structure and chemical composition of bacterial cell wall. These differences have a great practical importance directly correlate with the bacteria produced the kind of toxins, with the basic characteristic of antigenic structure and also with the susceptibility to antibiotics and chemotherapeutic agents. After gram staining, most of the air borne bacterial sampled through Andersen Cascade Impacter are found to be gram negative. Typical microscopic images of bacterial colonies after gram staining are presented in figure 5.66.

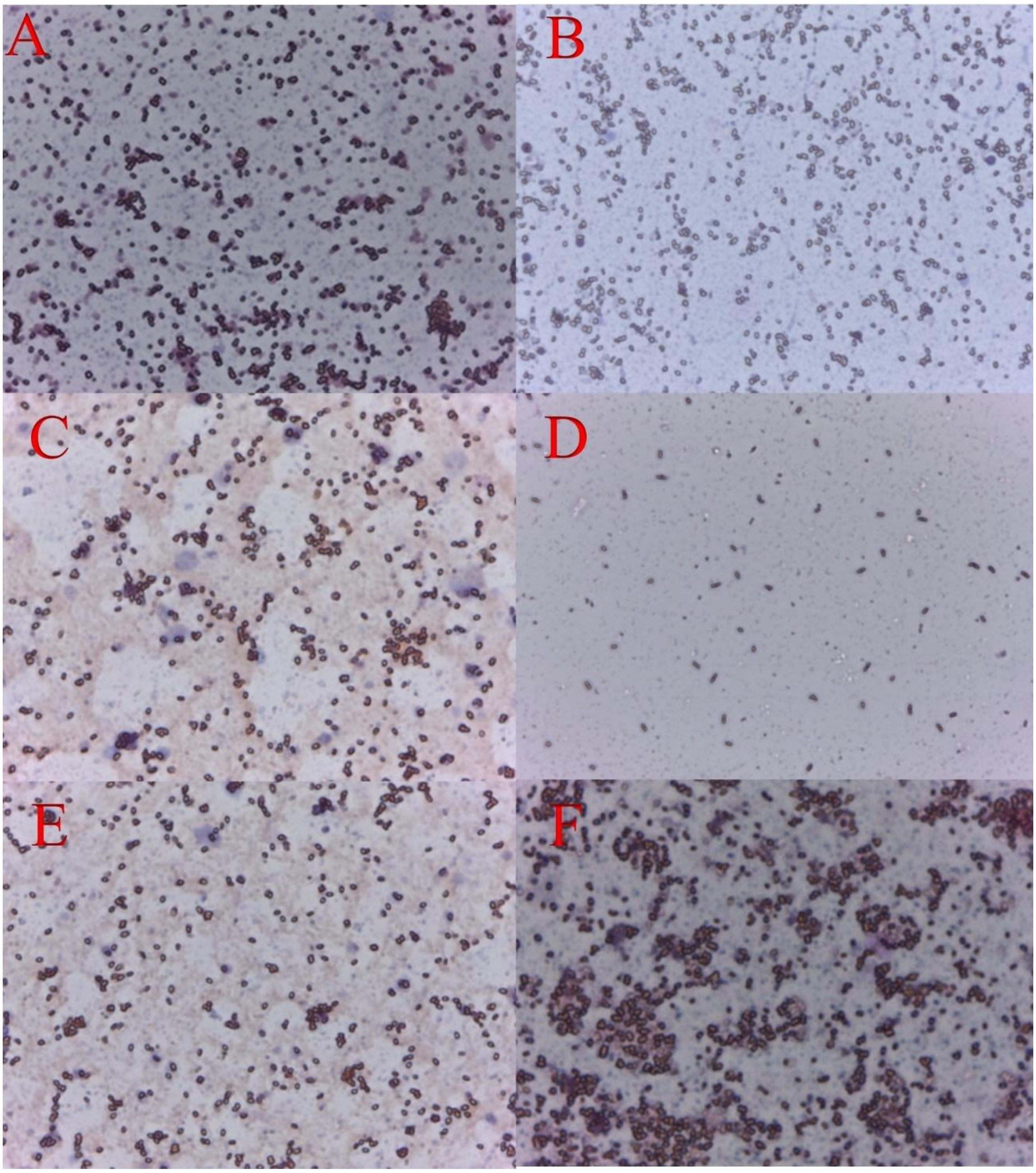

Figure 5.66: Microscopic view (1000×) of the Air borne bacterial colony after Gram Staining

Note: A: Gram Negative Coccus; B: Gram Negative Coccus; C: Gram Negative Coccus; D: Gram Negative Coccus; D: Gram Negative Coccus; F: Gram Negative Coccus

5.4 Antibiotic susceptibility profiling

In this study the antimicrobial susceptibility testing is very important. This antimicrobial testing was done in the clinical microbiology laboratory to ensure the susceptibility of chosen antimicrobial agent or detect the resistance of individual air borne bacterial isolates. In this investigation we observed that bacteria which were isolated from ambient air has been highly susceptible to antimicrobial activity of Erythromycin (15mcg) and Amoxyclav (Amoxicillin / Clavulanic) (30 mcg [20/10 mcg]) (AMC), whereas less susceptible to Amoxicillin (AMX) (15mcg) and Ampicillin (Amp) (10mcg). The result is presented in the Table 5.5 and 5.6, Figure 5.67 and 5.68.

The overall resistance of isolates to the antimicrobial agent is repented as a MAR index. MAR index of the isolates ranged from o to 1 [Table 5.6], whereas the MAR index of the sampling sites ranged from 0 to 0.75 [Figure 5.68].

Table 5.5: Antibiotic susceptibility pattern of the air borne bacterial isolates in different location

Location	Dominated Colony	Antibiotics			
		Erythromycin	Amoxicillin	Amoxyclav	Ampicillin
JU Gate no.3	3	3(100%)	3(100%)	3(100%)	3(100%)
8B Bus Stand	5	2(50%)	1(25%)	4(80%)	1(25%)
Shyambazar	4	3(75%)	3(75%)	4(100%)	3(75%)
Dunlop	5	5(100%)	0(0%)	5(100%)	1(20%)
Gariahat	3	3(100%)	0(0%)	3(100%)	0(0%)
Baishnabghata	4	4(100%)	1(25%)	4(100%)	1(25%)
Beliaghata	4	4(100%)	0(0%)	4(100%)	0(0%)
Rajarhat	3	3(100%)	0(0%)	3(100%)	0(0%)
Salt Lake	3	2(66.7%)	1(33.3%)	3(100%)	1(33.3%)
Paribesh Bhawan	2	2(100%)	0(0%)	2(100%)	0(0%)

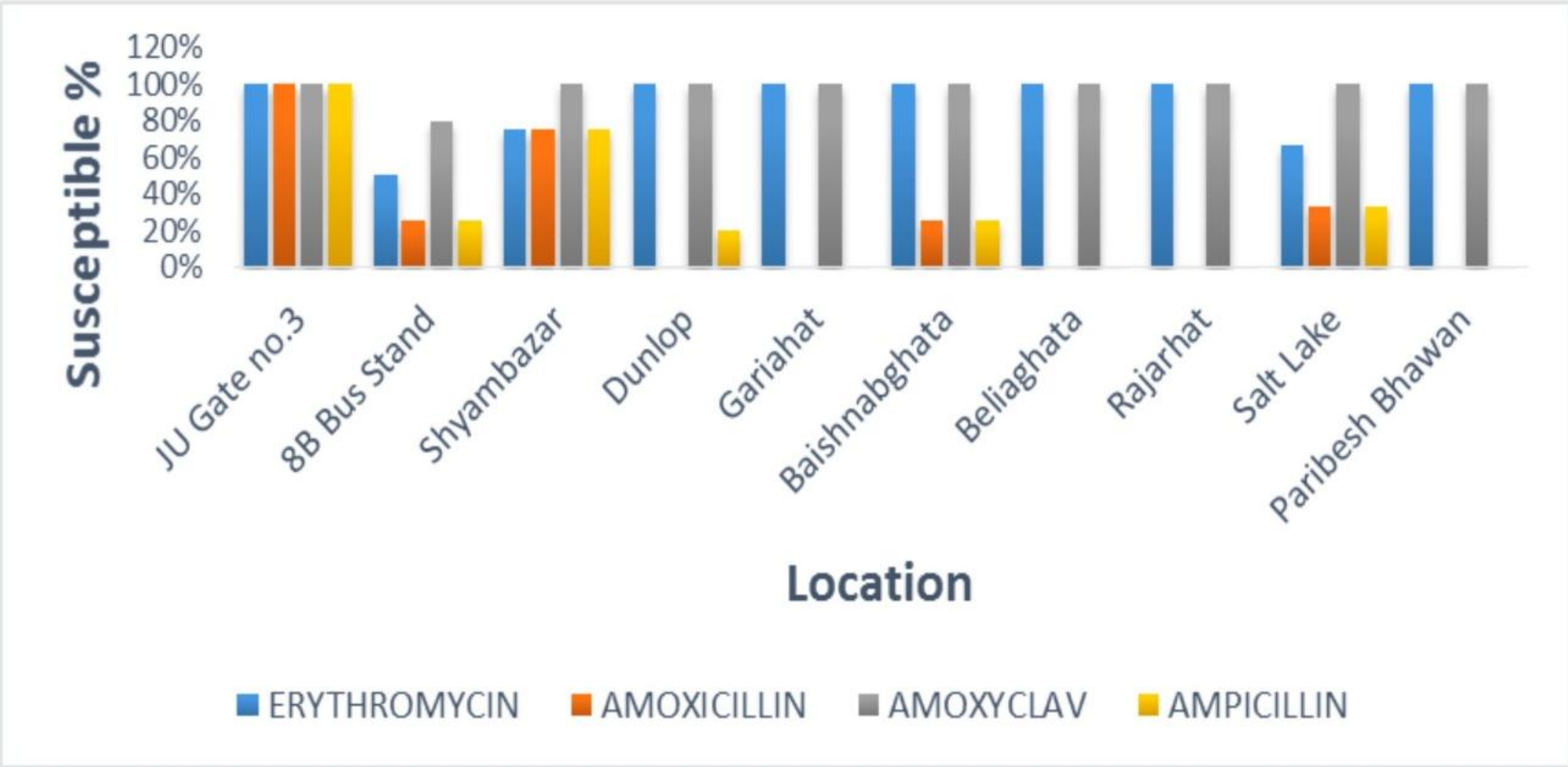

Figure 5.67: Antibiotic susceptibility for different bacterial colonies in various monitoring location

Table 5.6: Multiple antibiotic resistance (MAR) index for different location

JU Gate no.3				8B Bus Stand				Shyambazar				Dunlop				Gariahat			
DC	**b**	**a**	**MAR**	**DC**	**b**	**a**	**MAR**	**DC**	**b**	**a**	**MAR**	**DC**	**b**	**a**	**MAR**	**DC**	**b**	**a**	**MAR**
AB_07/1	4	0	0	AB_08/4	4	1	0.25	AB_08/9	4	0	0	AB_08/13	4	2	0.5	AB_10/18	4	2	0.5
AB_07/2	4	0	0	AB_08/5	4	4	0	AB_08/10	4	1	0.25	AB_08/14	4	1	0.25	AB_10/19	4	2	0.5
AB_07/3	4	0	0	AB_08/6	4	3	0.75	AB_08/11	4	2	0.5	AB_08/15	4	2	0.5	AB_10/20	4	2	0.5
				AB_08/7	4	2	0.5	AB_08/12	4	0	0	AB_08/16	4	2	0.5				
				AB_08/8	4	2	0.5					AB_08/17	4	2	0.5				

Baishnabghata				Beliaghata				Rajarhat				Salt Lake				Paribesh Bhawan			
DC	**b**	**a**	**MAR**	**DC**	**b**	**a**	**MAR**	**DC**	**b**	**a**	**MAR**	**DC**	**b**	**a**	**MAR**	**DC**	**b**	**a**	**MAR**
AB_11/21	4	2	0.5	AB_02/25	4	2	0.5	AB_02/29	4	2	0.5	AB_02/32	4	2	0.5	AB_02/35	4	2	0.5
AB_11/22	4	2	0.5	AB_02/26	4	2	0.5	AB_02/30	4	2	0.5	AB_02/33	4	3	0.75	AB_02/36	4	2	0.5
AB_11/23	4	0	0	AB_02/27	4	2	0.5	AB_02/31	4	2	0.5	AB_02/34	4	0	0				
AB_11/24	4	2	0.5	AB_02/28	4	2	0.5												

Note: a: No. of antibiotics to which isolate is resistant; b: No. of antibiotics tested;
MAR: Multiple antibiotic Resistance; DC: Dominated colonies.

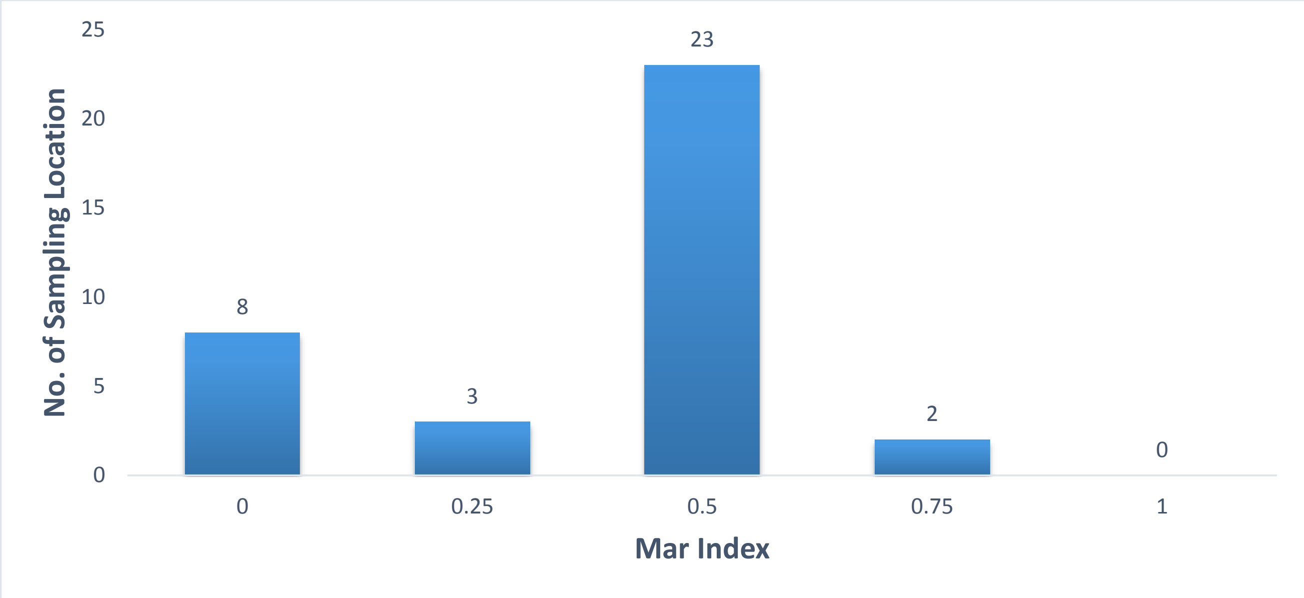

Figure 5.68: MAR index of sampling location

Chapter 6

Conclusions

6. Conclusions

AQI index in ambient air in Kolkata city has been shown to have crossed the national standards and exceeded the NAAQS. While interpreting the microbial concentration, most of the monitoring station has been found to fall under the critical and high pollution categories. The suspension of airborne particles that contain living organisms construct a very important class of air pollutants and are the main causes behind the various disease. The present study aimed that to develop the Air Quality Index (AQI) maps of Kolkata using Geographic Information System (GIS) technology and observe the variation over last five years and Special emphasis are given on the current scenario of bacterial load in airborne particulates, also represented through GIS maps, and their resistance to common antibiotics for a period of eight month starting from 18th August 2018 to 20th February 2019 in different location of Kolkata, West Bengal, India. Air pollution study through indexing and mapping of AQI is carried out so as to determine more properly the major causes behind the pollution in city. The microbial data were collected for 10 locations spreaded across the city. The data is composed of AQI for each location were analyzed and generated contour maps using ArcGIS 10.3. the microbial load in ambient is monitored by measuring bacterial counts in the collected particulates. Different meteorological parameters are also observed and recorded during the monitoring period in monitoring locations to analyse their correlation with the studied airborne microbial fractions in the ambient air. Preliminary characterization of the airborne bacteria sampled in the ambient air and their resistance to common antibiotics of Kolkata city. Based on the results of the monitoring, laboratory experiments and the theoretical analysis, following conclusions have been drawn from the present study:

- Air quality index values expressed as a contour maps that some of the locations of Kolkata had poor to moderately graded index value which gives a gesture that there are pollutants which are resulting in deterioration of the overall quality of air.
- A clear seasonal variation is observed in the count and concentration of airborne bacterial colony, showing higher concentration during winter months.
- All the air pollutant parameters appear to be moderately to well correlate with meteorological parameters. The concentration of air pollutants show a decreasing trend (negative r) with increasing temperature, dew point, relative humidity and wind speed.
- The bacterial load in the ambient air monitored through Andersen cascade Impacter also shows clear seasonal variations. However, the total bacterial count and concentration during winter is higher.
- Bacterial counts seems to have an increasing trend with decreasing relative humidity showing negative correlations, making the concentration higher during the winter months.

- Most of bacteria sampled through Andersen sampler are found to be gram negative. And also observed that bacteria which were isolated from ambient air has been highly susceptible to antimicrobial activity of Erythromycin (15mcg) and Amoxyclav (Amoxicillin / Clavulanic) (30 mcg [20/10 mcg]) (AMC), whereas less susceptible to Amoxicillin (AMX) (15mcg) and Ampicillin (Amp) (10mcg).

6.1 Future scope of work

The present study is the part of a regular coursework and has been carried out within limited time and resources. Followings are a few suggestions regarding future works to carry the present work forward:

- The study has been carried out in Kolkata city, the capital of the state of West Bengal. Similar such studies such be carried in other parts of state which can help determine the overall state air quality and more decisive idea about the microbial characteristics of the particulates in the ambient air of the city..
- The study need to be carried out few more years to get more decisive seasonal trends.
- The characterisation of airborne bacteria done in present study is at preliminary stage. More detailed characterisation need to be done for airborne bacteria for Kolkata city.
- Similar studies could be carried out looking for quantification and characterization of airborne virus and allergens in the ambient air of the city.
- Health surveys with particular focus on the disease related to airborne bacteria need to be simultaneously carried out to get a clear idea of the effects on the exposed population.

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Appendix

January 2018

Location	SO2	NO2	PM10	AQI
Baishnabghata	8.22222222	62	186.6296296	186.6296
Behala Chowrasta	14.7419355	80.64516129	234.5806452	327.5161
Beliaghata	9.25925926	66.2962963	195.5925926	195.5926
Dunlop Bridge	17.1111111	87.14814815	277.5555556	277.5556
Gariahat	10.037037	70.74074074	212.6666667	212.6667
Hyde Road	16.3703704	88	286.7037037	286.7037
Minto Park	10.483871	73.4516129	213.3225806	312.4839
Mominpore	9	62.81481481	183.5555556	183.5556
Moulali	16.3870968	89.67741935	276.7096774	338.9355
Paribesh Bhawan	10.5925926	71.22222222	203.9259259	203.9259
Picnic Garden	7.22222222	60.2962963	203.9259259	203.9259
Salt Lake	8.62962963	61.40740741	203.9259259	203.9259
Shyam Bazar	14.4193548	82.51612903	244.7096774	328.3226
Tollygunge	9.34615385	65.65384615	197.2692308	197.2692
Topsia	14.7407407	81.85185185	246.2222222	246.2222
Ultadanga	13.8518519	81.88888889	249.9259259	249.9259

February 2018

LOCATION	SO2	NO2	PM10	AQI
Baishnabghata	5.5	46.78571429	142.0357143	142.0357143
Behala Chowrasta	9.96428571	63.32142857	176.4642857	259.8214286
Beliaghata	6.21428571	54.39285714	147.8214286	147.8214286
Dunlop Bridge	13.1785714	73.78571429	204.6071429	204.6071429
Gariahat	8.07142857	56.60714286	166.2857143	166.2857143
Hyde Road	12.9285714	72.5	212.1785714	212.1785714
Minto Park	7.82142857	58.60714286	159.75	223.1428571
Mominpore	6.10714286	52.46428571	144.6071429	144.6071429
Moulali	12.9285714	71.82142857	206.7142857	291.9642857
Paribesh Bhawan	7.60714286	56.60714286	162.6785714	162.6785714
Picnic Garden	5.07142857	47.28571429	139.75	139.75
Salt Lake	5.17857143	49.14285714	140.0714286	140.0714286
Shyam Bazar	10.5714286	65.92857143	171.2142857	264.1428571
Tollygunge	5.82142857	55.64285714	141.1785714	141.1785714
Topsia	11.4285714	66.10714286	179.75	179.75
Ultadanga	10.4642857	64.85714286	187.1785714	187.1785714

March 2018

Location	SO2	NO2	PM10	AQI
Baishnabghata	4.11111111	40.22222222	112.2222222	
Behala Chowrasta	6.22222222	49.77777778	132.7777778	146.4444
Beliaghata	4.22222222	41.33333333	118	146.4444
Dunlop Bridge	7	55.77777778	142.6666667	
Gariahat	4.77777778	44.22222222	119	
Hyde Road	8.22222222	57.33333333	146.4444444	
Minto Park	5.33333333	45.55555556	124.6666667	133.4444
Mominpore	4.22222222	42.55555556	123	
Moulali	7.44444444	52.22222222	133.6666667	143.1111
Paribesh Bhawan	4.875	43.875	125.875	
Picnic Garden	3.33333333	37	103.5555556	
Salt Lake	3.88888889	39.22222222	117.2222222	
Shyambazar	6.77777778	51.88888889	134.4444444	148.1111
Tollygunge	4.44444444	40.88888889	113.5555556	
Topsia	7.55555556	53.44444444	140	
Ultadanga	6.44444444	49.88888889	135.6666667	

April 2018

Location	SO2	NO2	PM10	AQI
Baishnabghata	3.55555556	38	84.11111111	
Behala Chowrasta	4.11111111	44.22222222	83.66666667	68.66667
Beliaghata	3.33333333	37.88888889	75.66666667	
Dunlop Bridge	6.5	48.625	112.875	
Gariahat	4.22222222	41.11111111	84.66666667	
Hyde Road	5.55555556	47.66666667	116.3333333	
Minto Park	4.375	40.875	87.375	73.375
Mominpore	3.11111111	37.66666667	68.77777778	
Moulali	5.66666667	46.88888889	108.3333333	90.33333
Paribesh Bhawan	4.125	44.375	85.5	
Picnic Garden	3.11111111	34.88888889	70.55555556	
Salt Lake	3.11111111	36.11111111	64.33333333	
Shyambazar	4.55555556	44.11111111	90	75.33333
Tollygunge	3.22222222	36.66666667	71.77777778	
Topsia	4.88888889	46.88888889	91.88888889	
Ultadanga	5.625	45.625	105.75	

May 2018

LOCATION	Sox	Nox	PM10	AQI
Baishnabghata	3.125	35.625	50.625	50.625
Behala Chowrasta	4.222222	43.44444	71.88889	71.88889
Beliaghata	3	37.11111	51.88889	51.88889
Dunlop Bridge	5.666667	51.55556	81.77778	81.77778
Gariahat	3.375	38.5	55.125	55.125
Hyde Road	5.666667	48.44444	100.2222	100.2222
Minto Park	4.333333	41.44444	73.55556	73.55556
Mominpore	3.25	36.375	58.5	58.5
Moulali	4.75	44.875	69.375	69.375
Paribesh Bhawan	3.777778	39.55556	65.66667	65.66667
Picnic Garden	3	32.875	43.5	43.5
Salt Lake	3.111111	36.22222	53.66667	53.66667
Shyam Bazar	4.222222	43.22222	62.77778	62.77778
Tollygunge	3.111111	37.11111	50.44444	50.44444
Topsia	4.888889	46.44444	79.11111	79.11111
Ultadanga	4.777778	45.88889	77.33333	77.33333

January 2017

Location	SO2	NO2	PM10	AQI
Beliaghata	7.66666667	69.44444444	166.3333333	166.333333
Behala	11.7777778	83.66666667	193	303.666667
Belighata	9.22222222	80.11111111	194.5555556	194.555556
Dunlop	13.3333333	89.55555556	225	225
Gariahat	9.66666667	77.33333333	180.1111111	180.111111
Hyde Road	13.2222222	87.55555556	235	235
Minto Park	10	82.875	190.5	300.875
Mominpore	8.7	70.5	162.9	162.9
Moulali	12.4444444	87.88888889	197.4444444	312.222222
Paribesh Bhawan	9.22222222	78.88888889	188	188
Picnic Garden	7.55555556	68.44444444	171.4444444	171.444444
Saltlake	7.11111111	65.22222222	149.1111111	149.111
Shymabazar	11.5555556	89.66666667	217.5555556	318
Tollygunge	9.22988506	76.03065134	178.4367816	178.436782
Topsia	12.8888889	87.88888889	247.8888889	247.888889
Ultadanga	11.4444444	83.55555556	198.6666667	198.666667

February 2017

LOCATION	SO2	NO2	PM10	AQI
Baishnabghata	5.25	59.375	145.5	145.5
Behala	9	72.75	176.375	272.125
Beliaghata	6.5	65.625	158.5	158.5
Dunlop	12.375	84.25	202.5	202.5
Gariahat	8.5	70.5	179.75	179.75
Hyde road	11.75	79.75	199	199
Minto park	8.25	72.125	170.125	274.125
Mominpur	5.875	62.125	151.25	151.25
Moulali	11.5	79.875	205.75	297.375
Paribesh bhawan	8.125	68.75	166.75	166.75
Picnic garden	6	60.375	158.25	158.25
Saltlake	5.375	61.875	151.25	151.25
Shyambazar	9	74.5	177.125	283.75
Tollygunge	5.25	61	145.5	145.5
Topsia	10.57142857	77.14285714	190	190
Ultadanga	10.625	76.125	185.875	185.875

March 2017

LOCATION	SO2	NO2	PM10	AQI
Baishnabghata	3.375	39.25	95.75	95.75
Behala	5.66666667	51.1111111	119	128
Beliaghata	4.21577381	44.0486111	103.669643	103.6696429
Dunlop	7.5	59.125	136.5	136.5
Gariahat	4.55555556	46.8888889	115.333333	115.3333333
Hyde road	6.77777778	57.7777778	143.777778	143.7777778
Minto park	5.25	48.375	112	116.125
Mominpur	3.75	40.75	95.75	95.75
Moulali	7.11111111	58.1111111	135.111111	151.8888889
Paribesh bhawan	4.375	45.5	110.875	110.875
Picnic garden	3.44444444	39.2222222	100.777778	100.7777778
Saltlake	3.5	39.125	91.75	91.75
Shyambazar	5.11111111	49.6666667	115.666667	115.6666667
Tollygunge	3.22222222	40.2222222	99.4444444	99.44444444
Topsia	7.625	56.75	138.875	138.875
Ultadanga	6.22222222	53.4444444	127.444444	127.4444444

April 2017

Location	SO2	NO2	PM10	AQI
Baishnabghata	3	35.625	80.125	80.125
Behala	4.7777778	43.888889	94.666667	94.6666667
Beliaghata	3.375	36.625	78.125	78.125
Dunlop Bridge	5.75	46.125	105.625	105.625
Gariahat	3.7777778	39.222222	85.111111	85.1111111
Hyde Road	6.375	52.875	129.25	129.25
Minto Park	4	39.75	83.625	83.625
Mominpur	3.4444444	38.444444	83.333333	83.3333333
Moulali	5.3333333	46.555556	102.66667	102.666667
Paribesh Bhawan	4.25	41.125	87.875	87.875
Picnic garden	3.1111111	35	74.333333	74.3333333
Saltlake	3.1111111	36.222222	80.666667	80.6666667
Shymbazar	4.3125	42.0625	92.375	92.375
Topsia	6.3333333	48.666667	112.55556	112.555556
Ultadanga	5	44.222222	95.222222	95.2222222

May 2017

Location	SO2	NO2	PM10	AQI
Baishnabghata	3.1	33.6	69.7	69.7
Behala	4.444444	40.33333	91.55556	91.55556
Belighata	3	33.11111	61.22222	61.22222
Dunlop	4.6	44.1	92.4	92.4
Gariahat	3.25	35.625	76	76
Hyde Road	6.222222	46.33333	114.4444	114.4444
Minto Park	3.8	39.2	83.4	83.4
Mominpore	3.111111	33.55556	67.66667	67.66667
Moulali	5.125	43	96.875	96.875
Paribesh Bhawan	3.5	37.1	75.7	75.7
Picnic Garden	3.125	32.375	67.75	67.75
Saltlake	3.444444	34.77778	73.22222	73.22222
Shymabazar	4.666667	40.77778	89.77778	89.77778
Tollygunge	3.222222	34.66667	71.55556	71.55556
Topsia	5.444444	42.88889	100	100
Ultadanga	4.125	40.125	87.5	87.5

January 2016

Location	SO2	NO2	PM10	AQI
Baishnabghata	6.444444	76.88889	188.5556	188.5556
Behala	9.333333	87.44444	255.1111	315.4444
Dunlop	10.57143	90.85714	236.5714	236.5714
Gariahat	9.5	86.5	228	228
Hyde Road	11	93	241	
Minto Park	7	76	187.2857	307.1429
Momipore	7.142857	81.71429	212.7143	212.7143
Moulali	10.875	93.25	261.5	340
Paribesh Bhawan	7.571429	78.57143	195.5714	195.5714
Picnic Garden	8.6	83.4	201	201
Saltlake	6.666667	75.77778	196.2222	196.2222
Shyambazar	9.888889	91.44444	244.5556	338.3333
Tollygunge				
Topsia	10.42857	88.14286	242.7143	242.7143
Ultadanga	9.75	89	208.75	208.75

February 2016

LOCATION	SO2	NO2	PM10	AQI
Baishnabghata	4.75	65	141.625	141.625
Behala	8.888889	79.77778	182.4444	220.8889
Dunlop	6.714286	74.57143	148.2857	148.2857
Gariahat	6.428571	76.42857	169.1429	169.1429
Hyde Road	6.375	73.125	162.625	162.625
Minto Park	4.857143	63.14286	126.7143	157.5714
Mominpore	5.666667	71.22222	164	164
Moulali	8.571429	83.85714	182.8571	236.8571
Paribesh Bhawan	5.571429	67.42857	134.1429	134.1429
Picnic Garden	5.428571	69.42857	150.1429	150.1429
Saltlake	5.222222	66.77778	148.7778	148.7778
Shyambazar	8.625	81.375	185.375	250.5
Tollygunge	4.75	67.125	136.25	136.25
Topsia	9	80	176.8889	176.8889
Ultadanga	7.714286	78.28571	157.2857	157.2857

March 2016

Location	SO2	NO2	PM10	AQI
Baishnabghata	3.25	46.875	94.375	94.375
Behala	6.5	63.125	136.625	148.5
Beliaghata	4.25	54	121.75	121.75
Dunlop Bridge	6.444444	66.3333	134.5555	134.5555
Gariahat	4.6	56.7	117.3	117.3
Hyde Road	3.625	51.25	106.625	106.625
Minto Park	4.111111	55.11111	113.7778	135.4444
mominpore	4.625	56.125	124	124
Moulali	6.2	65.7	137.2	137.2
Paribesh Bhawan	5	60.66667	126.2222	126.2222
Picnic garden	3.4	50.7	99.5	99.5
Saltlake	4.125	52.625	121	121
Shyambazar	4.555556	58.22222	115.2222	115.2222
Tollygunge	5.1875	55.9375	120.8125	120.8125
Ultadanga	5.5	59.8	118.7	118.7

April 2016

LOCATION	SO2	NO2	PM10	AQI
Baishnabghata	3.125	43.125	75.375	75.375
Behala	5.1111	56.3333	101.5556	101.5556
Beliaghata	3.8889	46.5556	84.2222	84.2222
Dunlop Bridge	5.5556	55.8889	100	100
Gariahat	4.375	50.625	95.625	95.625
Hyde Road	4.2857	49.5714	91.8571	91.8571
Minto Park	3.5556	46.5556	80.8889	80.8889
Mominpore	3.7778	46.6667	84.8889	84.8889
Moulali	6.25	58.5	108.875	108.875
Paribesh Bhawan	3.7778	46.6667	82	82
Picnic Garden	3.625	43.75	78.625	78.625
Salt Lake	3.6667	45.8889	82.8889	82.8889
Shyamabazar	5.125	53.875	101	101
Tollygunge	3.625	46.75	90.5	90.5
Topsia	4.4444	52.8889	93.8889	93.8889
Ultadanga	5	52	92	92

May 2016

Location	SO2	NO2	PM10	AQI
Baishnabghata	3.5	40.25	49.875	49.875
Behala Chowrasta	5	51.25	86	86
Beliaghata	3.7778	44.8889	62.6667	62.6667
Dunlop Bridge	6.888889	58.125	95.5	95.5
Gariahat	3.5	41.5	55.125	55.125
Hyde Road	6.222222	52.55556	98.66667	98.66667
Minto Park	4.888889	47.66667	69.55556	69.55556
Mominpore	3.625	42.25	63.25	63.25
Moulali	4.75	46.875	70.875	70.875
Paribesh Bhawan	4.777778	48.77778	71.66667	71.66667
Picnic Garden	3	37.5	48.125	48.125
Salt Lake	3.625	41.5	64.5	64.5
Shyambazar	6.111111	54.33333	90.88889	90.88889
Tollygunge	4.333333	44.44444	69.22222	69.22222
Topsia	5	49.875	815	81.5
Ultadanga	4.5	45.125	60.5	60.5

January 2015

LOCATION	Sox	PM10	Nox	AQI
Baishnabghata	7.777777778	164.2222222	86	164.2222
Behala Chowrasta	10	186.1111111	93	250.5556
Dunlop Bridge	9.777777778	163.8888889	93.11111	163.8889
Minto Park	8.111111111	145.5555556	84.33333	145.5556
Moulali	11.22222222	186.4444444	94.22222	186.4444
Paribesh Bhawan	8.777777778	171.4444444	80.44444	171.4444
Salt Lake	7	144.3333333	82.88889	144.3333
Shyambazar	9.555555556	181.5555556	90.55556	257.4444
Ultadanga	11.33333333	217.6666667	97.77778	217.6667

February 2015

LOCATION	SO2	NO2	PM10	AQI
Baishnabghata	4.375	63.875	124.625	124.625
Behala Chowrasta	5.875	76.5	131	153.875
Dunlop Bridge	7.75	81.375	148.625	148.625
Minto Park	5.25	71.25	131.75	131.75
Moulali	9.857143	87.85714	193.8571	193.8571
Paribesh Bhawan	10.33333	86	135.5	135.5
Salt Lake	3.875	63.25	104.25	104.25
Shyambazar	6	78.42857	134.5714	158.4286
Ultadanga	6.5	78.625	147.5	147.5

March 2015

LOCATION	SO2	NO2	PM10	AQI
Baishnabghata	3.222222	44.66667	88	88
Behala Chowrasta	3.625	55.5	118.375	118.375
Dunlop Bridge	4.888889	60.11111	122.6667	122.6667
Minto Park	3.333333	51.22222	101.4444	101.4444
Moulali	5	58.28571	115.1429	115.1429
Paribesh Bhawan	3	58.875	87.875	87.875
Salt Lake	3.25	40.875	64.625	64.625
Shyambazar	5.142857	62.85714	167.7143	167.7143
Ultadanga	4.222222	56.33333	110.3333	110.3333

April 2015

LOCATION	SO2	NO2	PM10	AQI
Baishnabghata	3	36.11111	58.55556	58.55556
Behala Chowrasta	3.5	43.5	73.5	83.625
Dunlop Bridge	3.888889	43.88889	93.44444	93.44444
Minto Park	3	36.66667	60.11111	60.11111
Moulali	3.75	45.25	79.25	79.25
Paribesh Bhawan	3.666667	54.11111	130.3333	130.3333
Salt Lake	3.125	36.625	65.5	65.5
Shyambazar	3.666667	44.66667	81.16667	92
Ultadanga	3.555556	43.77778	81.44444	81.44444

May 2015

LOCATION	Sox	Nox	PM10	AQI
Baishnabghata	3.142857	37.85714	77.28571	77.28571
Behala Chowrasta	3.222222	40.66667	73.66667	73.66667
Dunlop Bridge	3.888889	46.55556	86.33333	86.33333
Minto Park	3.222222	39	65.88889	65.88889
Moulali	4	47.66667	100.2222	100.2222
Paribesh Bhawan	3	42.5	73	73
Saltlake	3	34.55556	50.22222	50.22222
Shyambazar	4.111111	44.77778	97.33333	97.33333
Ultadanga	3.875	44.75	95.75	95.75

January 2014

LOCATION	SO2	NO2	PM10	AQI
Baishnabghata	14.66666667	93.55555556	181.3333333	181.3333333
Behala	20	106	254.6666667	321.25
Dunlop	21.22222222	109.4444444	205.6666667	205.6666667
Minto park	17.44444444	98.22222222	178.5555556	178.5555556
Moulali	22.66666667	109.2222222	245.5555556	245.5555556
Paribesh Bhawan	7.125	81.625	192.625	192.625
Saltlake	14	88.77777778	166.1111111	166.1111111
Shymbazar	16.73214286	98.12103175	198.7777778	288.6666667
Ultadanga	16.73214286	98.12103175	217.5555556	217.5555556

February 2014

LOCATION	SO2	NO2	PM10	AQI
Baishnabghata	9.285714	66.14286	149.7143	149.7143
Behala	12.85714	80.57143	199	251.4286
Dunlop	13.5	84.25	171.25	171.25
Minto Park	10.5	74.75	152.375	152.375
Moulali	12.85714	81.71429	184.8571	184.8571
Paribesh Bhawan	11.5	82	165.25	165.25
Saltlake	9.375	67.375	140.375	140.375
Shyambazar	11.625	80.875	161.625	229.25
Ultadanga	11.71429	76.42857	168.4286	168.4286

March 2014

LOCATION	SO2	NO2	PM10	AQI
Baishnabghata	7.3	52.9	112.9	112.9
Behala	10.2	65.4	156.5	188.5
Dunlop	10.11111	68	127.3333	127.3333
Minto park	8.444444	62.22222	120.7778	120.7778
Moulali	9.9	65.5	144.2	144.2
Paribesh Bhawan	6.222222	58.66667	118.7778	118.7778
Saltlake	7.444444	56.22222	115.2222	115.2222
Shyambazar	9.333333	65.44444	130.1111	158.5
Ultadanga	8.6	60	125.4	125.4

April 2014

LOCATION	SO2	NO2	PM10	AQI
Baishnabghata	4.375	31.25	77	77
Behala	6.875	38.625	117.625	117.625
Dunlop	7.25	40.875	106.25	106.25
Minto park	5	35.75	99.375	99.375
Moulali	6.75	39.625	112.375	112.375
Paribesh Bhawan	4.5	45.5	109.75	109.75
Saltlake	5.25	35.625	91.75	91.75
Shyambazar	5.875	38.875	96.625	96.625
Ultadanga	5.25	36.625	90.875	90.875

May 2014

LOCATION	SO2	NO2	PM10	AQI
Baishnabghata	3	29.33333	45.66667	45.66667
Behala	4	36.88889	76	76
Dunlop	5.666667	40.55556	85.66667	85.66667
Minto Park	3.777778	35.22222	69.88889	69.88889
Moulali	4.222222	39.33333	72.33333	72.33333
Paribesh Bhawan	3.111111	38	63.11111	63.11111
Saltlake	17.05556	47.33333	64.11111	64.11111
Shyambazar	4.666667	37.33333	77	77
Ultadanga	3.777778	35.11111	54.55556	54.55556