Spatial variability of soil quality in Cooch Behar urban area and surrounding peri-urban area

A thesis

Submitted to

Uttar Banga Krishi Viswavidyalaya
In partial fulfilment of the requirements for the award of
the Degree of Master of Science (Agriculture)
in

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

By

ARPITA SARKAR

Registration No: A-2018-7-M

Department of SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
Faculty of Agriculture
Uttar Banga Krishi Viswavidyalaya
Pundibari, Cooch Behar 736 165, West Bengal, India
2020

Uttar Banga Krishi Viswavidyalaya

Faculty of Agriculture
partment of Soil Science and Agricultural Chemistry
P.O. Pundibari, Pin 736 165, Dist. Cooch Behar
West Bengal
☎ +91 94346 85382 (M)/ 03582-225055 (R)
e-mail: shovikiitkgp@gmail.com

Dr Shovik Deb, MSc (Ag), PhD
Assistant Professor,
FDAAD; CSIR JRF and SRF; CSIR SPM Nominated; ICAR JRF; JBNSTS Fellow; Recipient of ISSS Zonal Award

September 16, 2020

CERTIFICATE

This is to certify that the thesis entitled **"Spatial variability of Soil Quality in Cooch Behar Urban area and surrounding Peri-urban areas",** submitted to the Faculty of Agriculture, Uttar Banga Krishi Viswavidyalaya in partial fulfillment of the requirements for the M.Sc. (Ag) programme in Soil Science and Agricultural Chemistry by Ms Arpita Sarkar embodies the results of bonafide work carried out by her under my supervision and guidance. No part of the thesis has been submitted by her for any other Degree or Diploma. I further certify that any help or information received during the work on this thesis has been acknowledged.

Shovik Deb

(Dr Shovik Deb)
Chairman, Advisory Committee

APPROVAL OF EXAMINERS FOR THE AWARD OF THE DEGREE OF SCIENCE (AGRICULTURE) IN SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

We, the undersigned, having been satisfied with the performance of **Ms Arpita Sarkar**, on final evaluation of thesis, conducted today, the 8th October 2020, recommended that the thesis be accepted for the award of the Degree of Master of Science (Agriculture) in Soil Science and Agricultural Chemistry.

Members of the Advisory Committee	**Signature**
1. **Dr Shovik Deb** Department of Soil Science and Agricultural Chemistry Chairman, Advisory Committee	Shovik Deb 8/10/2020
2. Dr Debasish Chakraborty (External Examiner)	Debasish Chakraborty 08.10.2020
3. **Prof Ashok Choudhury** Department of Soil Science and Agricultural Chemistry Member, Advisory Committee	
4. **Prof Abhas kumar Sinha** Department of Soil Science and Agricultural Chemistry Member, Advisory Committee	8/10/2020
5. **Dr Ganesh Chandra Banik** Department of Soil Science and Agricultural Chemistry Member, Advisory Committee	Banik 8.10.2020

Uttar Banga Krishi Viswavidyalaya

Faculty of Agriculture
epartment of Soil Science and Agricultural Chemistry
P.O. Pundibari, Pin 736 165, Dist. Cooch Behar
West Bengal
+91 94346 85382 (M)/ 03582-225055 (R)
e-mail: shovikiitkgp@gmail.com

Dr Shovik Deb, MSc (Ag), PhD
Assistant Professor,
FDAAD; CSIR JRF and SRF; CSIR SPM Nominated; ICAR JRF; JBNSTS Fellow; Recipient of ISSS Zonal Award

September 16, 2020

CERTIFICATE

Certified that the thesis entitled "**Spatial variability of soil quality in Cooch Behar urban area and surrounding peri-urban area**", submitted by **Ms. ARPITA SARKAR** bearing Registration number **A-2018-7-M** towards partial fulfilment of the requirement for the award of Master Degree from the **Department of Soil Science and Agricultural Chemistry** under Uttar Banga Krishi Viswavidyalaya has been checked against plagiarism through **URKUND software** on **8th September, 2020** and that the similarity index has been achieved as **1%** which is below the maximum tolerable range as per stipulation of this Viswavidyalaya. The thesis of **Ms. Sarkar** may be accepted for the award of the Master Degree in Soil Science and Agricultural Chemistry of Uttar Banga Krishi Viswavidyalaya.

Shovik Deb 16.09.2020
(Signature)

(Name in block letter): **Dr SHOVIK DEB**

(Chairman, Advisory Committee)

Certificate of Originality

To

The Chairman, Advisory Committee

Department of Soil Science and Agricultural Chemistry

Faculty of Agriculture

Uttar Banga Krishi Viswavidyalaya

Sub: **Undertaking regarding checking for similarity index of manuscript of submitted thesis**

Respected Sir / Madam:

I wish to submit the following:

i. Name of the student (in block letters): **ARPITA SARKAR**

ii. Registration number: **A-2018-7-M**

iii. Name of Chairman of Advisory Committee: **Dr Shovik Deb**

iv. Name of the Department: **Soil Science and Agricultural Chemistry**

v. Title of the Thesis: **Spatial variability of soil quality in Cooch Behar urban area and surrounding peri-urban area**

vi. Total Pages of the thesis: **41** (main text) **+ xviii** (reference)

I do hereby certify that the above-mentioned thesis was checked against plagiarism / for similarity detection. The process and outcome are stated below:

vii. Software used: **URKUND software**

viii. Date: **8th September, 2020**

ix. Similarity Index: 1%

The complete report is submitted for review.

Thanking you

Yours faithfully,

Arpita Sarkar

Signature of student

Name of the student (in block letters): **ARPITA SARKAR**

Only software for checking similarity index output is certified

18/09/2020

(Signature of In-charge, Central Library with official seal)

Contd..../- (PTO)

Contd…from pre-page (overleaf)

The complete report of the above-mentioned thesis has been reviewed by the Advisory Committee of the student (following to be ticked as appropriate).

☑ The similarity index of the above mentioned thesis is below the accepted norms.

☐ The similarity index of the above mentioned thesis is above the accepted norms, because of the following reasons:

1 ……………………………………………………………………………………

2 ……………………………………………………………………………………

3 ……………………………………………………………………………………

4 ……………………………………………………………………………………

5 ……………………………………………………………………………………

The thesis may be considered for the award of Degree (relevant software generated document attached).

Forwarded for consideration

Shovik Deb 18/09/2020

Signature of Chairman, Advisory Committee

Dr. Shovik Deb
Assistant Professor
Deptt. of Soil Sc. & Agril. Chem.
Uttar Banga Krishi Viswavidyalaya
Pundibari, Cooch Behar-736165, W.B.

Forwarded

18/9/2020

(Signature and Official Seal of Head of the Department)

Head
Dept. of Soil Science & Agril. Chem.
U.B.K.V. Pundibari, West Bengal-736165

The process for submission of thesis is allowed / not allowed to commence.

18.09.2020

(Signature and Official Seal of the Dean, Post Graduate Studies)

ACKNOWLEDGEMENT

I feel the inadequacy of words to express my deep sense of gratitude to Dr. Shovik Deb, Assistant Professor of Soil Science and Agricultural Chemistry, Department of Soil Science and Agricultural Chemistry, Uttar Banga Krishi Viswavidyalaya and Chairman of my Advisory Committee for his constant supervision, indelible inspiration and scholarly advice throughout the entire research work and sparing his valuable time in preparation of this manuscript. Gratitude is offered not only for his excellence as a teacher but also his gentle, persistent and wise mentoring.

I wish to express my sincere gratitude to the members of the Advisory Committee Prof. A. Choudhury, Professor of Soil Science and Agricultural Chemistry, Prof. A. K. Sinha, Professor of Soil Science and Agricultural Chemistry, Dr. G. C. Banik, Assistant Professor of Soil Science and Agricultural Chemistry for their inspiring guidance and constructive suggestions throughout this study.

I am greatly indebted to Dr. P. Mukhopadhyay, Professor of Soil Science and Agricultural Chemistry, Prof. D. Mukhopadhyay, Professor of Soil Science and Agricultural Chemistry, and Dr. Amrit Tamang, Assistant Professor of Soil Science and Agricultural Chemistry for their continuing encouragement, moral support and affectionate blessings.

I am thankful to Parimal Da, Anarul Da, Kalyan Da, Rattan Da, Tapan Da, Hassan Da, Madhusudan Da, Saddam Da, Faju Da, Salim Da, and all the other non teaching staffs of the Department of Soil Science and Agricultural Chemistry, Uttar Banga Krishi Viswavidyalaya, Pundibari and Library staffs of the University.

I would like to express my gratitude to my seniors, Rakesh Da, Princy Di, Samaresh Da, Parijat Da, Nandini Di, Rangaswami Da, Dewali Di, Munmun Di, Abhishek Da, Subhadeep Da, Puspendu Da, Barnali Di, Sumana Di, Jhutan Da, Prodipto Da for giving me valuable advice, constant encouragement and help throughout my year of study, research and writing this thesis.

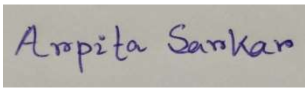
I want to acknowledge my deepest sense of gratitude to my classmates Souvik, Sagardeep, Jakir, Tulipa, Subhasis and my juniors Soumyasesh, Dipta, Attrayee, Sandip, Mithu for their support and encouragement.

Finally and foremost, without the encouragement, blessings, help and moral support provided by my parents Mr. Prithwish kumar Sarkar, Mrs. Aparna Sarkar, brother Partha pratim Sarkar and other

family members this thesis would remain the idea it has always been rather than the reality it has become. To all, I am extremely grateful.

There are many others who in various ways, have contributrd to and assisted in this research work directly or indirectly. I express my sincere thanks to them.

Mere acknowledgement will never be enough for their unfading sacrifice, love and good wishes which nourishes my hopes and ambitions.



Place-UBKV, Pundibari
Date- 16/09/2020

(Arpita Sarkar)

Spatial variability of soil quality in Cooch Behar urban area and surrounding peri-urban areas

Abstract

Maximum of the global urban soil researches are concentrates in megacities only. Very little importance has been given to the soils of small cities and towns till date. Although big cities have higher anthropogenic pressure, the sewage management system is also very functional there. On the contrary, small cities and towns have less urban pollutants, but also very weak waste management and disposal system. Therefore, soil pollution and quality of small cities and towns are matters of concern. In this context, this study selected Cooch Behar, a town in Northern part of West Bengal, India, along with its peri-urban areas with the objectives (i) to understand the impact of urbanization on soil quality and peri-urban area, and (ii) to estimate the extent of microplastics pollution in and around Cooch Behar town.

Soils of the study area belongs to two soil series *viz*. Lotafela series (sandy loam) and Balarampur series (silty loam). The soils were predominantly acidic to neutral in pH. However, a small portion of urban area showed higher soil pH (>7). The possible reason was dumping of unused and waste building materials like lime and cement in the soil. All the soils showed very high organic C ($\bar{x}$ 19.7 Mg ha^{-1}), which was much more than the national average (0.42 %). Soil available N was low ($\bar{x}$ 125.4 kg ha^{-1}) and spatially homogenously distributed. Soil NO_3^--N concentration was high ($\bar{x}$ 46.9 mg kg^{-1}) and even exceeded the permissible limit in some places. High soil available P status was observed in all the municipality area and also in few discrete peri-urban areas. The possible reason of high organic C, NO_3^--N and P concentration were urban waste dumping and improper waste management. Peri-urban agricultural activities and high fertilizer application might also be another reason. This was alarming as leaching of excess NO_3^- into groundwater and P-runoff in the surface waterbodies were possible. Soil available K status was found moderate. Among the heavy metals, the whole study area was found high in bio-available Cr ($\bar{x}$ 2.31 µg g^{-1}), while a small area of Cooch Behar municipality had bio-available Cd more than the critical limit. No lead (Pb) toxicity was found in any of the soils. This study found high concentration of microbial biomass C in discrete areas of Cooch Behar municipality and North-Western peripheral area. Soil respiration, which represents microbial activity, was found high in the municipality area mainly. A high correlation was observed among microbial biomass C, soil respiration and soil organic C. On the contrary, no correlation of heavy metals was found with any other soil properties. It indicated that the heavy metals were not associated with soil properties but with point source anthropogenic activities. Analysis of microplastic contamination in the soils showed high presence in certain part of municipality area and surrounding peri-urban area. Surprisingly, other urban areas had much less microplastic load. Detailed ground analysis indicated that microplastic pollution was not directly associated with urban population but with plastic waste dumping and improper waste removal. Observation under stereo-microscope and scanning electron microscope indicated presence of different types of microplastic particles in soil like thermocol fragments, microplastic films and fibres etc. Even presence of nano-plastic particles (< 10 µm) were found in the soil. Plant can uptake these nano-plastic particles and thus there is a chance that, these particles can enter into the food chain. This study indicated contamination and degraded soil health in Cooch Behar town and its peripheral area. It is recommended that number of future studies should focus on the soil quality and pollution status of small cities and towns worldwide.

Keywords: Urban soil; soil quality; contamination; heavy metal; microplastics

Contents

List of Tables

List of Figures

1. Introduction

1. Introduction

Currently, over 50% of total population lives in urban areas worldwide (Dye, 2008). In 2007, the United Nations has predicted that, the number of people residing in urban areas will reach to 9.2 billion from 6.7 billion globally between 2007 and 2050. Since the past 50 yrs, due to rapid urban growth the population density is increasing in very large cities of numerous developing countries. As a result, the rate of urban growth is more rapid in developing countries than in developed one (Godfrey and Julien, 2005). Mainly, population density is high in urban areas and maximum of the land area is occupied by building infrastructure. In general sense, urban ecosystem constitutes not only centre of the city but also surrounding areas of city core. The United States Census Bureau characterizes urban areas as the areas having min population of 2500 and population density of atleast 1000 people per square mile in center part.

Sometimes the expansion of urban area can create unhealthy environment for human being that may lead to the transmission of various diseases (Moore et al., 2003; Godfrey and Julien, 2005) and mental problems (Bhugra and Mastrogianni, 2004). The sealing of soil and contamination with various organic or inorganic pollutants are considered as main risks to soil in urban and surrounding peri-urban soil (Andrews and Carroll, 2002). The quality of soil is generally associated with several soil characteristics such as soil reaction or pH, organic carbon content, available nutrient content, microbial biomass content. Soil is considered as significant part of the urban ecology and the assessment of soil quality is important from management point of view. Generally, the soil quality of urban and adjacent areas varies spatially and depends on various anthropogenic activities and environmental condition of that area. It has been reported that, Phosphorus rich layer may form in soil of urban areas (Shen, 1990) and these soils normally show higher level of organic matter and nutrient content (Nitrogen, Potassium) (Jim, 1998; Zhang et al., 2011). Urban soils may have reduced hydraulic conductivity, increased compaction, poor structure and inadequate aeration facility (Scharenbroch et al., 2005). Usually, surface runoff increases from 10% to 30% in urban areas as compared to non-urban areas (Hough, 1995). The presence of various toxic substances in urban soil may pose threat to humans as these substances can enter the body (Abrahams, 2002). There are several negative impacts of urbanization on environment, economy and these impacts include decline in agricultural land and quality degradation, increased land utilization (Gayda et al., 2004). It is evidenced that, soil organisms are responding to altered soil physicochemical characteristics related to urbanization (Steinberg et al., 1997; Pavao-Zuckerman and Coleman, 2007). Air pollution is also a growing concern in urban and adjacent areas due to increased industrial activities, excessive traffic emission. Air pollution has adverse effects on urban and peri urban agriculture (Te Lintelo et al., 2002) and it may hamper the yield, quality of crops (Ashmore and Marshall, 1999). Increasing urban growth has the potential to contaminate water in several ways. Various water sources in urban and adjacent areas may be polluted from dumping of untreated solid waste, leaching from landfills (Zhang et al., 2012), ineffective treatment of waste water (Le Pape et al., 2013), industrial effluents. There is temperature difference between urban and adjacent areas mainly due to spatial heterogeneity of landscape in urban areas (Arnfield, 2003) and usually the core part of urban area is more warm than surrounding areas and this elevated temperature may increase ozone formation (Sukopp, 1998).

Perhaps the most important characteristic feature of urban soil is the pollution. Generally heavy metal pollution is seen in urban soil and several works have been conducted on behaviour of heavy metals in soil of cities, towns and in adjacent areas (Kelly and Thornton, 1996; Imperato et al., 2003; Biasioli et al., 2006; Wong et al., 2006). These studies in urban areas indicated that, soils of urban areas show greater concentration of Cu, Zn, Pb (Li et al., 2001; Wong et al., 2006) and Cd (Imperato et al., 2003) than that of rural areas. Lead pollution in urban environment usually occur from industrial discharge, coal burning, tyres etc (Andersen et al., 1978; Kuang et al., 2013). High level of Pb and Fe is found in groundwater of some cities (Kumar et al., 2009). Heavy metals may enter the food chain by way of plant uptake (Hu et al., 2006). So, evaluation of heavy metal contamination in urban and surrounding areas is becoming an important environmental issue in several countries. The increased concentration of heavy metals also has harmful effects on soil system (Cui et al., 2005).

Many cities have problems regarding disposal of wastes as the production of wastes is rising gradually due to urban growth and increase in population (Salleh et al., 2002; Idris et al., 2003). Due to rapid urban growth and variation in lifestyles, the composition of wastes is also changing and generally they are plastic materials or other wastes of inorganic nature. Usually open dumping is followed for urban waste disposal but this method is not an appropriate way of disposal as it poses several threats to soil, air and water quality (Kansal, 2002). The occurrence of microplastic pollution is also reported in many cities, industrial areas and neighbouring areas (Fuller and Gautam, 2016). Presence of microplastics in soil environment may have negative effects on the activity of earthworms (Huerta-Lwanga et al., 2017) and can alter soil physical, biological characteristics like soil aggregation, water holding capacity and bulk density (Wan et al., 2019). It's abundance in soil affects various functions of plants by altering soil structure (Peres et al., 2013), microbial activity (Wagg et al., 2014; Powell and Rilling, 2018). Therefore, analysis of microplastics as potential threat to urban environment is become an important task.

With the shift of rural population to urban areas, the demand for food is also increasing. So, rural areas may not be able to supply food solely in urban areas as per the increasing demand. In this perspective urban and peri-urban agriculture have a significant role to ensure food supply in urban areas. The salient characteristic of this type of agriculture is that, it is an indispensable element of urban ecosystem (Mougeot, 2000) and highly determined by various urban situation. It is estimated that, urban and peri-urban agriculture share 10% of food supply globally (Schnitzler et al., 1998). Agricultural activities in urban and adjacent areas can act as considerable source of income (Freidberg, 1996;Moustier and Danso, 2006), mitigate malnutrition (Egziabher et al., 1994), ensure food security to urban people (Atkinson, 1995) and thus upgrade their standards of living.

In the past years, many studies have been carried out in big cities, metropolitan areas but less attention has been given to small cities (Bell and Jayne, 2009). However, large proportion of urban inhabitants (around 61%) reside in small and medium sized city or town areas. These areas may not have proper waste recycling or management facilities, health services, sanitary facilities, water supply and other basic amenities

(Cohen, 2006; Montgomery, 2008). Usually, waste generation is more in large cities and they have improved waste dumping, waste treatment facilities but the waste disposal and waste management system of small cities (less than 100,000 population) are faulty, unregulated, unplanned (Oakley and Jimenez, 2012). In spite of having several difficulties in terms of waste handling, sanitary issues, pollution control, governmental support, health hazard, the study in small cities are commonly neglected. For this reason we selected urban and surrounding peri-urban areas of Cooch Behar district as our study area. It is a small district located in northern side of West Bengal. According to census 2011, the population of Cooch Behar town was 77,935 and 10.27% of total population inhabited in urban regions of the district. This study was carried out with following objectives:

1. To understand the impact of urbanization on soil quality of Cooch Behar municipality and peri-urban area
2. To estimate the extent of microplastics pollution in and around Cooch Behar town

2. Review of Literatures

2. Review of Literatures

Following the set of objectives, this part is based on understanding of the subject matter of previous studies. This part tried to discuss about the reviews on variation of soil qualities in urban and surrounding peri-urban areas.

2.1. Urbanization

Generally, urbanization refers to the increase in the proportion of people living in cities, use of agricultural or unmanaged land for recreational, industrial, residential purpose. It is mainly the process by which towns, cities are formed. Urban expansion resulted in the change of land cover of existing cities, metropolitan areas (Dwyer et al., 2000; United Nations, 2001). Urban land areas are increasing globally and expected to become threefold between 2000 and 2030 (Seto et al., 2012). Studies showed that in 1800, 2% of the world population inhabited in cities or towns or metropolitan areas but gradually this number raised to 14% in 1900, 29% in 1950 and at present it become more than 50% (Wu et al., 2014). It is predicted that, 70% and 100% of world population will live in urban areas by 2050 and 2092 respectively (Batty, 2011). With this rapid urbanization, there is transformation of natural land to urban area and it has direct or indirect effects on soil, food security (Blum, 1997). Though urbanization has positive correlation with economic development, it has several negative impacts on environment (Grimm et al., 2008; Pickett et al., 2011; Ghosh et al., 2019). In urban areas, various anthropogenic activities are associated with urban pollution and may lead to the release of greenhouse gases. It has been studied that, the concentration of CO_2 is considerably higher in urban areas than nonurban, rural areas (Pataki et al., 2007). Anthropogenic activities in urban areas influence local and regional climate. It has been reported that higher surface and soil temperatures are prevalent in urban areas than neighbouring rural areas (Oke, 1985; Voogt, 2002). Water cycle and stream flows are also influenced by urbanization as it alters the runoff pattern, evaporation and transpiration rates, contaminates water, changes land cover (Pickett et al., 2001, 2011). Generally, soils in urban area have high degree of spatial variability in terms of carbon, nitrogen, soil organic matter, pollutants and other elements (Jenerette et al., 2006; Wu et al., 2011; Ghosh et al., 2019). It has been reported that, expansion of urban areas and increase in population density lead to decrease in land for agricultural production (Yang and Li, 2000; Lin and Ho, 2003; Zhang et al., 2004).

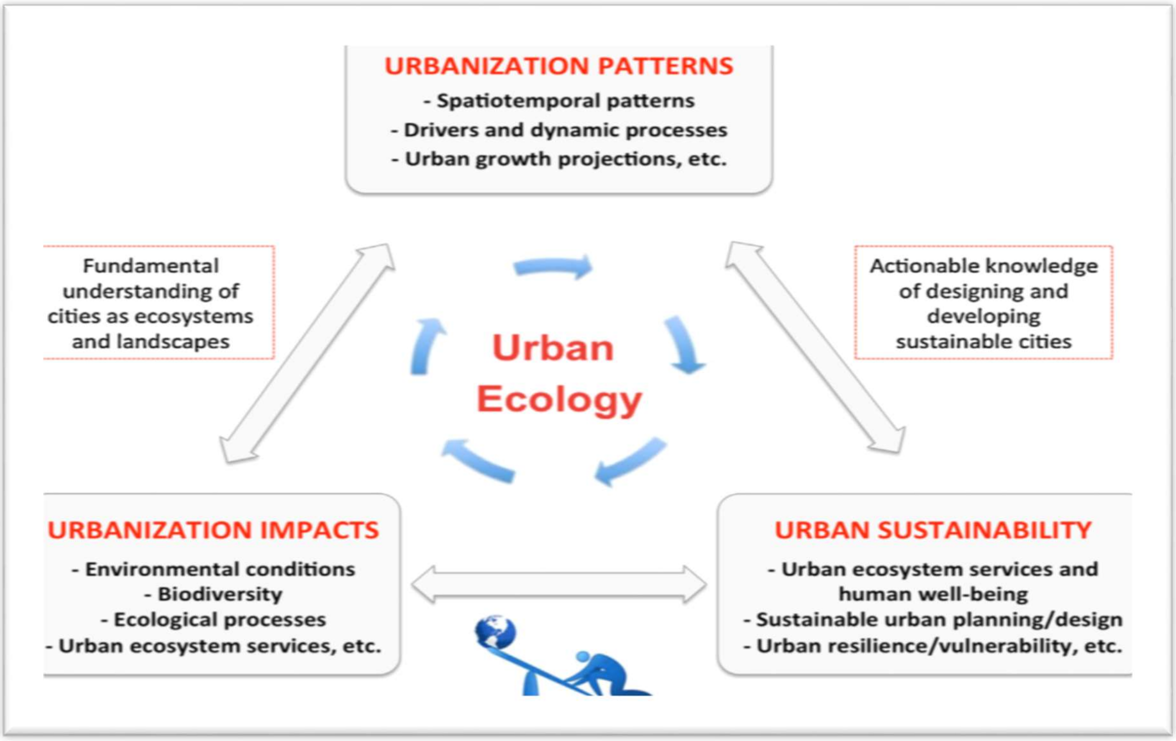


Fig 2.1. Conceptual diagram of urban ecology which shows interactions between spatiotemporal patterns, environmental and social impacts and sustainability of Urbanization (Wu, 2014).

2.2. Soil quality

Soil quality is an important component of environmental quality, besides air and water quality (Andrews et al., 2002). Sustaining soil quality is the most effective method to ensure sufficient food for supporting life. Soil quality is commonly defined as "the capacity of a specific kind of soil to function within the ecosystem boundaries, to sustain biological productivity, protect environmental quality, and ensure community viability" (Doran and Parkin, 1994). The various opinions associated with soil quality were introduced to allocate agricultural inputs in correct proportion and at right time (Warkentin and Fletcher, 1977). Soil quality has two aspects viz., inherent and dynamic soil quality (Seybold et al., 1999). Intrinsic or inherent part of soil quality depends on natural or inherent composition of soil like particle size distribution, mineralogical composition and can't be altered easily whereas the dynamic part changes over a relatively short time period due to various anthropogenic activities and are affected by different agronomic practices (Larsen and Pierce, 1994). The abundance of soil organic carbon is an important factor for the soil quality (Deb et al., 2019). It is necessary to cover chemical, physical and biological characteristics of soil to understand the concept of quality of soil (Frankenberger and Dick, 1983; Nannipieri et al., 1990; Dick, 1994; Gelsomino et al., 2006). The quality of soil, generally the degree of pollution has various effects on human health and ecosystem (Chen et al., 2010; Zhang et al., 2011). Microbial biomass and enzymatic activity are reduced in heavy metal contaminated soil (Wang et al., 2007). Various human activities in urban area may change the physical characteristics of soils. Generally soil texture, structure, plasticity, hydraulic conductivity, temperature, moisture content and bulk density are the physical characteristics of soils. There are reduced soil structure, limited oxygen supply, surface crust, compaction, altered pH, temperature and restricted drainage in urban soils (Green and Oleksyszyn, 2002). Several development practices in urban areas may also result increase in bulk density, degradation of soil health, decrease of vegetative cover and disruption of Carbon cycles (Jim, 1998b; Kaye et al., 2006; Woltemade, 2010). In urban soils, the layers may not always parallel to the soil surface and sometimes may show abrupt changes at one or more layers within the profile and exhibit broken horizons in vertical plane (Craul, 1992). Soils in urban area show strong spatial heterogeneity (Schleuss et al., 1998).

2.3. Urbanization and soil pollution

Soil pollution in urban areas mainly caused by discharge of municipal and industrial sewage, urban wastes, irrigation with sewage and polluted water. Urbanization leads to the collapse of agro ecosystem and causes a significant deterioration of soil quality (Li et al., 2003; Chen et al., 2001). Various anthropogenic activities like urban expansion, transportation, industrial growth have negative impacts on the soil environment generally in terms of heavy metal accumulation (Zhong et al., 2007; Zhang et al. 2012). Generally urban centers are characterized by higher population densities, different anthropogenic activities and also produce a large amount of waste which may also contain plastics in significant amount (Fendall and Sewell, 2009;

Hidalgo-Ruz et al., 2012). It has been reported that microplastics are highly accumulated in some industrial areas. For example, in Australia, the neighboring soils of an industrial area received a large amount of microplastics which varied from 0.03% to 6.7% (Fuller and Gautam, 2016).

High concentration of nitrate may present in urban and peri-urban areas. In urban environment, nitrogen sources are landfills, atmospheric deposition, industries etc (Lerner et al., 1999; Wakida and Lerner, 2005). Nitrate also come from agricultural field due to use of fertilizers.

Heavy metal contamination

Rapid industrial development and increase in urban areas may lead to the soil pollution by accumulating heavy metals in soil and this problem is increasing day by day in several countries (Mireles et al., 2012; Wei and Yang, 2010; Yaylali-Abanuz, 2011). Availability of accumulated heavy metals in soil depends on different factors like soil temperature, pH, nutrient concentration, available water content (Alloway, 2013). The elements which are considered as heavy metals in soils include Cr, Cu, Cd, Hg, Pb, Zn, Mn, Mo and Co. These elements can convert to different forms and may develop toxicity in soil. The concentration of heavy metals in soil has significant influence in determining the quality of soil in urban areas and may be used to observe natural variability in the soil composition. The concentration of heavy metals in soil system and their bioavailable forms influence the rate of pollution in environment (Lu et al., 2003; Santos et al., 2005; Watmough et al., 2005). Heavy metals enter into soils through numerous ways, including atmospheric deposition (Han et al. 2006), use of pesticides, fertilizers for agricultural production (Lu et al. 1992), accumulation of solid waste (Zheng et al. 2005), use of sewage water for irrigation. It has also been studied that, the heavy metals in urban soil can be accumulated in excessive quantities mainly by traffic emission and industrial emission (Hamzeh et al., 2011; Faciu et al., 2012). Contamination of heavy metals in urban environment may change soil physical, chemical properties, deteriorate soil biological function and create other environmental problems (Papa et al., 2010).

Microplastics contamination

Microplastic contamination in soil or water may lead to several ecological problems due to their negative impacts on nature, extensive use, small particle size (Wright et al., 2013; Scheurer and Bigalke, 2018**).** Nowadays the use of plastic products is inevitable as they are cost-effective, durable, light-weight (Barnes et al., 2009). Therefore, enormous amount of plastics are transferred in the seas (Thompson et al., 2004) and also a large quantity of plastic wastes are accumulated in soil. Plastic pollution in marine environment was 1st reported in 1972 (Carpenter et al., 1972; Carpenter and Smith, 1972).

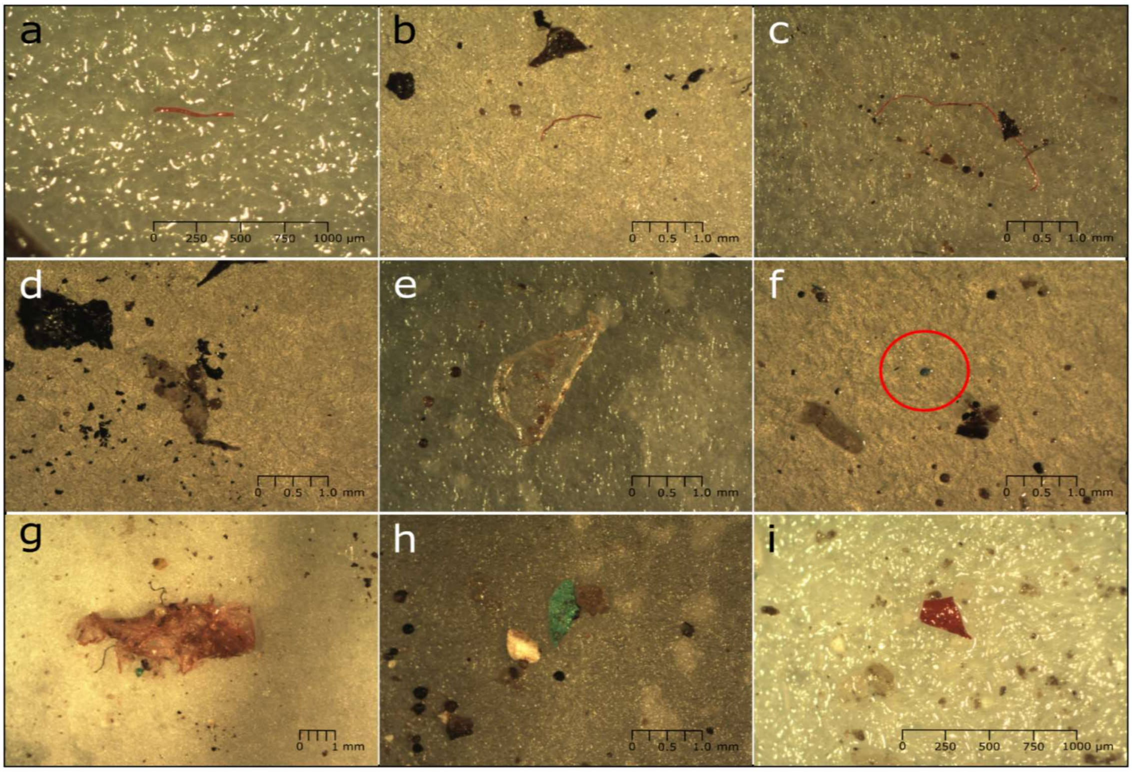


Fig 2.2. Microplastics images observed by microscope (SMZ 745 T, Nikon, Tokyo, Japan) Fibres (a, b, c) films (d, e) pellets (f) fragments (g, h, i) Source: Corradini et al., 2019)

Many researches have been carried out on the occurrence and impacts of microplastics in marine environment but only a few studies have been accomplished about terrestrial ecosystem. However, recently some studies have conducted to understand the sources, contamination level of microplastics in soil and their impacts on various organisms in soil system (Huerta Lwanga et al., 2016; Rodriguez-seijo et al., 2017; Zhang and Liu, 2018). These studies show that, microplastics are generally omnipresent and persist in soil environment (Zhang and Liu 2018) and they have negative effects on survival, growth and health of many organisms in soil system (Huerta Lwanga et al., 2016). Microplastics are the small plastic particles generally <5 mm in size (Rilling et al., 2017). Nowadays, the most commonly used synthetic plastics include polypropylene, polyvinyl chloride, polyethylene terephthalate and polystyrene. These plastics constitute nearly 90% of world total plastic production (Andrady and Neal., 2009).

Different studies are showed that microplastics have been detected in aquatic environment and are detrimental to various aquatic organisms (Matthew et al., 2011; Rilling and Bonkowski, 2018). Several researches also pointed out the undesirable impacts of plastic materials and microplastic particles in soil ecosystems (Rilling, 2012). It has been found that land may contain 4-23 times more microplastics than oceans (de Souza Machado et al., 2018). It has been reported that, plastic may account 54% by mass of anthropogenic wastes which are liberated to environment (Hoellein et al., 2014). The bioavailability of microplastics depends on their various physicochemical properties (Zhang et al., 2018). Various pathways by which microplastics can enter in terrestrial environment are use of organic fertilizers and sludge as an input in agricultural field (Zubris and Richards, 2005; Zhang and Liu, 2018), use of personal care products like cosmetics, bath foam, toothpaste etc. (Mason et al., 2016), atmospheric deposition (Dris et al., 2016), plastic greenhouse covers (Song et al., 2017), use of plastic mulches in agriculture (Yan et al., 2015). Other routes of entry of microplastics in environment are the use of wastewater for irrigation, illegal dumping of wastes near roads, runoff from urban area, plastic packaging materials, water pipes (Bläsing and Amelung, 2018). It has been reported that sludge may contain upto 90% of microplastics of influent wastewater (Mintenig et al., 2017; Li et al., 2018). In urban environment 70% of microplastics may come from tire materials (Lassen et al., 2015). In soil, the accumulated plastic materials are subjected to various physical stresses, chemical, biological degradation (Barnes et al., 2009; Briassoulis et al., 2015). This break down of plastic materials into smaller fragments results microplastics or even nanoplastics and these small pieces release to the environment and soil may act as sink for contamination (Rilling, 2012; Zubris and Richards, 2005). Generally, topsoil provides favourable condition for degradation of plastic wastes due to direct impact of weathering agents, comparatively high temperature and increased O_2 availability (Chae and An, 2018). Moreover, agricultural practices like tillage and crop rotation may enhance the fragmentation process. However, the breakdown of plastic debris in soil may occur at slower rate. It has been reported that, after 1 year of soil accumulation, there is only 0.4% weight loss of Polypropylene (Ali et al., 2014).

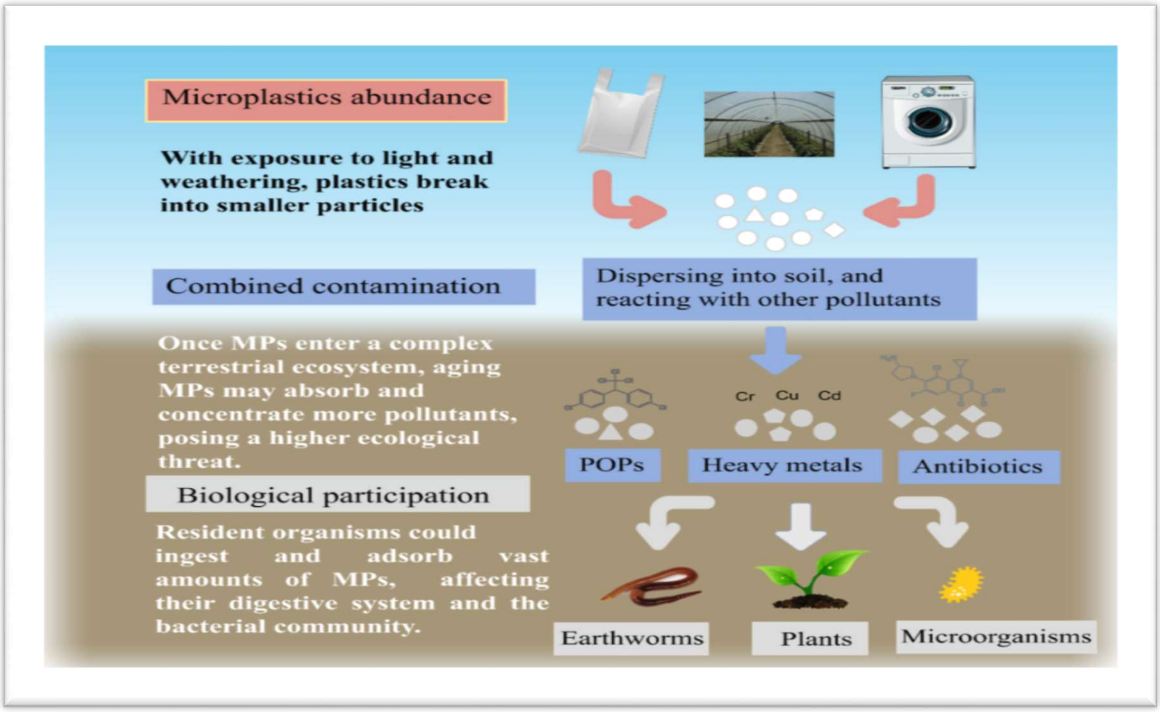


Fig 2.3. Interactions of microplastics in soil system (Wang et al., 2019)

Microplastics may be stored in soil aggregates for longer period and this process depends on environmental condition as the stability of soil aggregates is correlated with soil health (Gupta and Germida, 2015). After entering in terrestrial environment, microplastics react with other pollutants like heavy metals, persistent organic pollutants (POPs) such as polycyclic aromatic hydrocarbon, polychlorinated biphenyls and antibiotics (Hodson et al., 2017). For example, polyethylene film used in horticulture may act as vector of transport of pesticides (Ramos et al., 2015). Zinc, a terrestrial contaminant may be adsorbed by microplastics and by ingestion process it can be transported from micrplastics to earthworm (Hodson et al., 2017). Interactions between plastics and other pollutants depend on environmental conditions

(Karapanagioti and Klontza, 2008; Bakir et al., 2014; Koelmans et al., 2016). Texture and particle size are also considered as important factors which determine the binding capacity of microplastics with other contaminants. It has expected that physical weathering of particles results greater surface area (Ivar do Sul and Costa, 2014). It has also been studied that microplastics have adverse effects on terrestrial birds (Zhao et al., 2016) and seabirds (Tanaka et al., 2013; Van Franeker and Law, 2015).

2.4. Impact of urbanization on plants, soil organisms and human health

Heavy metals have adverse effects on human health as they are very toxic, non-biodegradable and liable to bioaccumulate (Wei and Yang, 2010). Heavy metals in urban area can be accumulated in human body by inhalation, ingestion or dermal absorption. However, the soil-crop system is considered as an important pathway of entry of heavy metals in human body in agricultural area (Oliver, 1997; Boim et al., 2016; Liu et al., 2017). It has been reported that risk is involved to human being due to lead (Pb) contamination in soil as it can damage the nervous system (Kaufmann et al., 2003). Long term exposure to Cd can cause bone fractures and kidney failure. The negative impact of human exposure to contaminated soil depends on various factors like the several ways of exposure, ingestion and behaviour of contaminants in human body (Madrid et al., 2008; Morton-Bermea et al., 2009; Dao et al., 2010). It has also been reported that, another important factor is age. Generally, children and infants are at higher risk of exposure than adults to soil contaminants (Johnsson and Bretsch, 2002; Yáñez et al., 2003; Ljung et al., 2007; Madrid et al., 2008).

Only a few studies have focused on effect of microplastics on the growth, survival, reproduction, feeding habit and metabolic activity of soil organisms including nematodes, earthworms. In urban areas microplastics can be inhaled by humans and animals and create problem to human health. Microplastics may also enter in food chain via aquatic organisms and thus poses potential threat to human (Wright et al., 2013; Nelms et al., 2018). Huerta Lwanga et al. (2016) reported that mortality of earthworms is increased in microplastics contaminated soil, whereas growth rate followed the opposite pattern. Terrestrial organisms may ingest microplastics by mistaking those as food or use as habitat (Sun et al., 2012). Size is considered as an important factor to determine toxic effects of microplastics on nematodes (Lei et al., 2018; Kim et al., 2019). It has been studied that different factors like soil physical, chemical, biological properties, types of microplastics and their concentration in soil influence the interactions between microplastics and microorganisms (de Souza Machado et al., 2019; Wang et al., 2019; Zhang et al., 2019). Bacterial community structure can be altered by microplastics (Zhang et al., 2019).

Few researches have focused on the impacts of microplastics on plants. Root growth of duckweed (*Lemna minor*) can be affected by microbeads by reducing root cells viability (Kalčíková et al., 2017; Abel et al., 2018). Plant-soil-microorganism systems can also be influenced by microplastics and it has adverse effects on symbiotic associations in soil (Abel et al., 2018). Nitrate contamination in surface and ground water can create many health problems to infants and animals (Fennesy and Cronk, 1997).

3. Materials and Methods

3. Materials and Methods

The materials and methods for research were selected scientifically to estimate various parameters in surface soils (0-15 cm).

3.1. Study area

The study was carried out in urban area and surrounding peri-urban areas of Cooch Behar District, West Bengal, India. In order to achieve the objectives, agricultural land, industrial area, forest and town area were chosen for soil sampling. The location of Forest is 26˚33´ N latitude, 89˚46´ E longitude and that of industrial area is 26˚34´ N latitude, 89˚48´ E longitude. Climatic parameters like rainfall, temperature of the study area have been obtained from ClimWat (FAO). The average min. and max. temperature of the area varied from 23°C to 33°C. The study area belongs to warm and humid climate and there is a short spell of winter from December to February.

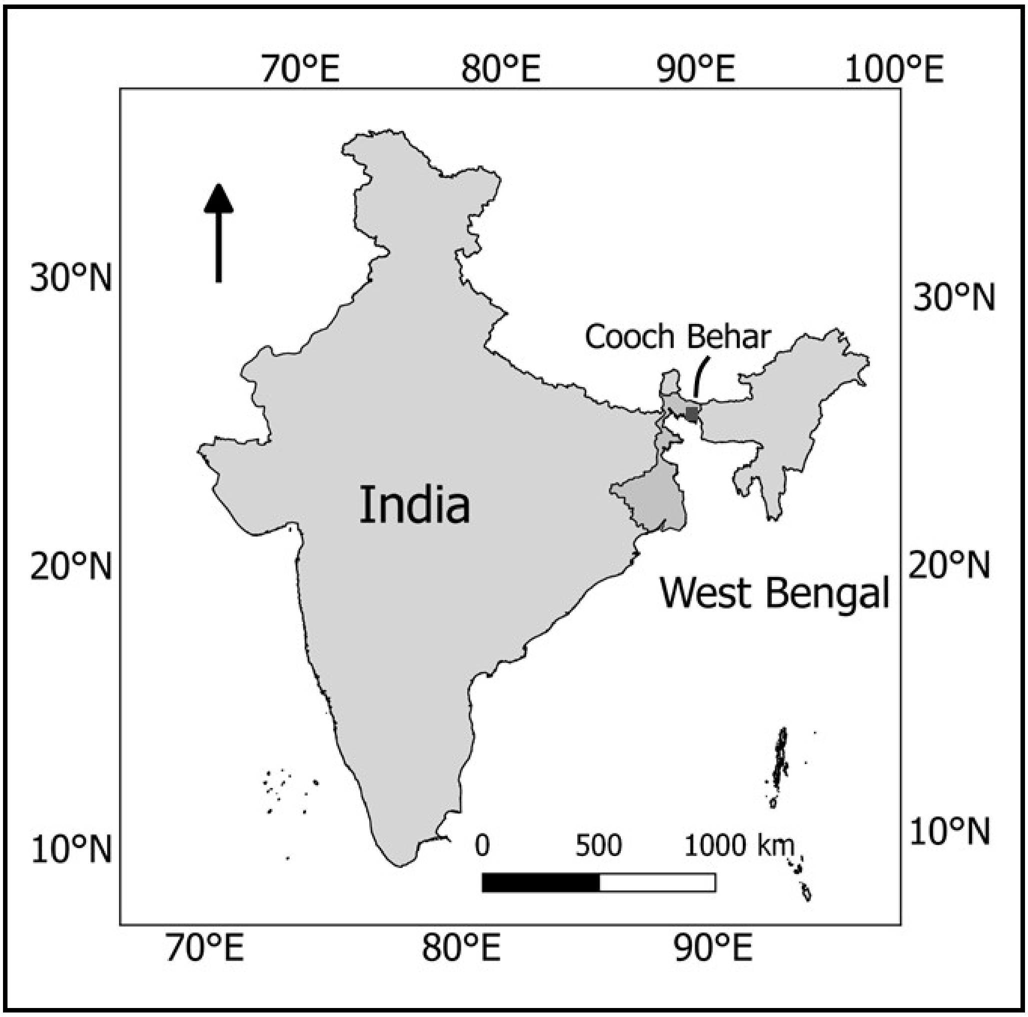


Fig 3.1. Study Area and Sampling locations

3.2. Soil Sampling

Soil sampling was done in the month of December, 2018 from forest, agricultural land, town area and industrial area. Total 26 number of soil samples (0-20 cm) were collected from agricultural land, town area, forest land, industrial area. To know the exact sampling locations, hand-held GPS receiver (Garmin, Olathe, KS, USA) was used.

Fig 3.2. Soil sampling

3.3. Soil analysis

A part of soil samples were kept in the refrigerator for determination of the biological parameter and the rest of the soils were air dried (Deb et al., 2018). This air dried soil samples were then passed through 2 mm sieve and finely ground for different chemical analysis (Deb et at., 2020). Separate sub-samples were collected using Core sampler for determination of soil bulk density. The methods associated with estimation of different parameters are mentioned below.

Soil reaction (pH)

To determine the pH of the soil samples, a pH meter (Utech instrument pH 700) with glass electrode was used. At first, the pH meter was set for the temperature and then calibrated using buffers. In this case soil to water suspension ratio of 1:2.5 was used. After that, the suspension was stirred occasionally for 30 min by using a glass rod and the pH of the samples was determined.

Calculation of bulk density

Bulk density was determined by tube core method (Blake and Hartge, 1986). The samples were collected from undisturbed surface soil by core sampler, then kept the samples in aluminium box and oven dried for 48 hrs (105℃). Then bulk density was calculated from the measurement of the bulk volume, using the length and diameter of the sampler.

Determination of soil texture

Soil texture was measured using international pipette method (Gee and Or, 2002). It was further verified as per the soil resource map from National Bureau of Soil Survey and Land Use Planning (2001).

Estimation of organic C

Soil organic carbon was estimated by oxidizing the soil samples with potassium dichromate ($K_2Cr_2O_7$) solution and titrating the excess potassium dichromate against 0.5 N Ferrous ammonium sulphate (Walkley and Black, 1934; Deb et al., 2016). In this case, after mixing of potassium dichromate solution with soil samples, concentrated sulfuric acid (H_2SO_4) was added to it to raise the heat of reaction as this increased temperature is favourable for oxidation. Phosphoric acid (H_3PO_4) was also used in the analysis to get sharper end point at the time of titration.

Determination of available nitrogen

Alkaline potassium permanganate ($KMnO_4$) method was followed to determine available nitrogen in soil (Subbiah and Asija, 1956; Bandyopadhyay et al., 2010). For the analysis a Kelplus distillation semi autolyzer was used. In this process soil was treated with 0.32% $KMnO_4$ solution in the presence of 2.5% NaOH solution and distillate was collected in boric acid mixed indicator and then absorbed ammonia was titrated against 0.005 N H_2SO_4.

Estimation of NO_3^--nitrogen

For estimation of NO_3^--N, the soil sample was extracted with 2M KCl and analyzed by Kjeldahl steam-distillation method using magnesium oxide, Devardas alloy, sulfamic acid (Bremner and Keeney, 1966; Russow et al., 2009; Peralta et al., 2015). In this case, distillate was collected in boric acid indicator mixture and the absorbed ammonia was titrated with 0.005 N H_2SO_4. For extraction, soil to KCl ratio of 1:10 was used. In this analysis, magnesium oxide was added to liberate ammonium, Devardas alloy to reduce nitrate and nitrite to ammonium and sulfamic acid to destruct nitrite.

Determination of available phosphorus

For determination of available phosphorus content in soil the Bray and Kurtz 1 method was followed (Bray and Kurtz, 1945; Frank et al., 1998; Heuck et al., 2015). The chemical composition of Bray and Kurtz 1 extractant is 0.03 N NH_4F in 0.025 N HCl. Soil to extractant ratio of 1:10 was taken for the analysis. After filtration, sample reading was taken using Spectrophotometer at 882 nm wavelength.

Analysis of available potassium

Available potassium was estimated by shaking the soil sample with 1 N ammonium acetate (NH_4OAc) solution (McLean and Watson, 1985; Meena et al., 2014a). In this case, the pH of the extracting solution should be kept at 7. After filtration, the amount of potassium was determined by a flame photometer. In this method soil to extractant ratio of 1:5 was used.

Estimation of microbial biomass carbon

For this analysis, field moist soil samples which were stored at 4°C were exposed to Chloroform vapour ($CHCL_3$) for 24 hr. After that, K_2SO_4 (0.5 M) was used for extracting the soil samples. Then another non-fumigated set of samples was extracted with 0.5 M K_2SO_4 after keeping them at room temperature for 24 hrs. In this case soil to K_2SO_4 ratio of 1:4 was taken for extraction. The difference between carbon derived from the fumigated and non-fumigated soil samples was expressed as microbial carbon flush and converted to microbial biomass carbon by following the formula as mentioned by Voroney and Paul (1984).

Estimation of soil respiration (CO_2-carbon release)

For analysis of CO_2-carbon release, field moist soil samples, kept at 4℃, were used. In this method 50 g of soil samples were placed in 1 L glass jars along with vials which contain 10 ml NaOH (0.5 N) to trap the evolved CO_2. These soil samples were incubated for 23 days at 27 ± 2℃ . The alkali traps were changed at 3rd, 6th and 13th day and finally removed at 23rd day. The amount of CO_2 evolved was estimated by titration with 0.5 N HCl (Deb et al., 2018). Soil respiration was evaluated from the rate of CO_2-carbon release during this incubation period (Deb et al., 2018). The total quantity of CO_2-carbon released during incubation period was considered as the measure of mineralizable carbon of the soil (Franzluebbers and Arshad, 1996; Gan et al., 2012).

Quantitative estimation of microplastics

For estimation of microplastics, a technique was developed from previous testing procedures of soil texture determination and studies associated with marine sediments (Abbott, 1987; Imhof et al., 2012; Nuelle et al., 2014). In this method, 30 g soil sample was taken and 10 ml of 35% hydrogen peroxide (H_2O_2) was added to it in increments to remove organic particles. Then, the sample was treated with 1 ml of 10% Ferrous Sulfate ($FeSO_4$) and heated on sand bath at 50℃. To control excessive frothing, little amount of butyl alcohol was added. After complete destruction of organic matter, again 1 ml of 10% ferrous Sulfate ($FeSO_4$) was added. Then the sample was stored for 24 hr after addition of 30 ml NaOH (0.5 M). Next, volume make up was done to 150 ml with distilled water and then agitated properly by a sonifier for 20 min. After that, centrifugation of the sample was carried out at 2300 rpm for 10 min. Then 150 ml saturated Sodium iodide (NaI) solution was added to the sample after removing the supernatant and mixed well, then centrifuged at 2300 rpm for 10 min. Microplastic particles should present in supernatant as the density of saturated Sodium iodide solution (1.8 g cm^{-3}) is more than that of microplastic particles (for example density of Polyvinyl chloride is $\leq$1.58 g cm^{-3}) (Nuelle et al., 2014). After collecting the supernatant, a 0.05 mm sieve was used for filtration. Then microplastic particles were air dried and weighted for quantitative estimation. Images were also taken under Zeiss Stemi 508 Stereo Microscope.

Analysis of heavy metals (Cd, Pb, Cr) in soil

DTPA-extraction method was followed to estimate bio-available levels of heavy metals (Cd, Pb, Cr) in soil (Lindsay and Norvell, 1978; Zahedifar et al., 2017). DTPA extractant consists of 0.005M Diethylene triamine penta acetic acid (DTPA), 0.01 M $CaCl_2.2H_2O$ and 0.1 M Triethanolamine (TEA) at pH 7.3. Then available form of Pb, Cd, Cr were analyzed by an atomic absorption spectrophotometer (AAS) (Perkin Elmer PinAAcle 900 F).

3.4. Estimation of spatial distribution

The spatial distribution of each of the soil parameters were done by interpolation method as per Inverse Distance Weight in Quantum GIS 2.18.

3.5. Statistical analysis

Statistical analysis was performed using Microsoft Excel software with XLstat (add-on) data analysis software (Addinsoft, France).

Fig 3.3. Soil analysis at laboratory

4. Results and Discussion

4. Results and discussion

Following the set of objectives of the present study, first soil quality parameters were assessed in and around Cooch Behar town. Next, the extent of microplastic pollution in these soils were studied along with their spatial distribution. The following sub-sections described the findings and discussed the possible reasons for that.

4.1. Land Use and Land Cover (LULC) of the study area

As evident from the Google Earth™ image and ground survey (Fig 4.1), the study area (Cooch Behar municipality area and peripheral peri-urban area) is having settlements (built-up area), water bodies, urban greeneries, bare earth and even some crop lands.

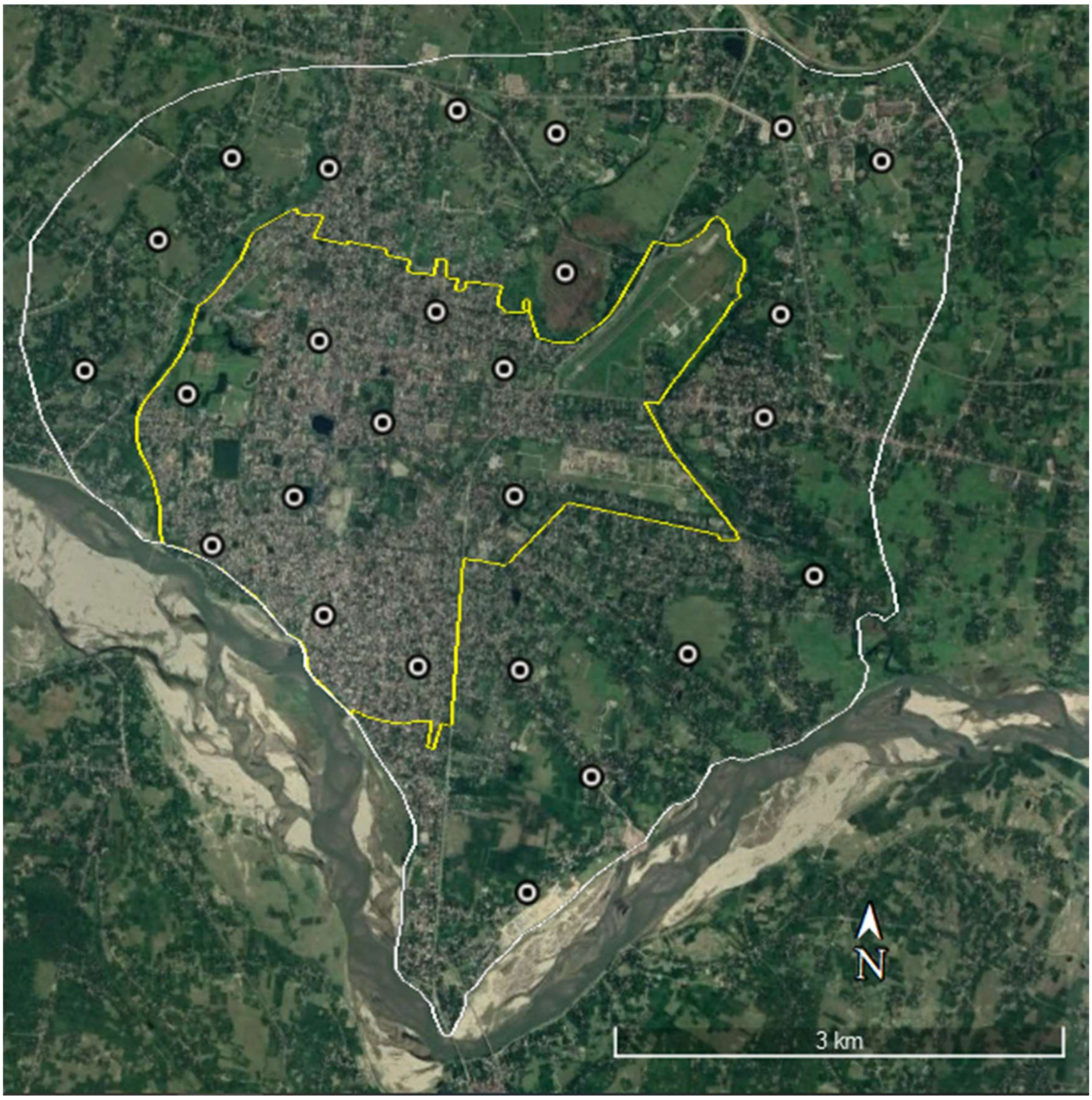


Fig 4.1. Land use land cover of the study area

The distribution of settlement is mainly concentrated in the municipality area and bit towards the northern side as well as in the South-East side. Detailed ground survey indicated presence of number of waterbodies in this area. Among them, some are even maintained by regulatory bodies. The urban greenery is mainly comprised of urban parks and roadside trees. A small social plantation (local name Salbon) is located just outside the municipality area in the northern side.

4.2. Study of soil properties along with their spatial distribution

To understand the type of soil and its physicochemical behaviour, study of the basic soil parameters is important. Following that we estimated the soil texture and found that, average soil clay % was >20 for the Cooch Behar municipality as well as for the peri-urban area (Table 4.1). For Cooch Behar municipality average silt % was approximately 60 while 51 % silt was present on an average in all the soils. Urban soil had comparatively lesser sand % ($\bar{x}$ 19.13 %) in comparison to the peri-urban soils ($\bar{x}$ 28.83 %) (Table 4.1). However, spatial distribution showed a very interesting trend.

Table 4.1. Distribution of basic soil properties in Cooch Behar municipality and surrounding peri-urban area

Soil parameters	Urban soil		Peri-urban soil	
	Mean	Standard deviation	Mean	Standard deviation
Bulk density (Mg ha^{-1})	1.16	0.06	1.16	0.06
Clay (%)	20.88	1.73	20.28	3.82
Silt (%)	60.02	5.04	50.89	17.33
Sand (%)	19.13	4.26	28.83	20.87
pH	6.5	0.47	5.8	0.53
Organic C (Mg ha^{-1})	26.98	6.50	16.39	6.30
Available N (kg ha-^{1})	136.6	57.45	120.4	26.91
NO_3-N (mg kg^{-1})	52.51	21.17	44.33	10.73
Available P (kg ha^{-1})	81.4	66.44	27.30	38.88
Available K (kg ha^{-1})	203.7	60.87	168.5	58.69

The sand, silt and clay % shifted widely spatially. In the South-Western part of the study area, just outside the municipality boundary, sand % was >30, while silt % was <50 and in some place even <25 .The clay % of this area was <20. On the contrary, clay and silt % were >20 and >50 respectively in rest of the study area (Fig 4.2). Upon comparing with the NBSSLUP soil resource map, we identified presence of two series in this area viz. Lotafela series (sandy loam) and Balarampur series (silty loam) in this area (Nayek et al., 2001). The average soil bulk density was found 1.16 Mg ha^{-1}.

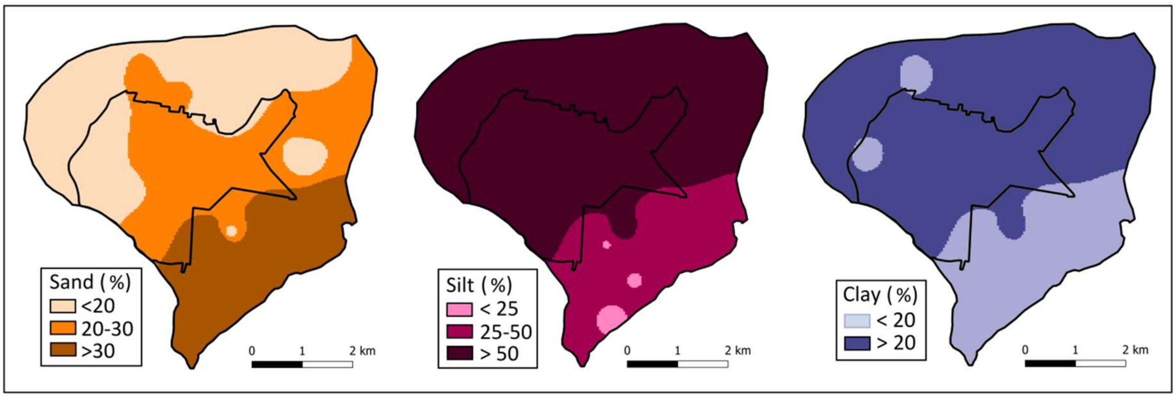


Fig 4.2. Distribution of soil separates in Cooch Behar municipality and surrounding peri-urban area

In general, soils of Northern part of West Bengal is acidic in nature due to high rainfall, sandy parent material and leaching of bases (Panwar et al., 2011). Outcome of this study also showed soil pH <7 (Fig 4.3). However, it was more acidic in peri-urban areas ($\bar{x}$ 5.8) in comparison to urban areas ($\bar{x}$ 6.5) (Table 4.1). Ground survey indicated that, dumping of wasted building materials (lime, cement) rich in Ca, was the principle reason of comparatively higher pH in urban area. Possibly due to this, a small urban area also showed pH > 7.

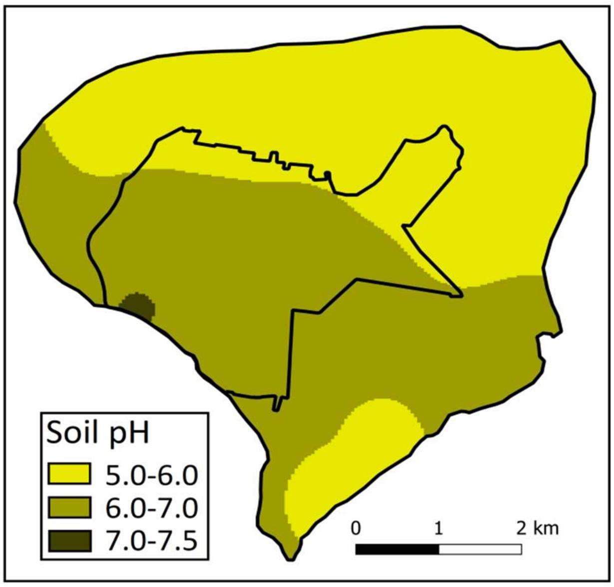


Fig 4.3. Soil pH status in Cooch Behar municipality and surrounding peri-urban area

Soil organic C is one of the major parameters towards soil quality (Deb et al., 2018). Unfortunately, Indian soils are deficient in C due to its tropical condition and high temperature (Deb et., 2020). However, soils of this study area showed much higher C than the National average (0.42 %) (Minasny et al., 2017). The organic C status in the soils were found even higher ($\bar{x}$ 26.98 Mg ha^{-1}) in the municipality areas in comparison to peri-urban soils ($\bar{x}$ 16.39) (Table 4.1, Fig 4.4). Earlier studies also showed high organic C in urban soils (Ghosh et al., 2019). The possible reason was uncontrolled dumping of urban and municipal wastes in the soil.

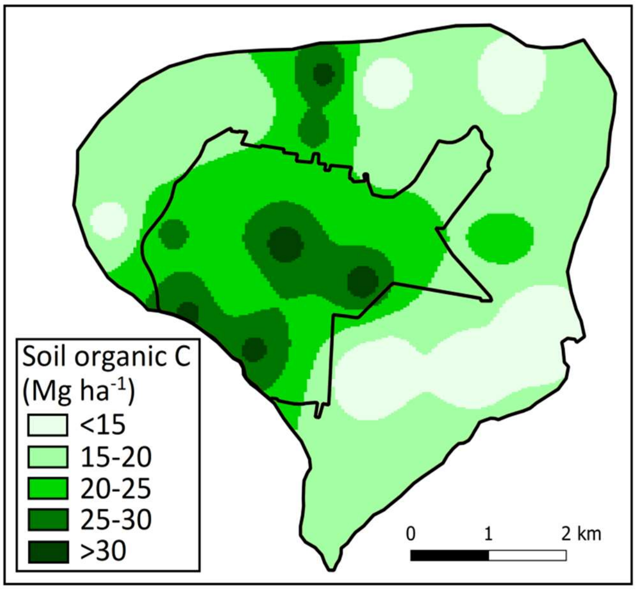


Fig 4.4. Soil organic C status in Cooch Behar municipality and surrounding peri-urban area

Along with organic C, dynamics of available N, P and K in soil are important as in limited quantity they help in plant growth while in their excess presence results environmental pollution (Strebel et al., 1989; Wakida and Lerner, 2005). Analysis of soils showed low N status (Urban soil: $\bar{x}$ 136.6 kg ha-1; Peri-urban soil: $\bar{x}$ 120.4 kg ha-1) (Table 4.1) (Baruah and Barthakur, 1997). The spatial distribution of N was also homogenous (Fig 4.5). NO_3^--N represents a significant portion of soil available N. The presence of NO_3^--N in soil in excess amount might lead to environmental pollution (Zupanc et al., 2011) as leaching of NO_3^--N from soil profile and accumulation in below ground aquifer is a serious risk for human health. Following that 50 mg NO_3^--N per kg soil is considered as a permissible limit (Pattison et al., 2010). This study showed NO_3^--N concentration more than this limit in urban soils ($\bar{x}$ 52.51 mg kg-1) while the peri-urban soils were also high in NO_3^--N ($\bar{x}$ 44.33 mg kg-1) (Table 4.1). Now, NO_3^--N is considered as an agricultural pollutant principally (Wakida and Lerner, 2005). Application of high amount of fertilizers is considered as the main reason of NO_3^--N pollution worldwide. Therefore, NO_3^--N pollution in urban areas, as found in this study, was a bit surprising. Spatial distribution of NO_3^--N showed high concentration specifically in certain parts of study area i.e. in the North and North-Eastern part (Fig 4.5). Detailed ground survey indicated peri-urban agricultural activities in these areas. It resulted addition of NO_3^--N in the form of fertilizer. In the municipality areas, the main source of NO_3^--N pollution was municipal waste deposition and waste water pollution.

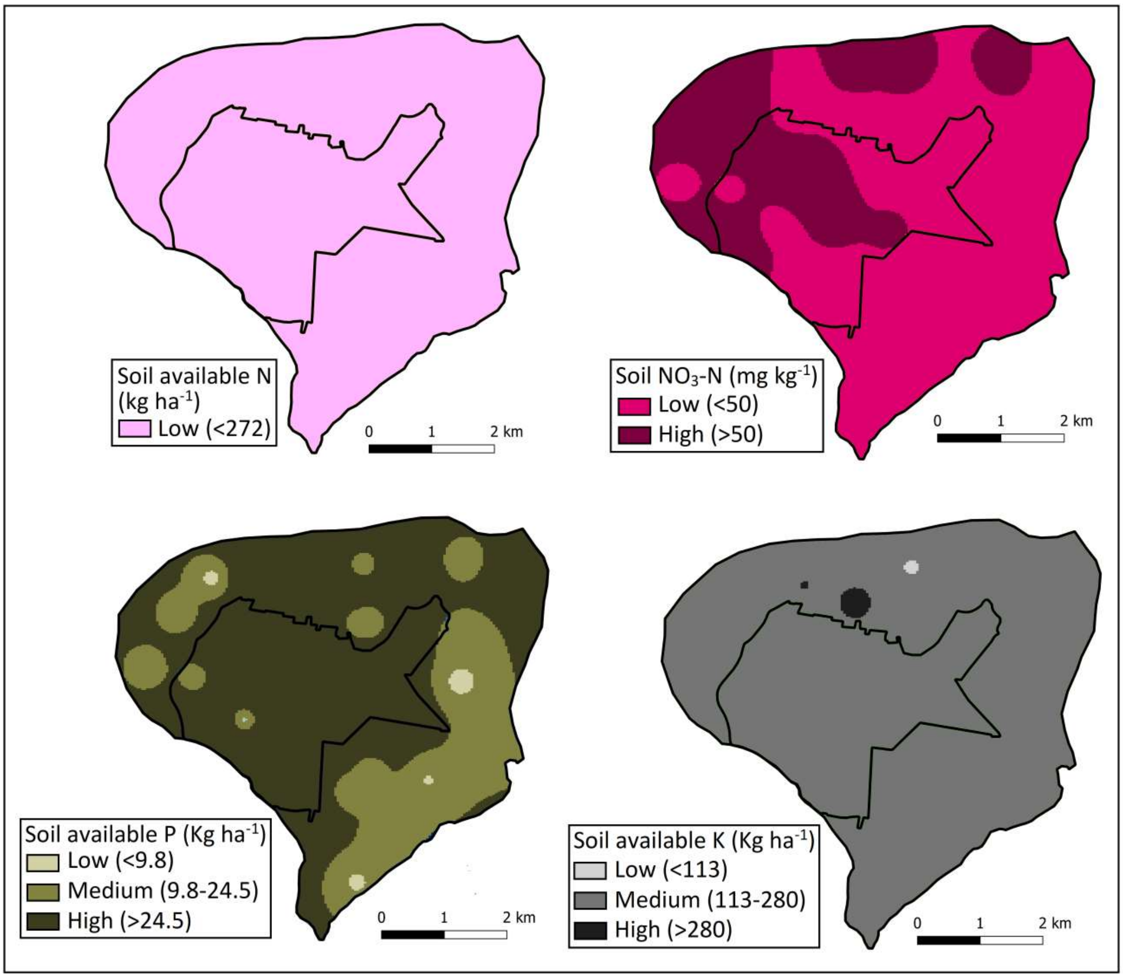


Fig 4.5. Soil available N, NO_3^--N, available P and available K status in Cooch Behar municipality and surrounding peri-urban area

Analysis showed high P content in major areas. However, in some peri-urban areas, the P content was medium and even low (Fig 4.5). The average available P content in municipal soils was 81.4 kg ha-1 while it was much low in peri-urban soils ($\bar{x}$ 27.3 kg ha-1) (Table 4.1). The possible source of this high P was anthropogenic activities like dumping of wastes. In some parts of peri-urban areas, application of phosphatic fertilizers was also found. Now, in acid soils P is generally get fixed as Fe-P or Al-P. However, there was a little chance that excess P pollution may even lead to P runoff to the nearby waterbodies, which might lead to P accumulation in surface water and subsequent eutrophication.

Fig 4.6. Algal bloom in different waterbodies

This study did not measure the P content in any waterbody. However, through ground survey, many waterbodies with algal bloom were noticed (Fig 4.6). Might be this was related to P runoff. Soils of the study area had moderate concentration of available K (Urban soils: $\bar{x}$ 203.7 kg ha-1: Peri-urban soils: $\bar{x}$ 168.5 kg ha-1) (Table 4.1). Similar available K status in soils of this region was also observed by earlier studies (Patra et al., 2016).

This study also considered heavy metal pollution in the study area. Particularly Pb, Cd and Cr were considered as concentration of these heavy metals are related with anthropogenic activities and urban pollution. Arsenic (As) was not considered in this study as arsenic (As) concentration in soils is mainly associated with geochemical or pedochemical As addition. This part of West Bengal, India do not have history of such As contamination. Instead of soil total heavy metals, bio-available forms were considered in this study as bioavailabity of pollutants determines actual risk towards health hazards. DTPA-extractable bio-available form of Pb, Cd and Cr was used and the critical limit for these heavy metals in soil were determined following Wallace and Wallace (1994) and Cheng et al. (2004). Outcomes indicated no Pb pollution in study area (Fig 4.7) while presence of high Cr in all the soils (Urban soil: $\bar{x}$ 2.18 µg g-1; Peri-urban soil: $\bar{x}$ 2.37 µg g-1) (Table 4.2, Fig 4.7). Cd concentration was observed below critical level in maximum areas (Fig 4.7) while a certain part of municipality area had high Cd concentration in soil above critical limit. The high concentration of Cr in all the soils and Cd in certain areas was expected to be associated with anthropogenic activities as heavy metal pollution in urban soils are generally associated with point source pollution activities. Municipal waste dumping, traffic pollution and improper disposal of urban waste were considered as the main reason of these heavy metal pollution (Liu et al., 2012). Higher clay % of municipal area than the south-eastern peripheral area might also be associated with this higher Cd accumulation.

Table 4.2. Distribution of heavy metals in soils in Cooch Behar municipality and surrounding peri-urban area

DTPA extractable heavy metal in soil (µg g^{-1})	Urban soil		Peri-urban soil	
	Mean	Standard deviation	Mean	Standard deviation
Lead	5.36	3.48	3.59	1.80
Chromium	2.18	0.69	2.37	1.38
Cadmium	0.07	0.12	0.01	0.02

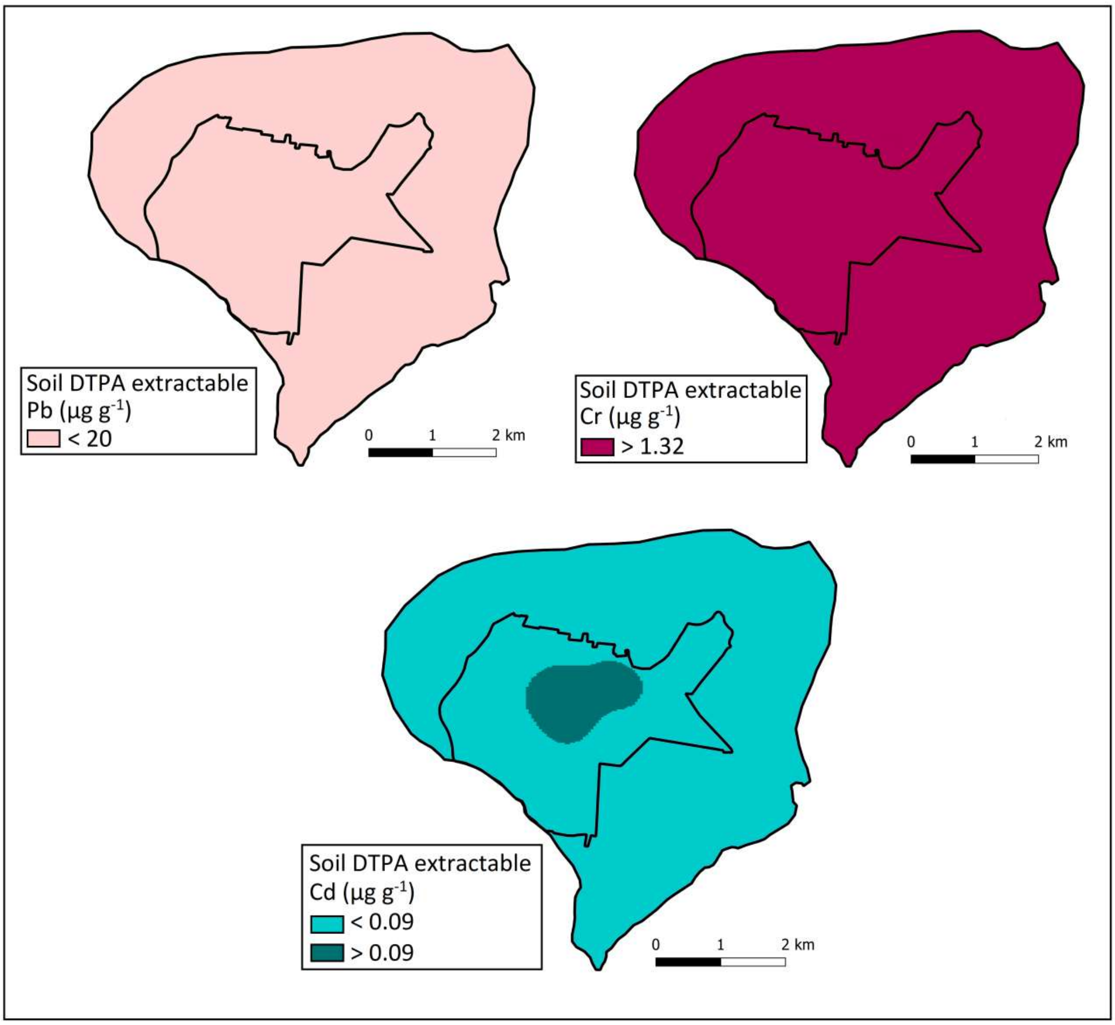


Fig 4.7. Bio-available (DTPA extractable) Pb, Cd and Cr in soils of Cooch Behar municipality and surrounding peri-urban area

Microbial dynamics is an important part of soil quality (Schutter and Dick, 2002). Microbes are the living section of soil and only they control soil C, nutrients, pollutants dynamics (Deb et al., 2018). In this study, soil microbial biomass C and soil respiration status were studied (Fig 4.8). Among these parameters, microbial biomass C basically represents the biomass of soil microbes while soil respiration represents microbial activity in any soil (Majumdar et al., 2008). Outcomes indicated a very high microbial biomass C in all the soils. Further, the urban soils ($\bar{x}$ 855.96 µg g^{-1}) showed even more microbial biomass C in comparison to peri-urban soils ($\bar{x}$ 719.06 µg g^{-1}) (Table 4.3). North-West part of peri-urban area also showed high microbial biomass C. Study of soil respiration showed an initial high rate of CO_2 emission from all the soils followed by a curbed rate of soil respiration. This is quite natural as in controlled laboratory condition high microbial activity prevails in initial stage, where there is high amount of organic C as a food source. The microbial activity go reduced with utilization of the maximum amount of soil C in the later days. Comparison of initial soil respiration indicated a highly diverse spatial distribution. Comparatively higher concentration was observed in Cooch Behar municipality area ($\bar{x}$ 32.76 μg CO_2 $24h^{-1}$ g^{-1}) (Table 4.3). However, advancement of incubation period in laboratory study resulted spatial homozenization of soil respiration in the study area (Fig 4.8). A comparison in spatial distribution indicated high correlation among soil organic C, soil microbial biomass C and initial soil respiration rate.

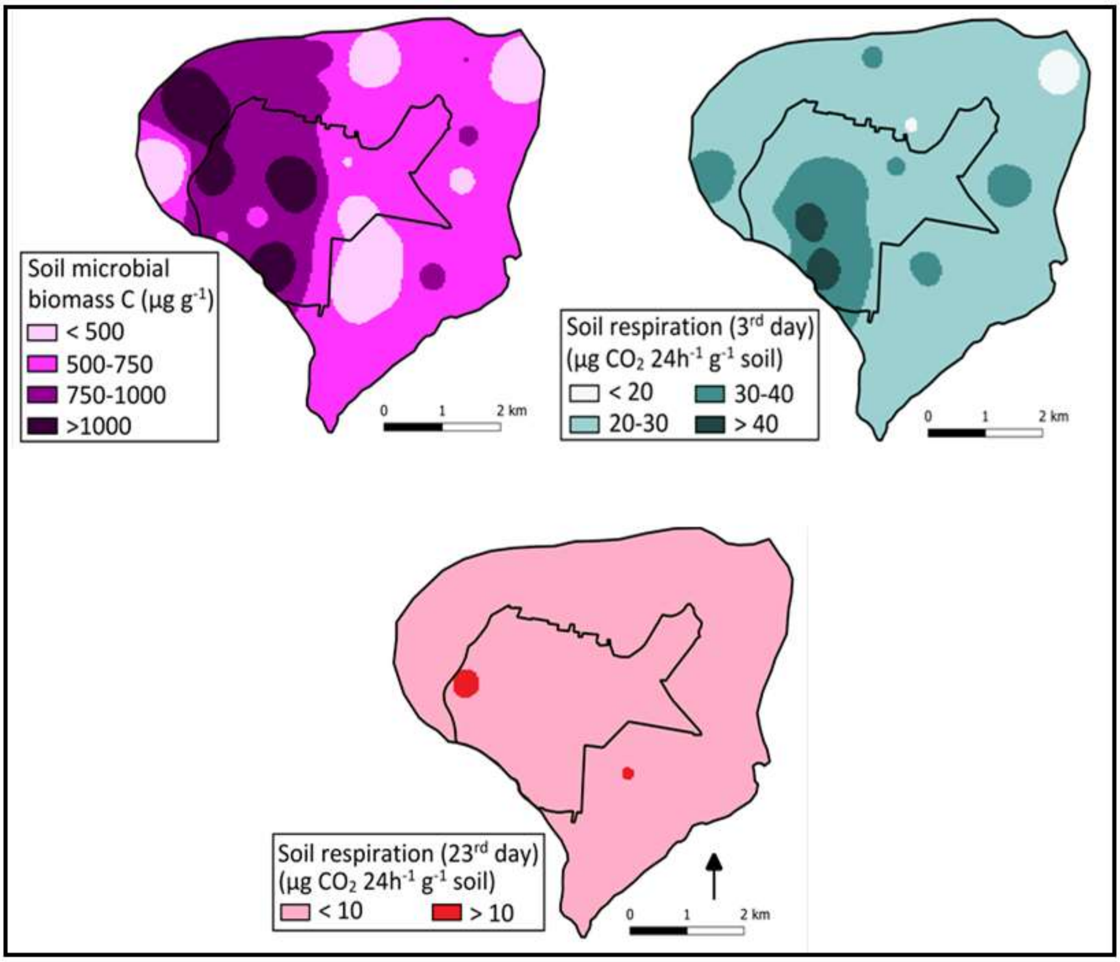


Fig 4.8. Spatial distribution of soil microbial biomass C and soil respiration (at 3rd and 23rd day)

Sometimes, soil microbes get involved in heavy metal remediation through their reduction. However, this was not the case in this study as Cr concentration remained high throughout the study area.

Table 4.3. Microbial biomass C and soil respiration status in soils of the study area

Microbial parameters	Urban soil		Peri-urban soil	
	Mean	Standard deviation	Mean	Standard deviation
Microbial Biomass C (µg g^{-1})	855.96	183.28	719.06	158.52
Soil respiration (µg CO_2 $24h^{-1}$ g^{-1} soil)				
3^{rd} day	32.76	10.64	25.06	5.46
6^{th} day	30.06	5.28	25.49	4.92
13^{th} day	13.92	3.27	8.72	3.04
23^{rd} day	7.61	2.33	7.71	1.40
Cumulative soil respiration (µg CO_2 g^{-1} soil)	362.05	63.92	289.80	52.29

4.3. Extent of microplastics pollution in and around Cooch Behar town

Following the 2^{nd} objective, this study tried to find out the microplastic contamination in the soils of study area. Microplastic is a comparatively newly identified soil contaminant, which can cause serious damage to soil structure, physico-chemical properties and soil biology, biochemistry (Rilling et al., 2017). Further, presence of nano-plastic particles (<10 µm) in soil might lead to their uptake by plant roots. Separation of microplastics from soil following Nuelle et al. (2014) and their quantitative estimation showed a high contamination in the soils of study area (Table 4.4). While soils of Cooch Behar municipality area had higher presence of microplastic ($\bar{x}$ 0.19 mg g^{-1}), the peri-urban soil also showed an alarming presence ($\bar{x}$ 0.12 mg g^{-1}). However, spatial distribution of microplastic was found to be very discrete (Fig 4.9).

Table 4.4. Soil microplastic pollution status of the study area

	Urban soil		Peri-urban soil	
Soil parameter	Mean	Standard deviation	Mean	Standard deviation
Microplastic (mg g^{-1})	0.196	0.181	0.106	0.0454

Highest microplastic contamination was found near the Cooch Behar railway station and in surrounding urban and peri-urban location. On the contrary, other municipality area showed much less microplastic contamination. Detailed ground survey indicated that not the anthropogenic pressure but dumping of plastic wastes and poor waste management were the main reason behind the microplastic pollution.

Stereomicroscopic observation indicated presence of diverse type of microplastics *viz*. thermocol fragments, microplastic films and fibres. Images taken by Scanning Electron Microscope showed presence of nano-plastic particles in the soils. It indicated a high chance of plant uptake and plastic contamination in the food chain.

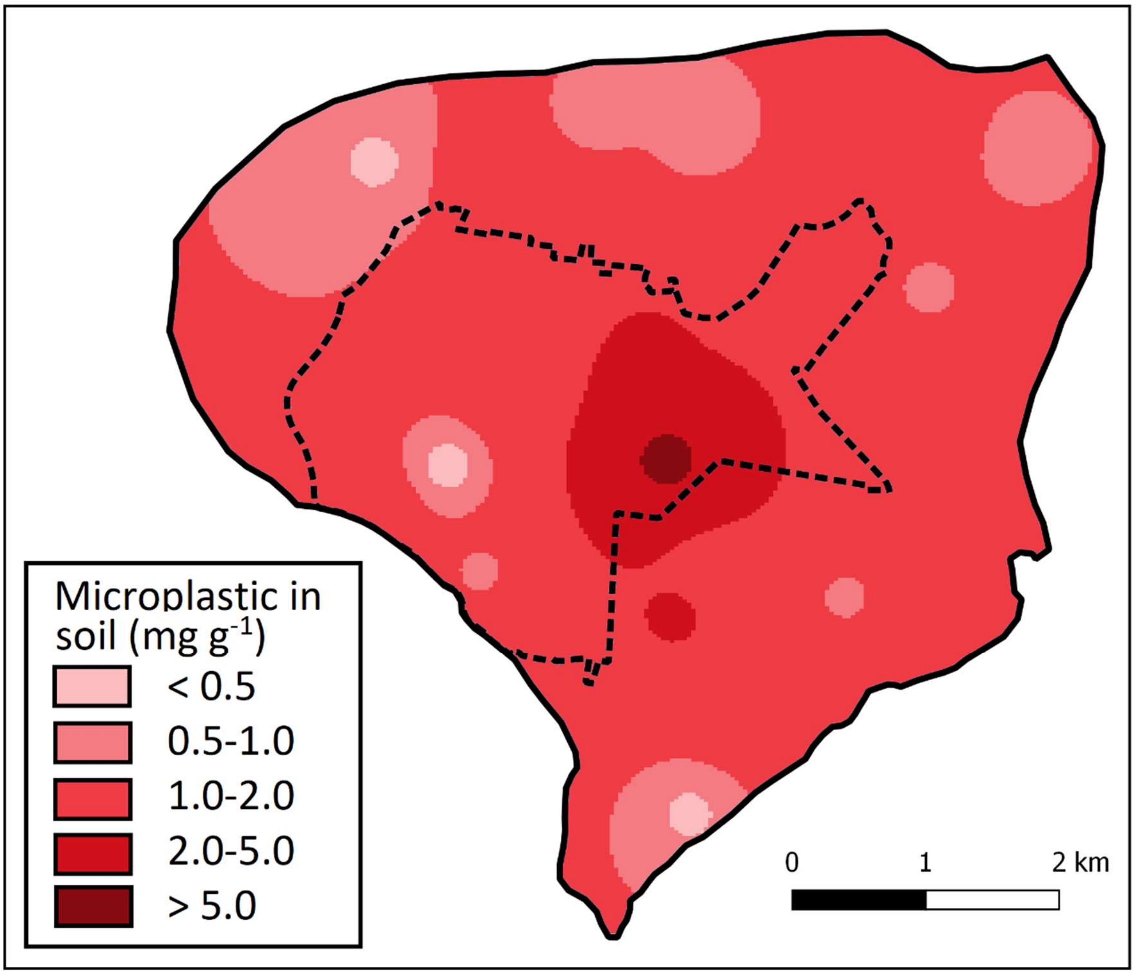


Fig 4.9. Microplastic pollution in the study area

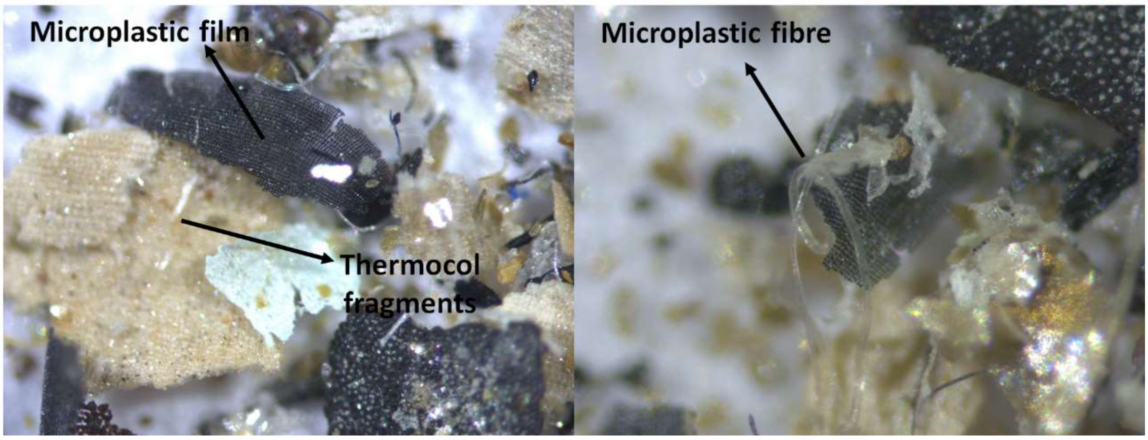


Fig 4.10. Types of microplastic particles in soils (as seen in stereomicroscope)

Fig 4.11. Plastic dumping in the roadside in Cooch Behar

4.4. Quality of spatial interpolation

This study used Inverse Distance Weighing (IDW) technique in Quantum GIS software for spatial interpolation. The IDW computes an average value for unsampled locations using values from nearby weighted locations. To understand the quality of this spatial interpolation, Root mean square error (RMSE) of the interpolated data were estimated (Table 4.5). In addition, the laboratory measured data and interpolated data of the same known points were correlated using Pearson's correlation. Low RMSE error indicated the high accuracy of the interpolation, which was further confirmed by correlation values > 0.99 for all the parameters.

This study showed the soil pollution status and deterioration of soil quality in Cooch Behar town and surrounding peri-urban areas. Although it is a town without any large industry, heavy metal pollution was observed along with the presence of high amount of soil NO_3^--N and P. Further, soils of this town store alarming level of microplastic, which is enough to deteriorate soil physico-chemical, detrimental to soil biota and also risky for human health. This study clearly indicated the importance of study of urban soil of small cities and towns.

Table 4.5. Quality testing of spatially interpolated data

Parameters	RMSE	Parameters	RMSE
Sand	**0.2406**	Available K	**0.6018**
Silt	**0.2300**	Bio-available Pb	**0.0297**
Clay	**0.0873**	Bio-available Cr	**0.0256**
pH	**0.0051**	Bio-available Cd	**0.0007**
Organic C	**0.0932**	Microbial biomass C	**1.6227**
Available N	**0.5570**	Soil respiration (3rd day)	**0.1242**
NO_3^--N	**0.2182**	Soil respiration (23rd day)	**0.0197**
Available P	**0.4789**	Microplastics	**0.0014**

5. Summary and Conclusions

5. Summary and Conclusions

The increasing population pressure and related anthropogenic activities have several negative impacts on soil, human health and surrounding environment in urban area and adjoining peri-urban areas. This impact is even more prominent in countries like India and specially in West Bengal, which is having one of the highest population density in World. Besides, urbanization is a global trend, which results continuous flow of people from rural areas to cities. This trend started during industrial revolution and become intense in last few decades.

As per the United Nations, 70 % of world population will reside in urban areas by 2050. To feed this burgeoning population, partial support will need to be taken from urban and peri-urban agriculture. So, urban and peri-urban soils also have a significant role in meeting the challenges of a growing city.

Urban soil also acts as a sink for waste disposal. It acts as a buffer between the anthropogenically dumped wastes and pure drinking water in below ground aquifer. Therefore, the soil health of urban and peri-urban areas is a matter of concern for continuous food supply as well as for human health. In this view, this study analysed the soil quality and pollution status of a town of Northern part of West Bengal. Soils from the Cooch Behar municipality and peripheral areas were collected, analysed for several parameters and their spatial distribution were studied. In a nutshell, this study highlighted the following:

- The organic C concentration of the study area was much higher than the national average as well as the agricultural soils of Cooch Behar district. Dumping of urban waste, municipal waste water were considered as the principal reason for that.
- The study area showed high concentration of NO_3-N and available P. Deposition of urban waste in municipality areas as well as intense peri-urban agricultural practices and fertilizer application were considered as the principal reason for that. Now, high NO_3-N in soil indicated potential risk of nitrate contamination in below ground aquifer water. Besides, runoff and

seepage loss of P might be resulted nutrient enrichment in the surface waterbodies and algal bloom.

- This study found high bio-available Cr concentration in the soils of study area. Bio-available Cd concentration above permissible limit was also observed in few parts of the municipality area. Intense anthropogenic activities, dumping of garbage, waste water and traffic pollution were considered as the principal reason for this.
- The study area showed discrete spatial distribution of microplastics in soils. This microplastic pollution was higher in some parts of the town and peri-urban area in comparison to the other areas.

Therefore, this study found alarming health condition of the soils of Cooch Behar town and surrounding peri-urban areas. This study recommends proper waste disposal, management of urban waste, restricted use of plastic bags and continuous and proper monitoring of the soil quality of Cooch Behar municipality and surrounding areas. This is important for soil itself as well as for the human health.

6. Future Scopes

6. Future Scopes

The spotlight of soil research was always focussed to the agricultural soils, soil fertility and crop productivity. Urban soil, although occupying a large portion of earth surface and holding a lion's share of global population, always remained in the shadow. However, with increase in urban population, pressure on peri-urban soil for food production got increased several fold in last few decades. In addition, continuous anthropogenic malpractices degrade the quality of urban and peri-urban soil itself. Scientists started to give importance to urban soil quality and soil pollution since the starting of this century. However, the focus of urban soil studies principally remains on and around megacities. Small cities and towns got least priority.

Small cities and towns have less population, less anthropogenic pressure in comparison to megacities and metropolitan areas. However, they also do not have proper waste disposal and management system and sewage network like the megacities. Thus, chances of accumulation of waste in the soils of these small cities and towns are also very acute. Lack of any significant research on this topic makes the condition worse. Number of studies in future should be done about the soil health and soil pollution of the small cities and towns across the globe. In addition, this study only focused on surface soil dynamics. In future, depthwise soil studies should be considered to understand a few soil pollutant dynamics (like NO_3) in a better way.

References

Abbott, T.S., 1987. Physical tests. In: Abbott, T.S. (Ed.), Soil Testing Service-methods and Interpretation. Department of Agriculture New South Wales, Rydalmere, N.S.W, pp. 62-64.

Abel, D.S.M.A., Kloas, W., Zarfl, C., Hempel, M.C., 2018. Microplastics as an emerging threat to terrestrial ecosystems. Global Change Biology 24, 1405-1416.

Abrahams, P.W., 2002. Soils: their implications to human health. Science of the Total Environment 291, 1-32.

Ali, M.I., Ahmed, S., Robson, G., Javed, I., Ali, N., Atiq, N., Hameed, A., 2014. Isolation and molecular characterization of polyvinyl chloride (PVC) plastic degrading fungal isolates, Journal of Basic Microbiology 54, 18-27.

Alloway, B.J., 2013. Heavy metals and metalloids as micronutrients for plants and animals. In: Alloway, B.J. (Ed.) Heavy metals in soils. Springer, The Netherlands, pp. 195-209.

Andersen, A., Hovmand, M. F., Johnsen, I., 1978. Atmospheric heavy metal deposition in the Copenhagen area. Environmental Pollution 17, 133-150.

Andrady, A.L., Neal, M.A., 2009. Applications and societal benefits of plastic. Philosophical Transactions of the Royal Society B 364, 1977-1984.

Andrews, S. S., Carroll, C. R., 2002. Designing a soil quality assessment for sustainable agroecosystem management. Ecological Applications 11, 1573-1585.

Andrews, S.S., Karlen, D.L., Mitchell, J.P., 2002. A comparison of soil quality indexing methods for vegetable production systems in Northern California. Agriculture, Ecosystems and Environment 90, 25-45.

Arnfield, A.J., 2003. Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island. International Journal of Climatology 23, 1-26.

Ashmore, M.R., Marshall, F.M., 1999. Ozone impacts on agriculture: an issue of global concern. Advances in Botanical Research 29, 32-49.

Atkinson, S., 1995. Approaches and actors in urban food security in developing countries. Habitat International 19, 151-164.

Bakir, A., Rowland, S.J., Thompson, R.C., 2014. Enhanced desorption of persistent organic pollutants from microplastics under simulated physiological conditions. Environmental Pollution 185, 16-23.

Bandyopadhyay, K.K., Misra, A.K., Ghosh, P.K., Hati, K.M., 2010. Effect of integrated use of farmyard manure and chemical fertilizers on soil physical properties and productivity of soybean. Soil and Tillage Research 110, 115-125.

Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B 364, 1985-1998.

Baruah, T.C., Barthakur, H.P., 1997. A Textbook of Soil Analysis. Vikas Publishing House Private Limited, New Delhi.

Batty, M., 2011. When all the world's a city. Environment and Planning A 43, 765-772.

Bell, D., Jayne, M., 2009. Small Cities? Towards a research agenda. International Journal of Urban and Regional Research 33, 683-699.

Bhugra, D., Mastrogianni, A., 2004. Globalisation and Mental Disorders: Overview with Relation to Depression. The British Journal of Psychiatry 184(1), 10-20.

Biasioli, M., Barberis, R., Ajmone-Marsan, F., 2006. The influence of a large city on some soil properties and metals content. Science of the Total Environment 356, 154-164.

Blake, G.R., Hartge, K.H., 1986. Bulk Density1. Methods of Soil Analysis: Part 1 physical and Mineralogical Methods, 363-375.

Bläsing, M., Amelung, W., 2018. Plastics in soil: Analytical methods and possible sources. Science of the Total Environment 612, 422-435.

Blum, W.E.H., 1997. Soil degradation caused by industrialization and urbanization. Proceedings of the International Conference on Problems of Anthropogenic Soil Formation. Moscow, Russia, pp. 3-5.

Boim, A.G.F., Melo, L.C.A., Moreno, F.N., Alleoni, L.R.F., 2016. Bioconcentration factors and the risk concentrations of potentially toxic elements in garden soils. Journal of Environmental Management 170, 21-27.

Bray, R.H. and Kurtz, L.T. 1945 Determination of total, organic and available forms of phosphorus in soils. Soil Science 59, 39-45.

Bremner, J.M., Keeney, D.R., 1966. Determination and isotope-ratio analysis of different forms of nitrogen in soils: 3. Exchangeable ammonium, nitrate, and nitrite by extraction-distillation methods. Soil Science Society of America Proceedings 30, 577-582.

Briassoulis, D., Babou, E., Hiskakis, M., Kyrikou, I., 2015. Analysis of long-term degradation behaviour of polyethylene mulching films with pro-oxidants under real cultivation and soil burial conditions. Environmental Science and Pollution Research 22, 2584-2598.

Caravaca, F., Barea, J.M., Figueroa, D., Roldán, A., 2002. Assessing the effectiveness of mycorrhizal inoculation and soil compost addition for enhancing reafforestation with *Olea europaea* subsp. *sylvestris* through changes in soil biological and physical parameters. Applied Soil Ecology 20, 107–118.

Carpenter, E.J., Anderson, S.J., Harvey, G.R., Miklas, H.P., Peck, B.B., 1972. Polystyrene spherules in coastal waters. Science 178, 749-750.

Census of India. 2011. Website of Census of India. (http://census2011.co.in/towns.php). Accessed on 30th April, 2020.

Chae, Y., An, Y.J., 2018. Current research trends on plastic pollution and ecological impacts on the soil ecosystem: a review. Environmental Pollution 240, 387-395.

Chen, F., Pu, L., Peng, B., Bao, H., 2001. The effect of land use changes on soil conditions in Korla City, Xinjiang. Acta Ecologica Sinica 21, 1290-1295.

Chen, X., Xia, X., Zhao, Y., Zhang, P., 2010. Heavy metal concentrations in roadside soils and correlation with urban traffic in Beijing, China. Journal of Hazardous Materials 181, 640-646.

Cheng, W., Zhang, G., Yao, H., Dominy, P., Wu, W., Wang, R., 2004. Possibility of predicting heavy-metal contents in rice grains based on DTPA-extracted levels in soil. Communications in Soil Science and Plant Analysis 35, 2731-2745.

Cohen, B., 2006. Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. Technology in Society 28, 63-80.

Corradini, F., Meza, P., Eguiluz, R., Casado, F., Huerta-Lwanga, E., Geissen, V., 2019. Evidence of microplastic accumulation in agricultural soils from sewage sludge disposal. Science of the Total Environment 671, 411-420.

Craul, P.J., 1992. Urban soil in landscape design. John Wiley & Sons, New York.

Cui, Y.J., Zhu, Y.G., Zhai, R.H., 2005. Exposure to metal mixtures and human health impacts in a contaminated area in Nanning, China. Environment International 31, 784-790.

Dao, L., Morrison, L., Zhang, C., 2010. Spatial variation of urban soil geochemistry in a roadside sports ground in Galway, Ireland. Science of the Total Environment 408, 1076-1084.

de Souza Machado, A.A., Lau, C.W., Kloas, W., Bergmann, J., Bachelier, J.B., Faltin, E., et al., 2019. Microplastics can change soil properties and affect plant performance. Environmental Science and Technology 53, 6044-6052.

Deb, S., Chakraborty, S., Weindorf, D. C., Murmu, A., Banik, P., Debnath, M. K., Choudhury, A., 2016. Dynamics of organic carbon in deep soils under rice and non-rice cropping systems. Geoderma Regional 7, 388-394.

Deb, S., Kumar, D., Chakraborty, S., Weindorf, D. C., Choudhury, A., Banik, P., Deb, D., De, P., Saha, S., Patra, A. K., Majhi, M., Naskar, P., Panda, P., Hoque, A. 2019. Comparative carbon stability in surface soils and subsoils under submerged rice and upland non-rice crop ecologies: a physical fractionation study. Catena 7, 400-410.

Deb, S., Mandal, B., Bhadoria, P.B.S., 2020. Influence of sea water ingression on carbon sequestration in soils under coastal agro-ecosystems of eastern India. Agricultural Research. (https://doi.org/10.1007/s40003-020-00456-5)

Deb, S., Mandal, B., Bhadoria, P.B.S., Schulz, E., Ghosh, S., Debnath, M.K., 2018. Microbial biomass and activity in relation to accessibility of organic carbon in saline soils of coastal agro-ecosystem. Proceedings of the National Academy of Sciences, India, Section B: Biological Sciences 88, 633-643

Dick, R.P., 1994. Soil enzyme activities as indicators of soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.), Defining Soil quality for a Sustainable Environment. SSSA Special publication, vol. 35, Madison, Wisconsin, USA, pp. 107-124.

Doran, J.W., Parkin, T.B., 1994. Defining and assessing soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.), Defining Soil Quality for a Sustainable Environment. SSSA, Madison, WI, pp. 3-21.

Dris, R., Gasperi, J., Saad, M., Mirande, C., Tassin, B., 2016. Synthetic fibers in atmospheric fallout: a source of microplastics in the environment? Marine Pollution Bulletin 104, 290-293.

Dwyer, J.F., Nowak, D.J., Noble, M.H., 2000. Connecting people with ecosystems in the 21st century: an assessment of our nation's urban forests. United States Department of Agriculture Forest Service, PNW-GTR-4990.

Dye, C. 2008. Health and Urban Living. Science 319, 766-769.

Egziabher, A.G., Lee-Smith, D., Maxwell, D.G., Memon, P.A., Mougeot, L.J.A., Sawio, C.J., 1994. Cities Feeding People: An Examination of Urban Agriculture in East Africa. International Development Research Centre: Ottawa.

Faciu, M.E., Ifrim, I.L., Lazar, G., 2012. Building an integrated environmental monitoring system for heavy metals in Romanian soils: Moldova region case study. Environmental Engineering and Management Journal 11, 2185-2201.

Fendall, L.S., Sewell, M.A., 2009. Contributing to marine pollution by washing your face: Microplastics in facial cleaners, Marine Pollution Bulletin 58, 1225-1228.

Fennessy, M.S., Cronk, J.K., 1997. The effectiveness and restoration potential of riparian ecotones for the management of nonpoint source pollution, particularly nitrate. Critical Reviews in Environmental Science and Technology 27, 286-317.

Frank, K., Beegle, K.D., Denning, J. 1998. Phosphorus. In Brown, R. (Ed.) Recommended Chemical Soil Test Procedures for the North Central Region. North Central Reg. Res. Publ. No. 221, pp. 21-30.

Frankenberger, W., Dick, W.A., 1983. Relationships between enzyme activities and microbial growth and activity indices in soil. Soil Science Society of America Journal 47, 945-951.

Franzluebbers, A.J., Arshad, M.A., 1996. Soil organic matter pools during early adoption of conservation tillage in north western Canada. Soil Science Society of America Journal 60, 1422-1427.

Freidberg, S., 1996. Making a living: a social history of market-garden work in the regional economy of Bobo-Dioulasso, Burkina Faso. PhD Dissertation. University of California: Berkeley, CA.

Fuller, S., Gautam, A., 2016. A procedure for measuring microplastics using pressurized fluid extraction. Environmental Science and Technology 50, 5774-5780.

Gan, Y., Liang, C., Campbell, C.A., Zentner, R.P., Lemke, R.L., Wang, H., 2012. Carbon footprint of spring wheat in response to fallow frequency and soil carbon changes over 25 years on the semiarid Canadian prairie. European Journal of Agronomy 43, 175-184.

Gee, G.W., Or, D., 2002. Particle-size analysis. In: Dane, J.H., Topp, G.C. (Eds.), Methods of Soil Analysis Part 4. American Society of Agronomy and Soil Science Society of America, Madison, WI, pp. 255-293.

Gelsomino, A., Badalucco, L., Ambrosoli, R., Crecchio, C., Puglisi, E., Meli, S.M., 2006. Changes in chemicals and biological soil properties as induced by anthropogenic disturbance: a case study of an agricultural soil under recurrent flooding by wastewaters. Soil Biology and biochemistry 38, 2069-2080.

Ghosh, S., Deb, S., Ow, L.F., Deb, D., Yusof, M.L., 2019. Soil characteristics in an exhumed cemetery land in Central Singapore, Environmental Monitoring and Assessment 191, 174.

Godfrey, R., Julien, M., 2005. Urbanisation and Health. Clinical Medicine 5, 137-141.

Green, D.M., Oleksyszyn, M., 2002. Enzyme activities and carbon dioxide flux in Sonoran desert urban ecosystem. Soil Science Society of America Journal 66, 2002-2008.

Grimm, N.B., Faeth, S.H., Golubiewski, N.E., Redman, C.L., Wu, J., Bai, X., 2008. Global change and the ecology of cities. Science 319, 756-760.

Gupta, V.V.S.R., Germida, J.J., 2015. Soil aggregation: influence on microbial biomass and implications for biological processes. Soil Biology and Biochemistry 80, A3-A9.

Hamzeh, M.A., Aftabi, A., Mirzaee, M., 2011. Assessing geochemical influence of traffic and other vehicle-related activities on heavy metal contamination in urban soils Kerman City, using a GIS-based approach. Environmental Geochemistry and Health 33, 577-594.

Han, Y., Du, P., Cao, J., Posmentier, E.S., 2006. Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China. Science of the Total Environment 355, 176-186.

Heuck, C., Weig, A., Spohn, M., 2015. Soil microbial biomass C:N:P stoichiometry and microbial use of organic phosphorus. Soil Biology and Biochemistry 85, 119-129.

Hidalgo-Ruz, V., Gutow, L., Thompson, R.C., Thiel, M., 2012. Microplastics in the marine environment: a review of the methods used for identification and quantification. Environmental Science and Technology 46, 3060-3075.

Hodson, M.E., Duffus-Hodson, C., Clark, A., Prendergast-Miller, M., Thorpe, K.L., 2017. Plastic bag derived-microplastics as a vector for metal exposure in terrestrial Invertebrates. Environmental Science and Technology 51, 4714-4721.

Hoellein, T., Rojas, M., Pink, A., Gasior, J., Kelly, J., 2014. Anthropogenic litter in urban freshwater ecosystems: distribution and microbial interactions. PLOS One 9, 0098485.

Hough, M., 1995. Cities and Natural Processes. Routledge, London.

Hu, K., Zhang, L., Li, G., 2006. Spatial patterns of soil heavy metals in Urban-rural transition zone of Beijing. Pedosphere 16, 690-696.

Huerta Lwanga, E., Gertsen, H., Gooren, H., Peters, P., Salánki, T., Van, d.P.M., Besseling, E., Koelmans, A.A., Geissen, V., 2016. Microplastics in the terrestrial ecosystem: Implications for *Lumbricus terrestris* (Oligochaeta, Lumbricidae). Environmental Science and Technology 50, 2685-2691.

Huerta-Lwanga, E., Gertsen, H., Gooren, H., Peters, P., Salanki, T., van der Ploeg, M., Besseling, E., Koelmans, A. A., Geissen, V., 2017. Incorporation of microplastics from litter into burrows of *Lumbricus terrestris*. Environmental Pollution 220, 523-531.

Idris, A., Nasir Hassan, M., Chong, T.L., 2003. Overview of municipal solid waste landfill sites in Malaysia. Proceedings of the 2nd Workshop on Material Cycles and Waste Management in Asia, December 2-3, Tsukuba, Japan.

Imhof, H.K., Schmid, J., Niessner, R., Ivleva, N.P., Laforsch, C., 2012. A novel, highly efficient method for the separation and quantification of plastic particles in sediments of aquatic environments. Limnology and Oceanography: Methods 10, 524-537.

Imperato, M., Adamo, P., Naimo, D., Arienzo, M., Stanzione, D., Violante, P., 2003. Spatial distribution of heavy metals in urban soils of Naples city (Italy). Environmental Pollution 124, 247-256.

Ivar do Sul, J.A., Costa, M.F., 2014. The present and future of microplastic pollution in the marine environment. Environmental Pollution 185, 352-364.

Jenerette, G.D., Wu, J., Grimm, N.B., Hope, D., 2006. Points, patches, and regions: Scaling soil biogeochemical patterns in an urbanized arid ecosystem. Global Change Biology 12, 1532-1544.

Jim, C.Y., 1998a. Soil characteristics and management in an urban park in Hong Kong. Environmental Management 22, 683-695.

Jim, C.Y., 1998b. Urban soil characteristics and limitations for landscape planting in Hong Kong. Landscape and Urban Planning 40, 235-249.

Johnsson, D., Bretsch, J., 2002. Soil lead and children's blood lead levels in Syracuse, NY, USA. Environmental Geochemistry and Health 24, 375-385.

Kalčíková, G., Žgajnar Gotvajn, A., Kladnik, A., Jemec, A., 2017. Impact of polyethylene microbeads on the floating freshwater plant duckweed Lemna minor. Environmental Pollution 230, 1108-1115.

Karapanagioti, H.K., Klontza, I., 2008. Testing phenanthrene distribution properties of virgin plastic pellets and plastic eroded pellets found on Lesvos island beaches (Greece). Marine Environmental Research 65, 283-290.

Kaye, J.P., Groffman, P.M., Grimm, N.B., Baker, L.A., Pouyat, R.V., 2006. A distinct urban biogeochemistry? Trends in Ecology and Evolution 21, 192-199.

Kelly, J., Thornton, I., 1996. Urban geochemistry: a study of the influence of anthropogenic activity on the heavy metal content of soils in traditionally industrial and non-industrial areas of Britain. Applied Geochemistry 11, 363-370.

Kim, H.M., Lee, D.K., Long, N.P., Kwon, S.W., Park, J.H., 2019. Uptake of nanopolystyrene particles induces distinct metabolic profiles and toxic effects in *Caenorhabditis elegans*. Environmental Pollution 246, 578-586.

Koelmans, A.A., Bakir, A., Burton, G.A., Janssen, C.R., 2016. Microplastic as a vector for chemicals in the aquatic environment: critical review and model-supported reinterpretation of empirical studies. Environmental Science and Technology 50, 3315-3326.

Kuang, Y.W., Zhu, X.M., Xi, D., Li, J., 2013. Distribution of anthropogenic lead estimated by Pb isotopic composition in the upper layers of soil from a mixed forest at Dinghushan, southern China. Journal of Soils and Sediments 13, 394-402.

Kumar, S., Bhattacharyya, J.K., Vaidya, A.N., Chakrabarti, T., Devotta, S., Akolkar, A.B., 2009. Assessment of the status of municipal solid waste management in metro cities, state capitals, class I cities, and class II towns in India: An insight. Waste Management 29, 883-895.

Larsen, W.E., Pierce, F.J., 1994. The dynamics of soil quality as a measure of sustainable management. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.), Defining Soil Quality for a Sustainable Environment. SSSA. Special Publication. No.35. SSSA and ASA, Madison, Wisconsin, USA, pp. 37-51.

Lassen, C., Hansen, S.F., Magnusson, K., Norén, F., Hartmann, N.I.B., Jensen, P.R., Nielsen, T.G., Brinch, A., 2015. Microplastics: occurrence, effects and sources of releases to the environment in Denmark. The Danish Environmental Protection Agency, Copenhagen.

Le Pape, P., Ayrault, S., Michelot, J.L., Monvoisin, G., Noret, A., Quantin, C., 2013. Building an isotopic hydrogeochemical indicator of anthropogenic pressure on urban rivers. Chemical Geology 344, 63-72.

Lei, L., Liu, M., Song, Y., Lu, S., Hu, J., Cao, C., Xie, B., Shi, H., He, D., 2018. Polystyrene (nano) microplastics cause size-dependent neurotoxicity, oxidative damage and other adverse effects in *Caenorhabditis elegans*. Environmental Science 5, 2009-2020.

Lerner, D.N., Yang, Y., Barrett, M.H., Tellam, J.H., 1999. Loading of non-agricultural nitrogen in urban groundwater. In: Ellis, J.B. (Ed.), Impacts of urban growth on surface and groundwater quality, IAHS publication. No. 259. IAHS Press.

Li, J., Liu, H., Chen, J.P., 2018. Microplastics in freshwater systems: a review on occurrence, environmental effects, and methods for microplastics detection. Water Research 137, 362-374.

Li, R., Cheng, X., Sui, X., 2003. The spatial-temporal pattern and driving forces of land use change in the Jianghan Plain during 1990-2000. Geographical Research 22, 423-431.

Li, X., Poon, C., Liu, P.S., 2001. Heavy metal contamination of urban soils and street dusts in Hong Kong. Appl. Geochemistry 16, 1361-1368.

Lin, G.C.S., Ho, S.P.S., 2003. China's land resources and land-use change: insights from the 1996 land survey. Land Use Policy 20, 87-107.

Lindsay, W.L. and Norvell, W.A., 1978. Development of DTPA soil tests for Zinc, Iron, Manganese, and Copper. Soil Science Society of America Journal 42, 421-428.

Liu, Q., Liu, Y., Zhang, M., 2012. Mercury and Cadmium Contamination in Traffic Soil of Beijing, China. Bulletin of Environmental Contamination and Toxicology 88, 154-157.

Ljung, K., Oomen, A., Duits, M., Selinus, O., Berglund, M., 2007. Bioaccessibility of metals in urban playground soils. Journal of Environmental Science and Health, Part A Toxic/ Hazardous Substances and Environmental Engineering 42, 1241-1250.

Lu, Y., Gong, Z., Zhang, G., Burghardt, W., 2003. Concentrations and chemical speciations of Cu, Zn, Pb and Cr of urban soils in Nanjing, China. Geoderma 115, 101-111.

Madrid, F., Biasioli, M., Ajmone-Marsan, F., 2008. Availability and bioaccessibility of metals in fine particles of some urban soils. Archives of Environmental Contamination and Toxicology 55, 21-32.

Majumder, B., Mandal, B., Bandyopadhyay, P.K., 2008. Soil organic carbon pools and productivity in relation to nutrient management in a 20-year-old rice-berseem agroecosystem. Biology and Fertility of Soils 44, 451-461.

Mason, S.A., Garneau, D., Sutton, R., Chu, Y., Ehmann, K., Barnes, J., Fink, P., Papazissimos, D., Rogers, D.L., 2016. Microplastic pollution is widely detected in US municipal wastewater treatment plant effluent. Environmental Pollution 218, 1045-1054.

Matthew, C., Pennie, L., Claudia, H., Galloway, Tamara S., 2011. Microplastics as contaminants in the marine environment: a review. Marine Pollution Bulletin 62, 2588-2597.

McLean, E.O., Watson, M.E., 1985. Soil measurement of plant-available potassium. In: Munson, R.D. (Ed.) Potassium in Agriculture. American Society of Agronomy, Madison, pp. 277-278.

Meena, V.S., Maurya, B.R., Verma, J.P., 2014. Does a rhizospheric microorganism enhance K^+ availability I agricultural soils? Microbiological Research 169, 337-347.

Minasny, B., Malone, B.P., McBratney, A.B., Angers, D. 583 A., Arrouays, D., Chambers, A., Chaplot, V., Chen, Z-S, Cheng, K., Das, B.S., Field, D.J., Gimona, A., Hedley, C.B., Hong, S.Y., Mandal, B., Marchant, B.P., Martin, M., McConkey, B.G., Mulder, V.L., O'Rourke, S., Richer-de-Forges, A.C., Odeh, I., Padarian, J., Paustian, K., Pan, G., Poggio, L., Savin, I., Stolbovoy, V., Stockmann, U., Sulaeman, Y., Tsui, C-C., Vågen, T-G., Wesemael, B.V., Winowiecki, L., 2017. Soil carbon 4 per mille. Geoderma 292, 59-86.

Mintenig, S., Int-Veen, I., Löder, M. G., Primpke, S., Gerdts, G., 2017. Identification of microplastic in effluents of waste water treatment plants using focal plane array-based micro-Fourier-transform infrared imaging. Water Research 108, 365-372.

Mireles, F., Davila, J.I., Pinedo, J.L., Reyes, E., Speakman, R.J., Glascock, M.D., 2012. Assessing urban soil pollution in the cities of Zacatecas and Guadalupe, Mexico by instrumental neutron activation analysis. Microchemical Journal 103, 158-164.

Montgomery, M.R., 2008. The urban transformation of the developing world. Science 319, 761-764.

Moore, M., Gould, P., Keary, B.S., 2003. Global Urbanization and Impact on Health. International Journal of Hygiene and Environmental Health 206, 269-278.

Morton-Bermea, O., Hernández-Álvarez, E., González-Hernández, G., Romero, F., Lozano, R., Beramendi-Orosco, L.E., 2009. Assessment of heavy metal pollution in urban topsoils from the metropolitan area of Mexico City. Journal of Geochemical Exploration 101, 218-224.

Mougeot, L.J.A., 2000. Urban agriculture: Definition, presence, potentials and risks. In Growing Cities, Growing Food: Urban Agriculture on the Policy Agenda. In: Bakker, N., Dubbeling, M., Gündel, S., Sa bel-Koschella U., De Zeeuw, H. (Eds.) A Reader on Urban Agriculture, pp. 99-117. Feldafing, Germany: DSE/ETC.

Moustier, P., Danso, G., 2006. Local economic development and marketing of urban produced food. In: van Veenhuizen, R. (Ed.), Cities Farming for the Future: Urban Agriculture for Green and Productive Cities, pp. 174-195. Manilla, The Philippines: IIRR/RUAF Foundation/IDRC.

Nannipieri, P., Grego, S., Ceccanti, B., 1990. Ecological significance of the biological activity in soils. In: Bollag, J.M., Stotzky, G. (Eds.), Soil Biochemistry. Marcel Dekker, New York, pp. 293-355.

Nayek, D.C, Sarkar, D., Velayutham, M., 2001. Soil Series of West Bengal. NBSS Publication No. 89, NBSS&LUP, Nagpur.

Nazeri Salleh, M., Idris, A.,Yunus, M. N. M., Kathiravale, S., 2002. Physical and chemical characteristics of solid waste in Kuala Lumpur, Malaysia. In: Kocasoy, G., Atabarut, T., Nuhoglu, I. (Eds), Appropriate environmental and solid waste management and technologies for developing countries, vol 1, Istanbul. pp. 461–468.

Nelms, S.E., Galloway, T.S., Godley, B.J., Jarvis, D.S., Lindeque, P.K., 2018. Investigating microplastic trophic transfer in marine top predators. Environmental Pollution 238, 999-1007

Nomura, T., Tani, S., Yamamoto, M., Nakagawa, T., Toyoda, S., Fujisawa, E., Yasui, A., Konishi, Y., 2016. Cytotoxicity and colloidal behavior of polystyrene latex nanoparticles toward filamentous fungi in isotonic solutions. Chemosphere 149, 84-90.

Nuelle, M.T., Dekiff, J.H., Remy, D., Fries, E., 2014. A new analytical approach for monitoring microplastics in marine sediments. Environmental Pollution 184, 161-169.

Oakley, S. M., Jimenez, R., 2012. Sustainable sanitary landfills for neglected small cities in developing countries: The semi-mechanized trench method from Villanueva, Honduars. Waste Management 32, 2535-2551.

Oke, T.R. 1995. The heat island of the urban boundary layer: Characteristics, causesand effects. In: Cermak, J.E., Davenport, A.G., Plate, E.J., Viegas D.X., (Eds.), Wind Climate in Cities, Dordrecht Kluwer Academic, pp. 81–107.

Oliver, M.A., 1997. Soil and human health: a review. European Journal of Soil Science 48, 573-592.

Panwar, P., Pal, S. Reza, S.K., Sharma, B., 2011. Soil fertility index, soil evaluation factor, and microbial indices under different land uses in acidic soil of humid subtropical India. Communications in Soil Science and Plant Analysis 42, 2724-2737.

Papa, S., Bartoli, G., Pellegrino, A., Fioretto, A., 2010. Microbial activities and trace elemement contents in an urban soil. Environmental Monitoring and Assessment 165, 193-203.

Pataki, D.E., Xu, T., Luo, Y.Q., Ehleringer, J.R., 2007. Inferring biogenic and anthropogenic carbon dioxide sources across an urban to rural gradient. Oecologia 152, 307-322.

Patra, K., Poddar, P., Mitra, B., 2016. Effect of varying levels of fertility on seed production of various Olitorius jute varieties in Terai zone of West Bengal. Journal of Crop and Weed 12, 65-67.

Pattison, T., Moody, P., Bagshaw, J., 2010. Soil health for vegetable production in Australia. The State of Queensland, Department of Employment, Economic Development and Innovation. Queensland Government.

Pavao-Zuckerman, M.A., Coleman, D.C., 2007. Urbanization alters the functional composition, but not taxonomic diversity, of the soil nematode community. Applied Soil Ecology 35, 329-339.

Peralta, N.R., Costa, J.S., Balzarini, M., Franco, M.C., Córdoba, M., Bullock, D., 2015. Delineation of management zones to improve nitrogen management of wheat. Computers and Electronics in Agriculture 110, 103-113.

Peres, G., Cluzeau, D., Menasseri, S., Soussana, J., Bessler, H., Engels, C., Habekost, M., Gleixner, G., Weigelt, A., Weisser, W., 2013. Mechanisms linking plant community properties to soil aggregate stability in an experimental grassland plant diversity gradient. Plant and Soil 373, 285-299.

Pickett, S.T.A., Cadenasso, M.L., Grove, J.M., Boone, C.G., Groffman, P.M., Irwin, E., 2011. Urban ecological systems: Scientific foundations and a decade of progress. Journal of Environmental Management 92, 331-362.

Powell, J.R., Rillig, M.C., 2018. Biodiversity of arbuscular mycorrhizal fungi and ecosystem function. New Phytologist 220, 1059-1075.

Prata, J.C., 2018. Airborne microplastics: consequences to human health? Environmental Pollution 234, 115-126.

Ramos, L., Berenstein, G., Hughes, E.A., Zalts, A., Montserrat, J.M., 2015. Polyethylene film incorporation into the horticultural soil of small periurban production units in Argentina. Science of the Total Environment 523, 74-81.

Rillig, M.C., Bonkowski, M., 2018. Microplastic and soil protists: a call for research. Environmental Pollution 241, 1128-1131.

Rilling, M. C., 2012. Microplastic in terrestrial ecosystems and the soil? Environmental Science and Technology 46, 6453-6454.

Rilling, M. C., Ziersch, L., Hempel, S., 2017. Microplastic transport in soil by earthworms. Scientific Reports 7, 1362.

Rodriguez-Seijo, A., Lourenco, J., Rocha-Santos, T.A., da Costa, J., Duarte, A.C., Vala, H., Pereira, R., 2017. Histopathological and molecular effects of microplastics in *Eisenia andrei* Bouché. Environmental Pollution 220, 495-503.

Russow, R., Stange, C.F., Neue, H.U., 2009. Role of nitrite and nitric oxide in the processes of nitrification and denitrification in soil: Results from ^{15}N tracer experiments. Soil Biology and Biochemistry 41, 785-795.

Santos, I. R., Silva-Filho, E. V., Schaefer, E. G. R., Albuquerque-Filho, M. R., Lúcia, S., Campos, L. S., 2005. Heavy metal contamination in coastal sediments and soils near the Brazilian Antarctic Station, King George Island. Marine Pollution Bulletin 50, 185-194.

Scharenbroch, B.C., Lloyd, J.E., Johnson-Maynard, J.L., 2005. Distinguishing urban soils with physical, chemical, and biological properties. Pedobiologia 49, 283-296.

Scheurer, M., Bigalke, M., 2018. Microplastics in Swiss floodplain soils. Environmental Science and Technology 52, 3591-3598.

Schleuss, U., Wu, Q., Blume, H.P., 1998. Variability of soils in urban and periurban areas in Northern Germany. Catena 33, 255-270.

Schnitzler, W. H., Holmer, R. J., Heinrich, V. B., 1998. Urban agriculture-an essential element in feeding the world's cities. Development and Cooperation 5, 26-27.

Schutter, M.E., Dick, R.P., 2002. Microbial Community Profiles and Activities among Aggregates of Winter Fallow and Cover-Cropped Soil. Soil Science Society of America 66, 142-153.

Seto, K.C., Güneralp, B., Hutyra, L.R., 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proceedings of the National Academy of Sciences 109, 16083-16088.

Seybold, C.A., Herrick, J.E., Brejda, J.J., 1999. Soil resilience: A fundamental component of soil quality. Soil Science 164, 224-234.

Shen, H., 1990. Characteristics of element transformation and accumulation of soils In Beijing outskirts. Acta Pedologica Sinica 27, 104-112.

Song, Y.K., Hong, S.H., Jang, M., Han, G.M., Jung, S.W., Shim, W.J., 2017. Combined effects of UV exposure duration and mechanical abrasion on microplastic fragmentation by polymer type, Environmental Science and Technology 8, 4368-4376.

Steinberg, D.A., Pouyat, R.V., Parmelee, R.W., Groffman, P.M., 1997. Earthworm abundance and nitrogen mineralization rates along an urban-rural land use gradient. Soil Biology and Biochemistry 29, 427-430.

Strebel, O., Duynisveld, W.H.M., Bottcher, J., 1989. Nitrate pollution of groundwater in Western Europe. Agriculture, Ecosystem and Environment 26, 189-214.

Subbiah, B.V., Asija, H.L., 1956. A rapid procedure for the estimation of the available nitrogen in soils. Current Science 259-260.

Sukopp, H., 1998. Urban ecology - scientific and practical aspects. In: Breuste, J., Feldman, H., Uhlmann, O. (Eds.), Urban Ecology. Springer-Verlag, Berlin, pp. 3-16.

Sun, Y., Luo, X., Wu, J., Mo, L., Chen, S., Zhang, Q., Zou, F., Mai, B., 2012. Species- and tissue-specific accumulation of Dechlorane Plus in three terrestrial passerine bird species from the Pearl River Delta, South China. Chemosphere 89, 445-451.

Tanaka, K., Takada, H., Yamashita, R., Mizukawa, K., Fukuwaka, M.A., Watanuki, Y., 2013. Accumulation of plastic-derived chemicals in tissues of seabirds ingesting marine plastics. Marine Pollution Bulletin 69, 219-222.

Te Lintelo, D.T.H., Marshall, F.M., Bhupal, D.S., 2002. Urban Food: the role of urban and peri urban agriculture in India: A case study from Delhi. Food, Nutrition and Agriculture 29 (FAO), 4-13.

Thompson, R.C., Olsen, Y., Mitchell, R.P., Davis, A., Rowland, S.J., Anthony, W.G.J., McGonigle, D., Russell, A.E., 2004. Lost at sea: where is all the plastic? Science 304, 838.

United Nations, 2001. World Urbanization Prospects. United Nations Population Division, New York, United Statesvan Franeker, J.A., Law, K.L., 2015. Seabirds, gyres and global trends in plastic pollution. Environmental Pollution 203, 89-96.

United Nations, 2007. State of World Population 2007: Unleashing the Potential of Urban Growth (p. 108) New York: United Nations Population Fund. Retrieved February 10, 2014.

Voogt, J.A., 2002. Urban heat island. In: Douglas, I. (Ed.), Encyclopaedia of Global Environmental Change. Chichester, John Wiley & Sons, pp. 660-666.

Voroney, R.P., Paul, E.A., 1984. Determination of kC and kN in situ for calibration of the chloroform fumigation incubation method. Soil Biology and Biochemistry 16, 9-14.

Wagg, C., Bender, S.F., Widmer, F., van der Heijden, M.G.A., 2014. Soil biodiversity and soil community composition determine ecosystem multifunctionality. Proceedings of the National Academy of Sciences USA 111, 5266-5270.

Wakida, F. D., Lerner, D. N., 2005. Non-agricultural sources of groundwater nitrate: a review and case study. Water Research 39, 3-16.

Walkley, A., Black, I.A., 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37, 29-38.

Wallace, G.A., Wallace, A., 1994. Lead and other potentially toxic heavy metals in soil. Communications in Soil Science and Plant Analysis 25, 137-141.

Wan, Y., Wu, C., CXue, Q., Hui, X., 2019. Effects of plastic contamination on water evaporation and desiccation cracking in soil. Science of the Total Environment 654, 576-582.

Wang, G., Jiang, G., Zhou, Y., Liu, Q., Ji, Y., Wang, S., Chen, S., Liu, H., 2007. Biodiversity conservation in a fast-growing metropolitan area in China: a case study of plant diversity in Beijing. Biodiversity and Conservation 16, 4025-4038.

Wang, J., Liu, X., Li, Y., Powell, T., Wang, X., Wang, G., 2019. Microplastics as contaminants in the soil environment: a mini-review. Science of the Total Environment 691, 848-857.

Warkentin, B.P., Fletcher, H.F., 1977. Soil quality for intensive agriculture. In: Proceedings of the International Seminar on Soil Environment and Fertility Management in Intensive Agriculture. Society of Science of Soil and Manure, Japan, pp. 594-598.

Watmough, S.A., Dillon, P.J., Ekaterina, N., Epova, E.N., 2005. Metal partitioning and uptake in central Ontario forests. Environmental Pollution 134, 493-502.

Wei, B.G., Yang, L.S., 2010. A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. Microchemical Journal 94, 99-107.

Woltemade, C.J., 2010. Impact of residential soil disturbance on infiltration rate and storm water runoff. Journal of the American Water Resources Association 46, 700-711.

Wong, C. S. C., Li, X., Thornton, I., 2006. Urban environmental geochemistry of trace metals. Environmental Pollution 142, 1-16.

Wright, S.L., Thompson, R.C., Galloway, T.S., 2013. The physical impacts of microplastics on marine organisms: a review. Environmental Pollution 178, 483-492.

Wu, J.G., 2014. Urban ecology and sustainability: the state-of-the-science and future directions. Landscape and Urban Planning 125, 209-221.

Wu, J.G., Buyantuyev, A., Jenerette, G.D., Litteral, J., Neil, K., Shen, W., 2011. Quantifying spatiotemporal patterns and ecological effects of urbanization: a multiscale landscape approach. In Richte, M., Weiland U. (Eds.), Applied urban ecology: A global framework, Oxford Blackwell, pp. 35–53.

Wu, J.G., Xiang, W-N., Zhao, J.Z., 2014. Urban ecology in China: Historical developments and future directions. Landscape and Urban Planning 125, 222-233.

Yáñez, L., García-Nieto, E., Rojas, E., Carrizales, L., Mejía, J., Calderón, J., 2003. DNA damage in blood cells from children exposed to arsenic and lead in a mining area. Environmental Research 93, 231-240.

Yang, H., Li, X., 2000. Cultivated land and food supply in China. Land Use Policy 17, 73-88.

Yaylali-Abanuz, G., 2011. Heavy metal contamination of surface soil around Gebze industrial area, Turkey. Microchemical Journal 99, 82-92.

Zahedifar, M., Dehghani, S., Moosavi, A.A., Gavili, E., 2017. Temporal variation of total and DTPA-extractable heavy metal contents as influenced by sewage sludge and perlite in a calcareous soil. Archives of Agronomy and Soil Science 63, 136-149.

Zhang, C., Tian, H., Chen, G., Chappelka, A., Xu, X., Ren, W., Hui, D., Liu, M., Lu, C., Pan, S., 2012. Impacts of urbanization on carbon balance in terrestrial ecosystems of the Southern United States. Environmental Pollution, 164, 89-101.

Zhang, G.S., Liu, Y.F., 2018. The distribution of microplastics in soil aggregate fractions in southwestern China. Science of the Total Environment 642, 12-20.

Zhang, J., Pu, L., Peng, B., Gao, Z., 2011. The impact of urban land expansion on soil quality in rapidly urbanizing regions in China: Kunshan as a case study. Environmental Geochemistry and Health 33, 125-135.

Zhang, M., Zhao, Y., Qin, X., Jia, W., Chai, L., Huang, M., 2019. Microplastics from mulching film is a distinct habitat for bacteria in farmland soil. Science of the Total Environment 688, 470-478.

Zhang, S., Yang, X., Gertsen, H., Peters, P., Salánki, T., Geissen, V., 2018. A simple method for the extraction and identification of light density microplastics from soil. Science of the Total Environment 616-617, 1056-1065.

Zhang, W.H., Wu, Y.X., Simonnot, M.O., 2012. Soil Contamination due to E-Waste Disposal and Recycling Activities: A Review with Special Focus on China. Pedosphere 22, 434-455.

Zhang, X., Mount, D.T., Boisvert, R.N., 2004. Industrialization, urbanization and land use in China. Journal of Chinese Economic and Business Studies 2, 207-224.

Zhao, S., Zhu, L., Li, D., 2016. Microscopic anthropogenic litter in terrestrial birds from Shanghai, China: not only plastics but also natural fibers. Science of the Total Environment 550, 1110-1115.

Zheng, Y., Luo, J., Chen, T., 2005. Cadmium accumulation in soils for different land uses in Beijing. Geographical Research 24, 542-548.

Zhong, X., Zhou, S., Zhao, Q., 2007. Spatial characteristics and potential ecological risk of soil heavy metals contamination in the Yangtze river delta- a case study of Taicang City, Jiangsu Province. Scientia Geographica Sinica 27, 395-400.

Zubris, K.A.V., Richards, B.K., 2005. Synthetic fibers as an indicator of land application of sludge. Environmental Pollution 138, 201-211.

Zupanc, V., Šturm, M., Lojen, S., Maršić-Kacjan, N., Adu-Gyamfi, J., Bračič-Železnik, B., Urbanc, J., Pintar, M., 2011. Nitrate leaching under vegetable field above a shallow aquifer in Slovenia. Agriculture, Ecosystem and Environment 144, 167-174.