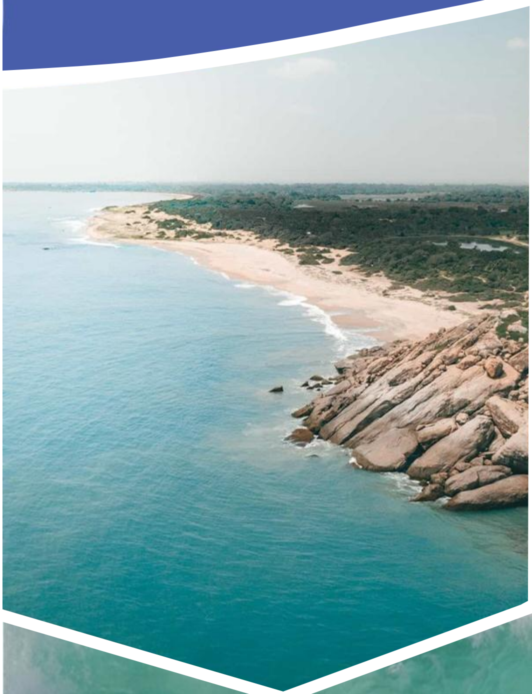
Coast Conservation and Coastal Resource Management Department

# Coastal Water Quality Monitoring Program

## Analysis Report - 2019

Arugambay, Nilaveli, Polhena, Unawatuna
Hikkaduwa, Mount Lavinia



# COASTAL WATER QUALITY MONITORING PROGRAMME ANALYSIS REPORT - 2019

## SRI LANKA

Coast Conservation and Coastal Resource Management Department

CONSULTATION BY

ENGINEERING DESIGN CENTER
FACULTY OF ENGINEERING
UNIVERSITY OF PERADENIYA

# Message from

# the Director General, Coast Conservation & Coastal Resource Management Department

Coastal water quality monitoring is extremely important to us as island nation with the World Water Assessment Programme reporting that every day a staggering two million tons of human waste is disposed into water courses. In Sri Lanka having 103 waterways connected to the sea, these wastes are the main source of coastal water pollution.

Regularly monitoring water quality is a crucial part of identifying any existing problems, or any issues that could emerge in the future. For example, data has been used to reveal that over the past few years, increase in fecal pollution in our coastal waters.

When designing and developing pollution prevention and management strategies data collected from water quality monitoring efforts is hugely helpful. With the increase of untreated industrial waste discharge straight into inland water systems, pollution management is a must to safe guard our coastal waters.

Mr. B.K. Prabath Chandrakeerthi

Director General

Coast Conservation and Coastal Resource Management Department

# Message from

# the Additional Director General (Coastal Engineering), Coast Conservation & Coastal Resource Management Department

Water quality monitoring data is incredibly useful however; it is not always easy to gather. Specialists use a range of different techniques to put together results, including taking samples of chemical conditions, analyzing sediments, using tissue extracts to find traces of metals, oils, pesticides, dissolved oxygen and nutrients. Physical conditions such as temperature, erosion and flow offer valuable insight while biological measurements regarding plant and animal life indicate the health of aquatic ecosystems.

At the end of the day, water quality monitoring is an essential part of keeping the planet healthy and sustainable. As we continue to build cities, clear land for farming and make other man-made changes to the natural environment, water quality monitoring becomes increasingly important.

Land based activities can have a huge impact on water systems and it's critical that we realize how these affect waterbodies, both above and below ground.

I am glad that Coast Conservation & CRM, R&D section has taken initiatives from 2009 to fulfill the task.

Mrs. I.M. Wickramanayake

Additional Director General (Coastal Engineering)

Coast Conservation and Coastal Resource Management Department

# Contribution & Guidance

Mrs. I.M. Wickrmanayake

Mr. R.P.S.D. Pathmasiri

Mrs. S.A. Mahaarachichi

Mr. D.T. Rupasinghe

Mrs. D.M.P.S. Dissanayake

Mr. K.M.S. Perera

Mrs. M.R. Lakmini

# Consultation & Research Team

1. **Dr. Shameen Jinadasa –** Team Leader

   Senior Lecturer, Faculty of Engineering, University of Peradeniya.

2. **Dr. Aruna Manipura**

   Senior Lecturer, Faculty of Engineering, University of Peradeniya.

3. **Dr. Hemali Nandalal**

   Senior Lecturer, Faculty of Engineering, University of Peradeniya.

4. **Mr. Daham Dias**

   Senior Lecturer, Faculty of Engineering, University of Peradeniya.

5. **Ms. Dinesha Jayawardena**

   Lecturer, Faculty of Animal Science and Export Agriculture, Uva Wellassa University.

6. **Mr. Ramodh Jayawardena**

   Research Assistant, Faculty of Engineering, University of Peradeniya.

- **Prof. Rohan Weerasooriya – Internal Reviewer**

  Research Professor, National Institute of Fundamental Studies

- **Prof. K.W.D. Nandalal – Internal Reviewer**

  Senior Professor, Faculty of Engineering, University of Peradeniya

- **Prof. Ng Wun Jern - External Reviewer**

  Executive Director

  Nanyang Environment & Water Research Institute - Singapore

# Acknowledgements

The Research & Design Division of the Coast Conservation and Coastal Resource Management Department had carried out the Coastal Water Quality Monitoring Program for a 05 year period time, from 2009 in order to identify & update the quality of the coastal waters with the intention of improving the quality of the coastal waters to add value for the coastal zone, improving the living standards of the coastal community, increasing the productivity of the coastal zone and enhancing the ability of regional and rural livelihood.

The data was collected from six coastal stretches as Arugambay, Nilaweli, Unawatuna, Hikkaduwa, Polhena and Mt Lavinia. The study was initiated by Mr. K.D.D. Wijewardena (Former Chief Engineer–R&D), Mr. B. Wickramarachchi (Former Senior Engineer) & continued by Mr. R.A.S. Ranawaka (Senior Engineer-R&D) which should be greatly appreciated. Also, the Former Director General, Dr. Anil Premarathne is highly appreciated for recognizing the importance of this study.

We personally thank Dr. Mahesh Jayaweera, University of Moratuwa for his kind support & guidance to start the programme at the beginning & providing his knowledge.

The present Director General, Mr. B.K. Prabath Chandrakeerthi and the Additional Director General (Coastal Engineering), Mrs. I.M. Wickramanayake are acknowledged for their support throughout the study. Eng. D.T. Rupasinghe, Deputy Director (R&D) is highly appreciated for all the coordination work carried out to make this report a successful & Eng. (Mrs.) B.M.V. Basnayake, Mrs. D.M.P.S. Dissanayake, Ms. Rajitha Lakmini, Mr. N.W.J. Nipun Tharuka, Mr. H.A.W.C. Sirilal and Mr. P.H. Tharanga Dilip Kumar for carrying out all background work.

We would like to thank Dr. Samaranayake, Director of Engineering Design Centre, University of Peradeniya & Dr. Shameen Jinadasa, Faculty of Engineering, University of Peradeniya who conducted the consultation to prepare this study a success.

Finally, we thank our Honorable State Minister of Environment and Mahaweli Development, Mr. Ajith Mannapperuma for the personal interest taken to make this study a success.

# Contents

# Tables and Figures

# Abbreviations

| | |
|---|---|
| AFS | – Anti Fouling Systems |
| AMWQC | – ASEAN Marine Water Quality Criteria |
| ANC | – Annual National Conference |
| ASEAN | – Association of South East Asian Nations |
| BOD | – Biochemical Oxygen Demand |
| BS | - British Standard |
| CC&CRMD | – Coast Conservation and Coastal Resource Management Department |
| CEA | – Central Environment Authority |
| CLC | – Convention on Civil Liability for Oil Pollution Damage |
| COD | – Chemical Oxygen Demand |
| CRD | - Completely Randomized Design |
| CRM | – Coastal Resources Management |
| CWQI | – Coastal Water Quality Index |
| DO | – Dissolved Oxygen |
| EC | – Electrical Conductivity |
| GIS | – Geographic Information Systems |
| HNS | – Hazardous Noxious Substances |
| IDW | – Inverse Distance Weight |
| ISO | - International Organization for Standardization |
| ITI | – Industrial Technology Institute |
| MEPA | – Marine Environment Protection Agency |
| MPN | – Most Probable Number |
| NARA | - National Aquatic Resources Research and Development Agency |
| NBGS | – National Beach Grading Scheme |
| NCWQMP | – National Coastal Water Quality Monitoring Plan |
| NGO | – Non Government Organization |
| NHMRC | – National Health and Medical Research Council |

| | |
|---|---|
| NTU | – Nephlometric Turbidity Units |
| OPRC | – Oil Pollution, Preparedness Response & Cooperation |
| TBT | – Tributyltin |
| TDS | – Total Dissolved Solids |
| TSS | - Total Suspended Solids |
| UNEP | – United Nations Environment Programme |
| USEPA | - United States Environment Protection Agency |
| WFD | – Water Framework Directive |

# Executive Summary


The coastal area is important because of economic activities therein such as tourism, fishing, aquaculture and industrial activities. This, however, is also an environmentally sensitive area because of the existence of delicate ecology. Such areas with anthropogenic impact are often subject, in addition to hazards arising from natural phenomena, to human activities. While natural disasters such as tsunamis can cause severe impact over a short period, anthropogenic activities can disturb these areas significantly over much longer periods. These activities can include the inappropriate disposal of wastewater and solid waste, destruction of coral reefs, unsustainable fishing practices, and inadequately planned constructions and human settlements. For example, disposal of wastewater containing toxic chemicals, oxygen-depleting organics, nutrients, and pathogens have adversely impacted the quality of marine water, the health of communities living near such waters, and disruption of the whole coastal ecosystem. Consequently, policy formulation and implementation to curtail marine water pollution is necessary and scientific evidences based. Sri Lanka has developed policies, rules and regulations to prevent coastal pollution since the 1980s. However, with economic and societal development over the last decades, there is need for policy reviews and modified or new rules and regulations may be necessary. This has become especially urgent since following the end of the 30-years civil war there has been rapid economic development in sectors such as tourism, industries and resettlements along the coast.

As an initial step, the Coast Conservation and Coastal Resources Management Department (CC&CRMD) of Sri Lanka conducted a monitoring programme for assessing the status of coastal water quality from 2009 to 2011 and 2014 to 2016 at six popular recreational sites (Arugambay, Hikkaduwa, Mount Lavinia, Nilaweli, Polhena, and Unawatuna). The programme monitored water quality parameters such as pH, dissolved oxygen (DO), salinity, electrical conductivity (EC), temperature, turbidity, faecal coliform and total dissolved solids (TDS).

A key objective of the study was to determine if there are trends in the measured parameters, and, if there are, how these compared with national and relevant international standards. Seasonal weather such as impact of the monsoons was considered. Currently, Sri Lanka does not have a national marine water quality standard although the Central Environmental Authority (CEA) has introduce limits on wastewater discharges into marine water. Due to the absence of national marine water quality standards, the ASEAN Marine Quality Standard was used. This is in recognition of the similar challenges faced by ASEAN member countries and Sri Lanka. However, of the 17 parameters in the ASEAN standards, only DO, temperature and faecal coliform had been measured in the CC&CRMD monitoring programme.

While DO and temperature were within the ASEAN standards, faecal coliform was not. Average coliform concentrations over the monitoring period were from 105 MPN/100 ml to 1,640 MPN/100 ml. The ASEAN standard for faecal coliform is 100 MPN/100 ml. pH had varied from 6.5 to 8.1; DO from 6.1 to 8.5 mg/L; electrical conductivity from 3.6 to 57.6 mS/cm; salinity from 2.1 to 36.0 PSU; temperature from 28 to 29 °C; and TDS from 42 to 55 g/L. The high coliform concentrations was attributable to factors such as sampling close to outfalls, sampling method (grab), haphazard discharge of faecal wastewater, overflowing of faecal sludge during rainy seasons, and the absence of sanitary facilities. Owing to the difficulty of getting rainfall data at the monitoring sites, it was not established if there was significant relationship between faecal coliform increase and rainfall. The weather data made available to the study was some 10 km from the monitoring sites. Irrespective of the monitoring site and monsoon season, pH, DO, EC, salinity and TDS had remained largely unchanged. However, turbidity had varied from 4 NTU to 198 NTU. This was attributable to sudden discharges containing suspended materials or algal blooms on the day of sampling.

When assessing the CC&CRMD data and making comparisons, it is necessary the data acquisition practices be comparable with those used to develop the regional and/or global benchmarks. These practises may be placed in a framework which includes the objectives of coastal water quality monitoring, selection of parameters (chemical, physical and biological), sampling protocols (spot, composite) and frequency (real-time, daily, weekly, monthly, annually), duration, locations (distance and depth from the MSL, impact of low/high tides, coastal morphology), land use and patterns at and close to the sampling locations (pollutant sources and transport), sample storage and preservation, equipment used and their calibration procedures, and data handling and interpretation (compilation, analysis and presentation). Inadequate information on this framework would lead to difficulties when analysing and interpreting the collected data and making comparisons. Constrained resources (manpower and relevant expertise, equipment and operational budget) at the CC&CRMD and absence of marine water quality standards/guidelines in Sri Lanka would have hindered implementation of an effective monitoring programme. Notwithstanding this and given the presence of other relevant regulatory frameworks (e.g. National Environmental Act, Marine Pollution Prevention Act and Coast Conservation Act) and international conventions (e.g. London Convention, MARPOL 73/78), the effort made recognised the importance of assessing marine water quality.

Given the web of requirements by various regulatory agencies such as the CEA, National Aquatic Resources Research and Development Agency (NARA), Marine Environmental Protection Agency (MEPA) and the CC&CRMD, there is argument for avoidance of unnecessary work replication. Setting up a multi-agency steering committee to develop scope, objectives, coastal water quality standards, a monitoring plan and its execution, and agreement on equitable sharing of resources and data sharing shall be helpful. The composition of such a steering committee may include a water quality expert or an environmental engineer, a civil engineer, a marine biologist, an analytical chemist, a costal morphologist, a GIS specialist, a sociologist, an urban planner, an economist, a legal expert, and a policy and planning expert. Further, consultation and consensus building among the various stakeholders to determine the scope of the monitoring programme and implementation of its outcomes shall be necessary.

The development of an Operational Protocol Manual to inform on standard operating procedures for sampling, sample storage, transportation and analyses will be required to ensure consistency in actions. This manual should be easy for the field officers and analysts to use. The standard practices used by organizations such as the USEPA/ISO/BS for the selected water quality parameters are recommended to be followed as this would facilitate comparison of datasets within Sri Lanka and with benchmarks used in other countries. Involvement of existing set ups and resource centers such as universities can help reduce the cost of man-power, sample storage time, sample transportation due to the geographical distribution of monitoring locations, and logistics required for transporting them to a central lab. However, an appropriate mechanism is needed to coordinate and quality check the work of these outsourced units. The activities articulated above can be encapsulated in a roadmap which can then serve to guide the programme over a considerable period of time while ensuring the work meets with national and international standards for monitoring coastal water quality.

# Executive Summary - Sinhala

සංචාරක කර්මාන්තය, ධීවර කර්මාන්තය, ජලජීවී වගාව වැනි ආර්ථික වශයෙන් වටිනාකමක් සහිත විවිධ කර්මාන්ත නිසා වෙරළබඩ ප්‍රදේශයට වැදගත්කමක් හිමිවේ. එමෙන්ම ඉතා සියුම් ජීවී පද්ධති නිසා එය පාරිසරික වශයෙන්ද සංවේදී ප්‍රදේශයක් වෙයි. ස්වභාවික උවදුරු වලට අමතරව මිනිස් ක්‍රියාකාරකම් නිසා  ඇතිවෙන ප්‍රතිවිපාක වලට ද මෙම ප්‍රදේශ මුහුණ දෙමින් පවතී. සුනාමි වැනි ස්වභාවික ව්‍යසනයන් කෙටි කාලීන දරුණු බලපෑම් ඇති කරන අතර මානව ක්‍රියාකාරකම් දීර්ඝ කාලීන ලෙස බලපෑම් ඇතිකරයි. අවිධිමත් ලෙස අපජලය සහ ඝන අපද්‍රව්‍ය බැහැර කිරීම, කොරල් පර විනාශය, තිරසාර නොවන ධීවර කර්මාන්තය සහ අක්‍රමවත් ලෙස සිදුකරන ඉදිකිරීම් කටයුතු සහ ජනාවාස මෙම මානව ක්‍රියාකාරකම් වලට අයත් වේ. නිදසුනක් වශයෙන්, විෂ රසායන ද්‍රව්‍යය, ඔක්සිජන් ක්ෂය කිරීමේ කාබනික ද්‍රව්‍යය, පෝෂක ද්‍රව්‍යය, සහ රෝගකාරක ක්ෂුද්‍ර ජීවීන් අඩංගු අපජලය බැහර කිරීම සාගර ජලයෙහි තත්ත්වය ට සහ සාගර ජලය ආශ්‍රිතව වෙසන සත්ව ප්‍රජාවන්ගේ සෞඛ්‍ය ට දරුණු ලෙස අහිතකර බලපෑම් එල්ල කිරීම නිසා සමස්ථ වෙරළබඩ ජෛව පද්ධතියම විනාශයට බඳුන් ව ඇත. එබැවින්, සමුද්‍ර දූෂණය වැළැක්වීම සඳහා අවශ්‍යය ප්‍රතිපත්ති සම්පාදනය හා ක්‍රියාත්මක කිරීම අත්‍යවශ්‍යය වන අතර ඒවා විද්‍යාත්මක සාක්ෂි මත පදනම් විය යුතුය. 1980 වර්ශයේදී ශ්‍රී ලංකාවේ මෙම ප්‍රතිපත්ති සහ නීති රීති සම්පාදනය ආරම්භ කර ඇත. කෙසේවෙතත්, පසුගිය දශක කිහිපය තුල ඇති වූ ආර්ථික සහ සමාජයීය දියුණුව සැලකිල්ලට ගනිමින්, මෙම පවතින ප්‍රතිපත්ති සමාලෝචනය කිරීම සහ නව නීතිරීති සම්පාදනය කිරීම අවශ්‍යය වී ඇත. තිස් වසරක සිවිල් යුද්ධය නිමවීමත් සමඟ සංචාරක, කර්මාන්ත සහ නැවත පදිංචි කිරීම වැනි අංශ වල සීඝ්‍රයෙන් ඇති වූ ආර්ථික සංවර්ධනය ඉහත කී අවශ්‍යතාවය ඉක්මණින් සපුරා ගත යුත්තක් බවට පත්කර ඇත.

ආරම්භක පියවරක් ලෙස, වෙරළාශ්‍රිත ජනප්‍රිය විනෝදාත්මක ස්නාන හයක (ආරුගම්බේ, හික්කඩුව, ගල්කිස්ස, නිලාවැලි, පොල්හේන සහ උණවටුන) 2009 වසරේ සිට 2011 වසර දක්වාත් 2014 වසරේ සිට 2016 වසර දක්වාත් ජලයේ තත්ත්වය අධීක්ෂණ කිරීමේ වැඩසටහනක් ශ්‍රී ලංකාවේ වෙරළ සංරක්ෂණ සහ වෙරළබඩ සම්පත් කළමනාකරණ දෙපාර්තමේන්තුව (CC&CRMD) විසින් ක්‍රියාත්මක කරන ලදී. මෙහිදී ජලයේ pH අගය, ද්‍රාව්‍ය

ඔක්සිජන් ප්‍රමාණය, ලවණතාවය, විද්‍යුත් සන්නායකතාවය, උෂ්ණත්වය, මළ අපද්‍රව්‍යය ප්‍රමාණය සහ ද්‍රාවිත ඝන ද්‍රව්‍යය ප්‍රමාණය අධීක්ෂණය කෙරිනි.

මෙම අධ්‍යයනයේ ප්‍රධාන අරමුණ වූයේ මනින ලද පරාමිතීන්ගේ යම් රටාවක් හෝ ප්‍රවණතාවයක් ඇතිද යන්න සොයා බැලීමත් ඒවා ජාතික සහ ජාත්‍යන්තර ප්‍රමිති සමඟ සංසන්දනය කල හැකි ආකාරය සොයා බැලීමත් ය. මෙහිදී මෝසම් සහ සෘතුමය කාලගුණයෙහි බලපෑමද සැලකිල්ලට ගැනිණි. මධ්‍යම පරිසර අධිකාරිය විසින් සාගර ජලයට අපජලය බැහැර කිරීමේදී පවත්වා ගතයුතු ප්‍රමිතීන් හඳුන්වා දී තිබුනද, සාගර ජලය සඳහා පවත්වා ගතයුතු ජාතික මට්ටමේ තත්ත්ව ප්‍රමිතීන් හඳුන්වා දී නැත. මෙම තත්ත්ව ප්‍රමිතීන් නොමැති වීම හේතුවෙන් ASEAN Marine Quality Standards මෙහිදී භාවිතා කරන ලදී. ASEAN සාමාජික රටවල් සහ ශ්‍රී ලංකාව මුහුණ දෙන සමාන අභියෝග මෙම තෝරාගැනීමට හේතු පාදක විය. කෙසේවෙතත් ASEAN ප්‍රමිතීන් හි භාවිතා වන පරාමිතීන් 17 අතරින් CC&CRMD අධීක්ෂණ ව්‍යාපෘතිය තුළ මැනීමට බඳුන් වූයේ ද්‍රාව්‍ය ඔක්සිජන් ප්‍රමාණය, උෂ්ණත්වය සහ මළ අපද්‍රව්‍ය ප්‍රමාණය පමණි.

ද්‍රාව්‍ය ඔක්සිජන් ප්‍රමාණය සහ උෂ්ණත්වය ASEAN ප්‍රමිතීන් වලට අනුකූල වුවද මළ අපද්‍රව්‍ය ප්‍රමාණය එසේ නොවිණි. අධික්ෂණ කාල සීමාව තුළදී මළ අපද්‍රව්‍ය සාන්ද්‍රණයෙහි සාමාන්‍ය අගය 105 - 1640 MPN/100ml වූ අතර ASEAN ප්‍රමිතීන්ගේ මෙම අගය 100 MPN/100ml ලෙස දැක්වේ. pH අගය 6.5 සිට 8.1 දක්වාත් ද්‍රාව්‍ය ඔක්සිජන් ප්‍රමාණය 6.1-8.5 mg/l ලෙසත් විද්‍යුත් සන්නායකතාවය 3.6- 57.6 mS/cm ලෙසත් ලවණතාවය 2.1 PSU සිට 36.0 PSU දක්වාත් උෂ්ණත්වය සෙල්සියස් අංශක 28-29 ලෙසත් ද්‍රාවිත ඝන ද්‍රව්‍යය ප්‍රමාණය 42g/l සිට 55g/l දක්වාත් වෙනස් වේ. අධික මළ අපද්‍රව්‍ය සාන්ද්‍රණයට හේතු සාධක ලෙස භාවිතා කරන ලද නියැදීමේ ක්‍රම සහ ස්ථාන, අවිධිමත් මළ අපජලය බැහැර කිරීම, වැසි සමයේදී මළ අපද්‍රව්‍ය බැහැර කිරීමේ පද්ධති උතුරා යාම සහ සනීපාරක්ෂක පහසුකම් නොමැතිවීම ගෙනහැර දැක්විය හැකිය. අධීක්ෂණ ස්ථාන වල වර්ෂාපතන දත්ත ලබාගැනීමේ අපහසුව මත වර්ෂාපතනයත් මළ අපද්‍රව්‍ය සාන්ද්‍රණය වැඩිවීමත් අතර සම්බන්ධයක් තිබේදැයි විමර්ශනය අපහසු විය. අධ්‍යයනය සඳහා ලබාදුන් කාලගුණික දත්ත අධීක්ෂණ ස්ථාන වල සිට 10km පමණ දුරකින් වූ ස්ථාන වලට අදාල විය. pH අගය, ද්‍රාවිත ඔක්සිජන් ප්‍රමාණය, විද්‍යුත් සන්නායකතාවය, ලවණතාවය සහ ද්‍රාවිත ඝන අපද්‍රව්‍ය ප්‍රමාණය අධීක්ෂණ ස්ථානය සහ මෝසම් සමය මත වෙනස් නොවී පවතී. නමුත් ටර්බිඩිටි අගය 4 NTU සිට 198 NTU දක්වා

වෙනස් වී ඇත. නියැදි දිනයේදී සිදුවූ අවලම්බිත ද්‍රව්‍යය සහිත අපජලය එකතුවීමක් හෝ ඇල්ගී සාන්ද්‍රණය වැඩිවීමක් මෙයට හේතු විය හැක.

CC&CRMD දත්ත විශ්ලේෂණය සහ සැසඳීම් සිදු කරන විට, එම දත්ත ලබාගැනීමේ ක්‍රමවේදයන් ප්‍රාදේශීය සහ/ හෝ ගෝලීය වශයෙන් යොදාගත් ක්‍රමවේදයන් සමඟ අනුකූල විය යුතුය. වෙරළබඩ ජල තත්ත්ව අධික්ෂණය කිරීමේ අරමුණු, පරාමිතීන් තෝරා ගැනීම (රසායනික, භෞතික සහ ජීව විද්‍යාත්මික), නියැදි සම්මුතීන්, නියැදි වාර ගණන (දිනපතා, සතිපතා, මාසිකව, වාර්ශිකව), නියැදි කාල සීමාව, නියැදි ස්ථාන (මුහුදු මට්ටමේ සිට දුර, උදම් රළෙහි බලපෑම), භූමිය භාවිතා කිරීමේ රටාවන්, නියැදීන් ගබඩා කිරීම හා සංරක්ෂණය, යොදාගත් උපකරණ සහ ක්‍රමාංකණ පටිපාටිය සහ දත්ත හැසිරවීම සහ අර්ථකථනය යනාදී දේ අඩංගු රාමුවකට ඉහත ක්‍රමවේදයන් යටත් විය යුතුය. මෙම රාමුව තුළ පවතින තොරතුරු ඌනතාවය නිසා දත්ත විශ්ලේෂණය, අර්ථකථනය සහ සංසන්දනය දුෂ්කර වනු ඇත. CC&CRMD හි ඇති සම්පත් (මිනිස් ශ්‍රමය, විශේශඥ දැනුම, උපකරණ සහ මූල්‍යමය පහසුකම්) ඌනතාවය සහ ශ්‍රී ලංකාව තුළ සාගර ජල තත්ත්ව ප්‍රමිතීන්/ නිර්ණායක නොමැතිවීම නිසා මෙම අධීක්ෂණ වැඩසටහන් ඵලදායි ලෙස ක්‍රියාත්මක කිරීමට බාධා පැමිණෙනු ඇත. කෙසේවෙතත්, අනිකුත් නියාමන රාමු (ජාතික පාරිසරික පනත, සමුද්‍ර දූෂණය වැළැක්වීමේ පනත සහ වෙරළ සංරක්ෂණ පනත) සහ අන්තර්ජාතික සම්මුතීන් (ලන්ඩන් සම්මුතිය, MARPOL 73/78) සැලකිල්ලට ගත්විට සාගර ජල තත්ත්ව විශ්ලේෂණයෙහි වැදගත් බව පිළිබිඹු වෙයි.

මධ්‍යම පරිසර අධිකාරිය, ජාතික ජලජ සම්පත් පයේෂණ හා සංවර්ධන ඒජන්සිය (NARA), සමුද්‍ර පරිසර සංරක්ෂණ ආයතනය (MEPA) සහ CC&CRMD ආදී විවිධ නියාමන ආයතන වල අවශ්‍යතා ජාලය අනුව කායීයන් අනවශ්‍ය ලෙස නැවත නැවත සිදුකිරීම වැළැක්වීම සාකච්චාවට බඳුන් වේ. විෂය පථය, අරමුණු, වෙරළබඩ ජල තත්ත්ව ප්‍රමිති, අධික්ෂණ සැලසුම් සහ එහි ක්‍රියාත්මකකිරීම් සහ සම්පත් සහ දත්ත සමානාත්මකව බෙදා ගැනීම පිළිබඳව එකඟතාවයක් ඇතිකරගැනීම සඳහා බහු නියෝජිත පාලන කමිටුවක් පිහිටුවීම උපකාරී වනු ඇත. එම කමිටුවේ සංයුතිය ජල තත්ත්ව පිලිබඳ විශේශඥයෙකු, පරිසර ඉංජිනේරුවෙකු, සිවිල් ඉංජිනේරුවෙකු, සාගර ජීව විද්‍යාඥයෙකු, රසායනඥයෙකු, GIS විශේශඥයෙකු, සමාජ විද්‍යාඥයෙකු, නාගරික සැලසුම්කරුවෙකු, ආර්ථික විද්‍යාඥයෙකු, නීති විශාරදයෙකු සහ පරිතිපත්ති සම්පාදන විශේශඥයෙකු යන අයගෙන් සමන්විත විය යුතුය.

තවද, අධීක්ෂණ වැඩසටහනෙහි විෂය පථය සහ ප්‍රතිඵල ක්‍රියාවට නැංවීම සඳහා විවිධ පාර්ශවකරුවන් අතර උපදේශනය සහ එකඟතාවය ගොඩනැගීම අත්‍යාවශ්‍ය වේ.

ක්‍රියාපටිපාටීන්ගේ අනුකූලතාවය සහතික කිරීම සඳහා නියැදීම, නියැදීන් ගබඩා කිරීම, ප්‍රවාහනය, සහ විශ්ලේෂණය පිලිබඳ සම්මත ක්‍රියාපටිපාටීන් අඩංගු මෙහෙයුම් අත්පොතක් සකස් කිරීම අවශ්‍ය වේ. මෙම අත්පොත ක්ෂේත්‍ර නිලධාරීන් සහ විශ්ලේෂකයන් සඳහා පහසුවක් විය යුතුය. තෝරාගත් ජල තත්ත්ව පරාමිතීන් සඳහා USEPA/ ISO/ BS වැනි සංවිධාන භාවිතා කරන සම්මත පුරුදු අනුගමනය කිරීමට යෝජනා කරමු. මෙමගින් ශ්‍රී ලංකාව තුල සහ අනිකුත් රටවල් සමඟ දත්ත සැසඳීම කළ හැකි වනු ඇත. විශ්ව විද්‍යාල වැනි සම්පත් මධ්‍යස්ථාන වල සහාභාගීත්වය මගින් මිනිස් බල පිරිවැය, නියැදීන් ගබඩා කිරීමේ කාලය, අධීක්ෂණ ස්ථාන වල භූගෝලීය ව්‍යාප්තිය නිසා ඇතිවන නියැදීන් ප්‍රවාහනය සහ මධ්‍යම රසායනාගරය වෙත නියැදීන් ප්‍රවාහනයට අවශ්‍ය දේ ආදිය අවම කරගත හැකිය. කෙසේවෙතත් මෙම බාහිර පාර්ශවයන්ගේ කාර්යයන් සම්බන්ධීකරණය කිරීම සහ ඒවාගෙ ගුණාත්මක බව පරීක්ෂා කිරීම සඳහා සුදුසු යාන්ත්‍රණයක් අවශ්‍ය වේ. ඉහත සඳහන් ක්‍රියාකාරකම් ඇතුලත් මාර්ගෝපදේශකයක් මගින් ජාතික සහ අන්තර්ජාතික ප්‍රමිතීන්ට අනුව වෙරළබඩ ජල තත්ත්ව නිරීක්ෂණය කිරීම සඳහා සැලකිය යුතු කාල සීමාවක් තුල මෙම වැඩසටහන මෙහෙයවනු ඇත.

# Executive Summary – Tamil

சுற்றுலாத்துறை, மீன்பிடி, மீன்வளர்ப்பு மற்றும் தொழில்துறை நடவடிக்கைகள் போன்ற பொருளாதாரம் சார்ந்த நடவடிக்கைகள் காரணமாக கடலோர பகுதி முக்கியத்துவம் வாய்ந்ததாக கருதப்படுகிறது. எனினும் நுண்ணிய சூழல்தொகுதியாகையால் சூழலியல் ரீதியாக மிகவும் முக்கியத்துவம் வாய்ந்த இடமாக விளங்குகின்றது. இந்த பிரதேசமானது பெரும்பாலும் இயற்கைத் தாக்கங்களினால் உருவாக்கப்படும் பாதிப்புக்களை விட மனித நடவடிக்கைகளால் ஏற்படும் தாக்கங்களிற்கு உள்ளாக்கப்படுகின்றன.

சுனாமிகள் போன்ற இயற்கை பேரழிவுகளால் பாரியளவிலான தாக்கத்தை குறுகியகாலத்திற்கு ஏற்படுத்தக்கூடிய போதிலும் மனித நடவடிக்கைகள் இந்தப் பிரதேசங்களை நீண்டகாலத்திற்கு கணிசமாக பாதிக்ககூடும். இந்த நடவடிக்கையானது, முறையற்ற கழிவு நீர் மற்றும் திண்மக்கழிவுகளின் வெளியேற்றம், பவளப்பாறைகளின் அழிப்பு, நிலையற்ற மீன்பிடி நடவடிக்கைகள், மற்றும் போதியளவு திட்டமிடப்படாத கட்டுமானங்கள் மற்றும் மனித குடியேற்றங்கள் ஆகியவற்றை உள்ளடக்கியதாகும். உதாரணமாக, நச்சு இரசாயனங்கள், ஒட்சிசனை சிதைவாக்கும் சேதனங்கள், ஊட்டச்சத்துக்கள் மற்றும் நோய்க்கிருமிகளை உள்ளடக்கிய கழிவு நீரினை அகற்றுவதன் மூலம் அவை கடல் நீரின் தரத்தை மட்டுமல்லாது, கடலுக்கு அண்மையிலுள்ள மக்களுக்கு பாதகமான விளைவுகளை ஏற்படுத்தி முழுமையாக கடலோர சூழற்தொகுதியை அழிவடைய செய்கிறது.

இதன் விளைவாக, கடல் நீர் மாசுபடுவதை குறைப்பதற்கான அறிவியல் ஆதாரங்களை அடிப்படையாக கொண்ட உருவாக்கம் மற்றும் செயற்படுத்தல் அவசியமானதாகும். இலங்கையினால் கடலோர மாசாக்கத்தை தடுப்பதற்காக கொள்கைகள், விதிகள் மற்றும் ஒழுங்குமுறைகள் 1980களில் இருந்து உருவாக்கப்பட்டுள்ளன. எனினும், கடந்த தசாப்தங்களில் ஏற்பட்ட பொருளாதார மற்றும் சமூக அபிவிருத்தியால் கொள்கை மீள்திருத்தம், மற்றும் கொள்கை மாற்றம் அல்லது புதிய விதிகள் மற்றும் ஒழுங்கு முறைகள் தேவையானதாகும். குறிப்பாக, 30 வருடகால உள்நாட்டு யுத்தம் முடிவடைந்த காலப்பகுதியில் இருந்து கரையோர பிரதேசங்களில் சுற்றுலாத்துறை, தொழில், மற்றும் மீள்குடியேற்றம் ஆகிய துறைகளில் ஏற்பட்ட விரைவான பொருளாதார அபிவிருத்தி காரணமாக இது ஒரு அவசரத் தேவையாக மாறியுள்ளது.

ஆரம்ப படியாக, 2009 தொடக்கம் 2014 வரையான காலப்பகுதி மற்றும் 2014 தொடக்கம் 2016 வரையான காலப்பகுதியில் இலங்கை கடலோர பாதுகாப்பு மற்றும் கடலோர வள முகாமைத்துவ

துறையினால் ஆறு பிரபல பொழுதுபோக்கு தளங்களில் கடல்நீரின் தரத்தினை மதிப்பிடும் கண்காணிப்பு திட்டமானது நடைமுறைப்படுத்தப்பட்டது. இத்திட்டத்தின் மூலம் நீரின் அளவீடுகளாக pH, நீரிலுள்ள ஒட்சிசன் அளவு, உவர் தன்மை, மின் கடத்துதிறன், வெப்பநிலை, கலங்கல், faecal coliform மற்றும், மொத்த திண்ம கரைதிறன் ஆகியன கண்காணிக்கப்பட்டன.

நீரின் தர அளவீடுகளின் மாறுபடும் தன்மை, தேசிய மற்றும் சர்வதேச நியமங்களுடன் நீரின் தரத்தின் ஒப்பீட்டு ரீதியான வேறுபாடுகள் என்பவற்றை தீர்மானிப்பதே இந்த ஆய்வின் முக்கிய நோக்கமாக இருந்தது. பருவ மழை போன்ற பருவகால வானிலை கருத்தில் கொள்ளப்பட்டது. மத்திய சுற்றுச்சூழல் அதிகாரசபையினால், கடல் நீரினுள் கழிவுநீர் வெளியேற்றம் தொடர்பான வரையறை அறிமுகப்படுத்தப்பட்ட போதிலும் தற்போது இலங்கையில், தேசிய கடல்நீர் தர நியமம் நடைமுறையில் இல்லை. தேசிய கடல்நீர் தர நியமம் இல்லாத காரணத்தால், ஆசிய கடல் தர நியமம் பயன்படுத்தப்பட்டது. ஆசியான் (ASEAN) நாடுகளும் இலங்கையும் இதே வகையிலான சவாலை முகம் நோக்குகின்றனர். எனினும், ஆசிய நியமத்திலுள்ள 17 அளவீடுகளில், நீரிலுள்ள ஒட்சிசன் அளவு, வெப்பநிலை, கலங்கல், faecal coliform மாத்திரம் CC & CRMD கண்காணிப்பு திட்டத்தின் மூலம் அளவிடப்பட்டன.

குறிப்பாக, நீரிலுள்ள ஒட்சிசன் அளவு மற்றும் வெப்பநிலை ஆகியன ஆசியான் நியம வரையறைக்குள் இருந்த போதிலும் faecal coliform நியம வரையறைக்குள் இருக்கவில்லை. கண்காணிப்பு காலப்பகுதியில் சராசரி coliform செறிவு 100 MPN/100ml முதல்1640 MPN /100ml வரை காணப்பட்டன. ஆசியான் தர நிர்ணயத்திற்கு அமைய faecal coliform இன் அதி கூடிய செறிவானது 100 MPN/100ml ஆகும். அதே சமயம், pH 6.5 முதல் 8.1 வரையிலும், நீரிலுள்ள ஒட்சிசன் அளவு 6.1 முதல் 8.5mg/l வரையிலும், மின் கடத்துதிறன் 3.6 முதல் 57.6ms/cm வரையிலும் , உவர் தன்மை 2.1 முதல் 36.0 PSU வரையிலும், வெப்பநிலை 28 முதல் 29$^{\circ}$C வரையிலும், மொத்த திண்ம கரைவு 42 முதல் 55g/l வரையிலும் மாறுபட்டன.

வடிகாலுக்கு அண்மையிலான மாதிரி சேகரிப்பு/மாதிரி சேகரிப்பு முறை, முறையற்ற மலக்கழிவு நீர் வெளியேற்றம், மழைக் காலங்களில் நிரம்பி வழிகின்ற மல கழிவுகள் அல்லது சுகாதார வசதியின்மை போன்றவை அதிகளவிலான coliform செறிவிற்கு காரணமாக அமைகின்றன.

கண்காணிப்பு தளங்களில் மழைவீழ்ச்சி தொடர்பான தகவல்களை பெறுவது சிரமமாக இருந்த காரணத்தினால் faecal coliform அதிகரிப்பு மற்றும் மழைவீழ்ச்சி என்பவற்றுககிடையிலான தொடர்பை நிறுவ முடியவில்லை. கண்காணிப்பு தளத்திலிருந்து சுமார் 10km தொலைவில்

தயாரிக்கப்பட்ட வானிலை ஆய்வறிக்கை ஆய்வுக்காக பயன்படுத்தப்பட்டது. கண்காணிப்பு தளம் மற்றும் பருவமழைகால காரணிகளுக்கு அப்பால் pH, நீரிலுள்ள ஒட்சிசன் அளவு, மின் கடத்துதிறன், உவர் தன்மை மற்றும், மொத்த திண்ம கரைதிறன் ஆகியன பெரும்பாலும் மாறாமல் இருந்தன. எனினும், கலங்கல்தன்மை 4 NTU முதல் 198 NTU வரை மாறுபட்டுக் காணப்பட்டது. மாதிரி சேகரிக்கும் நாளில், கரையக்கூடிய பொருட்களைக் கொண்ட கழிவுகளின் திடீர் வெளியேற்றம் அல்லது அல்கா வளர்ச்சி போன்றன இதற்கான காரணிகளாக அமைகின்றது.

CC and CRMD தரவுகளை மதிப்பீடு மற்றும் ஒப்பிடுதல் செய்யும் பொழுது கையகப்படுத்தல் செயன்முறைகளானது பிராந்திய/ உலகளவில் பயன்படுத்தப்படும் தரவுகளுடன் ஒப்பிடக் கூடியவையாக இருத்தல் அவசியமாகும். பின் கூறப்பட அமைப்பானது பின்னர் ஒரு கட்டமைப்பினுள் வைக்கப்படலாம்.

பிராந்திய/ உலகளவில் பயன்படுத்தப்படும் தர நிர்ணய அமைப்பானது ஒரு கட்டமைப்பினுள் வைக்கப்படுவதுடன் அக்கட்டமைப்பானது கடல்நீர் தர கண்காணிப்பு, காரணிகளை தெரிவு செய்தல் ̇(இரசாயன, பௌதீக மற்றும் உயிரியல்), மாதிரியாக்க கோல்கள்(spot, கலப்பு), அளவீடுகளுக்கு இடையிலான காலப்பகுதி ˡ(உண்மை நேரம், தினமும், வாராந்தம், மாதந்தோறும், வருடந்தோறும்), இடம்(சராசரி கடல் மட்டத்திலிருந்தான தூரம் மற்றும் ஆழம், குறைந்த/ கூடிய அலைகளின் விளைவுகள், கடலோர உருவவியல்), மாதிரி சேமிப்பு மற்றும் பாதுகாத்தல், கருவிகளின் பாவனை மற்றும் அளவுத்திருத்த செயன்முறைகள், தரவுகளை கையாளுதல் மற்றும் அது தொடர்பான விளக்கங்கள்(தொகுப்பு, பகுப்பாய்வு மற்றும் அதவை வழங்குதல்) போன்ற நோக்கங்களை கொண்டிருக்க வேண்டும். .

இந்த கட்டமைப்பில் போதுமான தகவல்கள் இல்லாமை, பகுப்பாய்வு மற்றும் அதற்கான விளக்கங்களை ஏற்படுத்துவதிலும், ஒப்பீடு செய்வதிலும் சிரமங்களை ஏற்படுத்தும். CC and CRMD ல் உள்ள கட்டுப்படுத்தப்பட்ட வளங்கள் (மனிதவளம் மற்றும் தொடர்பான நிபுணத்துவ கருவிகள் மற்றும் செயற்பாட்டு வரவுசெலவுத்திட்டம் ) மற்றும் இலங்கையில் கடல்நீர் தர நியம அளவீடு இல்லாமை போன்றன பயனுள்ள கணிப்பீட்டு திட்டத்தினை செயற்படுத்துவதற்கு தடையாக இருக்கமுடியும். இதை தவிர, பிற தொடர்புடைய ஒழுங்கமைப்பு கட்டமைப்புக்கள் (தேசிய சுற்றுச்சூழல் சட்டம்- கடல் மாசாக்க தடுப்புச் சட்டம் மற்றும் கடலோர பாதுகாப்புச்சட்டம்) மற்றும் சர்வதேச மரபுகள் (லண்டன் மாநாடு MARPOL 73/78) போன்றன வழங்கப்பட்டு கடல்நீரின் தரத்தை மதிப்பிடுவதற்கான முக்கியத்துவத்திற்கான அங்கிகாரத்தை உருவாக்கியது. மத்திய சுற்றாடல் அதிகாரசபை, தேசிய கடல் நீரியல் வள ஆராய்ச்சி மற்றும் அபிவிருத்தி நிறுவனம், கடல்சூழல்

தடுப்பு நிறுவனம் மற்றும் CC&CRMD ஆகியவற்றினால் வலையமைப்பான தேவைகள் வழங்கப்படுவதால் தேவையற்ற பணி பிரதிகள் தவிர்க்கபட வேண்டும்

நோக்கம், இலக்குகள், கடலோர நீர் தர நியமம், கண்காணிப்பு திட்டம் மற்றும் அதனை நிறைவேற்றுதல் மற்றும் வளங்கள் மற்றும் தகவல்களின் சமமான பகிர்வு பற்றிய உடன்பாடுகளை உருவாக்குவதற்கு பல நிறுவனங்கள் ஒன்றிணைத்த வழிகாட்டும் குழு ஒன்றை அமைத்தல் உதவியாக இருக்கும்.

நீர் தர நிபுணர் அல்லது சூழல் பொறியியலாளர, குடி சார் பொறியியலாளர், கடல் உயிரியலாளர், பகுப்பாய்வு வேதியியலாளர், கடலோர உருவவியலாளர், GIS நிபுணர், சமூகவியலாளர், நகராக்க திட்டமிடுனர், பொருளியலாளர், சட்டநிபுணர் மற்றும் கொள்கை திட்டமிடல் நிபுணர் ஆகியோர் வழிகாட்டும் குழுவில் உள்ளடக்கப்படலாம். மேலும், கண்காணிப்பு திட்டத்தின் நோக்கத்தை தீர்மானிப்பதற்கும் அதனுடைய வெளிப்பாடுகளை நடைமுறைப்படுத்துவதற்கும் பல்வேறு பங்குதாரர்களுக்கிடையில் ஆலோசனை மற்றும் ஒருமித்த இணக்கப்பாடு அவசியமானதொன்றாகும்.

மாதிரியாக்கம், மாதிரி சேகரிப்பு, போக்குவரத்து மற்றும் பகுப்பாய்வு ஆகியவற்றுக்கான தரமான செயற்பாட்டு முறைகளை அறிவிப்பதற்கான செயன்முறை கையேட்டை மேம்படுத்துதல் செயல்களில் இணக்கத்தை உறுதிப்படுத்த வேண்டும். இக் கையேடானது, துறைசார் அலுவலர்கள் மற்றும் பகுப்பாய்வாளர்களின் பயன்பாட்டிற்கு இலகுவானதாக அமைய வேண்டும். தெரிவு செய்யப்பட்ட அளவுருக்களுக்காக நிறுவனங்களினால் பயன்படுத்தப்படும் USEPA/ISO/BS போன்ற நியம செயன்முறைகள் இலங்கையினுள் தரவுத் தொகுப்பையும் மற்றும் வேறு நாடுகளால் பயன்படுத்தப்படும் கோல்களையும் ஒப்பிடுவதற்கு தொடர்ந்து பின்பற்றுவதாக பரிந்துரைக்கப்பட்டுள்ளது.

# INTRODUCTION

Image Source – www.pinterest.com

# Introduction 1

## 1.1 Introduction

Coastal area of a country has an important role in its economy as well as in environmental ecology at the national and possibly international levels. The coastal area can be defined as the band of dry land adjacent to ocean space (water and submerged land) in which terrestrial processes and land uses directly affect oceanic processes and uses, and *vice versa* (Zhang, 2012). A complex ecological system can be identified in this area due to the interaction between land, ocean and habitats.

Economically, coastal areas are important as many urban centers (e.g. Colombo, Galle, Matara, and Trincomalee) are located therein. The presence of economic activities and the consequent interaction between humans and these areas can be high. For example, activities associated with the tourism industry are often concentrated in the coastal area. To this can be added various industrial activities, traditional resource-based activities such as fishing and aquaculture, and higher human habitation densities.

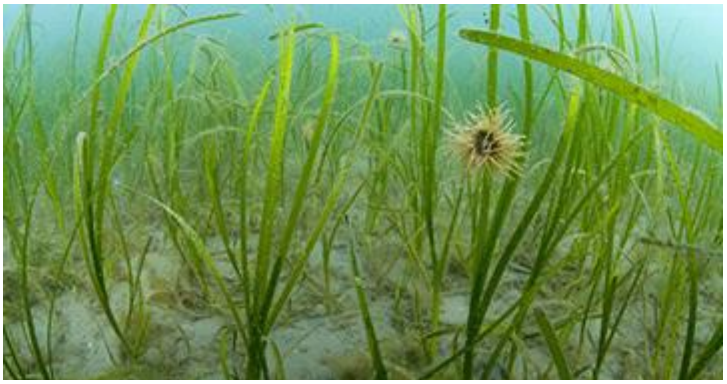
(a) (b)

**Figure 1.1:** Hotels and restaurants (a) and traditional fishing (b) in the coastal area

Ecologically, a coastal area is very important as it provides a number of environmental "goods and services". Coastal areas have high biological diversity and productivity as these receive nutrients from the land and freshwater courses. Habitats in the sea can include coral reefs, mangroves and sea grass beds. These coral reefs and mangrove forests are not only important fish nurseries but can also help mitigate effects of natural disasters like tsunami and coastal erosion.

(a)

(b)



(c)

**Figure 1.2:** Coral reefs (a), mangroves (b) and sea grass bed (c)

Both economy and ecology are combined and important in coastal areas as the ecology can directly influence the economy and vice-versa. For example, the ecology and the consequent aesthetics of a coastal area can support valuable tourism activities, as well as provide attractive sites for industrial development and human settlements. This can positively impact the income of a developing country like Sri Lanka.

**Table 1.1:** Type of pollution, sources, and adverse impacts

| Type of pollution | Key sources | Adverse impacts |
|---|---|---|
| Faecal pollution | • Municipal sewage;<br>• Industries;<br>• Tourist sector;<br>• Aquaculture;<br>• Squatter settlements. | • Water related diseases;<br>• Affects the growth of marine flora and fauna;<br>• Foul odours, spoils scenic value;<br>• May lead to anaerobic environments. |
| Visual pollution | • Industries;<br>• Tourist sector;<br>• Agriculture and aquaculture;<br>• Squatter settlements;<br>• Municipal and domestic solid waste. | • Spoils scenic value;<br>• Affects habitats and breeding grounds of fauna;<br>• Affects growth of marine vegetation such as sea grass by reducing light penetration. |
| Enrichment with nutrients such as nitrogen and phosphorus | • Municipal sewage;<br>• Industries;<br>• Tourist sector;<br>• Agriculture and aquaculture;<br>• Squatter settlements;<br>• Municipal and domestic solid waste. | • Municipal sewage;<br>• Industries;<br>• Tourist sector;<br>• Agriculture and aquaculture;<br>• Squatter settlements;<br>• Municipal and domestic solid waste. |
| Organic (non-toxic and toxic) and heavy metal pollution | • Industries;<br>• Tourist sector;<br>• Agriculture and aquaculture;<br>• Squatter settlements;<br>• Municipal and domestic solid waste. | • Bio-accumulation of substances that are carcinogenic or causes health hazards in marine fauna;<br>• Decline of biodiversity;<br>• Persistence in the marine or coastal environment for long periods;<br>• Affects growth and reproduction of marine fauna. |
| Oil pollution | • Industries<br>• Boats, ships, oil spills and service stations | • Spoils scenic value;<br>• Destroys marine fauna and flora. |
| Thermal pollution | • Power sector<br>• Industries | • Affects benthic fauna with the formation of oil slicks and tar balls;<br>• Affects migration patterns of fauna;<br>• Affects the growth of marine flora and fauna;<br>• Causes changes in ecosystems;<br>• Stimulates algal growth. |

(Source: Coastal Zone Management Plan (CZMP), 2006)

**Figure 1.3:** Beach tourism at a coastal area

Anthropogenic activities can adversely impact coastal areas by inappropriate wastewater and solid waste disposal, damaging coral reefs, and using unsustainable fishing practices.

**Figure 1.4:** Coastal pollution from garbage

**Figure 1.5:** Wastewater discharged into rivers flows to the ocean finally

A key coastal environmental issue is the littoral zone's water quality. This is related to coastal water pollution, destruction of ecological systems, and other environmental issues. The main contributor to reduced water quality is often wastewater discharges from industries containing toxic chemicals, oxygen-depleting organics, nutrients, and pathogens (Zhang, 2012). When wastewater is discharged without proper treatment to inland water surfaces that affects the coastal water quality as such waters flow into the ocean ultimately.

**Table 1.2:** Waste loads from industries located in coastal areas with high or medium pollution

| Type of industry or process | No. of units | Total waste water load ($m^3$/day) | Estimated pollution load (kg/day) | | |
|---|---|---|---|---|---|
| | | | $BOD_5$ | COD | Total toxic metals |
| Textiles | 41 | 7,100 | 4,970 | 11,360 | — |
| Food and beverages | 47 | 4,111 | 6,166 | 12,333 | — |
| desiccated coconut | 53 | 1,200 | 4,200 | 7,200 | — |
| Rubber processing | 229 | 4,840 | 9,670 | 29,040 | — |
| Tanning | 15 | 750 | 2,000 | 5,200 | — |
| Metal finishing and preparation | 76 | 6,692 | — | — | 669* |
| Paints and chemicals | 33 | 928 | — | — | 92.8* |

— Not measured; * based on assumed average concentration of 100 mg/l

(Source: CZMP, 2006)

There are concerns from environmental groups that hot water discharged from coal power plants can damage marine organisms. Cooling water drawn from the sea at an average temperature of 28°C will be returned to the sea at a higher temperature. This rise in seawater temperature can impact marine breading grounds.

The temperature profile (along with that salinity's) provides information on the circulation patterns. This affects growth and distribution of the fish population. The turbidity can adversely impact marine life (e.g. clogging fish gills and reducing photosynthesis) and aesthetics. The latter is an important feature in the beach tourism industry. The concentration of pathogens is a concern for humans coming into contact with the water (as in swimming) as well as for produce from farmed and wild caught marine organisms.

The reasons for the coastal pollution is likely failure in policy formulation and implementation of laws where such policy and legal frameworks already exist. Lack of factual and scientific evidences can be a contributory factor for failure of such formulation and implementation. When there is no properly collected data on coastal pollution and water quality, it becomes harder to make appropriate policy and policing interventions. In an effort to assess available data to initiate such action, this study considered the water quality parameters - pH, water temperature, DO, EC, TDS, turbidity, salinity and faecal coliform - at 6 coastal areas (Arugambay, Nilaweli, Polhena, Unawatuna, Hikkaduwa, and Mt. Lavinia) where data from August, 2009 to September, 2011 and March, 2014 to February, 2017 is available.

It should be noted a number of regulations has already been established in efforts to safeguard and to prevent coastal pollution such as the National Environmental Act No. 47 of 1980. Under these regulations published under the Gazette Notification No. 1534/18, the permissible discharge standards for industrial and domestic wastewaters into marine and coastal areas have been introduced (Table 1.3).

The existing policies concerning coastal and marine pollution are be listed below.

I National Environment Policy, 2003 by Ministry of Environment

II National Watershed Management Policy, 2004 by Ministry of Environment

III National Land Use Policy, 2007 by Ministry of Land and Land development

IV National Policy on Solid Waste Management by Ministry of Environment

V Cleaner Production Policy 2004, by Ministry of Environment

VI National Forestry Policy of 1995, by Forest Department

Marine Pollution Prevention Act No. 59 of 1981 and its amendment No.35 of 2008 and Coast Conservation Act No. 57 of 1981 and amendment of 1988 are the laws passed which directly concerns marine and coastal pollution.

**Table 1.3:** Tolerance limits of wastewater discharged to marine and coastal area

| No: | Parameter | Unit<br>Type of limit | Tolerance Limit Value |
|---|---|---|---|
| 1. | Total suspended solids | mg/l, max. | 150 |
| 2. | Particle size of-<br>(a) Floatable solids<br>(b) Settlable solids | <br>mm, max.<br>µm, max. | <br>3<br>850 |
| 3. | pH at ambient temperature | - | 5.5-9.0 |
| 4. | Biochemical Oxygen Demand ($BOD_5$ in five days at $20^0C$ or $BOD_3$ in three days at $27^0C$) | mg/l, max. | 100 |
| 5. | Temperature | $^0C$, max. | $45^0C$ at the point of discharge |
| 6. | Oils and greases | mg/l, max | 20 |
| 7. | Phenolic compounds (as $C_6H_5OH$) | mg/l, max | 5 |
| 8. | Chemical Oxygen Demand (COD) | mg/l, max | 250 |
| 9. | Total residual chlorine | mg/l, max | 1.0 |
| 10. | Ammonical Nitrogen | mg/l, max | 50 |
| 11. | Cyanide (as $CN^-$) | mg/l, max | 0.2 |
| 12. | Sulphides (as $S^{2-}$) | mg/l, max | 5.0 |
| 13. | Fluorides (as $F^{-)}$ | mg/l, max | 15 |
| 14. | Arsenic (as As) | mg/l, max | 0.2 |
| 15. | Cadmium (as Cd) | Mg/l, max | 2.0 |
| 16. | Chromium, total (as Cr) | Mg/l, max | 2.0 |
| 17. | Chromium, Hexavalent (as $Cr^{6+}$) | Mg/l, max | 1.0 |
| 18. | Copper (as Cu) | Mg/l, max | 3.0 |
| 19. | Lead (as Pb) | Mg/l, max | 1 |
| 20. | Mercury (as Hg) | Mg/l, max | 0.01 |
| 21. | Nickel (as Ni) | Mg/l, max | 5.0 |
| 22. | Selenium (as Se) | Mg/l, max | 0.1 |
| 23. | Zinc (as Zn) | Mg/l, max | 5.0 |
| 24. | Pesticides | Mg/l, max | 0.005 |
| 25. | Organo-Phosphorus compounds | Mg/l, max | 1.0 |
| 26 | Chlorinated hydrocarbons (as Cl) | Mg/l, max | 0.02 |
| 27. | Faecal Coliform | MPN/100ml, max. | 60 |
| 28. | Radio Active Material:<br>(e) Alpha emitters<br>(f) Beta emitters | <br>micro curie/ml, max<br>micro curie/ml, max | <br>$10^{-8}$<br>$10^{-7}$ |

But the need for coastal protection and conservation has increased given Sri Lanka's economic and societal development and hence the need for review, revision and possibly new policies and laws on coastal protection and coastal water quality. There is also growing public awareness on the need to protect the coastal environment and there is need for government agencies to respond to such interests.


**Figure 1.6:** Coastal Protection by general public

In this study, one of the purposes is to identify suitable new policy interventions where they are applicable and improve/develop a monitoring plan to mitigate coastal environment pollution.

## 1.2 Study Objectives

- To analyze and interpret the measured data with consideration of climate and other environmental conditions.
- To evaluate the state of the problem and propose criteria for coastal water quality standards along the identified coastal stretches.
- To prepare guidelines or measures for mitigation.
- To propose monitoring plan based on existing technology and resources.
- To prepare a report on water quality and contamination of pollutants in coastal waters including state of the problem in the study area.

## 1.3 Expected Outcomes

- An assessment on the condition of the selected coastal sites based on the water quality data provided and taking into account their relationship with climate and other environmental conditions (Chapter 2 and 3).
- A set of coastal water quality assessment criteria based on assessment of data provided and identification of gaps in the former (Chapter 4).
- An assessment of the current status of coastal water quality based on the data provided with comparison with similar situations in the region and the world (Chapter 2 and 4).
- Preparation of a set of guidelines for mitigating coastal water pollution based on practices consistent with those accepted by UNEP/ similar organizations (Chapter 4).
- Propose a monitoring plan using the state of the art technologies available in Sri Lanka (Chapter 4).
- Compilation of a report based on the above deliverables.

# STATISTICAL DATA ANALYSIS

# Statistical Data Analysis 2

Statistical data analysis was performed the data obtained and bar charts drawn to indicate year-wise trends over the four main seasons - i.e. first Inter-monsoon, South West monsoon, second Inter-monsoon and North East monsoon. The Completely Randomized Design (CRD) method was used to identify if there is significant difference in the water quality measurement over the year. Subsequently, comparison of means was done for each parameter. MINITAB 17 software was used for the data analysis. The Completely Randomized Design low p value (< 0.05) in the One Way ANOVA table suggested significant differences in the water quality parameters over the year at the 95% significance level.

Pearson Correlation Analysis was performed to determine if significant relationship existed between faecal coliform and average rainfall during the North East monsoon at all the stations. Rainfall data came from the nearest rain gauge station. Table 2.1 presents the rainfall stations used in the study.

**Table 2.1:** Rainfall stations used in the study

| Beach site | Nearest Rainfall Station |
|---|---|
| Arugambay | Pottuvil |
| Mount Lavinia | Rathmalana |
| Nilaweli | Trincomalee |
| Unawatuna | Galle |
| Hikkaduwa | Monrovia |
| Polhena | Kekanadura |

## 1. Arugambay

Arugambay is situated in the dry zone of Sri Lanka's South East coast. The bay is located 117 km South of Batticaloa, 320 km East of Colombo and approximately 4 km south of Pottuvil town. While traditional fishing dominates the local economy, tourism has grown rapidly in recent years. Tourism in Arugambay is primarily surf tourism due to existence of quality surf breaks. Although infrastructure was damaged by the 2004 tsunami, the area has been redeveloped with hotels and other constructions.  These can have adverse impact on the area's coastal environmental health.

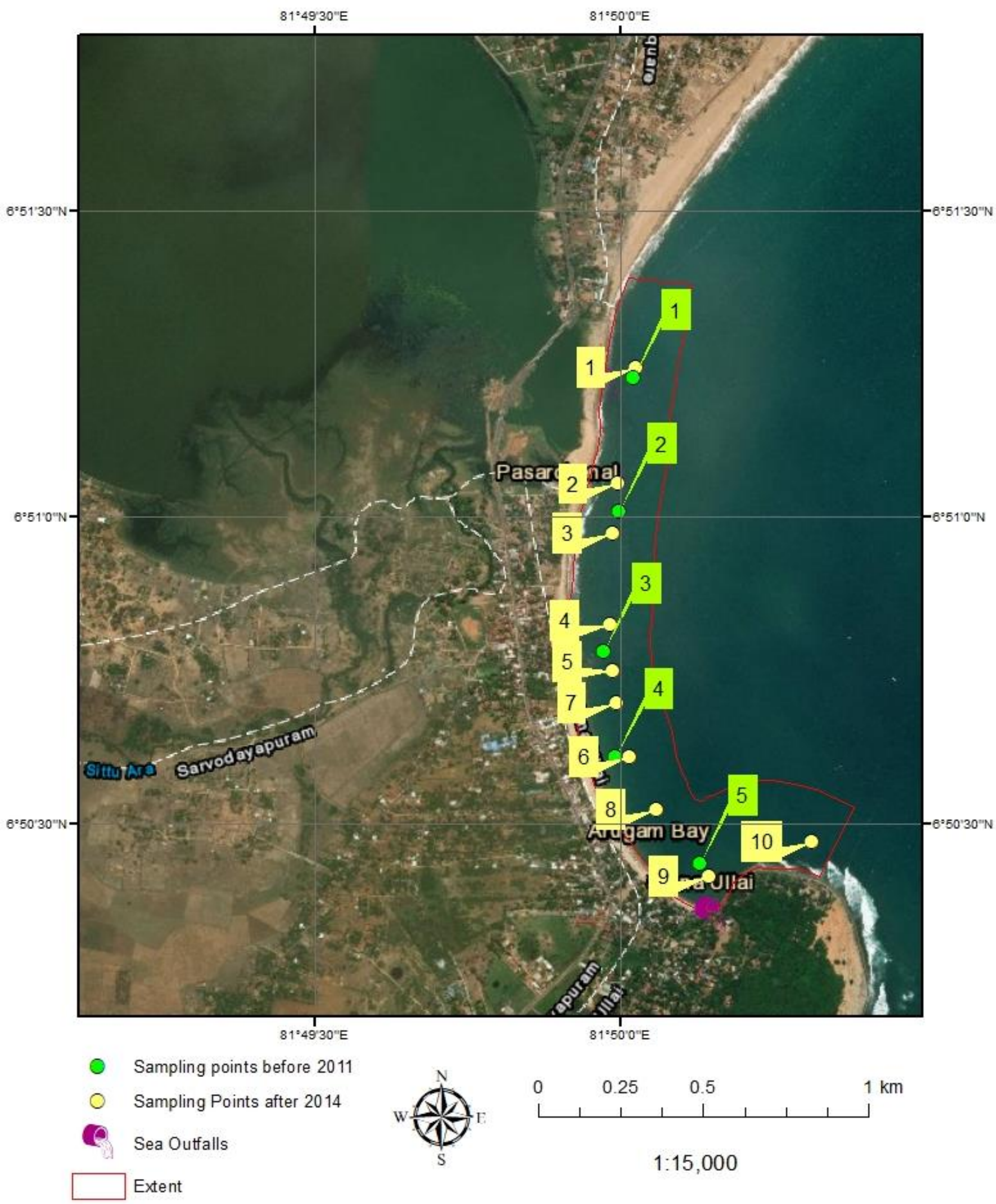



**Figure 2.1:** Sampling locations at Arugambay

## pH Profiles

pH variation over time and the impact of monsoons were studied. Table 2.2 shows average pHs and their standard deviations from 2009 to 2016. It was noted there had been no large pH variations over the 8 years period. Similarly, impact of monsoons on pH variation at the various sampling locations may be seen on Figure 2.2.

**Table 2.2:** Comparison of mean pH values at Arugambay Beach

| Year | pH |
|---|---|
| 2009 | 8.01 (±0.26) |
| 2010 | 7.97 (±0.14) |
| 2011 | 7.98 (±0.05) |
| 2014 | 7.82 (±0.33) |
| 2015 | 7.85 (±0.45) |
| 2016 | 8.00 (±0.08) |

In the absence of a National Marine Water Quality Guideline, the ASEAN and CEA guidelines for wastewater discharge into marine waterbodies were used to assess existing water quality. With mean pH values, varying between 7.82 and 8.01 at Arugambay, pH at the location had been stable and within the CEA limits for wastewater discharge into marine coastal areas (allowable pH range = 5.5 - 9.0). The monsoons have had little impact on pH.

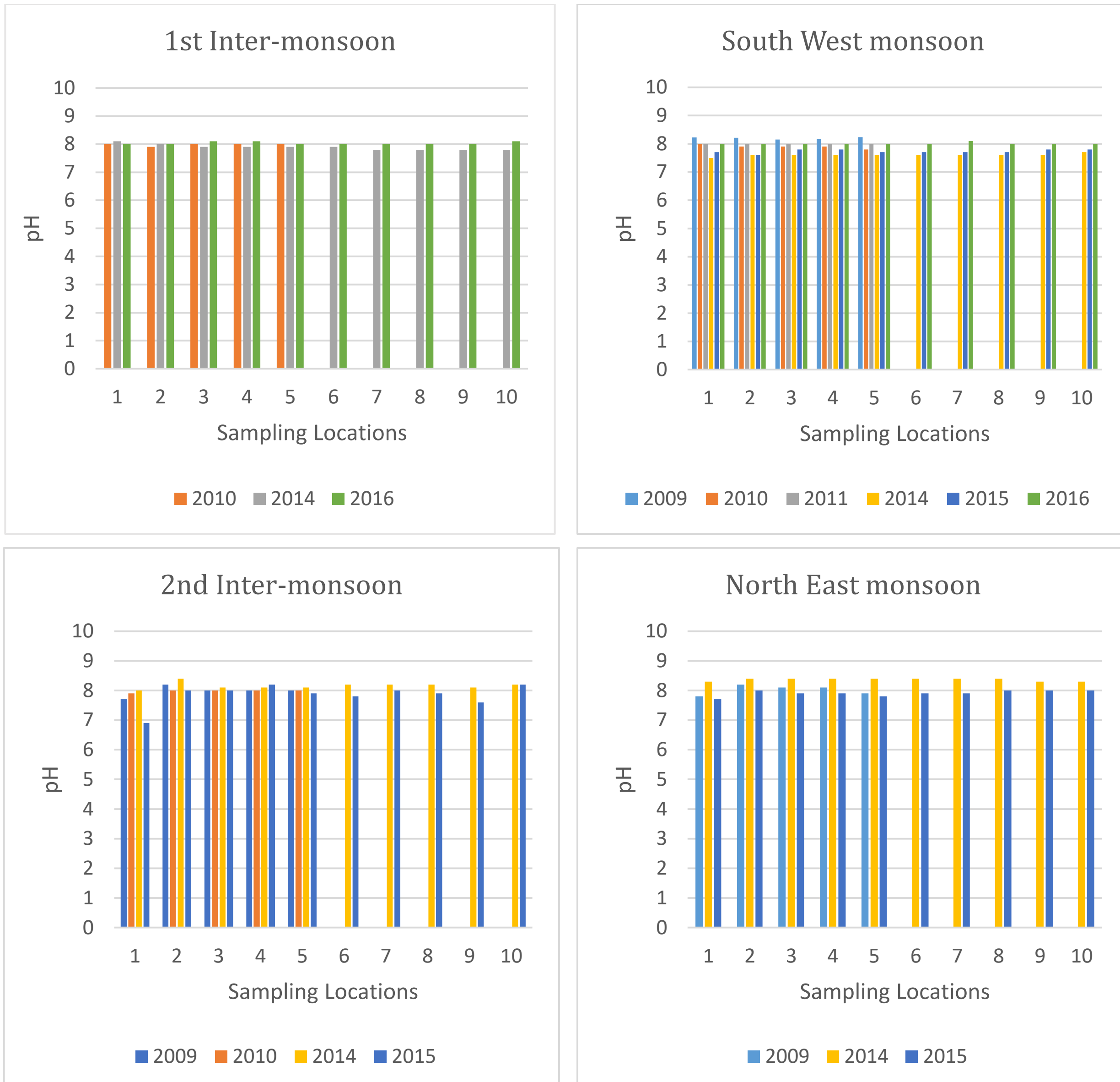



**Figure 2.2:** Seasonal variation of pH at Arugambay

### Dissolved Oxygen (DO) Profiles

Table 2.3 shows the mean DO variations at Arugambay (7.48 - 7.64 mg/L). The DO variations had been small from 2009 to 2016.

**Table 2.3:** Comparison of mean DO values at Arugambay Beach

| Year | DO (mg/L) |
|---|---|
| 2009 | 7.52 (±0.13) |
| 2010 | 7.64 (±0.44) |
| 2014 | 7.64 (±0.61) |
| 2015 | 7.48 (±0.60) |
| 2016 | 7.64 (±0.18) |

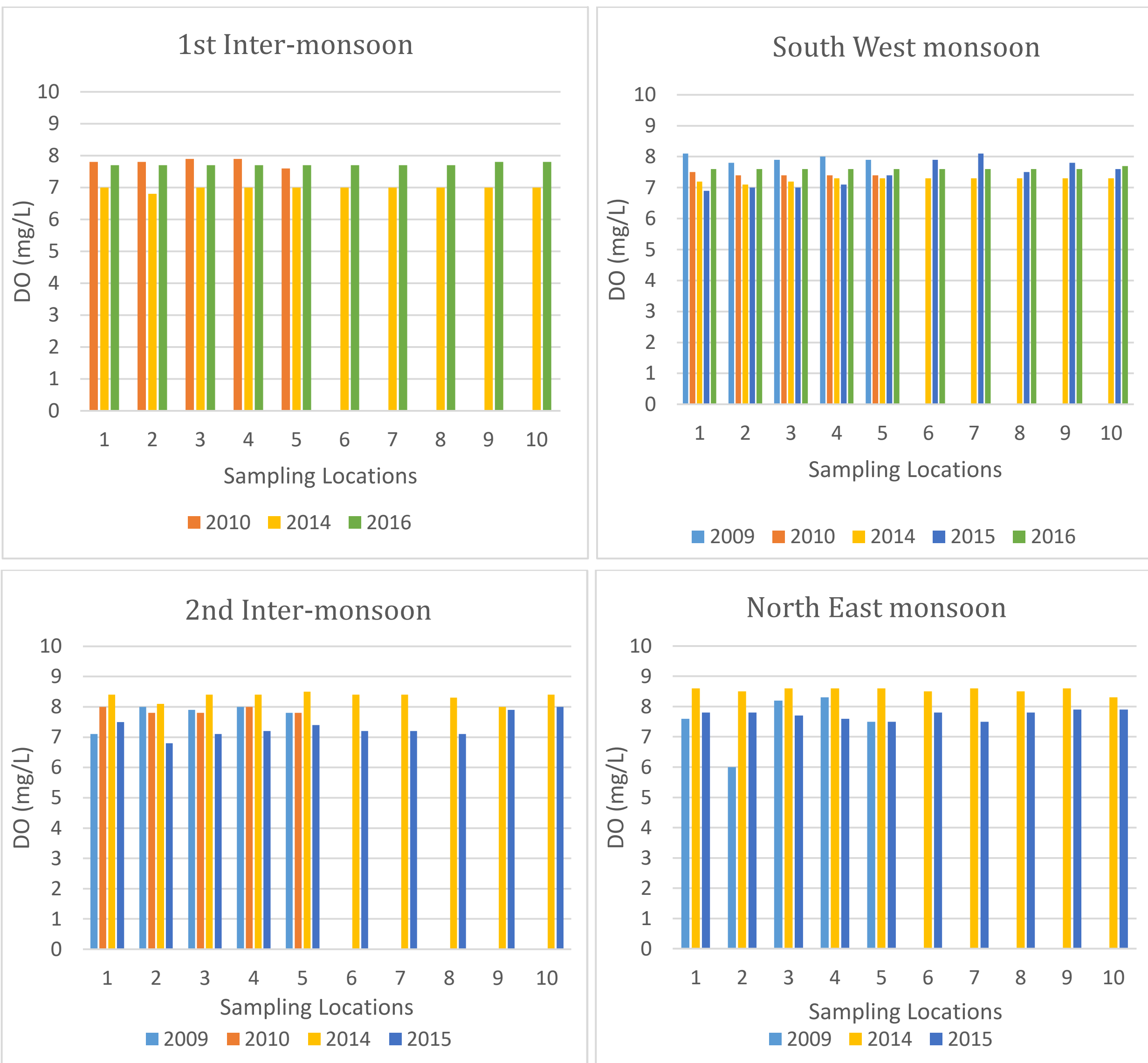



**Figure 2.3:** Seasonal variation of DO at Arugambay

Figure 2.3 illustrates the spatial variation of DO with respect to the monsoons. There was also little DO variation in terms of location along the beach and the monsoon seasons. DO values had been from 6.8 mg/L to 8.6 mg/L. The data would suggest DO levels had remained largely stable over the study period.

The measuring time, wind directions, mixing of sea water and algae concentration can affect DO data and its interpretation.

## Electrical Conductivity (EC) Profiles

The mean values of EC at Arugambay were 46.15 mS/cm to 58.95 mS/cm. No increasing or decreasing trend can be observed as shown in Table 2.4.

**Table 2.4:** Comparison of mean EC values at Arugambay Beach

| Year | EC (mS/cm) |
|---|---|
| 2009 | 46.15 (±12.97) |
| 2010 | 51.17 (±6.89) |
| 2014 | 52.32 (±8.29) |
| 2015 | 49.19 (±7.58) |
| 2016 | 58.95 (±6.72) |

There was, however, larger EC variation with respect to the monsoons, with values ranging from 36.9 mS/cm to 60.7 mS/cm - except for the 1$^{st}$ and 5$^{th}$ locations in 2009 in the North East and 2$^{nd}$ Inter-monsoons, respectively. The lower values may be attributed to the high rainfall and mixing at the sampling points. The EC values at many locations were less than 50 mS/cm in the 2$^{nd}$ Inter-monsoon but were more than 50 mS/cm in other monsoon periods. The EC can be lower due to dilution and mixing during high rainfalls and at major sea outfalls.

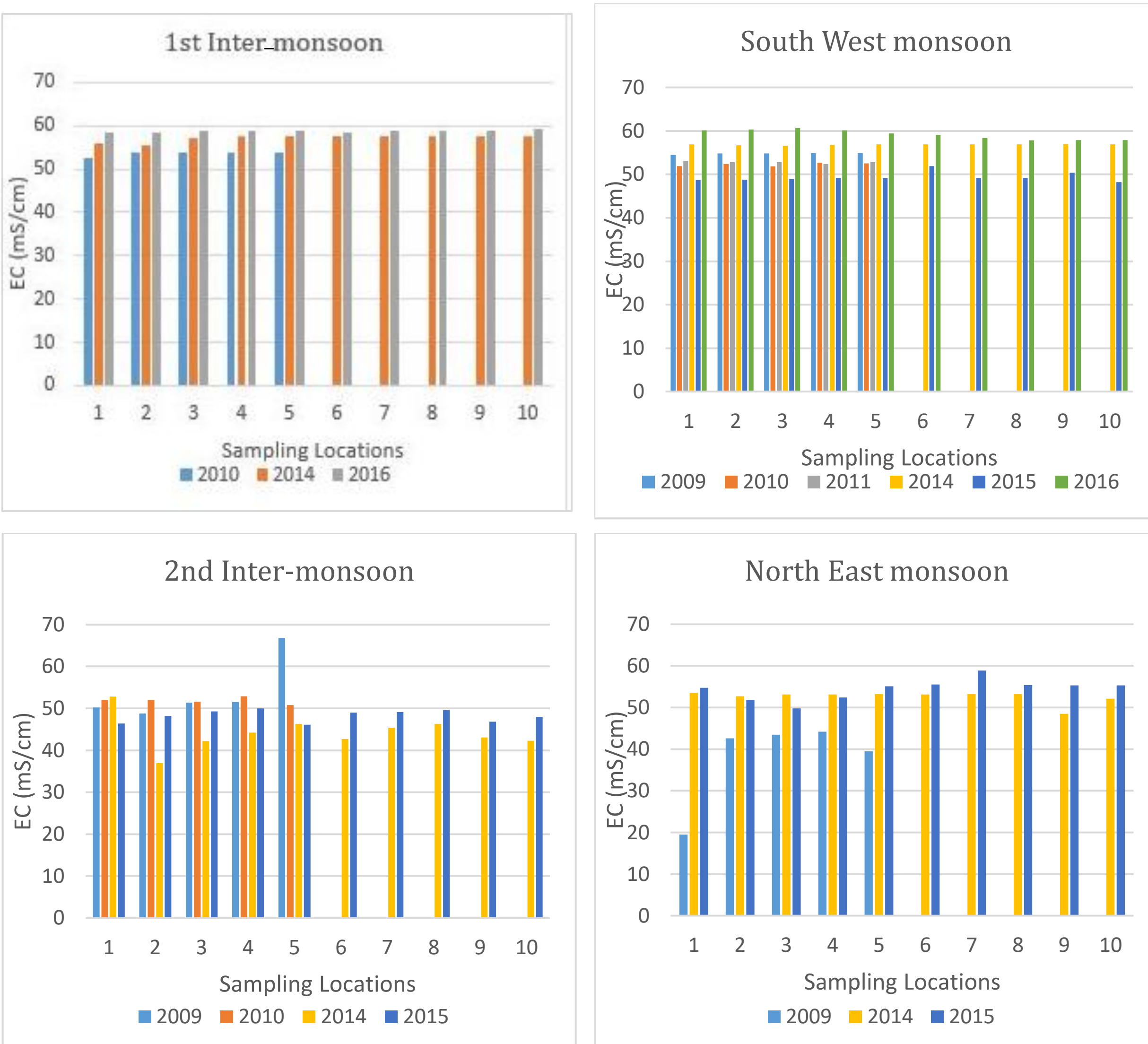



**Figure 2.4:** Seasonal variation of EC at Arugambay

Generally ambient marine water has an EC of 50 mS/cm (SWRCB, 2002). When considering the range of EC values at Arugambay, it can be noted Arugambay EC values had been similar with typical marine water EC values.

## Salinity Profiles

The mean salinity values vary from 24.31 % to 34.98 % as shown in Table 2.5. As a whole, there was no discernable trend in the changes over the 8 years.

**Table 2.5:** Comparison of mean salinity values at Arugambay Beach

| Year | Salinity (%) |
|---|---|
| 2009 | 24.31 (±10.50) |
| 2010 | 29.42 (±4.18) |
| 2011 | 34.98 (±0.62) |
| 2014 | 33.17 (±5.64) |
| 2015 | 31.14 (±2.67) |
| 2016 | 33.89 (±2.83) |

The variation in salinity is consistent with the EC variations (Figure 2.5). The highest obtained salinity value is 35.9 % and the lowest value is 10.6 %. The first five locations during the North East monsoon in 2009 showed lower values and this is consistent with the EC values as earlier discussed.

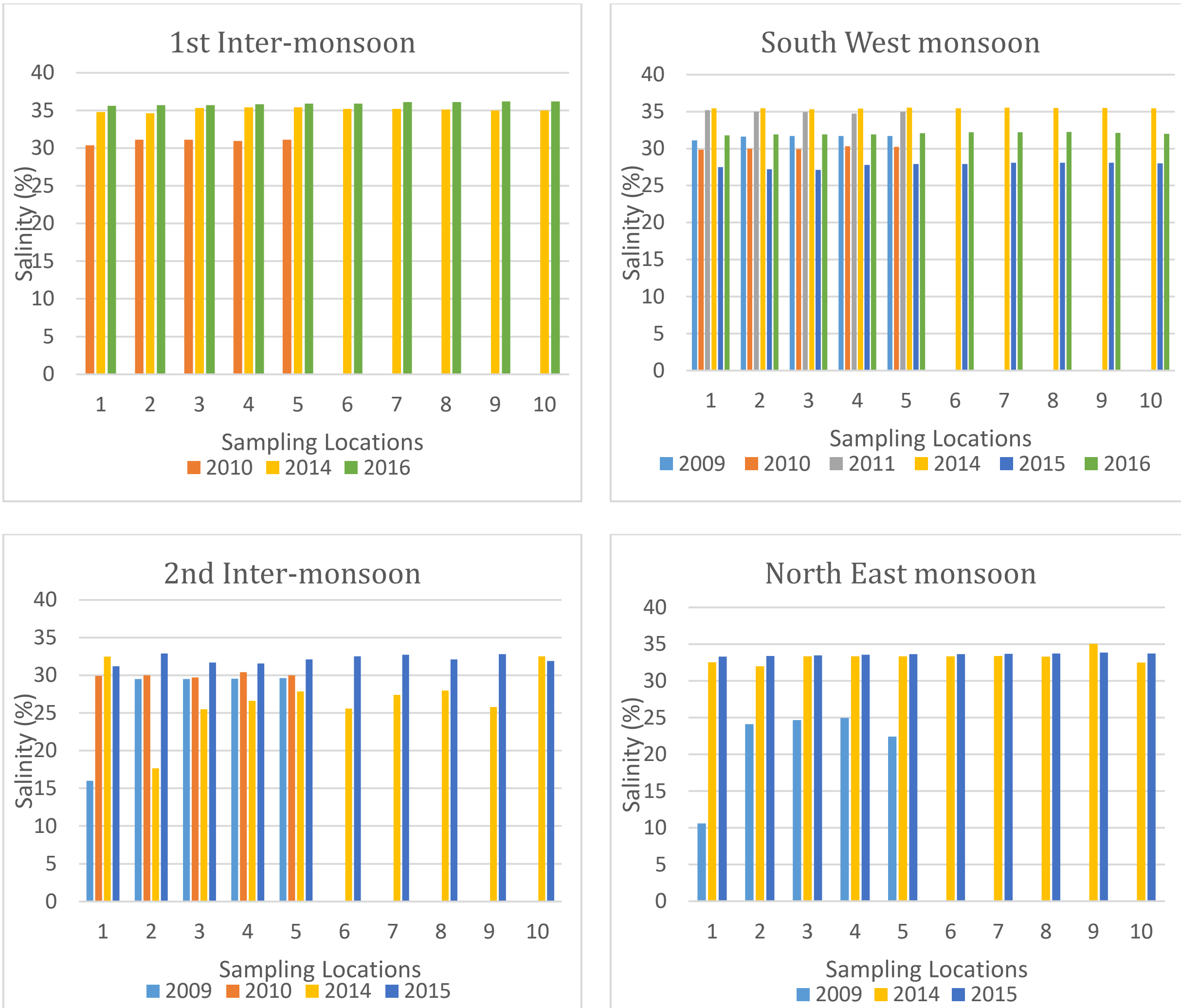



**Figure 2.5:** Seasonal variation of salinity at Arugambay

The ASEAN guideline does not introduce salinity as a parameter for marine water.

## Total Dissolved Solids (TDS) Profiles

Mean values of TDS ranged from 42.83 g/L to 52.06 g/L as shown in Table 2.6. The TDS had increased from 42.83 g/L in 2009 to 52.06 g/L in 2010. Since, the measurements have not been done for other years, a trend could not be identified.

**Table 2.6:** Comparison of mean TDS values at Arugambay Beach

| Year | TDS (g/L) |
|---|---|
| 2009 | 42.83 (±19.06) |
| 2010 | 52.06 (±7.44) |

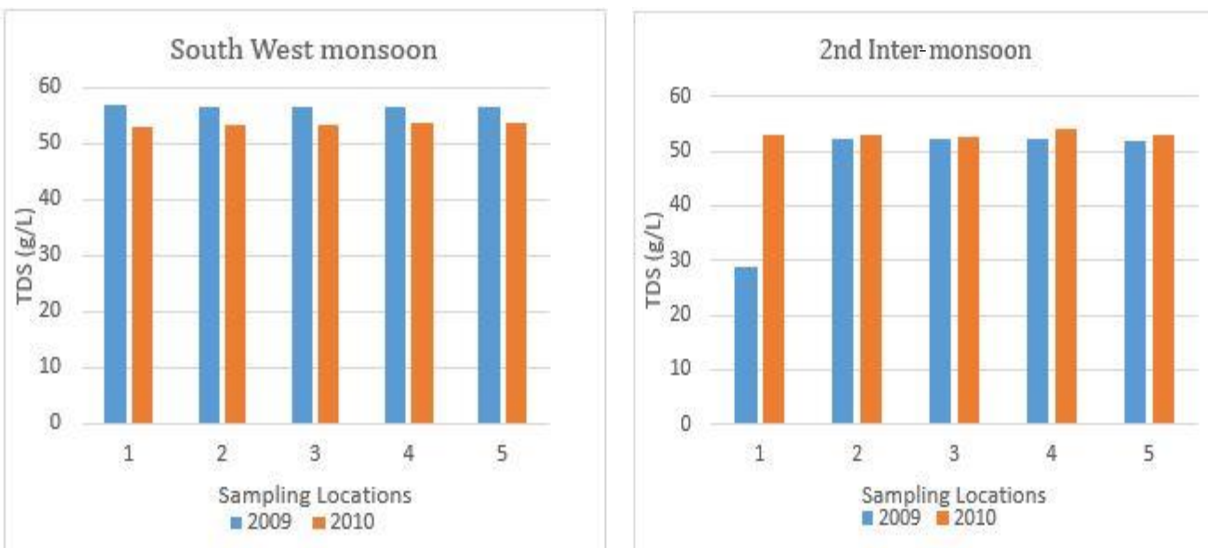



**Figure 2.6:** Seasonal variation of TDS at Arugambay

## Turbidity Profiles

Mean turbidity values at Arugambay were 77.66 NTU to 9.84 NTU. It was 77.66 NTU in 2009 but had decreased to 33.55 NTU in 2010 and to 9.84 in 2011 as shown in Table 2.7.

**Table 2.7:** Comparison of mean turbidity values at Arugambay Beach

| Year | Turbidity (NTU) |
|---|---|
| 2009 | 77.66 (±81.9) |
| 2010 | 33.55 (±57.56) |
| 2011 | 9.84 (±8.23) |

With respect to the monsoons, the highest turbidity value of 234 NTU was noted at the 1st location in the 2nd Inter-monsoon in 2009 (Figure 2.7). Turbidity can be affected by high rainfalls, topography, land use patterns and sea outfalls. Sediments could also be re-suspended due to turbulence. The latter may occur due to wind speed and direction, and land surface morphology near the sampling locations. The most of the locations show a decreasing trend of turbidity with the time except for 1st and 5th locations during the South West monsoon. In 2009, high rainfall could have increased turbidity (Appendix I). Since the CEA and the ASEAN guidelines do not provide standards for turbidity, the values could not be benchmarked.

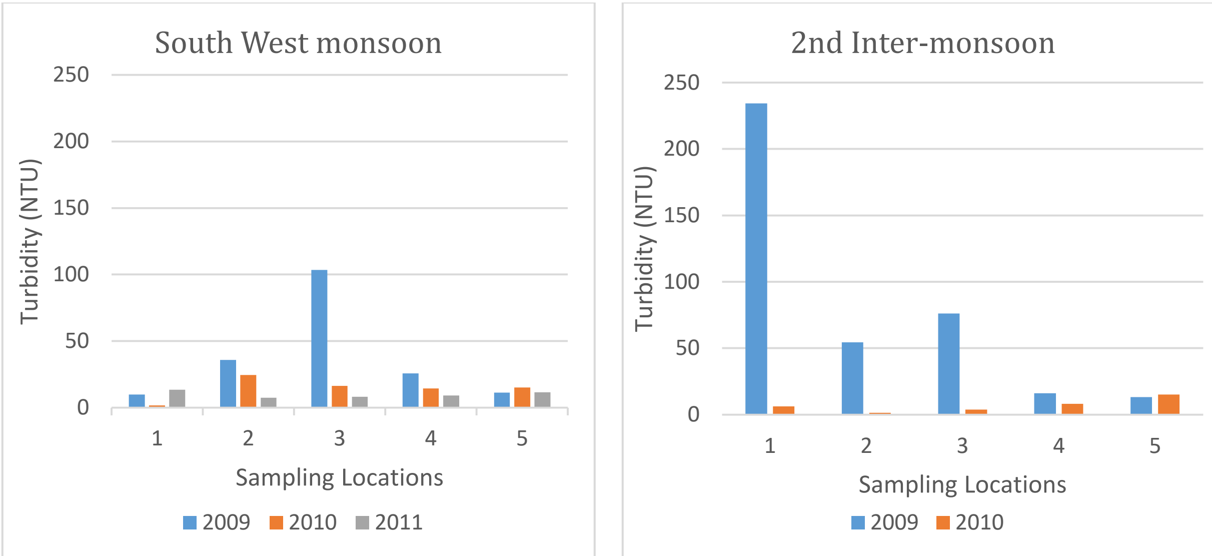



**Figure 2.7:** Seasonal variation of turbidity at Arugambay

## Temperature Profiles

Mean temperature values at Arugambay varied from 24.21 to 28.73 °C as shown in Table 2.8. The 24.21 °C in 2011 was unusually low compared with all the other years which had temperatures of more than 28 °C.

**Table 2.8:** Comparison of mean temperature values at Arugambay Beach

| Year | Temperature (°C) |
|---|---|
| 2009 | 28.48 (±0.82) |
| 2010 | 28.73 (±0.94) |
| 2011 | 24.21 (±0.80) |
| 2014 | 28.16 (±0.91) |
| 2015 | 28.04 (±0.93) |
| 2016 | 28.06 (±1.03) |

The typical temperature range across sampling locations at Arugambay was 27.1 °C to 29.4 °C - except for locations of 1,2,3,4 and 5 during the South West monsoon in 2011 (Figure 2.8). A decreasing trend can be seen in the 2nd Inter-monsoon at every location while it a slight temperature increase occurred in North East monsoon at all sampling locations. Water temperature may vary with rainfall, sea current and the air temperature changes.

When comparing with the international guidelines, the ASEAN guidelines do not provide a standard for marine water temperature for the purpose of human health and recreational activities. However, the increase over ambient temperature should be ≤2 °C when considering aquatic life.

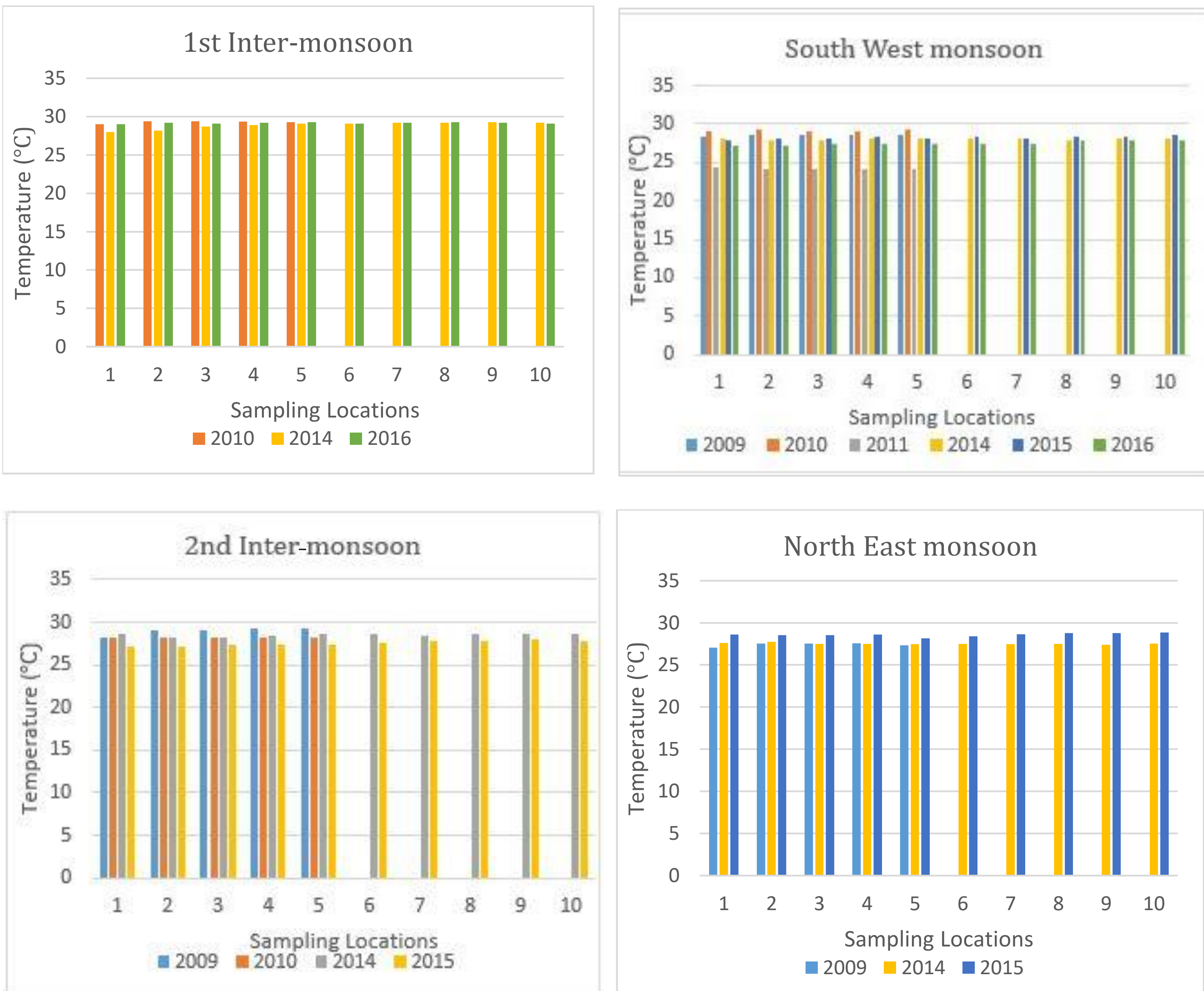



**Figure 2.8:** Seasonal variation of temperature at Arugambay

## Faecal Coliforms Profiles

Faecal coliforms count ranged from 13.34 MPN/100 ml and 463.17 MPN/100 ml (Table 2.9). There is no discernable trend over the years. The highest value obtained was 1256 MPN/100 ml while some locations had no detected coliforms.

**Table 2.9:** Comparison of mean faecal coliform values at Arugambay Beach

| Year | Coliform (MPN/100ml) |
|---|---|
| 2009 | 463.17 (±789) |
| 2010 | 73.31 (±149.5) |
| 2011 | 279.11 (±469.7) |
| 2014 | 13.34 (±8.67) |
| 2015 | 64.13 (±132.5) |
| 2016 | 101.52 (±362.2) |

Variation of faecal coliform is presented in Figure 2.9. When considering the national and international standards, the ASEAN guideline has 100 MPN/100 ml and CEA 60 MPN/100ml (wastewater discharge to marine water bodies). When considering the 1$^{st}$ Inter-monsoon, all locations had values lower than 100 MPN/100 ml which met the ASEAN limit. The South West monsoon also had values lower than 100 MPN/100ml, except for 5 locations. Most of the values which exceeded 100 MPN/100ml were recorded in 2011 in the South West monsoon. The increase in faecal coliform counts during the second and North East Monsoon could be attributed to surface runoff and increase in the groundwater table which caused the sewerage system to overflow into the sea following high rainfall. Lower rainfall could be the major reason for the lower faecal coliforms count during the 1$^{st}$ Inter-monsoon and South West monsoon (Appendix I).

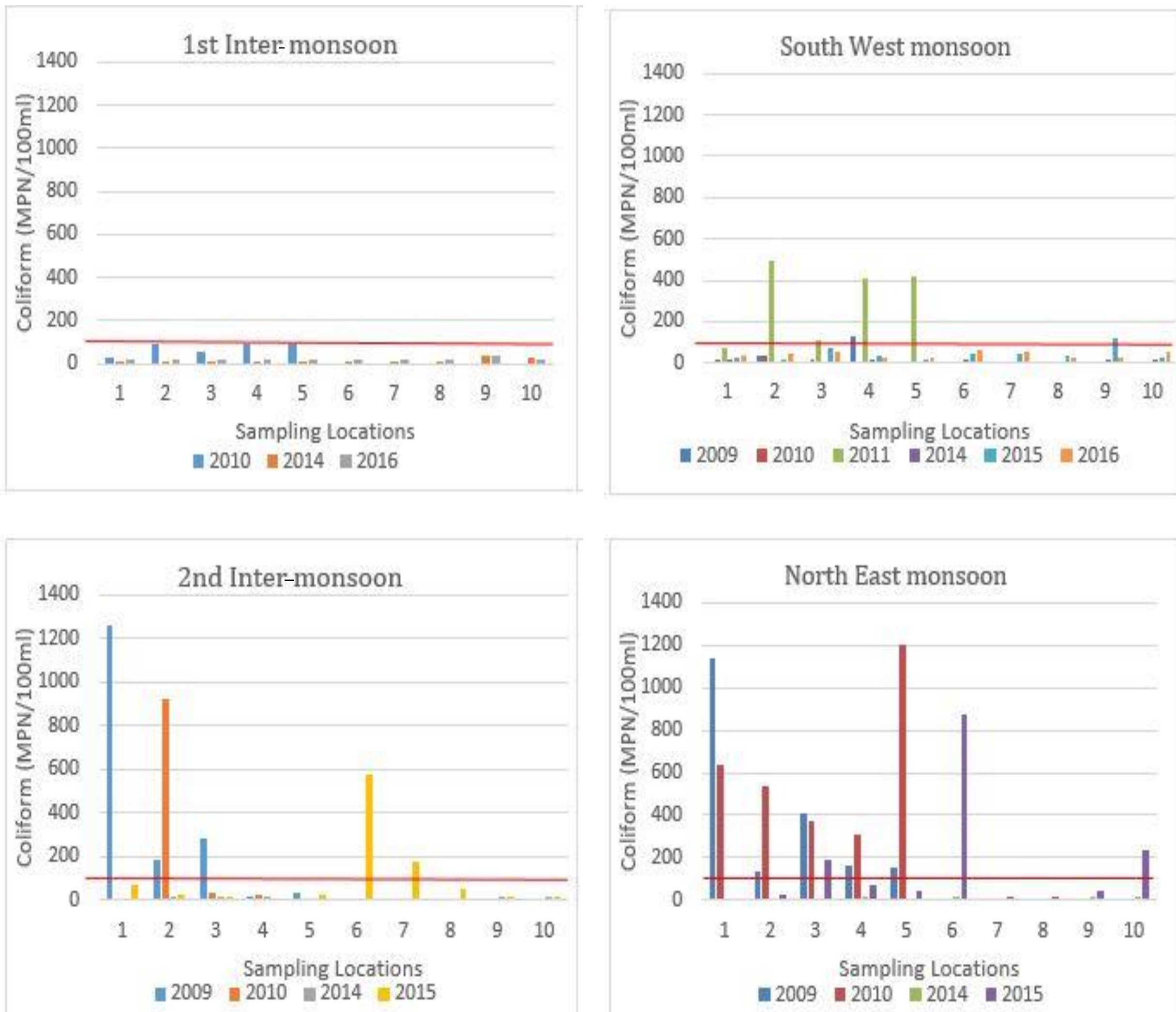



**Figure 2.9:** Seasonal variation of faecal coliform counts at Arugambay

## 2. Mount Lavinia

Mount-Lavinia is a suburb in Colombo, Sri Lanka, which is under the administration of Dehiwala-Mount Lavinia Municipal Council. The area is mostly a residential suburb, known as Colombo's beach retreat. It is famed for its "Golden Mile" of beaches, and has long been a hot spot for tourism and nightlife paving the way for higher coastal pollution. It is one of the most liberal regions in Sri Lanka.

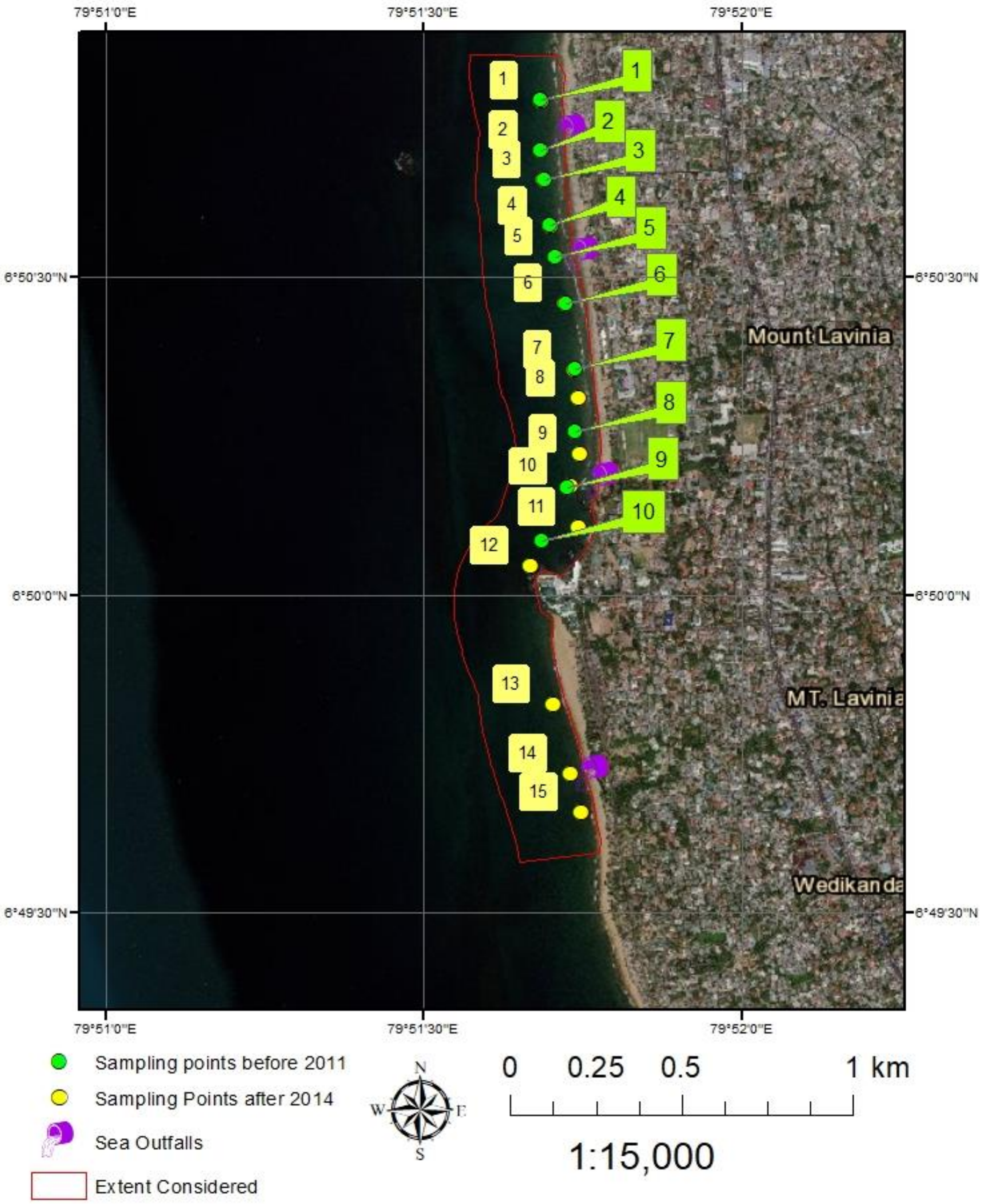



**Figure 2.10:** Sampling locations in Mount Lavinia Beach

## pH Profiles

Variation of pH with time and the monsoons were studied and the summary is shown in Table 2.10. This shows the mean pH and associated standard deviations from 2009 to 2016. Similarly as in Arugambay, it can be seen that there is no observable variations in pH throughout the monitoring period. Figure 2.11 shows the impact of monsoons with respect to pH in the given location.

**Table 2.10**: Comparison of mean pH values at Mt. Lavinia Beach

| Year | pH |
|---|---|
| 2009 | 8.12 (±0.14) |
| 2010 | 7.42 (±1.56) |
| 2011 | 8.03 (±0.03) |
| 2014 | 7.64 (±0.31) |
| 2015 | 7.65 (±0.48) |
| 2016 | 7.76 (±0.27) |

Based on the ASEAN and the CEA guidelines for wastewater discharge into marine water bodies, the mean pH values are within those standards and the variation is between 7.42 and 8.12 at Mt. Lavinia (the allowable range of pH is between 5.5 and 9.0). Additionally, there is no detectable variation of pH according to monsoon patterns and sampling locations.

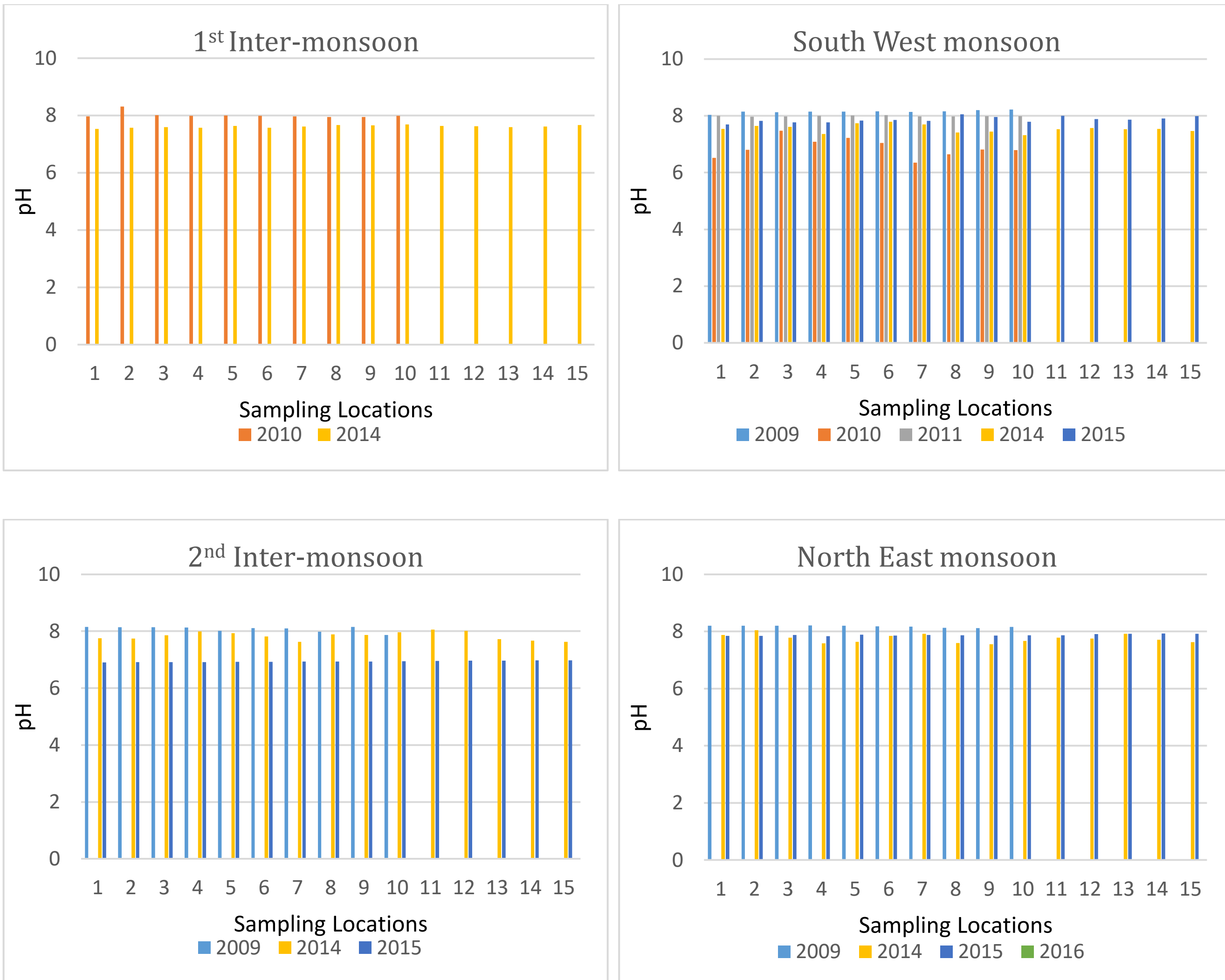



**Figure 2.11:** Seasonal variation of pH at Mount Lavinia

## DO Profiles

The temporal and the monsoon impact on DO variation at Mt. Lavinia was studied and the Table 2.11 shows the variation of the mean DO values at Mt. Lavinia (between 7.61 mg/L and 8.29 mg/L). Any considerable variation could not be observed, hence the DO has not changed during the monitoring period from 2009 to 2015.

**Table 2.11:** Comparison of mean DO values at Mt. Lavinia Beach

| Year | DO (mg/L) |
|---|---|
| 2009 | 7.73 (±0.25) |
| 2010 | 7.69 (±0.73) |
| 2014 | 7.61 (±0.59) |
| 2015 | 8.29 (±0.27) |

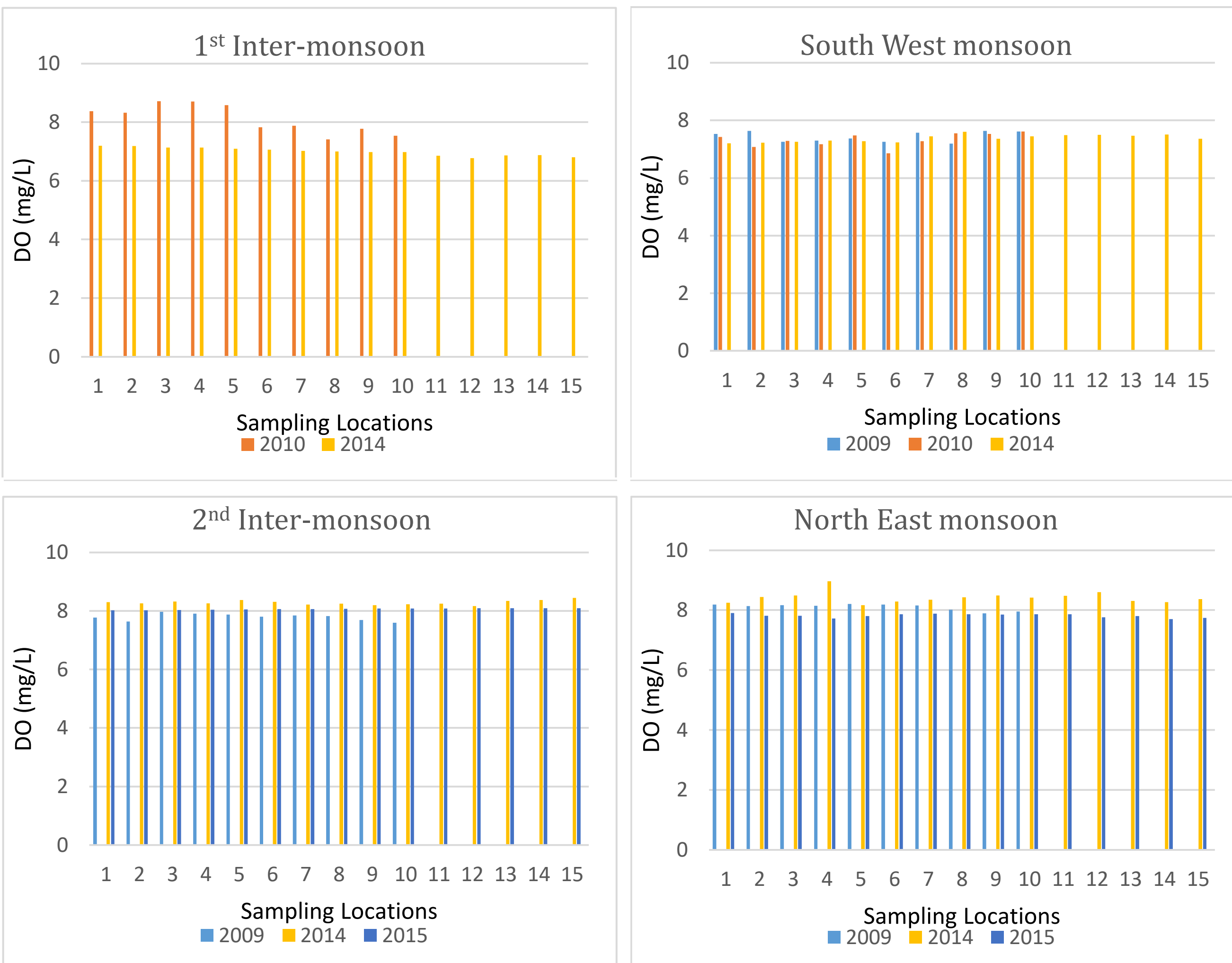



**Figure 2.12:** Seasonal variation of DO at Mount Lavinia

The Figure 2.12 shows the seasonal variation of DO with respect to monsoons at Mt. Lavinia. The mean DO values obtained are varied between 6.8 mg/L to 8.3 mg/L. Irrespective of the monsoon season and sampling locations, there is no visible variation of DO.

As mentioned previously, the measuring time, wind directions, mixing of sea water and algae concentration may have effected on DO. Therefore, these factors should be considered when sampling.

### EC Profiles

Table 2.12 shows the variation of the mean EC values at Mt. Lavinia which varied between 49.50 mS/cm and 55.95 mS/cm. The variation of EC values does not show any trend, hence the EC has not changed during the monitoring period from 2009 to 2016.

**Table 2.12:** Comparison of mean EC values at Mt. Lavinia Beach

| Year | EC (mS/cm) |
|---|---|
| 2009 | 51.31 (±2.76) |
| 2010 | 51.88 (±3.14) |
| 2014 | 49.50 (±0.86) |
| 2015 | 55.95 (±2.46) |
| 2016 | 55.83 (±3.65) |

When considering the EC, the values are varied within the range of 49.4 mS/cm and 59.8 mS/cm except for the 13$^{th}$ location during the North East monsoon in 2015 as shown in Figure 2.13. However, it can be seen that EC have relatively less values in 2$^{nd}$ Inter-monsoon and North East Monsoon in 2009. Dilution and mixing due to the high rainfalls could be a reason for the observed values.

Generally the ambient marine water has an EC of 50 mS/cm (SWRCB, 2002). When comparing the EC values at Mt. Lavinia with general sea water EC values, similarity can be observed.

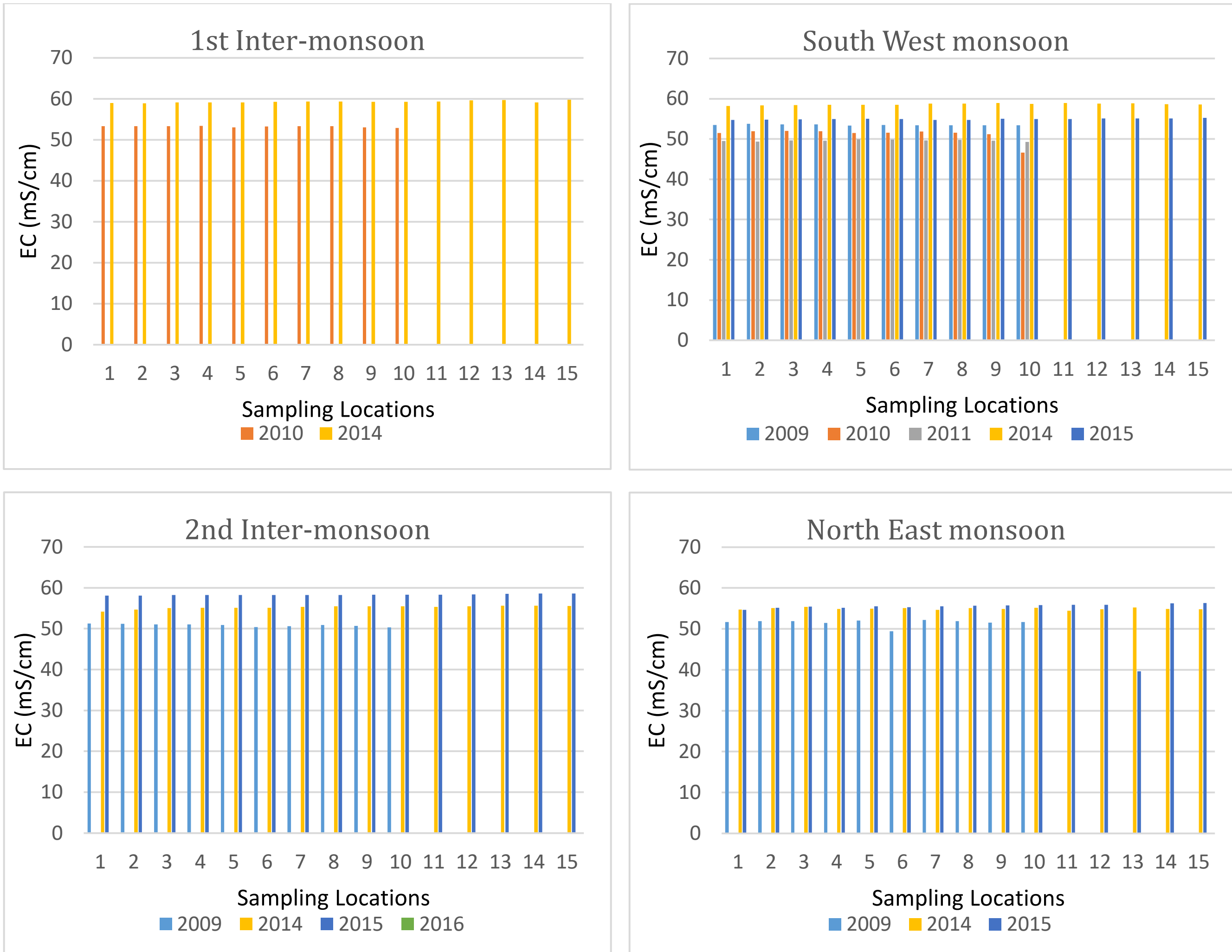



**Figure 2.13:** Seasonal variation of EC at Mount Lavinia

## Salinity Profiles

The mean values of salinity at Mt. Lavinia are within the range of 29.28 % to 35.76 %. The salinity has increased from 2009 to 2016. This variation may be attributed to mixing with outfall discharges or local turbulences at the time of sampling location. But the salinity did not vary much with the time as shown in Table 2.13.

**Table 2.13:** Comparison of mean salinity values at Mt. Lavinia Beach

| Year | Salinity (%) |
|---|---|
| 2009 | 29.28 (±1.72) |
| 2010 | 29.73 (±2.45) |
| 2011 | 32.82 (±0.90) |
| 2014 | 35.08 (±1.22) |
| 2015 | 35.76 (±1.49) |
| 2016 | 35.70 (±1.05) |

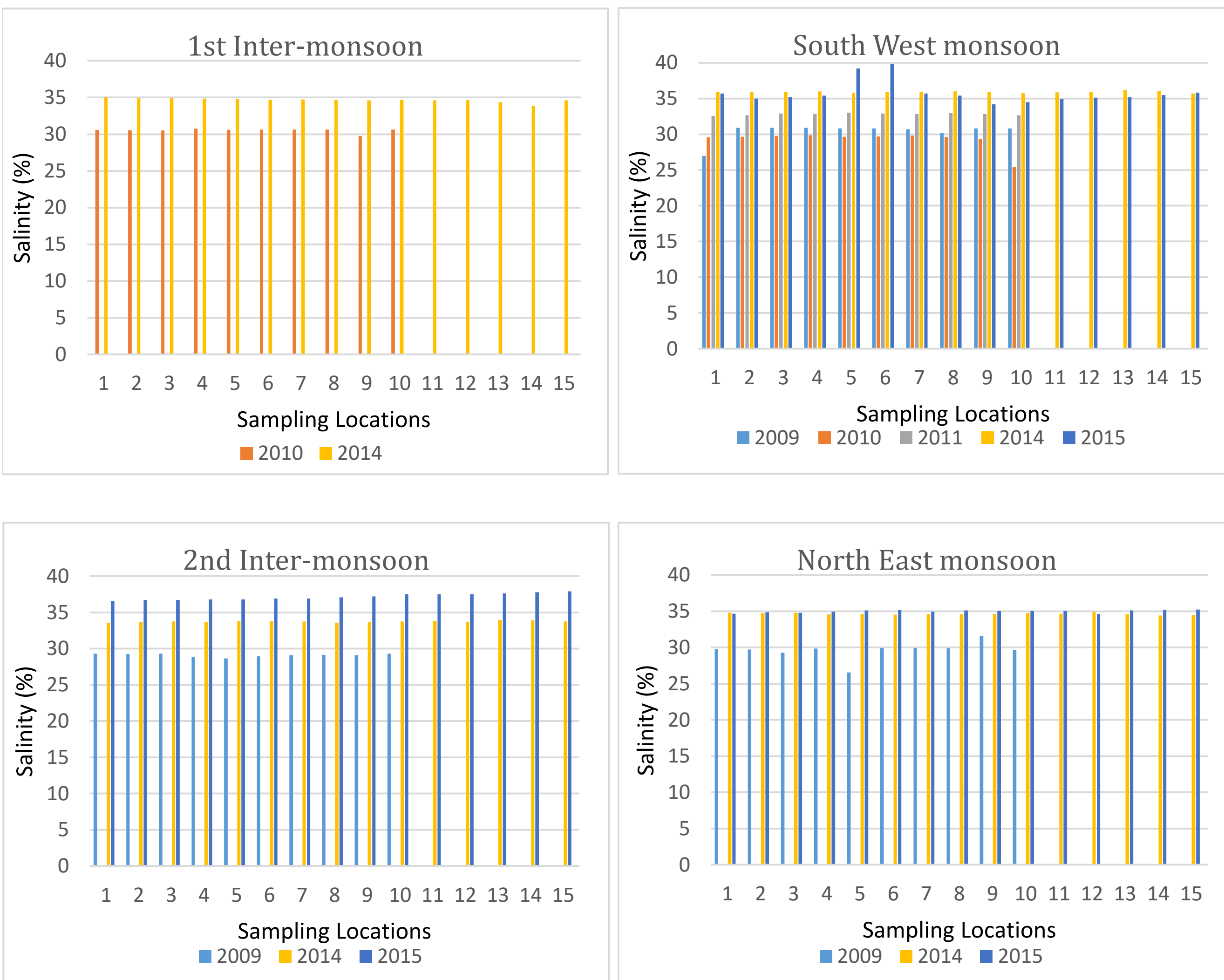



**Figure 2.14:** Seasonal variation of salinity at Mount Lavinia

As observed in Arugambay, the variation of EC can be perceived in salinity at Mt. Lavinia also. Relatively less values are being showed in 2009 as EC (Figure 2.14). This is acceptable since EC and salinity have a correlation. During the South West monsoon, salinity was decreased in 2010 and increased in other years for most locations (2 – 10). The salinity is varied between 27 % and 39.80 % during the monitoring period.

The ASEAN guideline does not introduced salinity as a parameter for marine water.

### TDS Profiles

As shown in Table 2.14, the mean TDS values are varied within 51.84 g/L to 52.63 g/L. Since, the measurements have not done for other years, a trend could not be identified.

**Table 2.14:** Comparison of mean TDS values at Mt. Lavinia Beach

| Year | TDS (g/L) |
|---|---|
| 2009 | 51.84 (±3.43) |
| 2010 | 52.63 (±3.96) |

When considering the TDS at Mt. Lavinia, it seems to be constant in 2009 in 2$^{nd}$ Inter-monsoon and North East monsoon. During the 1$^{st}$ Inter-monsoon in 2010, all the locations show higher values than 50 g/L except for 9$^{th}$ location. No any visible trend could be observed in salinity at Mt. Lavinia (Figure 2.15).

Neither CEA nor ASEAN provides TDS as a coastal water quality parameter.

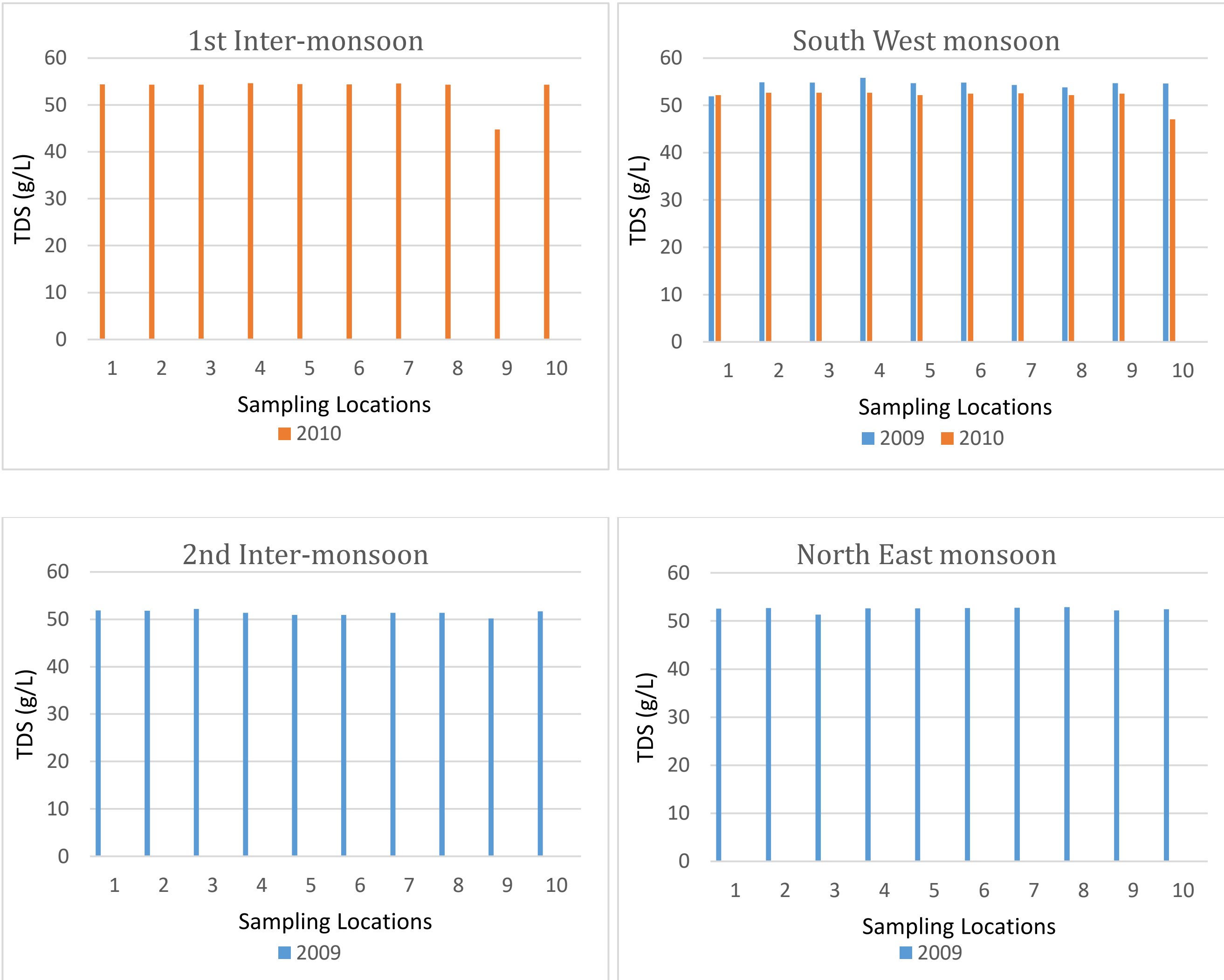



**Figure 2.15:** Seasonal variation of TDS at Mount Lavinia

## Turbidity Profiles

The variation of turbidity with temporal and monsoons was studied in this analysis and the mean values are within the range of 11.38 NTU and 146.62 NTU as presented in Table 2.15. The turbidity was increased to 146.62 in 2010 from 110.25 in 2009 and largely decreased to 11.38 NTU in 2011.

**Table 2.15:** Comparison of mean turbidity values at Mt. Lavinia Beach

| Year | Turbidity (NTU) |
|---|---|
| 2009 | 110.25 (±109.9) |
| 2010 | 146.62 (±169.6) |
| 2011 | 11.38 (±6.59) |

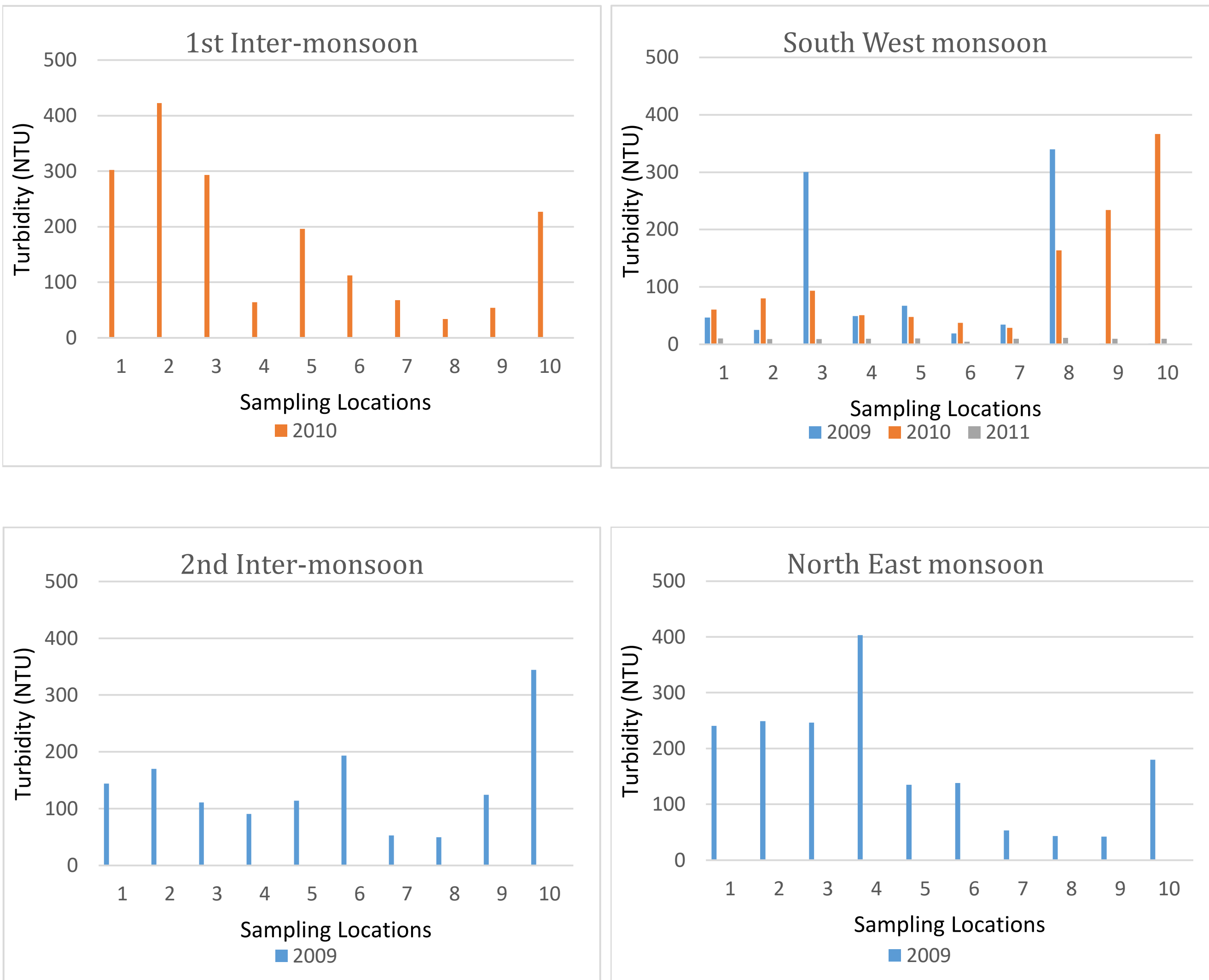



**Figure 2.16:** Seasonal variation of turbidity at Mount Lavinia

Most of the locations showed high turbidity values in 2009 and 2010 while 2011 has shown less values (Figure 2.16). High rainfalls and sea outfalls could be the reason for high values obtained. Since the CEA and the ASEAN guidelines do not provide standards for turbidity, the values could not be compared.

### Temperature Profiles

The mean values of temperature at Mt. Lavinia are within the range of 25.82 °C and 29.44 °C. It shows relatively high temperatures in 2009 and 2010 when considering the other years. The mean temperature values are shown in the Table 2.16.

**Table 2.16:** Comparison of mean temperature values at Mt. Lavinia Beach

| Year | Temperature (°C) |
|---|---|
| 2009 | 29.44 (±0.68) |
| 2010 | 29.07 (±1.48) |
| 2011 | 25.82 (±0.77) |
| 2014 | 28.70 (±3.12) |
| 2015 | 27.75 (±0.87) |
| 2016 | 26.64 (±1.07) |

Figure 2.17 illustrates the variation of temperature at Mt. Lavinia with monsoons. The temperature at Mt. Lavinia is varied between 25.5 °C and 32.2 °C during the monitoring period. A visible trend could not be observed in temperature with respect to monsoons. The rainfalls, sea currents and the air temperature can effect on marine water temperature.

As mentioned previously, the increase over ambient temperature should be ≤2 °C when considering the aquatic lives.

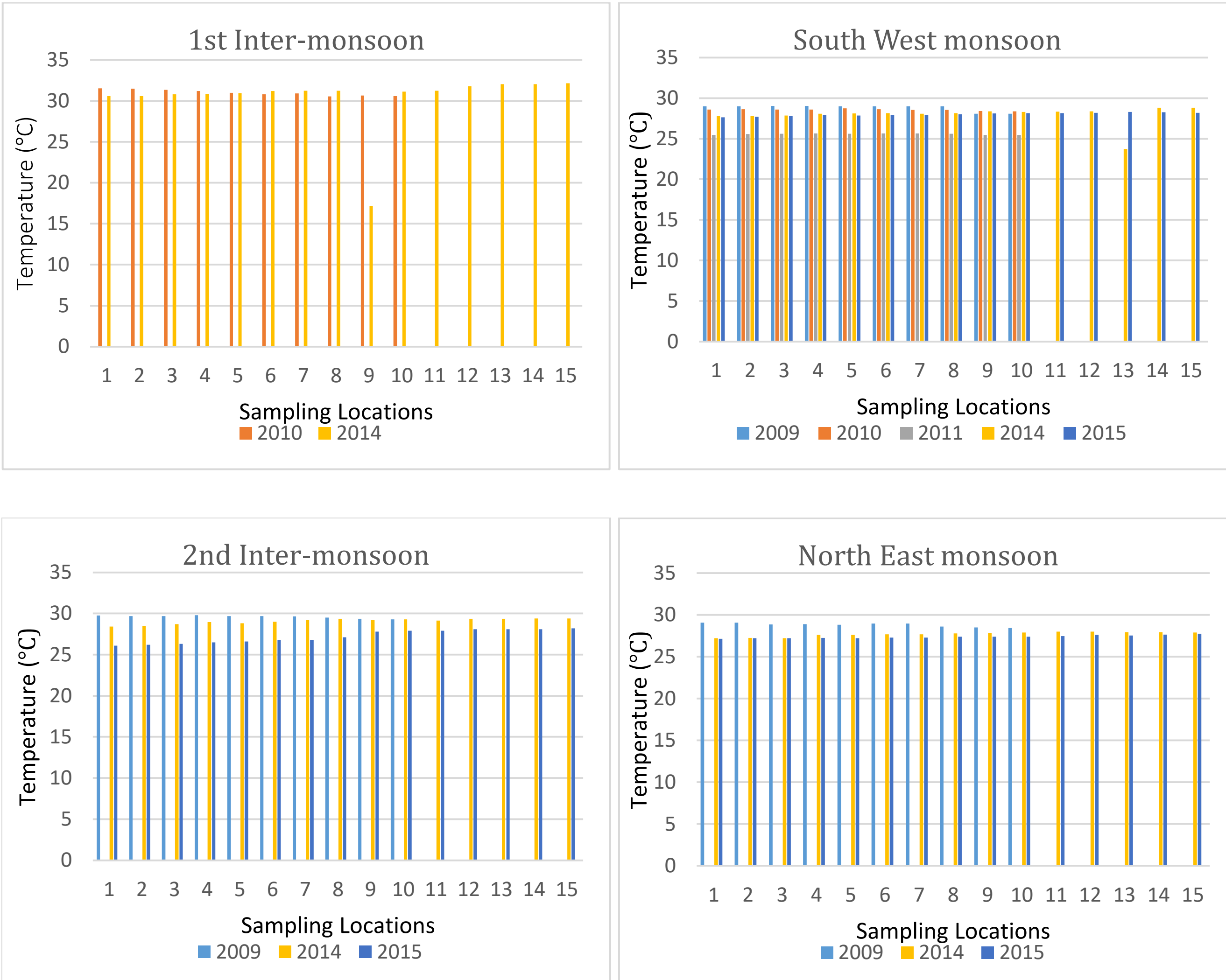



**Figure 2.17:** Seasonal variation of temperature at Mount Lavinia

## Faecal Coliform Profiles

The mean values are varied between 1009.38 MPN/100 ml and 3143.42 MPN/100 ml (Table 2.17). The faecal coliform concentration was increased moderately from 2009 to 2014, largely increased in 2015 and decreased in 2016.

**Table 2.17:** Comparison of mean faecal coliform values at Mt. Lavinia Beach

| Year | Coliform (MPN/100ml) |
|---|---|
| 2009 | 1009.38 (±1285) |
| 2010 | 1102.98 (±683.7) |
| 2011 | 1410.12 (±596.3) |
| 2014 | 1450.77 (±1854) |
| 2015 | 3143.42 (±4661) |
| 2016 | 1197.27 (±2964) |

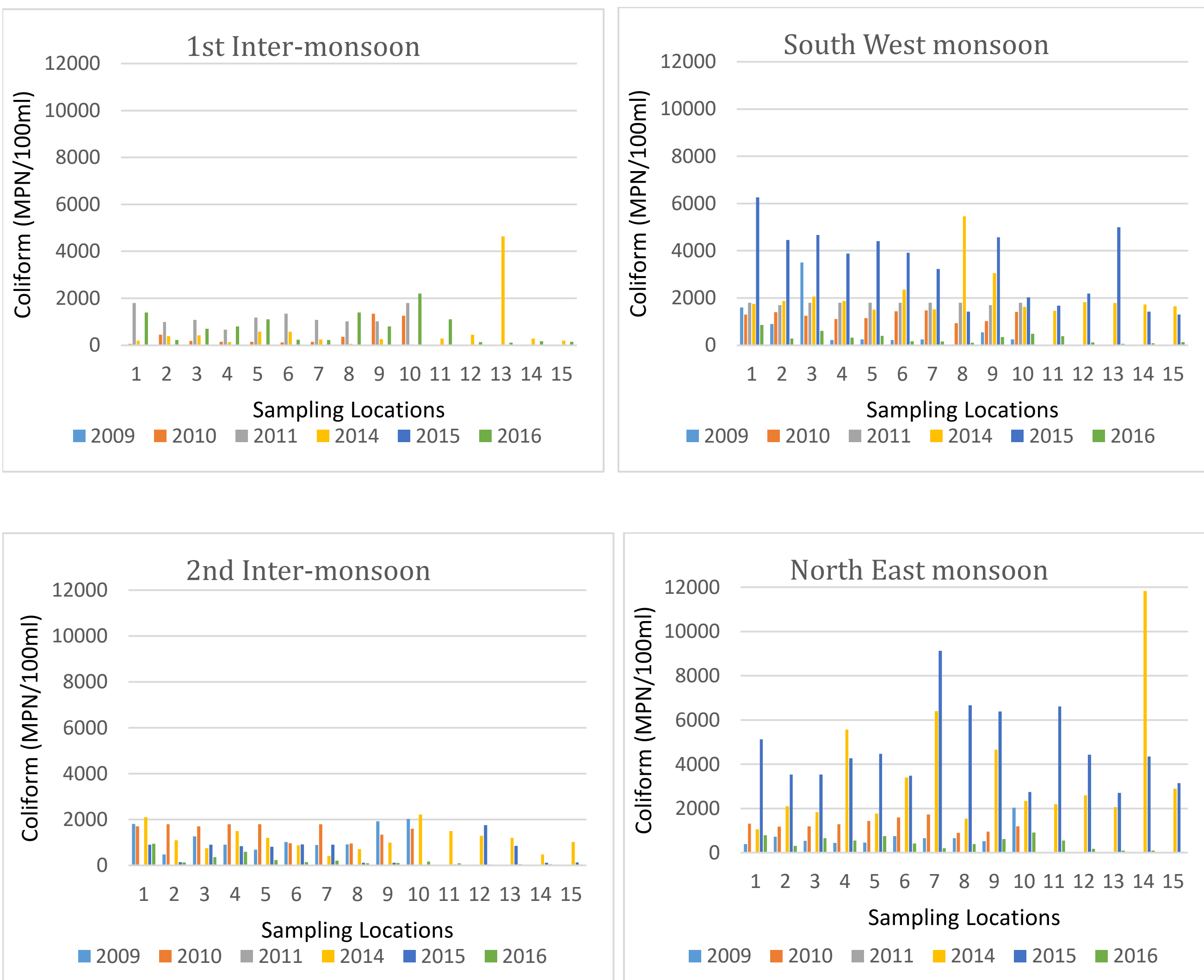



**Figure 2.18:** Seasonal variation of faecal coliform at Mount Lavinia

It can be seen that the coliform concentrations are lower in 2nd Inter-monsoon compared to the other monsoons (Figure 2.18). High coliform concentrations can be observed in North East monsoon for most of the locations. The variation of coliform concentration is irregular where a trend could not be identified with respect to monsoon patterns. When considering the national and international standards, the ASEAN guideline has defined 100 MPN/100 ml for faecal coliform and CEA as 60 MPN/100ml (wastewater discharge to marine water bodies). It can be observed that most of the locations have exceeded the standard limits for faecal coliform at Mt. Lavinia. Therefore, immediate actions should be taken in order to reduce the coliform concentration at Mt. Lavinia.

## 3. Nilaweli

Nilaweli is located in Trincomalee District, Sri Lanka. The beach is 16 km North West of Trincomalee. Pigeon Island National Park, one of the two marine national parks of the region is situated about 1 km off the coast of Nilaweli. High number of species of vegetation, coral and reef fish contribute to the richness of Nilaweli's biodiversity.

### pH Profiles

In this analysis, variation of pH with time and the monsoons were studied. Table 2.18 shows the summary of data with associated standard deviations from 2009 to 2016. Consequently, it can be seen that there is no visible variations in pH throughout the monitoring period. Also, the impact of monsoons were studied with respect to pH variation at Nilaweli as shown in Figure 2.20.

When considering the mean pH values at Nilaweli (6.52-8.02), there is no any large variation of pH at the location compared to the standards imposed by the CEA for discharging wastewater into marine coastal areas (the allowable range of pH is between 5.5 and 9.0). However, a slight decrease can be seen in 2016 compared to previous years. Further, there is no visible variation of pH with respect to the monsoon season and sampling locations.

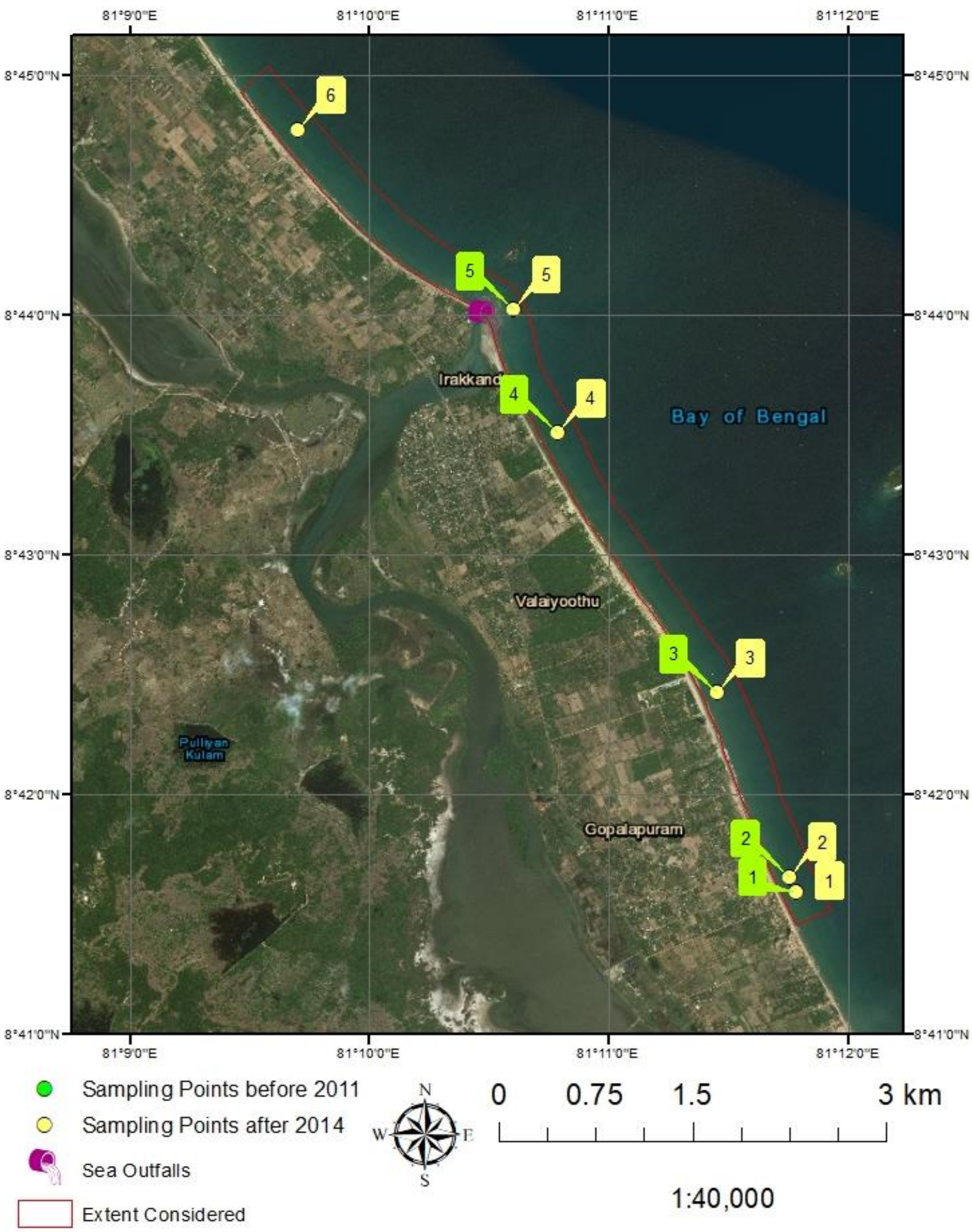



**Figure 2.19:** Sampling locations at Nilaweli Beach

**Table 2.18:** Comparison of mean pH values at Nilaweli Beach

| Year | pH |
|---|---|
| 2009 | 8.02 (±0.11) |
| 2010 | 7.95 (±0.40) |
| 2011 | 7.80 (±0.38) |
| 2014 | 7.60 (±0.47) |
| 2015 | 7.66 (±0.55) |
| 2016 | 6.52 (±0.51) |

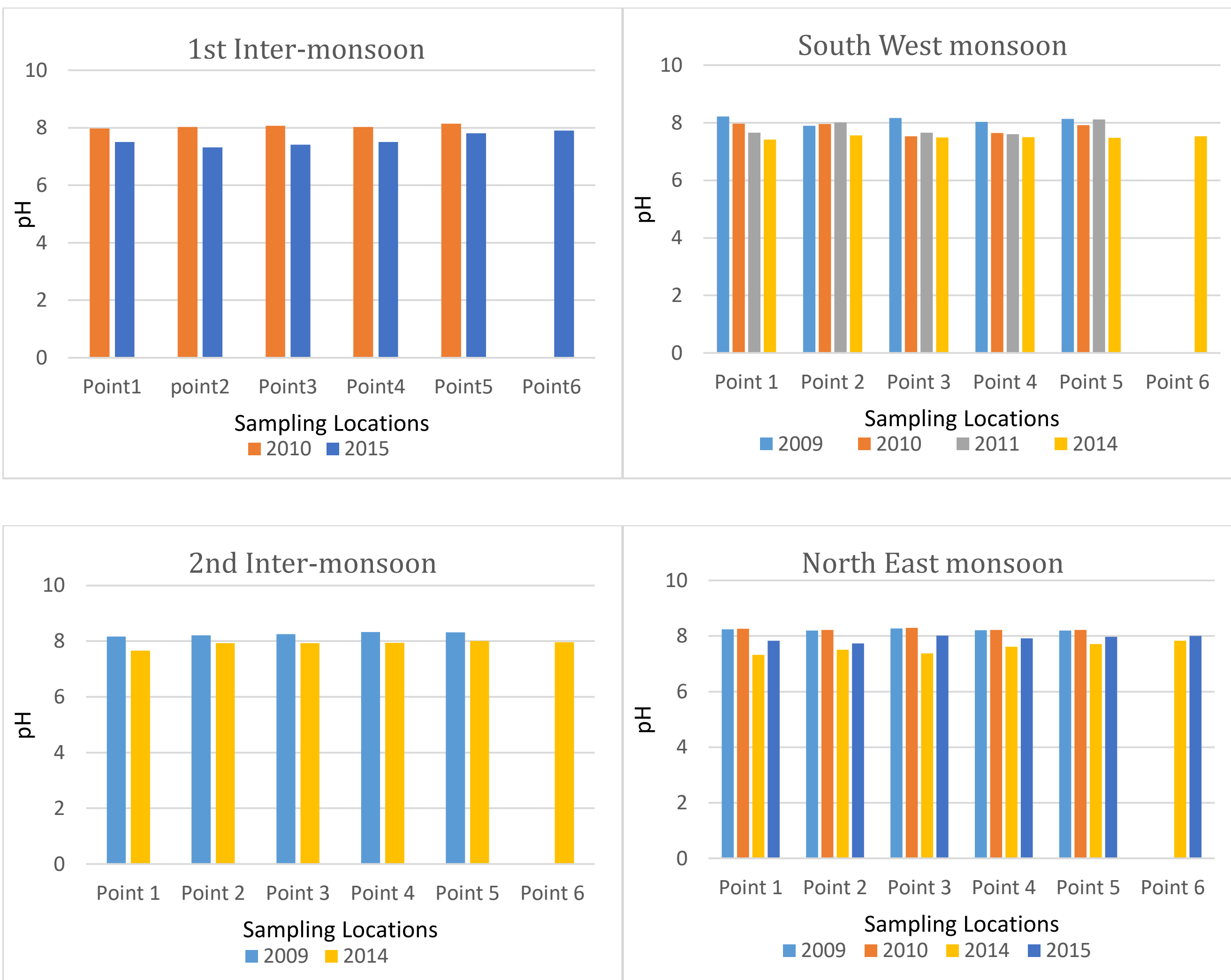



**Figure 2.20:** Seasonal variation of pH at Nilaweli

## DO Profiles

The mean DO values at Nilaweli are varied within the range of 6.92 mg/L to 8.20 mg/L (Table 2.19). No any visible trend with time could be identified in DO at Nilaweli.

The DO values are varied between 6.2 mg/L and 8.8 mg/L. The variation of DO values does not show any trend, hence the DO has not changed according to monsoons during the monitoring period from 2009 to 2016. When comparing with the ASEAN guideline, it was defined 4 mg/L as the minimum DO value.

**Table 2.19:** Comparison of mean DO values at Nilaweli Beach

| Year | DO (mg/L) |
|---|---|
| 2009 | 7.93 (±0.52) |
| 2010 | 8.20 (±1.32) |
| 2014 | 7.16 (±0.48) |
| 2015 | 7.58 (±0.92) |
| 2016 | 6.92 (±0.62) |

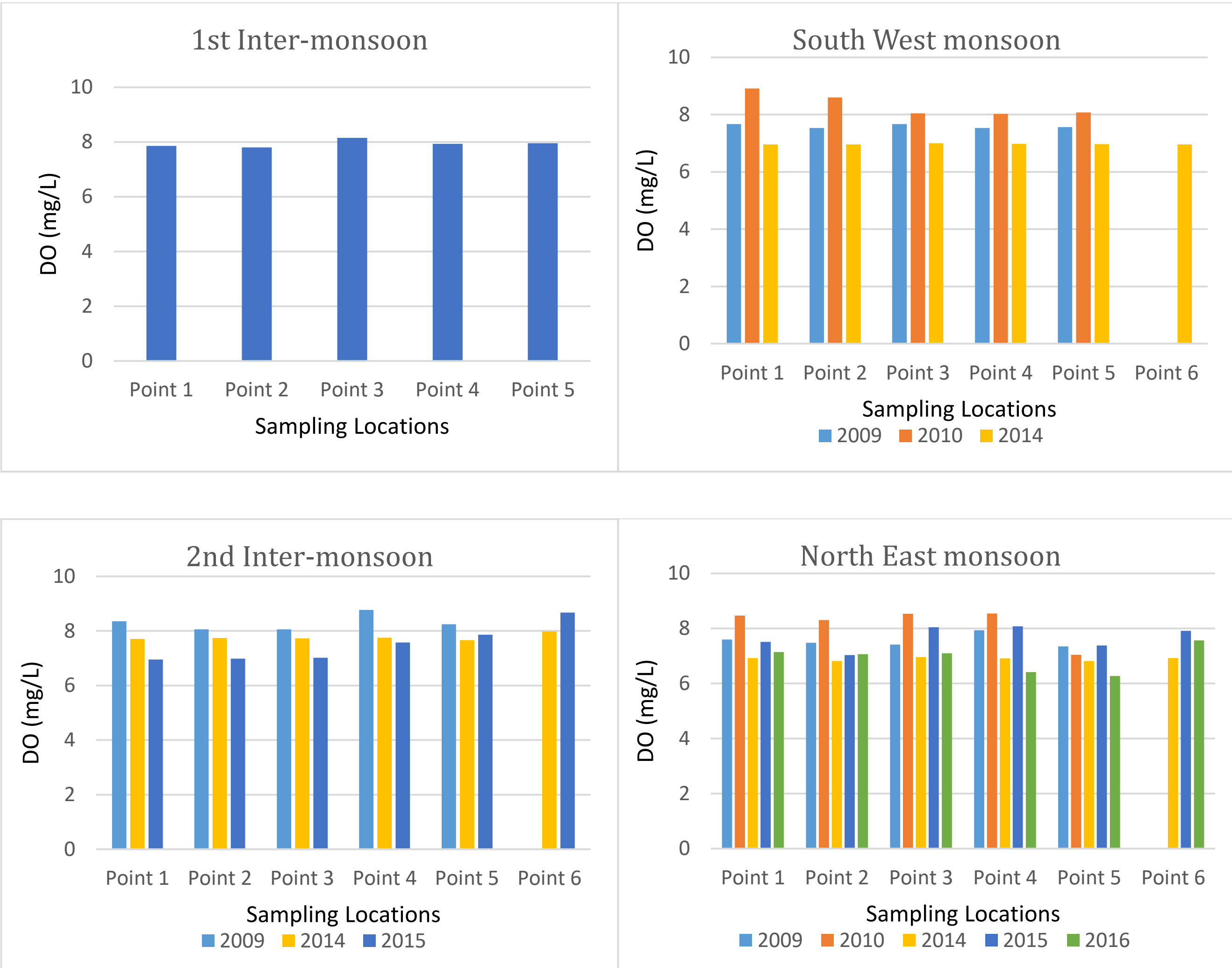



**Figure 2.21:** Seasonal variation of DO at Nilaweli

## EC Profiles

The mean values of EC at Nilaweli are within the range of 48.93 mS/cm to 56.06 mS/cm. A minor increase can be seen from 2009 to 2015 and decreased in 2016 as shown in Table 2.20.

The EC values are within the range of 46.9 mS/cm to 59.5 mS/cm except for the 5th location during the 2nd Inter-monsoon in 2014 (Figure 2.22). Furthermore, 2009 and 2010 show relatively low values during the North East monsoon which may be attributed to high rainfall and mixing at sampling points. As indicated in previous sections, the EC can be decreased due to dilution and mixing effect during high rainfalls and at major sea outfalls.

**Table 2.20:** Comparison of mean EC values at Nilaweli Beach

| Year | EC (mS/cm) |
|---|---|
| 2009 | 51.23 (±4.38) |
| 2010 | 52.65 (±1.93) |
| 2011 | 53.12 (±0.95) |
| 2014 | 55.77 (±9.23) |
| 2015 | 56.06 (±0.92) |
| 2016 | 48.93 (±0.59) |

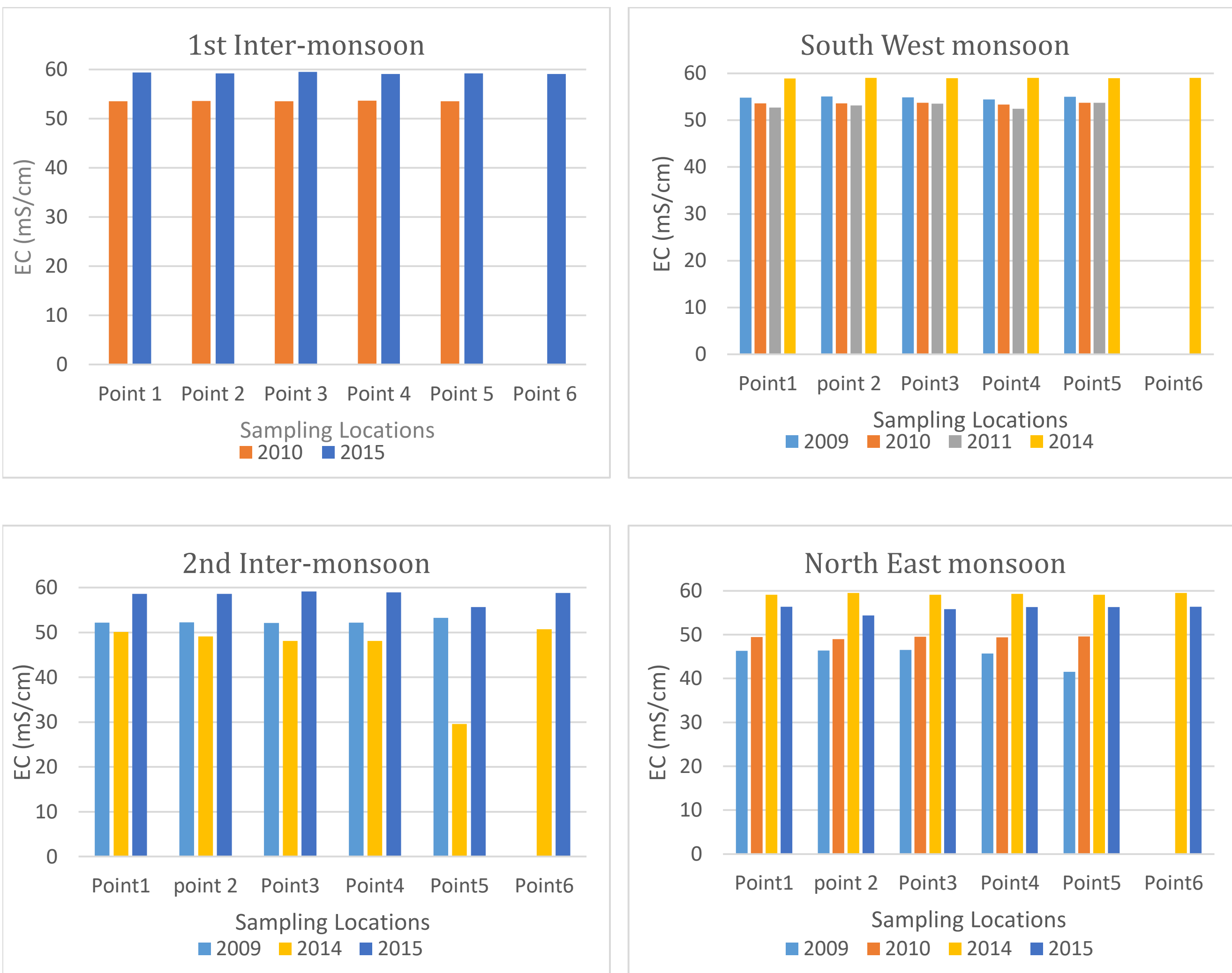



**Figure 2.22:** Seasonal variation of EC at Nilaweli

## Salinity Profiles

The mean salinity values are within the range of 29.40 % to 35.51 % as shown in Table 2.21. As a whole, a clear negative or a positive trend cannot be observed in salinity with the time.

**Table 2.21:** Comparison of mean salinity values at Nilaweli Beach

| Year | Salinity (%) |
|---|---|
| 2009 | 29.40 (±2.77) |
| 2010 | 30.30 (±1.17) |
| 2011 | 35.51 (±0.58) |
| 2014 | 33.60 (±5.62) |
| 2015 | 34.92 (±1.05) |
| 2016 | 34.96 (±0.87) |

The salinity values are varied within the range of 36.6 % and 26.1 % at Nilaweli. The same pattern of variation in EC can be seen in salinity also. The salinity values have been increased with the time during the 1$^{st}$ Inter-monsoon (Figure 2.23). Salinity has been increased until 2014 and slightly decreased in 2015 during the North East monsoon. Salinity seems to be constant during the 2$^{nd}$ Inter-monsoon except for 5$^{th}$ location in 2014. However, neither ASEAN nor CEA has presented salinity in marine water quality standards.


**Figure 2.23:** Seasonal variation of salinity at Nilaweli

## TDS Profiles

The mean TDS values are within the range of 51.88 g/L to 53.66 g/L at Nilaweli as shown in Table 2.22.

**Table 2.22:** Comparison of mean TDS values at Nilaweli Beach

| Year | TDS (g/L) |
|---|---|
| 2009 | 51.88 (±5.53) |
| 2010 | 53.66 (±2.40) |

It can be observed a decreasing variation of TDS with time during the South West monsoon while an increasing variation during the North East monsoon (Figure 2.24).

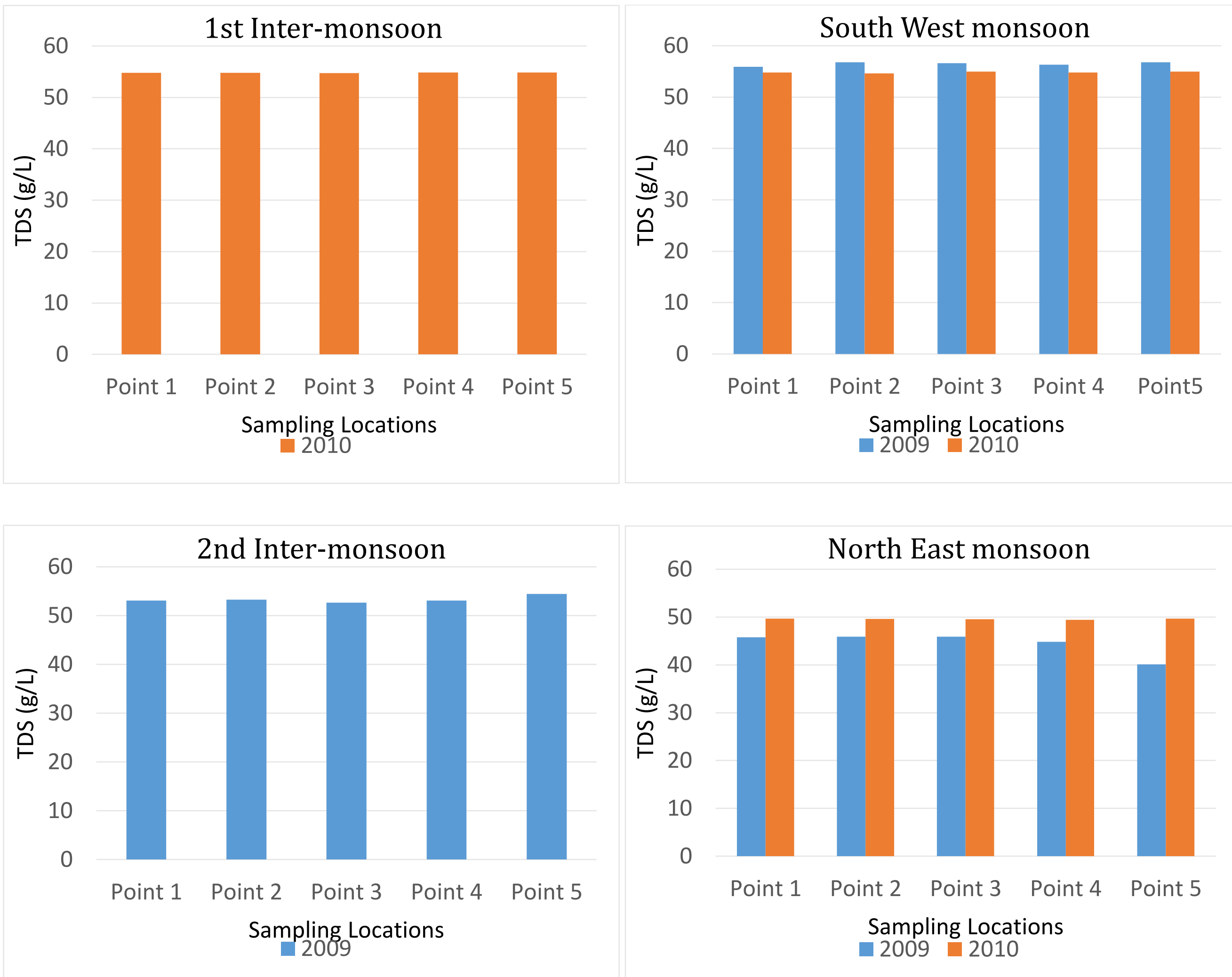



**Figure 2.24:** Seasonal variation of TDS at Nilaweli

## Turbidity Profiles

Mean turbidity values at Nilaweli are varied between 19.35 NTU and 122.38 NTU (Table 2.23). In 2009, it showed a value of 122.38 NTU, decreased to 77.26 NTU in 2010 and further decreased to 19.35 NTU in 2011. Here, a decreasing trend can be identified with the time.

**Table 2.23:** Comparison of mean turbidity values at Nilaweli Beach

| Year | Turbidity (NTU) |
|---|---|
| 2009 | 122.38 (±178.6) |
| 2010 | 77.26 (±102.3) |
| 2011 | 19.35 (±12.10) |

Turbidity has shown a low value in 2010 during the 1st Inter-monsoon (Figure 2.25). It can be seen that comparatively high values for turbidity have obtained during the South West monsoon in 2009 while the locations show lower values during the 2nd Inter-monsoon and North East monsoon.

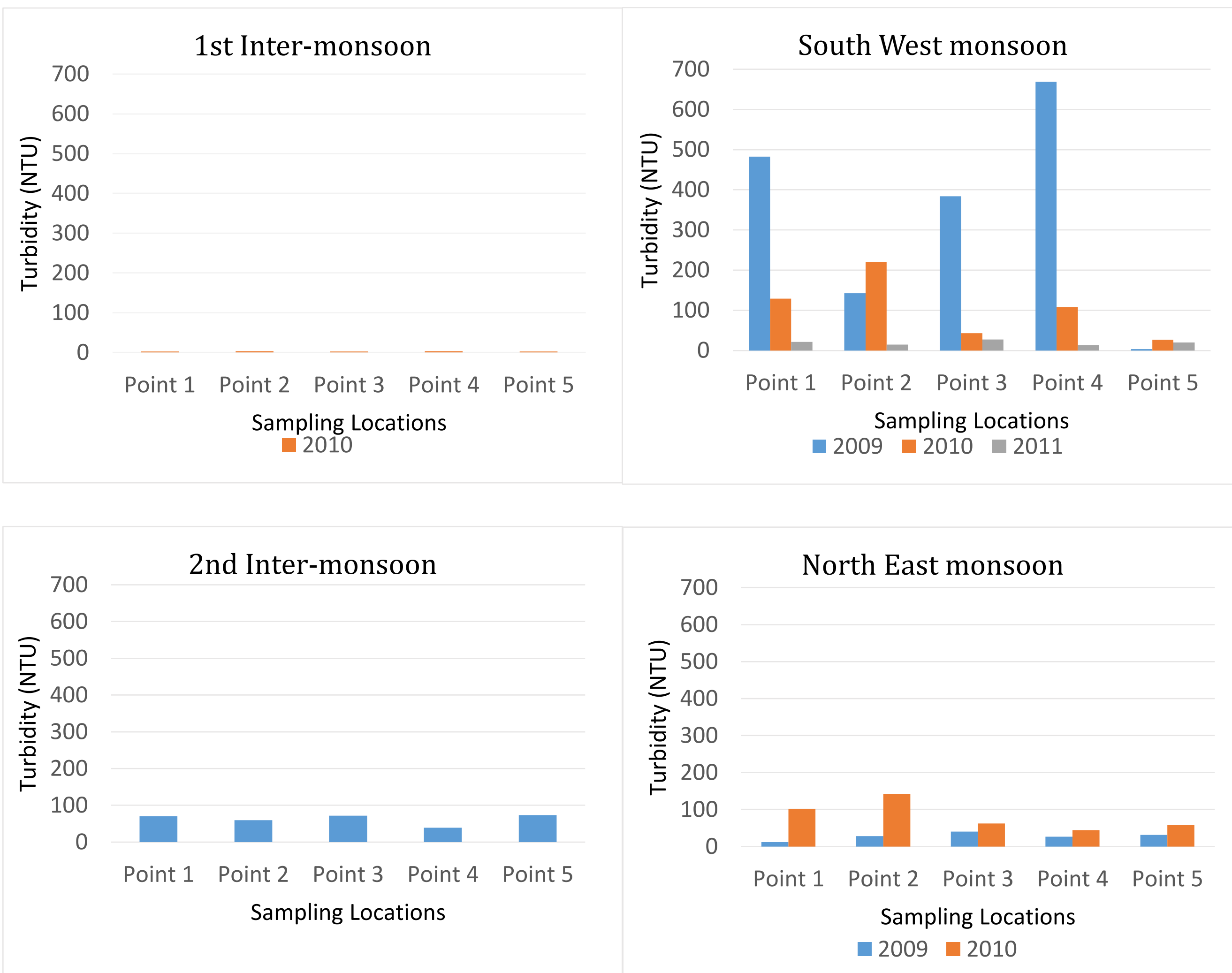



**Figure 2.25:** Seasonal variation of turbidity at Nilaweli

## Temperature Profiles

Mean temperature values at Nilaweli are varied between 25.40 °C and 29.70 °C as shown in Table 2.24. A regular pattern in temperature variation with time could not be observed at Nilaweli.

The temperature values are varied between 25.2 °C and 30.7 °C at Nilaweli. A visible variation with respect to monsoons could not be observed as shown in figure 2.26. Relatively lower values of temperature could be seen in 2011 during the South West monsoon.

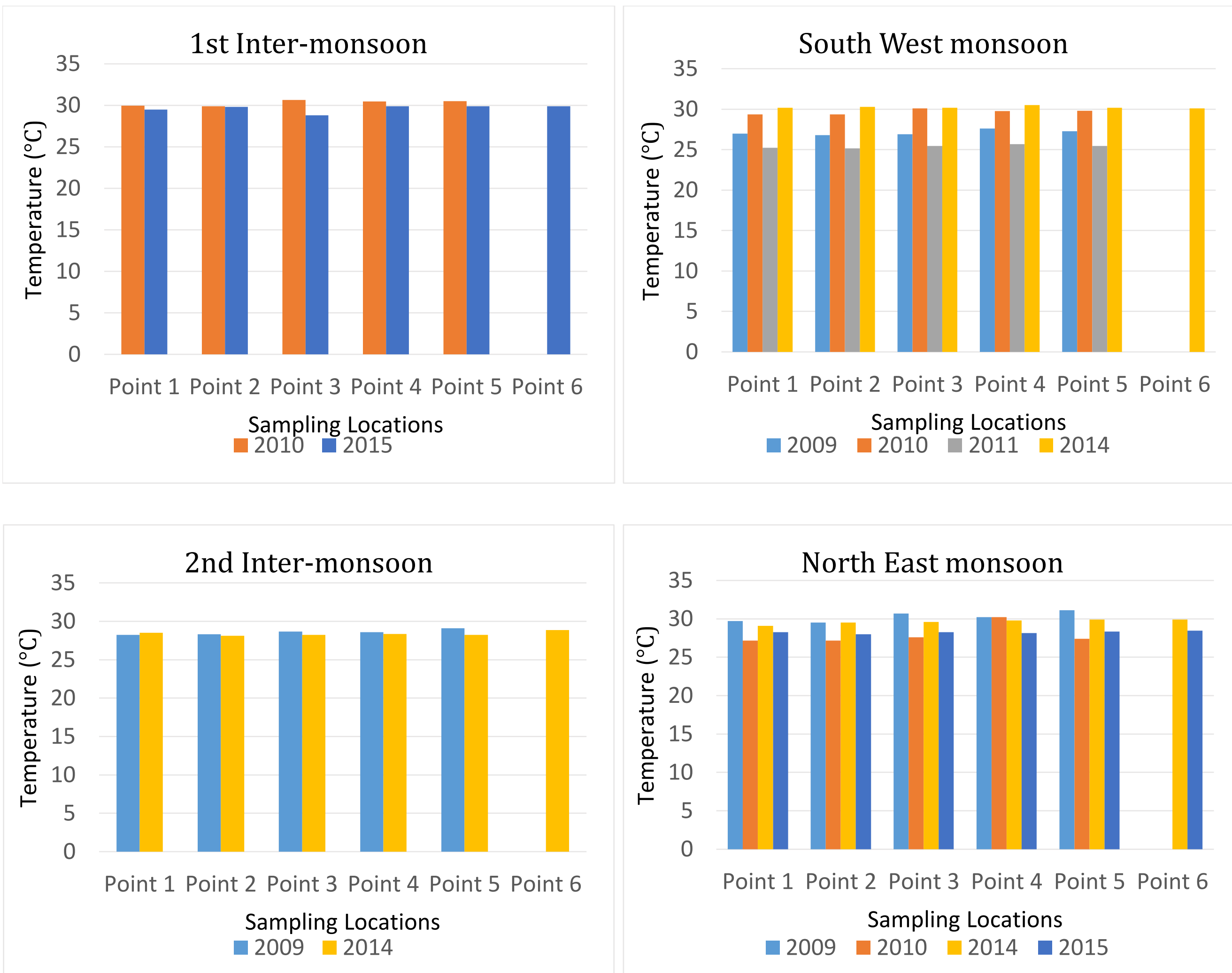



**Figure 2.26:** Seasonal variation of temperature at Nilaweli

**Table 2.24:** Comparison of mean temperature values at Nilaweli Beach

| Year | Temperature (°C) |
|---|---|
| 2009 | 28.63 (±1.23) |
| 2010 | 29.30 (±1.89) |
| 2011 | 25.40 (±1.30) |
| 2014 | 29.70 (±1.16) |
| 2015 | 29.06 (±0.92) |
| 2016 | 26.53 (±0.35) |

## Faecal Coliform Profiles

The mean value for faecal coliform is within the range between 9.88 MPN/100 ml and 721.48 MPN/100 ml as shown in Table 2.25. There is no any visible trend with the time in faecal coliform concentration. However, the faecal coliform concentrations are within the limits defined by ASEAN guideline except for 2015 and 2016. The concentrations have increased to 721.48 MPN/100 ml in 2015 and decreased to 221.45 MPN/100 ml in 2016.

**Table 2.25:** Comparison of mean faecal coliform values at Nilaweli Beach

| Year | Coliform (MPN/100ml) |
|---|---|
| 2009 | 22.35 (±60.6) |
| 2010 | 44.63 (±80.2) |
| 2011 | 11.35 (±24.28) |
| 2014 | 9.88 (±10.06) |
| 2015 | 721.48 (±2352) |
| 2016 | 221.45 (±753) |

It can be observed that coliform concentrations are lower during the 1$^{st}$ Inter-monsoon. The reason could be the low rainfall during that monsoon (Appendix I). An irregular variation could be observed in coliform concentration with respect to monsoons as illustrated in Figure 2.27.

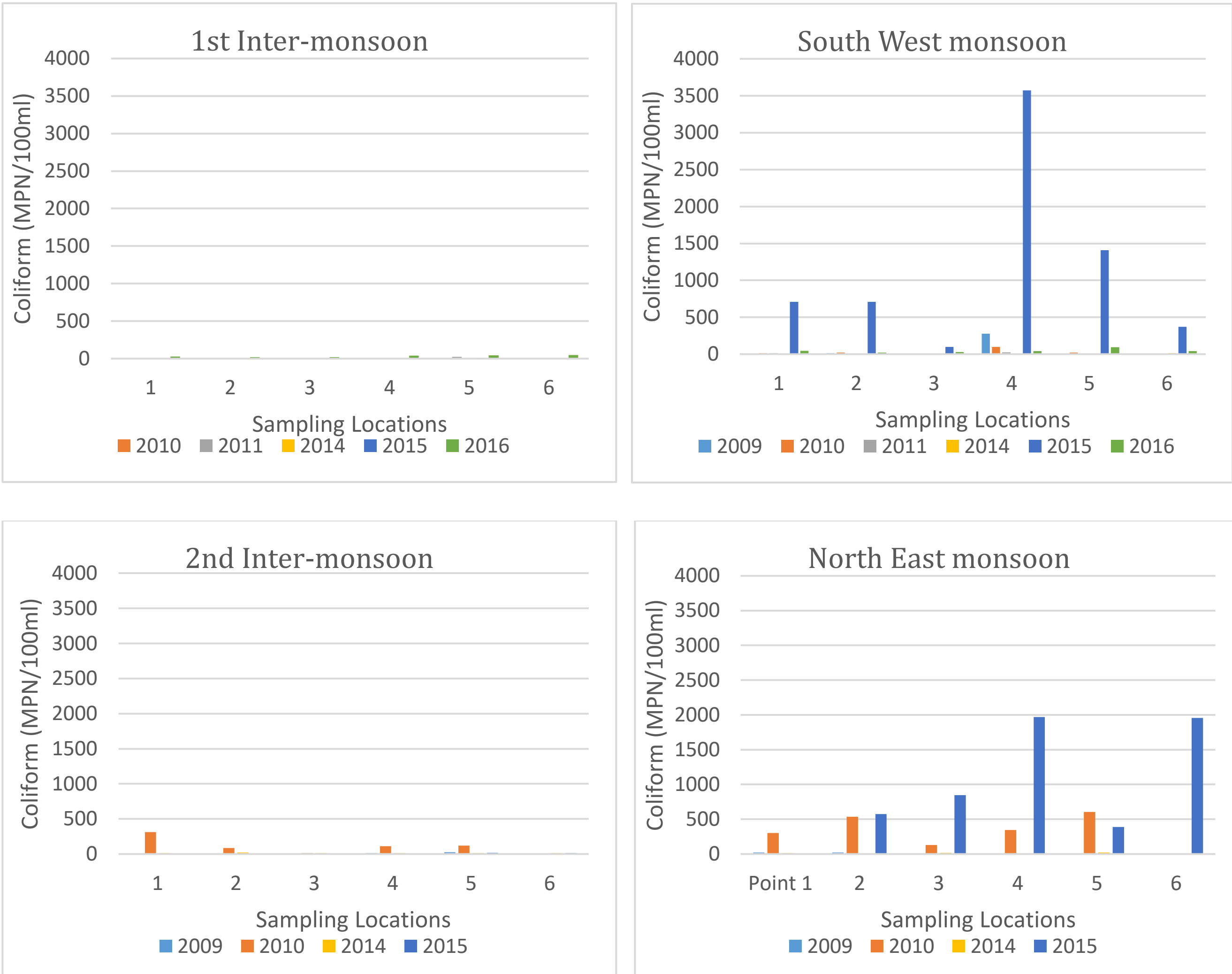



**Figure 2.27:** Seasonal variation of faecal coliform at Nilaweli

## 4. Unawatuna

Unawatuna is a coastal suburb in Galle about 5 km South East to the city center and approximately 108 km South of Colombo. This town is a major tourist attraction in the country and famous for its beautiful beach and corals.

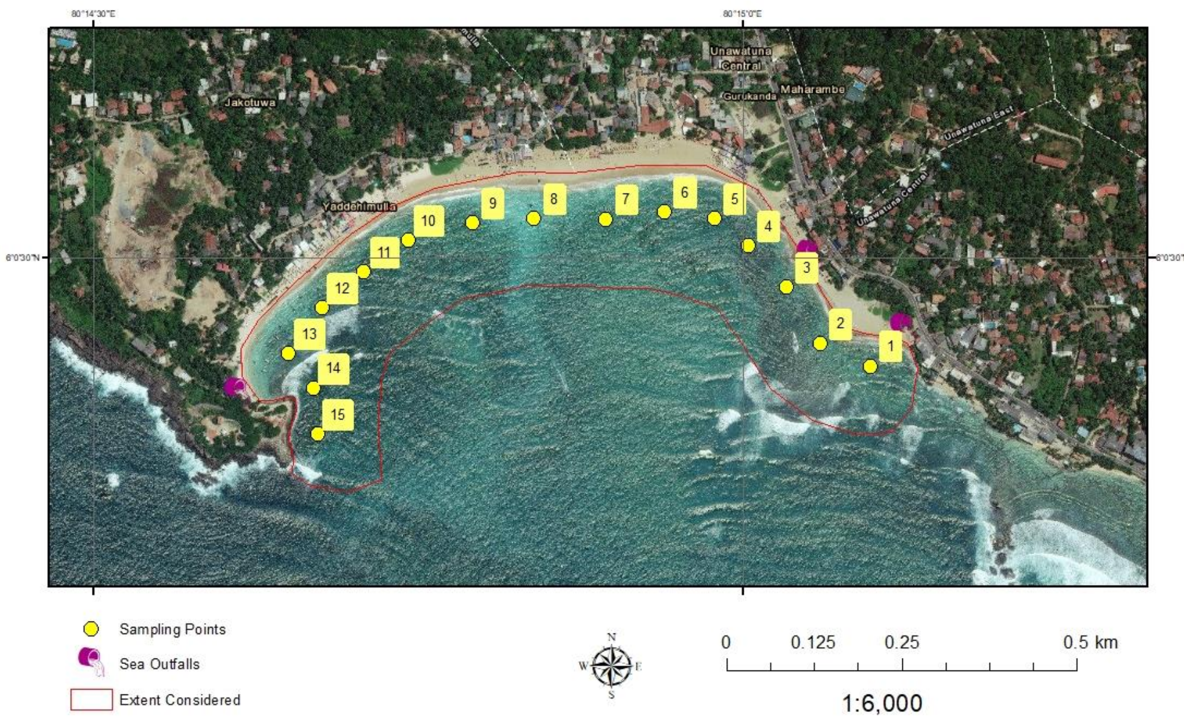



**Figure 2.28:** Sampling locations in Unawatuna Beach

## pH Profiles

In this analysis, variation of pH with time and the impact of monsoons were studied for Unawatuna. Table 2.26 shows the summary of data with associated standard deviations from 2009 to 2016. Accordingly, it can be observed that there is no large variations in pH throughout the monitoring period. Similarly, the impact of monsoons were studied with respect to pH variation in the given location as shown in Figure 2.29.

**Table 2.26:** Comparison of mean pH values at Unawatuna Beach

| Year | pH |
|---|---|
| 2009 | 8.13 (±0.11) |
| 2010 | 6.95 (±2.22) |
| 2011 | 7.89 (±0.08) |
| 2014 | 7.53 (±0.24) |
| 2015 | 7.62 (±0.49) |
| 2016 | 7.91 (±0.11) |

The mean pH values are varied between 6.95 and 8.13. When considering the pH with respect to monsoons, a visible variation could not be seen (Figure 2.29). However, it can be observed that unusual values were recorded during the 2nd Inter-monsoon in 2010 except for 1st and 9th locations. The very low pH measurements could be due to a calibration error or equipment fault as it is quite unusual to have lower pH of 2. Nevertheless, the values are within the range imposed by the CEA standards for wastewater discharge to marine water bodies except for mentioned locations.


**Figure 2.29:** Seasonal variation of pH at Unawatuna

## DO Profiles

It was studied the temporal and the monsoon impact on DO variation at Unawatuna similarly to pH. Table 2.27 shows the variation of the mean DO values at Unawatuna (between 7.41 mg/L and 8.44 mg/L). The variation of DO values does not show any variation, hence the DO has not changed during the monitoring period from 2009 to 2016.

**Table 2.27:** Comparison of mean DO values at Unawatuna Beach

| Year | DO (mg/L) |
|---|---|
| 2009 | 8.44 (±0.32) |
| 2010 | 7.67 (±0.57) |
| 2014 | 7.48 (±0.50) |
| 2015 | 7.62 (±0.49) |
| 2016 | 7.41 (±0.72) |

The DO values are varied within the range of 6.65 mg/L to 9.0 mg/L. A visible trend could not be identified with respect to monsoons (Figure 2.30). However, all the locations have exceeded the minimum value (4 mg/L) imposed by the ASEAN guideline for DO.

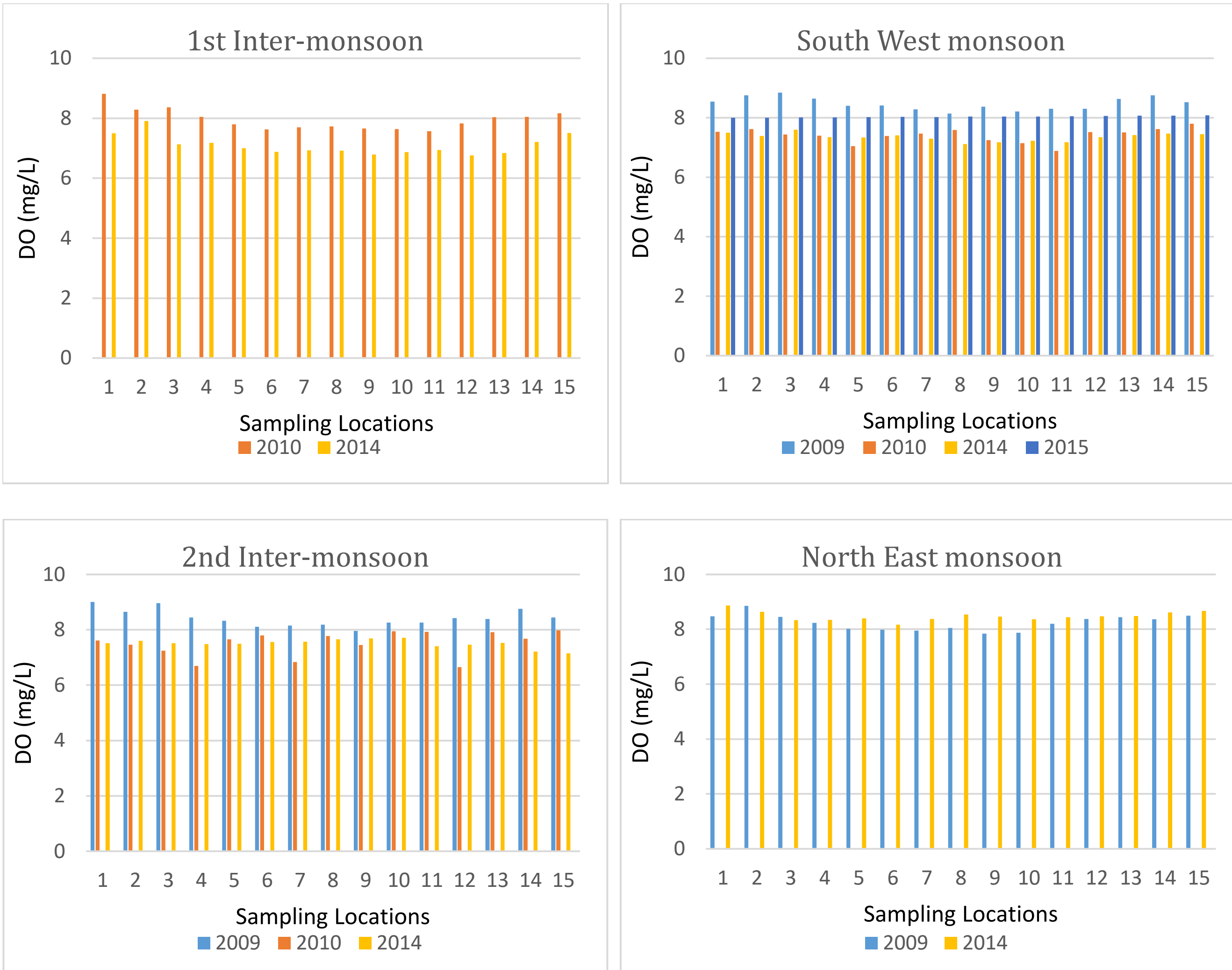



**Figure 2.30:** Seasonal variation of DO at Unawatuna

## EC Profiles

The mean values of EC at Unawatuna are within the range of 52.21 mS/cm to 56.75 mS/cm. Neither increase nor decrease trend can be observed. Hence, the EC did not vary much with the time as shown in Table 2.28.

The EC values are varied within the range of 50.50 mS/cm to 59.20 mS/cm except for 12$^{th}$ and 13$^{th}$ locations during the South West monsoon in 2009. It can be observed that EC has increased slightly during the 1$^{st}$ Inter-monsoon in 2010 and 2014. However, a variation of EC with respect to monsoons could not be seen at Unawatuna (Figure 2.31).

**Table 2.28:** Comparison of mean EC values at Unawatuna Beach

| Year | EC (mS/cm) |
|---|---|
| 2009 | 53.77 (±5.0) |
| 2010 | 52.86 (±1.16) |
| 2011 | 52.21 (±1.10) |
| 2014 | 56.25 (±2.19) |
| 2015 | 55.55 (±4.42) |
| 2016 | 56.75 (±4.80) |

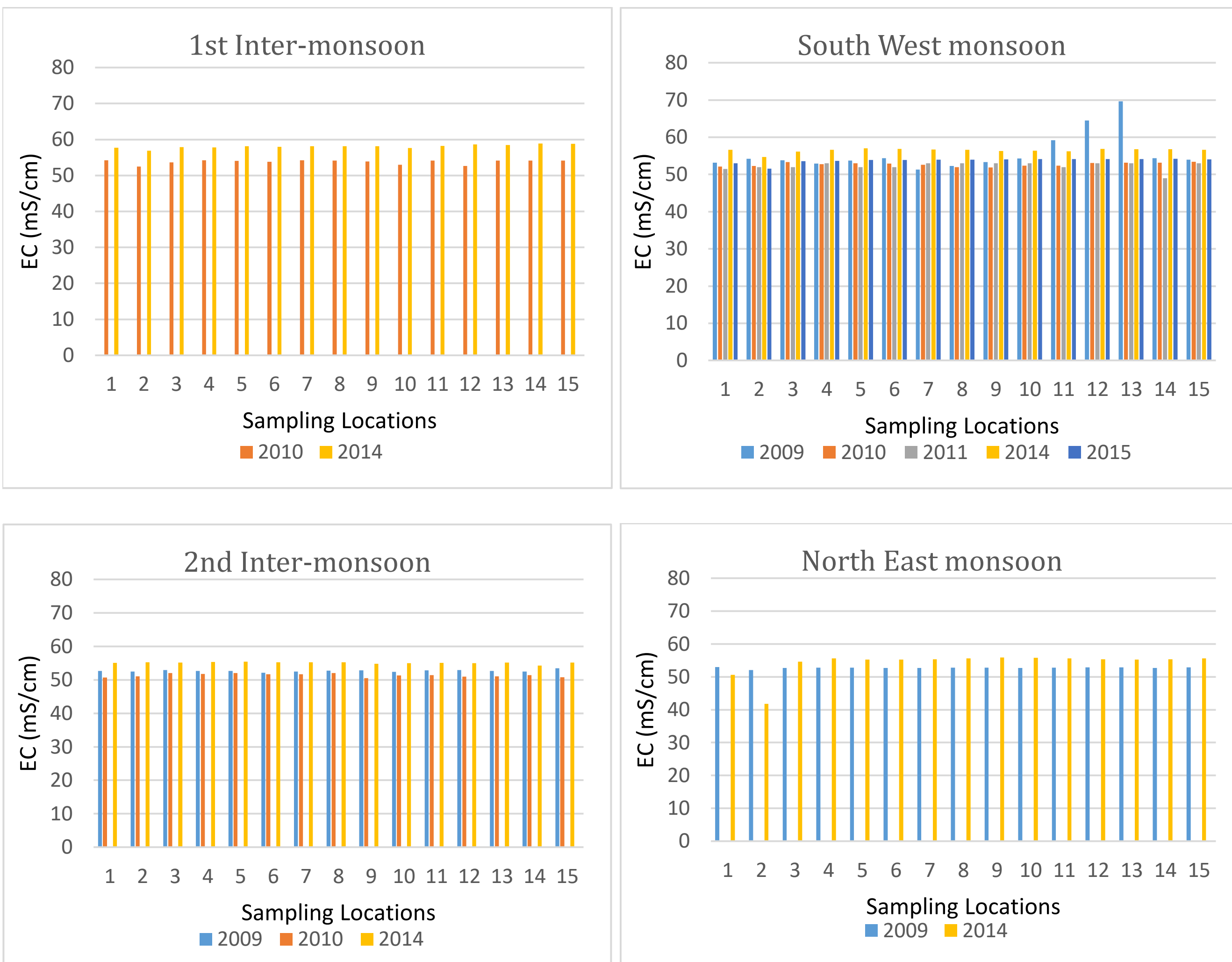



**Figure 2.31:** Seasonal variation of EC at Unawatuna

## Salinity Profiles

The mean salinity values are varied within the range of 30.25 % to 36.16 % at Unawatuna. A noticeable trend of salinity could not be seen during the monitoring period as shown in Table 2.29.

**Table 2.29:** Comparison of mean salinity values at Unawatuna Beach

| Year | Salinity (%) |
|---|---|
| 2009 | 31.29 (±4.63) |
| 2010 | 30.35 (±0.99) |
| 2011 | 34.61 (±0.79) |
| 2014 | 34.59 (±1.14) |
| 2015 | 36.16 (±2.89) |
| 2016 | 34.94 (±3.17) |

It can be observed that the salinity has increased with the time during the 1$^{st}$ Inter-monsoon (Figure 2.32). Fairly high values were recorded in 2014 compared to other years during the 2$^{nd}$ Inter-monsoon. The same pattern of change with time can be observed in every locations during the South West monsoon. The variations of salinity are consistent with the EC variations as observed in other locations also.

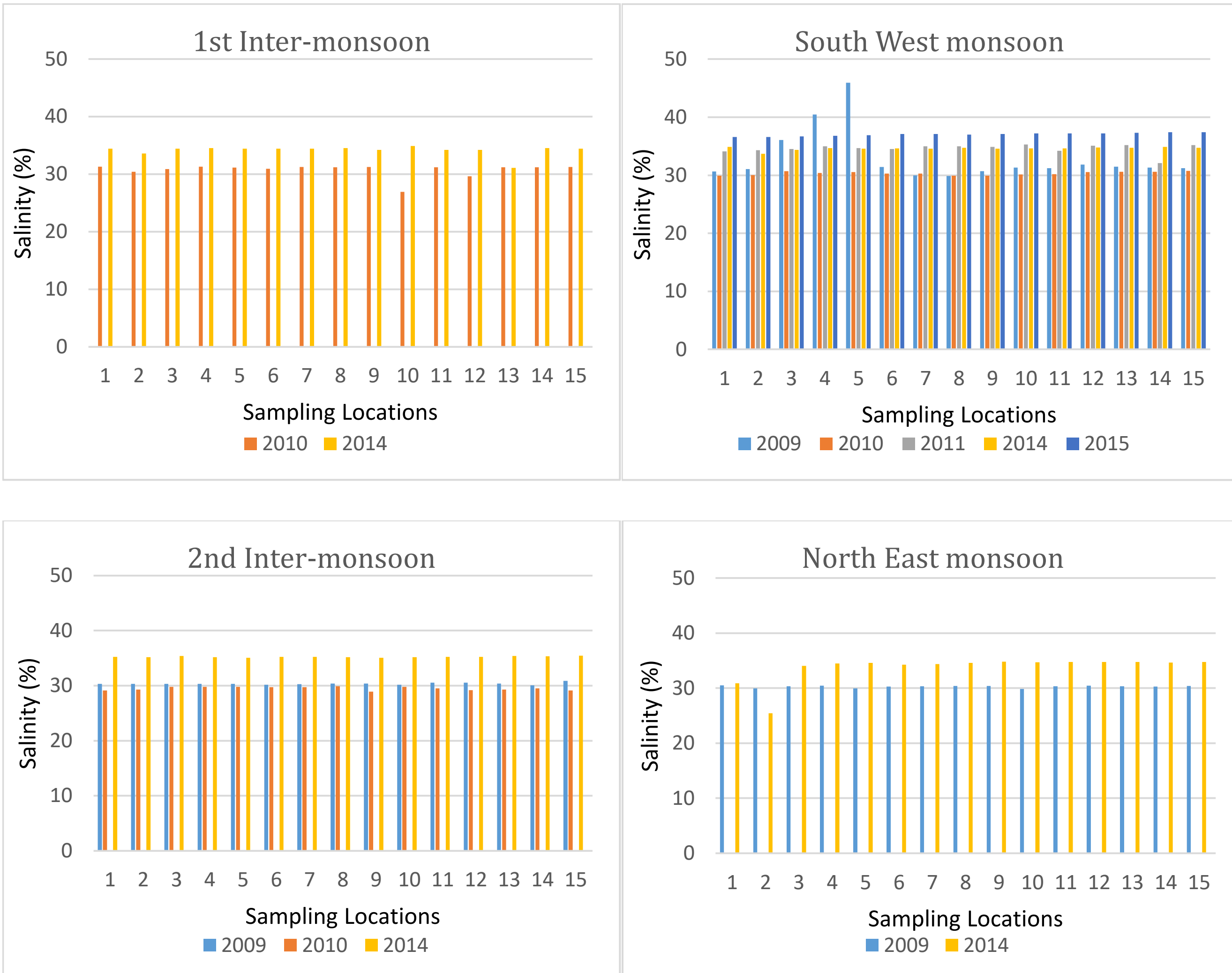



**Figure 2.32:** Seasonal variation of salinity at Unawatuna

## TDS Profiles

Mean TDS values are varied between 53.88 g/L and 54.05 g/L during the monitoring period at Unawatuna (Table 2.30).

**Table 2.30:** Comparison of mean TDS values at Unawatuna Beach

| Year | TDS (g/L) |
|---|---|
| 2009 | 54.05 (±2.48) |
| 2010 | 53.88 (±1.80) |

No any variation could be observed with respect to monsoons and sampling locations at Unawatuna as shown in Figure 2.33.

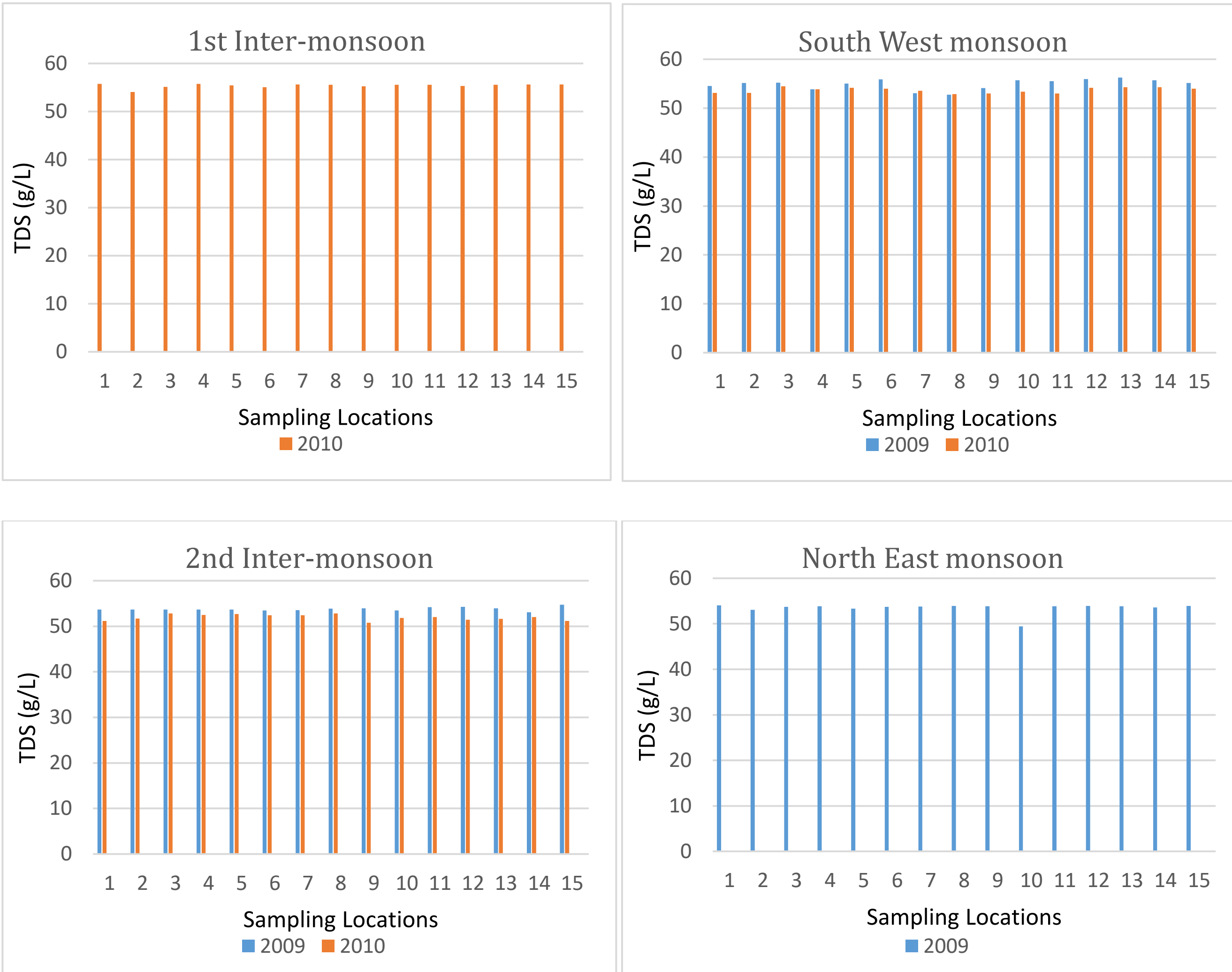



**Figure 2.33:** Seasonal variation of TDS at Unawatuna

## Turbidity Profiles

The mean turbidity values at Unawatuna are within the range of 13.72 NTU to 21.43 NTU. A regular pattern of varying could not be observed with the time as shown in Table 2.31.

**Table 2.31:** Comparison of mean turbidity values at Unawatuna Beach

| Year | Turbidity (NTU) |
|---|---|
| 2009 | 21.43 (±44.03) |
| 2010 | 13.72 (±43.08) |
| 2011 | 15.97 (±6.63) |

Both 1st and 2nd Inter-monsoons showed turbidity values lower than 50 NTU (Figure 2.34). It can be seen that even North East monsoon showed lower values except for 10th location. During the South West monsoon, few locations have exceeded 50 NTU in 2009. As previously stated, high rainfall could be a major reason for high turbidity values.

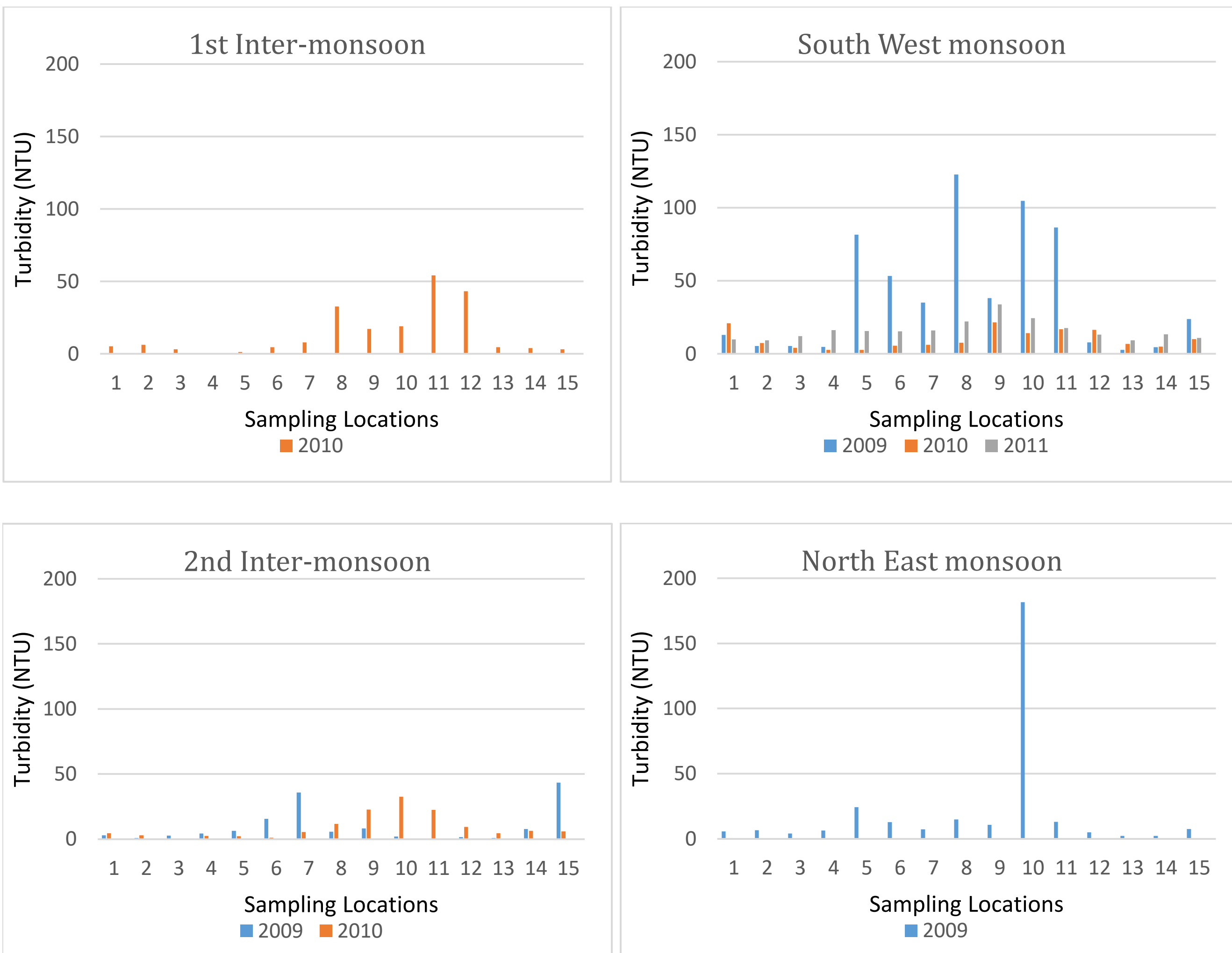



**Figure 2.34:** Seasonal variation of turbidity at Unawatuna

## Temperature Profiles

Mean temperature values at Arugambay varied from 24.31 to 29.34 °C as shown in Table 2.32. The 24.31 °C in 2011 was remarkably low compared with all the other years which had temperatures of more than 28 °C.

**Table 2.32:** Comparison of mean temperature values at Unawatuna Beach

| Year | Temperature (°C) |
|---|---|
| 2009 | 28.13 (±1.49) |
| 2010 | 28.66 (±1.04) |
| 2011 | 24.31 (±0.57) |
| 2014 | 29.34 (±1.06) |
| 2015 | 28.38 (±1.14) |
| 2016 | 28.70 (±0.17) |

The typical temperature range across sampling locations at Unawatuna was 26.9 °C to 30.9 °C except for all the locations during the South West monsoon in 2011 (Figure 2.35). It can be perceived that temperature values are relatively constant in 1st and 2nd Inter-monsoons while it showed a decreasing variation during the North East monsoon with time.

As mentioned, when comparing with the international guidelines, the ASEAN guidelines do not provide a standard for marine water temperature for the purpose of human health and recreational activities. However, the increase over ambient temperature should be ≤2 °C when considering aquatic life.

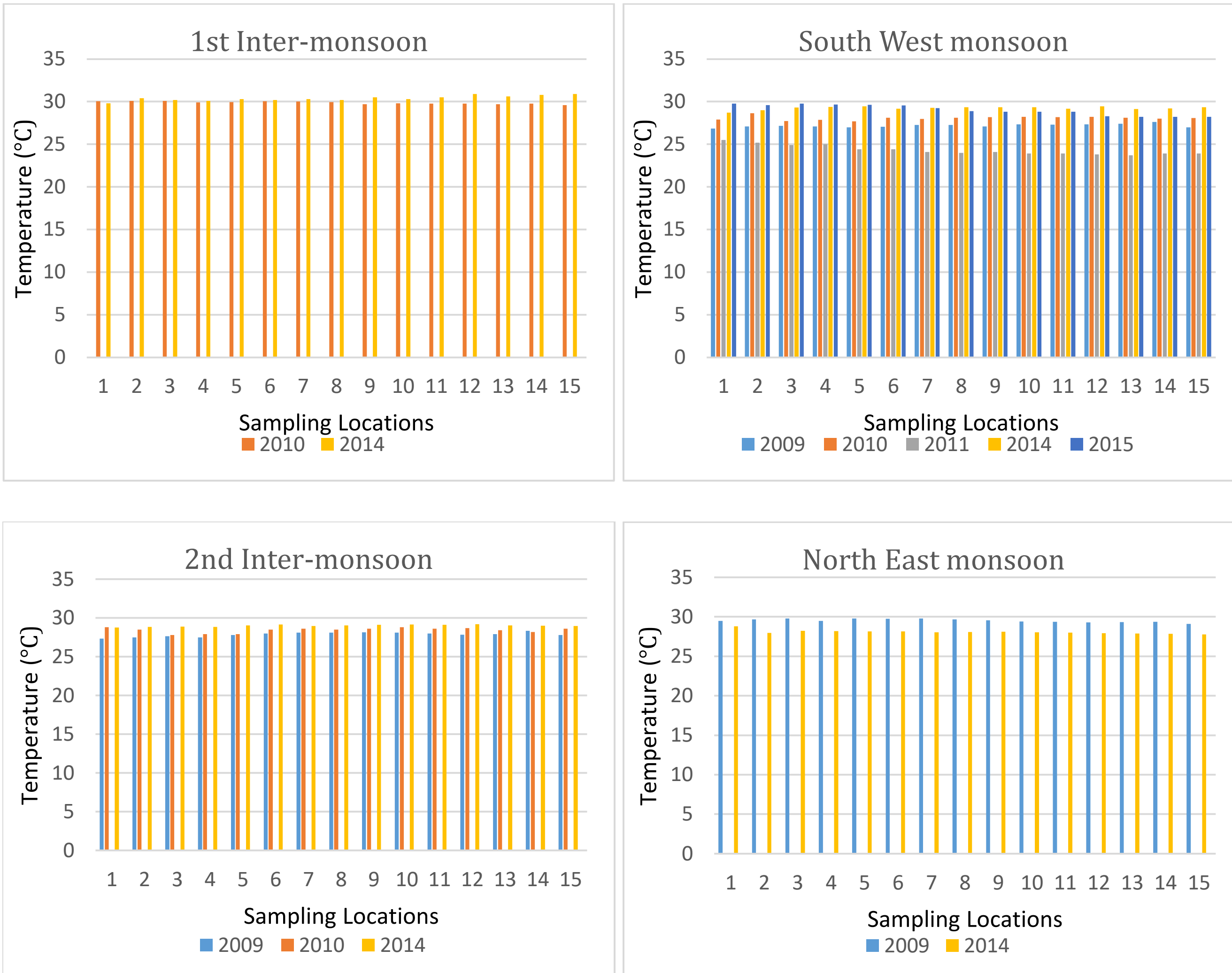



**Figure 2.35:** Seasonal variation of temperature at Unawatuna

## Faecal Coliform Profiles

Faecal coliforms count ranged from 49.90 MPN/100 ml to 3306.63 MPN/100 ml as shown in Table 2.33. There is no apparent trend over the years. When considering the ASEAN standards for faecal coliform, all the mean values have exceeded except for 2014.

Variation of faecal coliform concentrations is illustrated in Figure 2.36. The values lower than 2000 MPN/100 ml were recorded for all the sampling locations during 1$^{st}$ and 2$^{nd}$ Inter-monsoons. Also the values obtained were lower than 2000 MPN/100 ml during the North East monsoon except for 2$^{nd}$ location in 2009. Locations 1, 2, 3, 5, 7 and 8 showed higher values in 2015 during the South West monsoon.

**Table 2.33:** Comparison of mean faecal coliform values at Unawatuna Beach

| Year | Coliform (MPN/100ml) |
|---|---|
| 2009 | 155.12 (±321.5) |
| 2010 | 554.24 (±1327.9) |
| 2011 | 566.78 (±687.2) |
| 2014 | 49.90 (±125.4) |
| 2015 | 2287.18 (±8523) |
| 2016 | 3306.63 (±6766) |

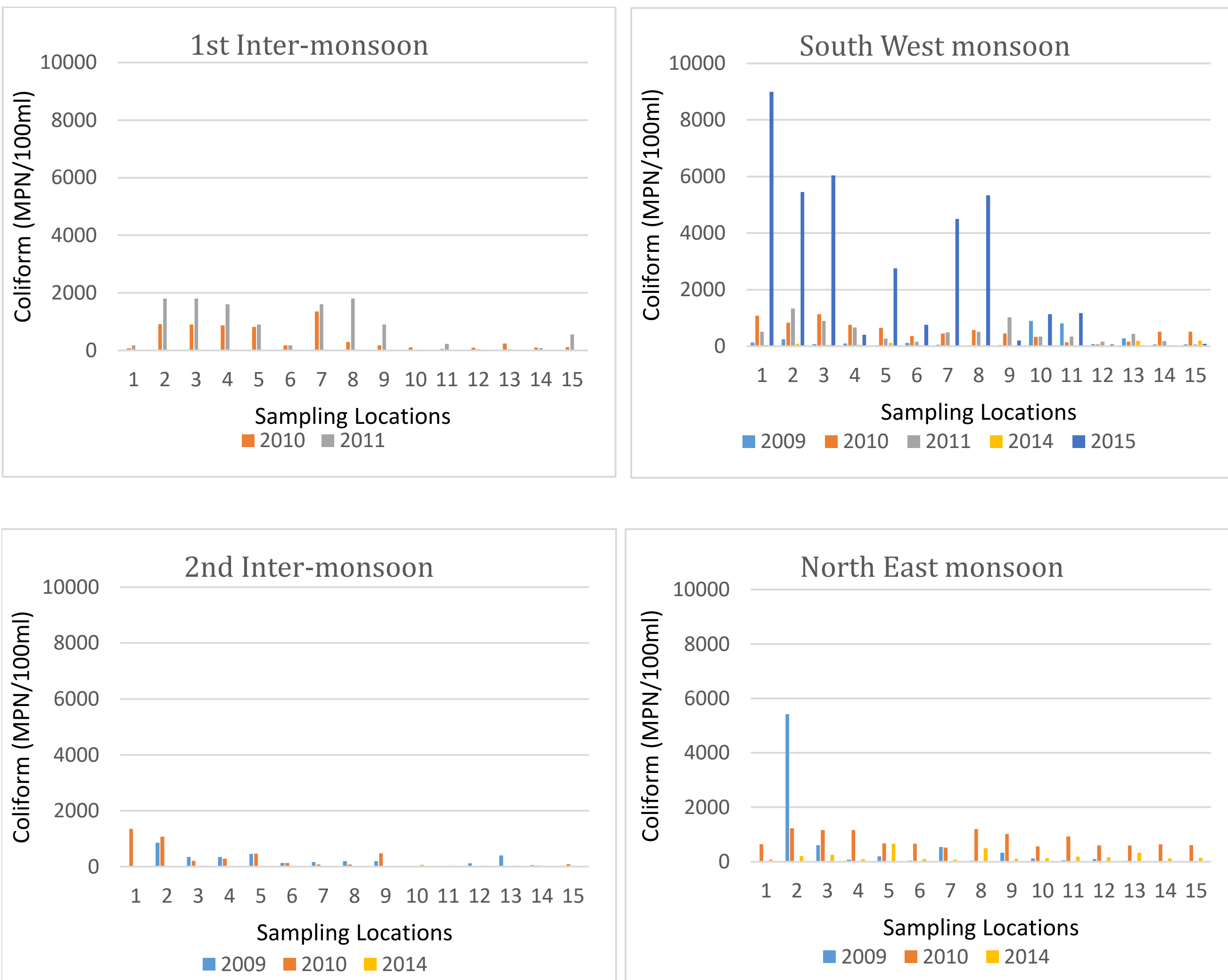



**Figure 2.36:** Seasonal variation of faecal coliform at Unawatuna

## 5. Polhena

Polhena beach is located in Matara District and contains a 4 km long coral reef about 200 m (660 feet) off the shore. Because of this, the water near the shore is relatively calm and is a common spot for tourists to swim. Numerous people can be seen in action with scuba diving, surfing and sunbathing along Polhena Beach.

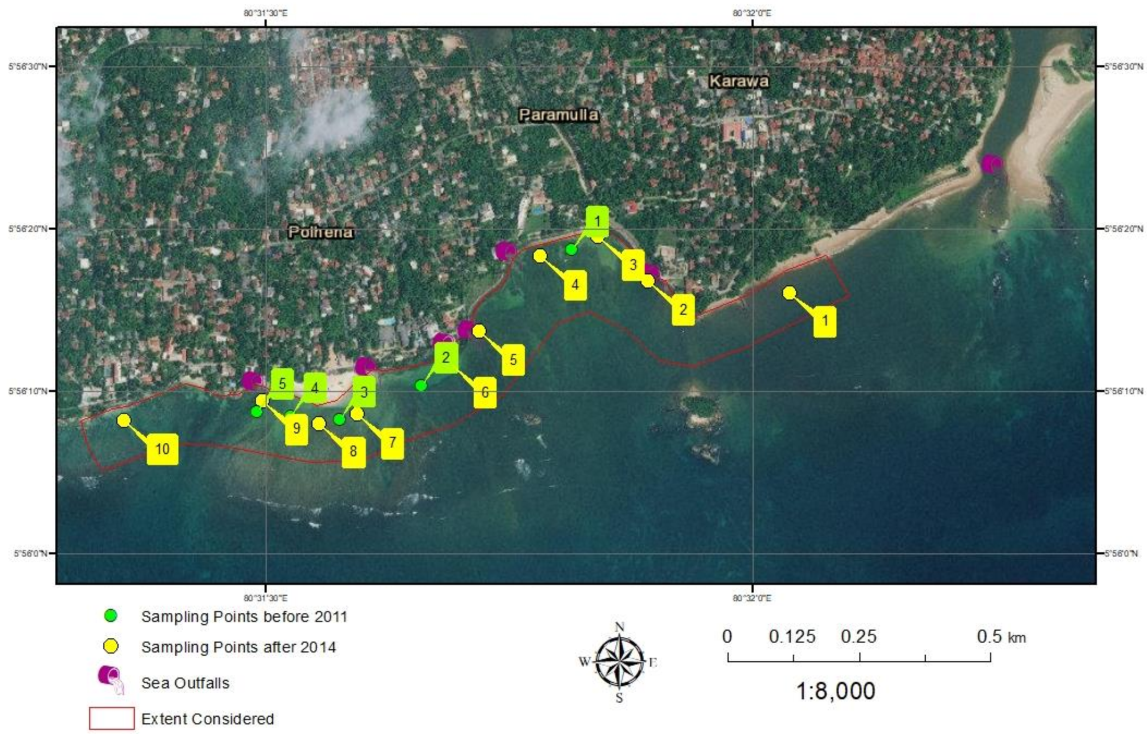



**Figure 2.37:** Sampling locations in Polhena Beach

### pH Profiles

The variation of pH with time and the impact of monsoons were studied for Polhena in this analysis. The summary of data with associated standard deviations from 2009 to 2015 are presented in Table 2.34. Accordingly, it can be observed that there is no large variations in pH throughout the monitoring period. The impact of monsoons were studied with respect to pH variation in the given location as shown in Figure 2.38.

**Table 2.34:** Comparison of mean pH values at Polhena Beach

| Year | pH |
|---|---|
| 2009 | 7.97 (±0.21) |
| 2010 | 7.85 (±0.32) |
| 2011 | 7.93 (±0.13) |
| 2014 | 7.73 (±0.52) |
| 2015 | 7.59 (±0.41) |

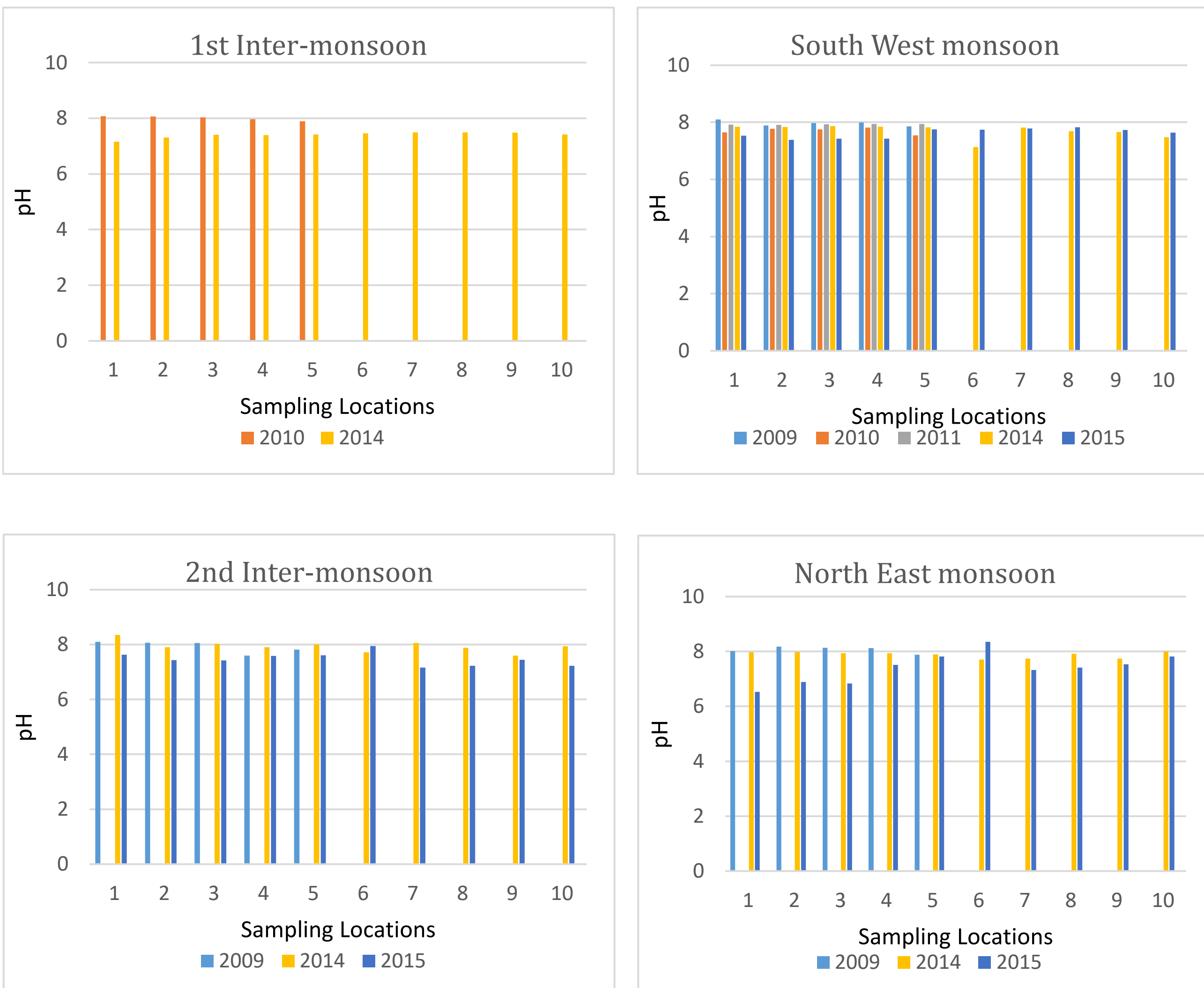



**Figure 2.38:** Seasonal variation of pH at Polhena

The mean pH values are varied from 7.59 to 7.97. When comparing with the standards imposed by the CEA for discharging wastewater into marine coastal areas (the allowable range of pH is between 5.5 and 9.0), pH values are within the limits at Polhena. Additionally, there is no detectable variation of pH according to monsoon patterns and sampling locations.

### DO Profiles

The temporal and the monsoon impact on DO variation at Polhena was studied and the Table 2.35 shows the variation of the mean DO values at Polhena (between 7.76 mg/L and 8.54 mg/L). Any considerable variation could not be observed, hence the DO has not changed during the monitoring period from 2009 to 2015.

**Table 2.35:** Comparison of mean DO values at Polhena Beach

| Year | DO (mg/L) |
|---|---|
| 2009 | 8.54 (±1.27) |
| 2010 | 7.89 (±1.61) |
| 2014 | 7.76 (±0.65) |
| 2015 | 7.96 (±0.71) |

No clear variation can be observed in DO with respect to monsoons (Figure 2.39). It has been recorded that 1$^{st}$, 2nd and 3$^{rd}$ locations showed higher DO values than 10 mg/L in 2010 during the 1$^{st}$ Inter-monsoon. As stated, the minimum value for DO is defined as 4 mg/L by the ASEAN guideline. All the locations have exceeded the ASEAN limit for DO.

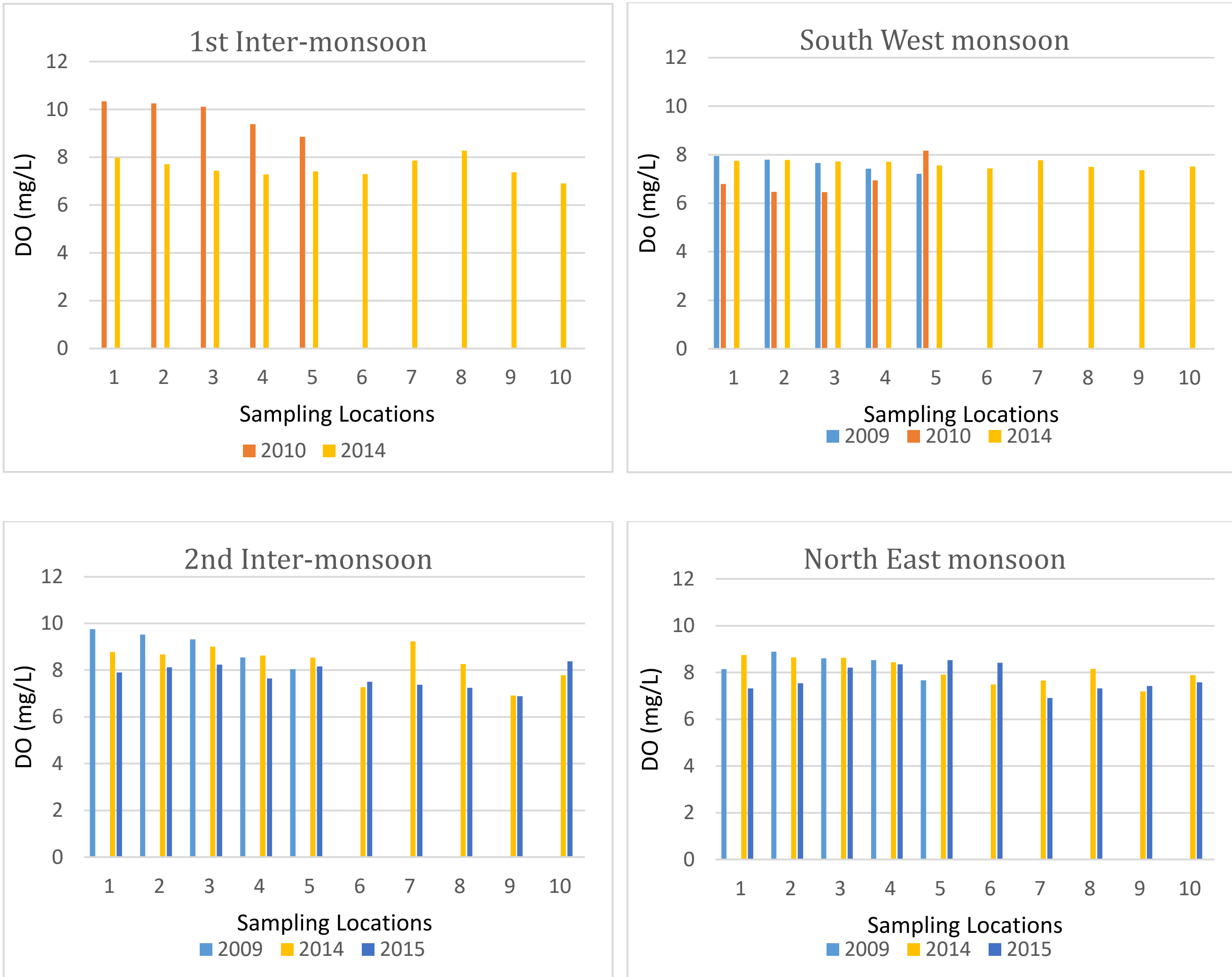



**Figure 2.39:** Seasonal variation of DO at Polhena

## EC Profiles

Table 2.36 shows the variation of the mean EC values at Polhena which varied between 49.01 mS/cm and 53.32 mS/cm. The variation of EC values does not show any trend, hence the EC has not changed during the monitoring period from 2009 to 2015.

**Table 2.36:** Comparison of mean EC values at Polhena Beach

| Year | EC (mS/cm) |
|---|---|
| 2009 | 49.01 (±8.13) |
| 2010 | 52.36 (±3.36) |
| 2011 | 53.32 (±0.29) |
| 2014 | 51.83 (±11.92) |
| 2015 | 52.27 (±4.76) |

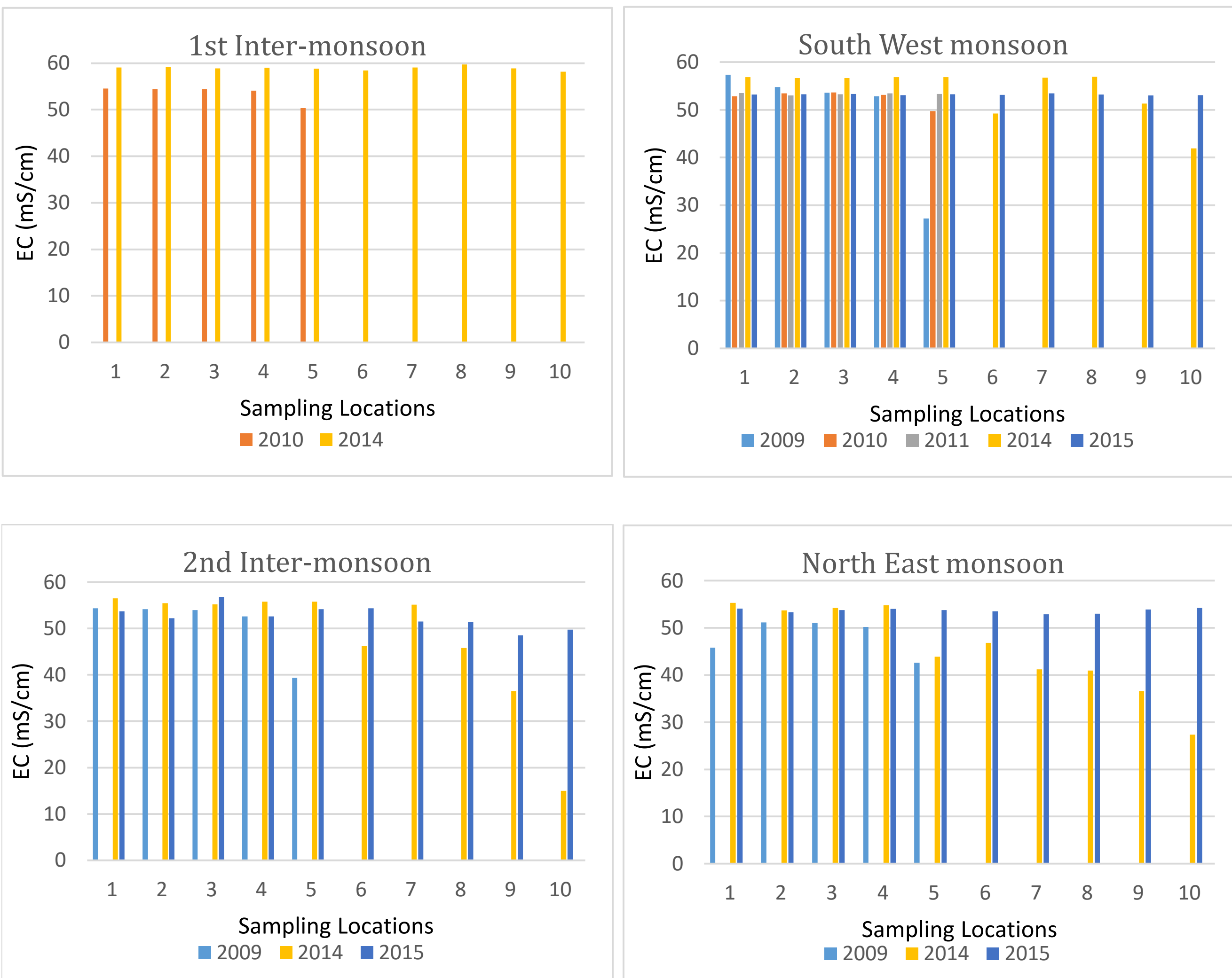



**Figure 2.40:** Seasonal variation of EC at Polhena

The variation of EC with respect to monsoons is presented in Figure 2.40. The EC has increased with the time during the 1st Inter-monsoon. Other monsoons did not show any visible trend of EC variation. However, the lower values were recorded in 2009 during the South West monsoon at 5th location and at the 9th and 10th locations in 2014 during the 2nd Inter-monsoon and North East monsoon.

## Salinity Profiles

The mean salinity values are varied between 28.41 % and 35.50 % (Table 2.37). The Salinity has increased until 2011 and decreased in 2014. It has slightly increased in 2015 to 33.73 %. A noticeable trend could not be observed during the monitoring period.

**Table 2.37:** Comparison of mean salinity values at Polhena Beach

| Year | Salinity (%) |
|---|---|
| 2009 | 28.41 (±3.40) |
| 2010 | 30.22 (±2.60) |
| 2011 | 35.50 (±0.23) |
| 2014 | 31.99 (±7.04) |
| 2015 | 33.73 (±4.28) |

When considering the salinity at Polhena, the variation is consistent with the EC variations at Polhena. This is quite acceptable since salinity has a correlation with EC. Salinity has increased with the time during the 1st Inter-monsoon (Figure 2.41). The salinity variation with the time during the other monsoons were not clear. 9th and 10th locations showed lower values in 2014 during the 2nd Inter-monsoon and North East monsoon similar to the EC.

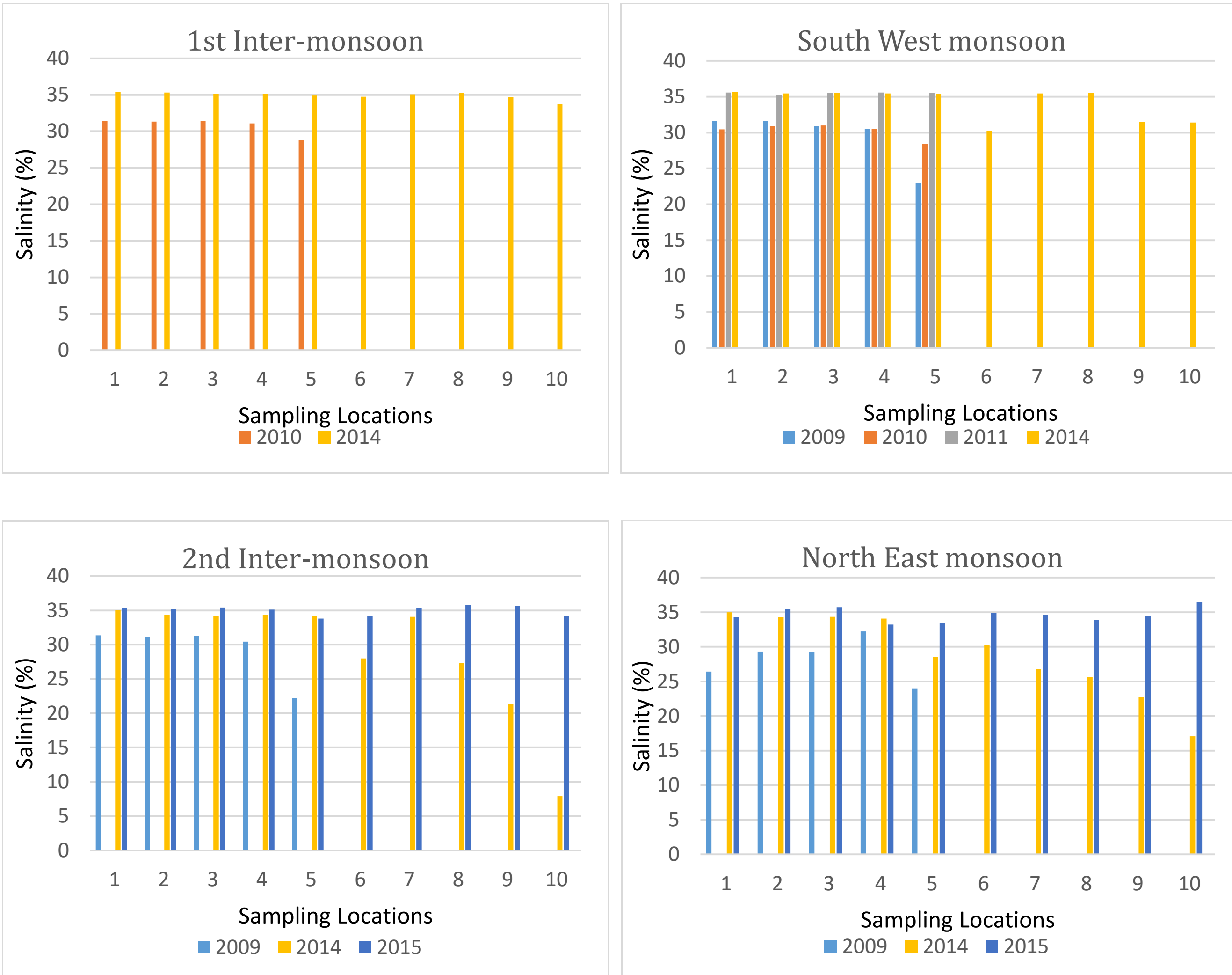



**Figure 2.41:** Seasonal variation of salinity at Polhena

## TDS Profiles

The mean TDS values are varied within the range of 50.01 g/L to 53.11 g/L as presented in Table 2.38. The variation of TDS with monsoons and sampling locations are illustrated in Figure 2.42.

**Table 2.38:** Comparison of mean TDS values at Polhena Beach

| Year | TDS (g/L) |
|---|---|
| 2009 | 50.01 (±7.87) |
| 2010 | 53.11 (±4.58) |

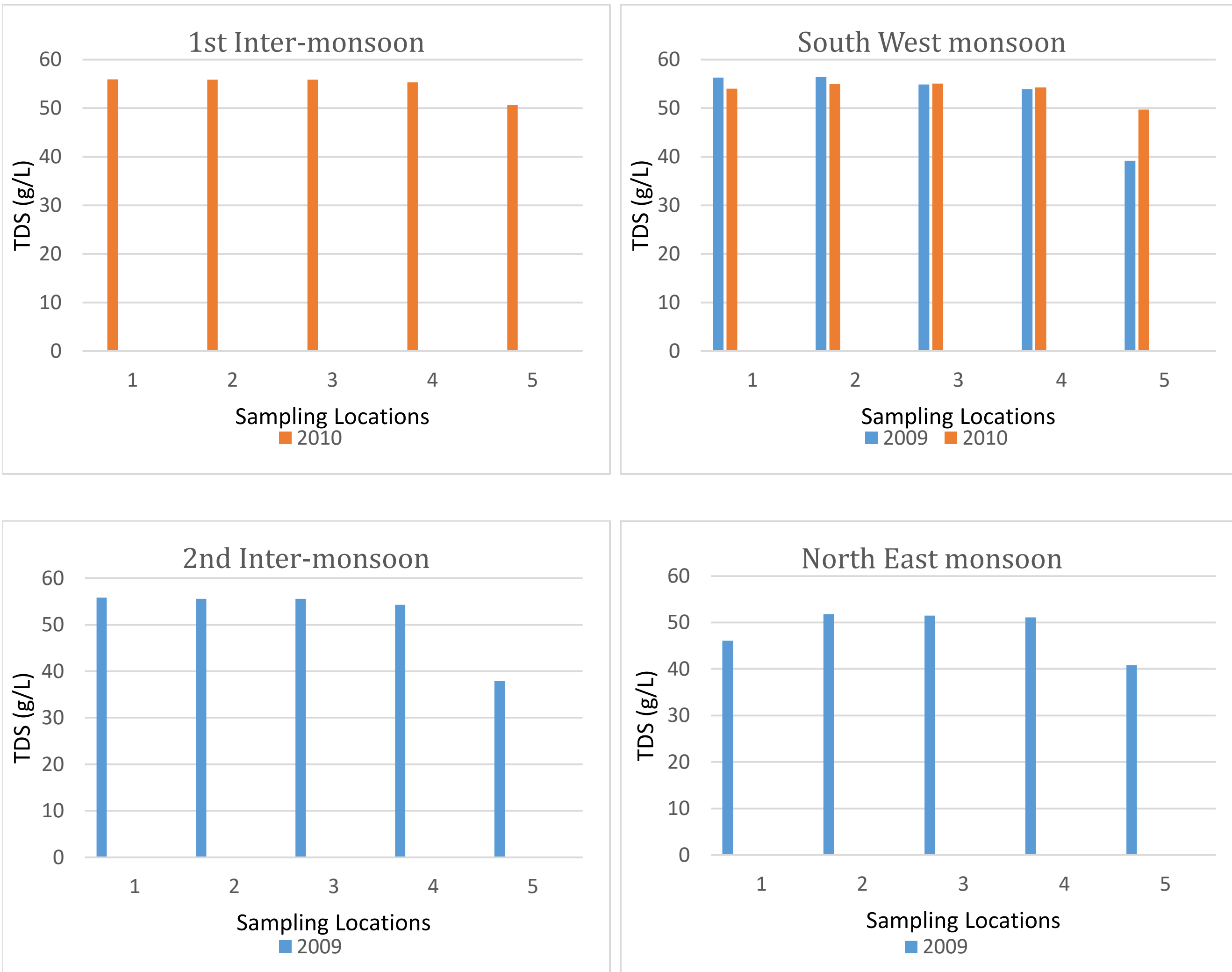



**Figure 2.42:** Seasonal variation of TDS at Polhena

## Turbidity Profiles

Mean turbidity values are varied between 10.85 NTU and 15.39 NTU as shown in Table 2.39. Turbidity has decreased to 10.85 NTU in 2010 and increased to 15.39 NTU in 2011.

**Table 2.39:** Comparison of mean turbidity values at Polhena Beach

| Year | Turbidity (NTU) |
|---|---|
| 2009 | 15.03 (±27.32) |
| 2010 | 10.85 (±20.66) |
| 2011 | 15.39 (±8.98) |

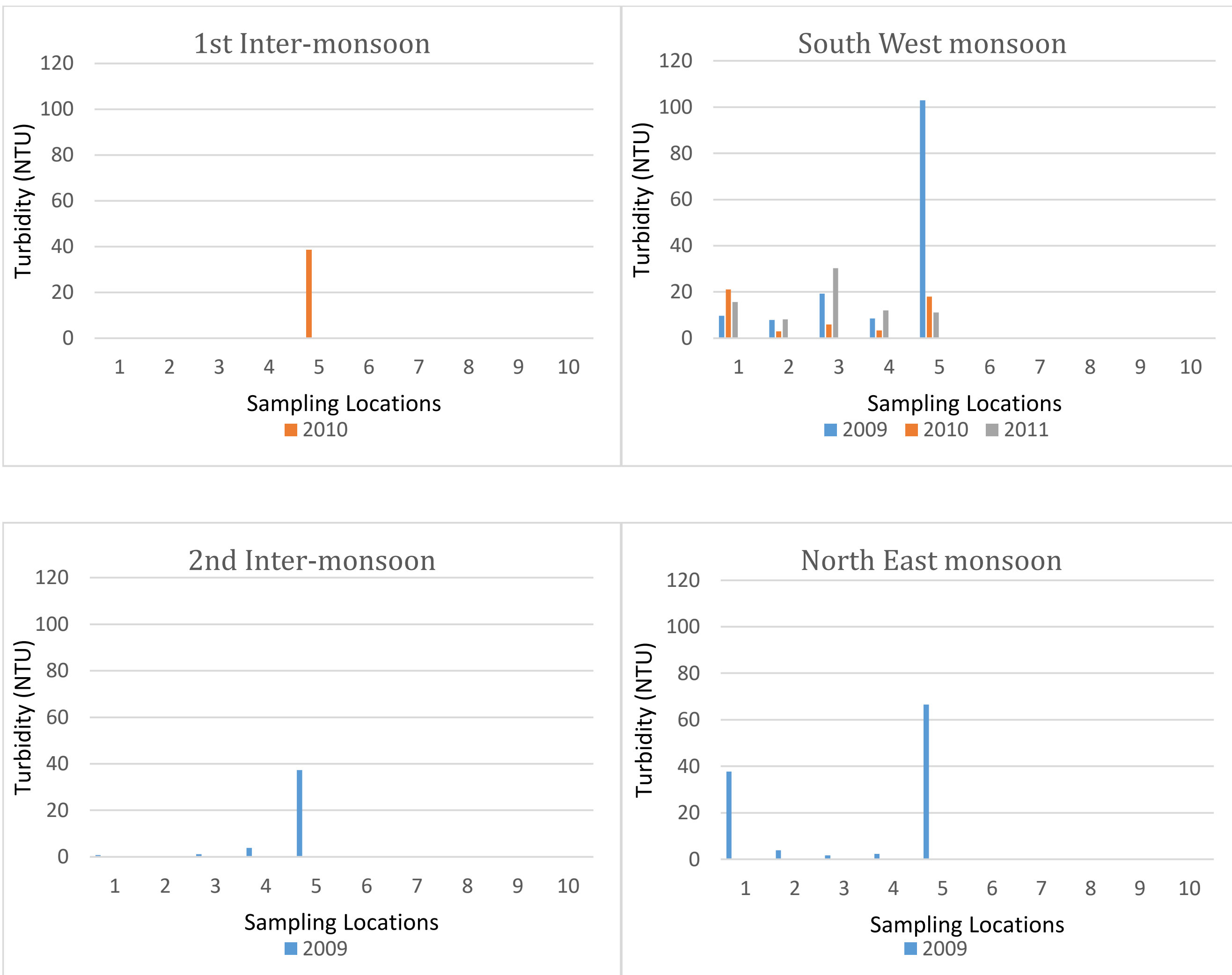



**Figure 2.43:** Seasonal variation of turbidity at Polhena

The measurements were not continued after 2014. However, highest turbidity value (>100 NTU) was recorded at 5th location in 2009 during the South West monsoon. All the other locations showed turbidity values less than 100 NTU.

Turbidity is not imposed by the ASEAN guideline as a marine water quality parameter.

## Temperature Profiles

Mean temperature values at Polhena are varied within the range of 25.23 °C to 28.73 °C as shown in Table 2.40. A visible trend during the monitoring period could not be observed. The variation with respect to monsoons is presented in the Figure 2.44.

**Table 2.40:** Comparison of mean temperature values at Polhena Beach

| Year | Temperature (°C) |
|---|---|
| 2009 | 27.52 (±1.68) |
| 2010 | 28.73 (±1.14) |
| 2011 | 25.23 (±1.04) |
| 2014 | 28.58 (±1.25) |
| 2015 | 27.32 (±0.51) |

No any clear trend could be observed with respect to monsoons. However, the relatively higher values for temperature were observed during the 1$^{st}$ Inter-monsoon.

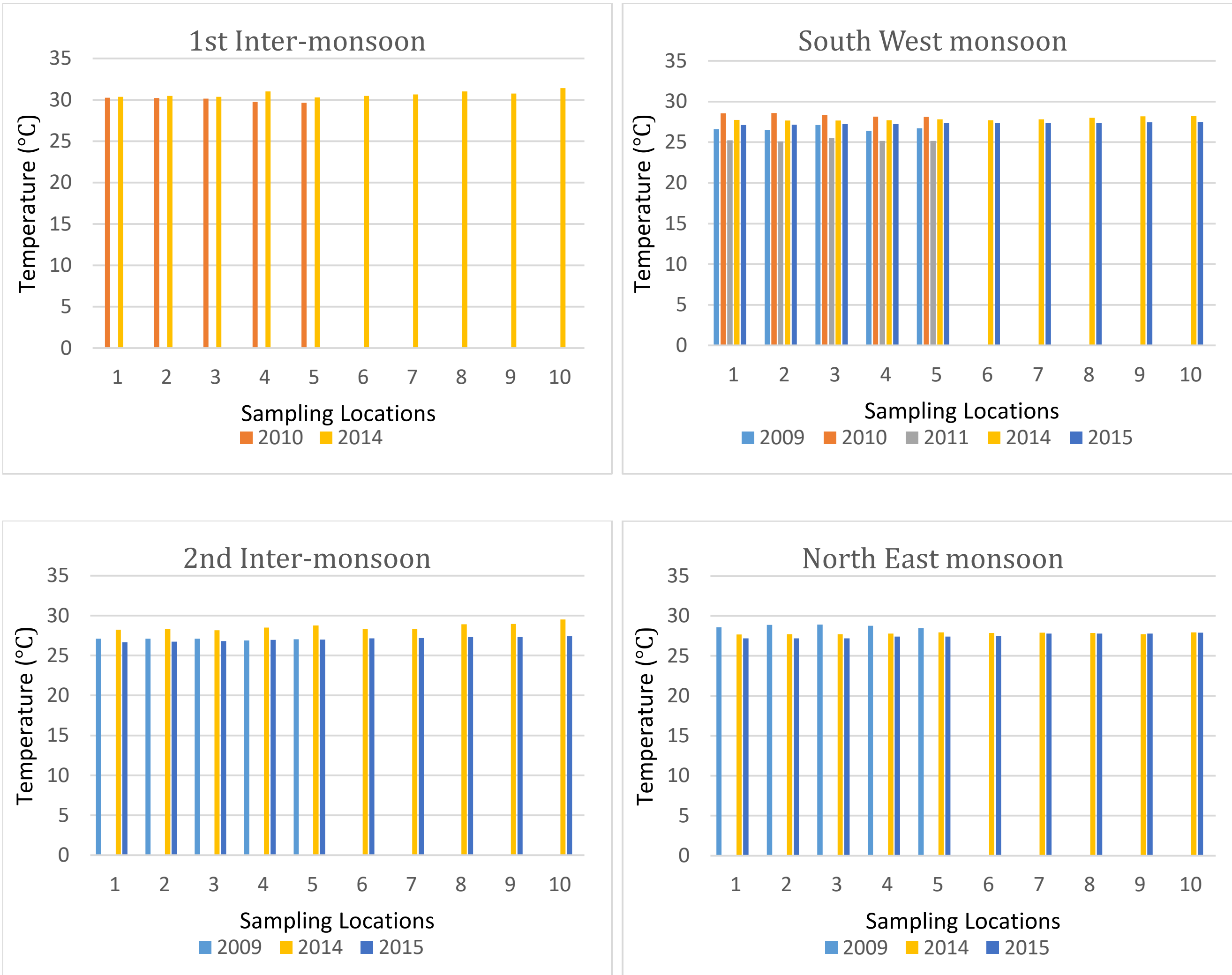



**Figure 2.44:** Seasonal variation of temperature at Polhena

## Faecal Coliform Profiles

The mean values are varied between 32.62 MPN/100 ml and 1949.75 MPN/100 ml as shown in Table 2.41. The faecal coliform concentration was decreased from 2009 to 2014, largely increased in 2015 and decreased in 2016. When considering the annual rainfall, Polhena received a high rainfall in 2015 compared to other years (Appendix I). This could be a major reason for increase in coliform concentrations in 2015 at Polhena.

**Table 2.41:** Comparison of mean faecal coliform values at Polhena Beach

| Year | Coliform (MPN/100ml) |
|---|---|
| 2009 | 1949.75 (±4059) |
| 2010 | 729.17 (±2149) |
| 2011 | 622.31 (±687) |
| 2014 | 32.62 (±47.06) |
| 2015 | 1369.44 (±3500) |
| 2016 | 287.79 (±604.4) |

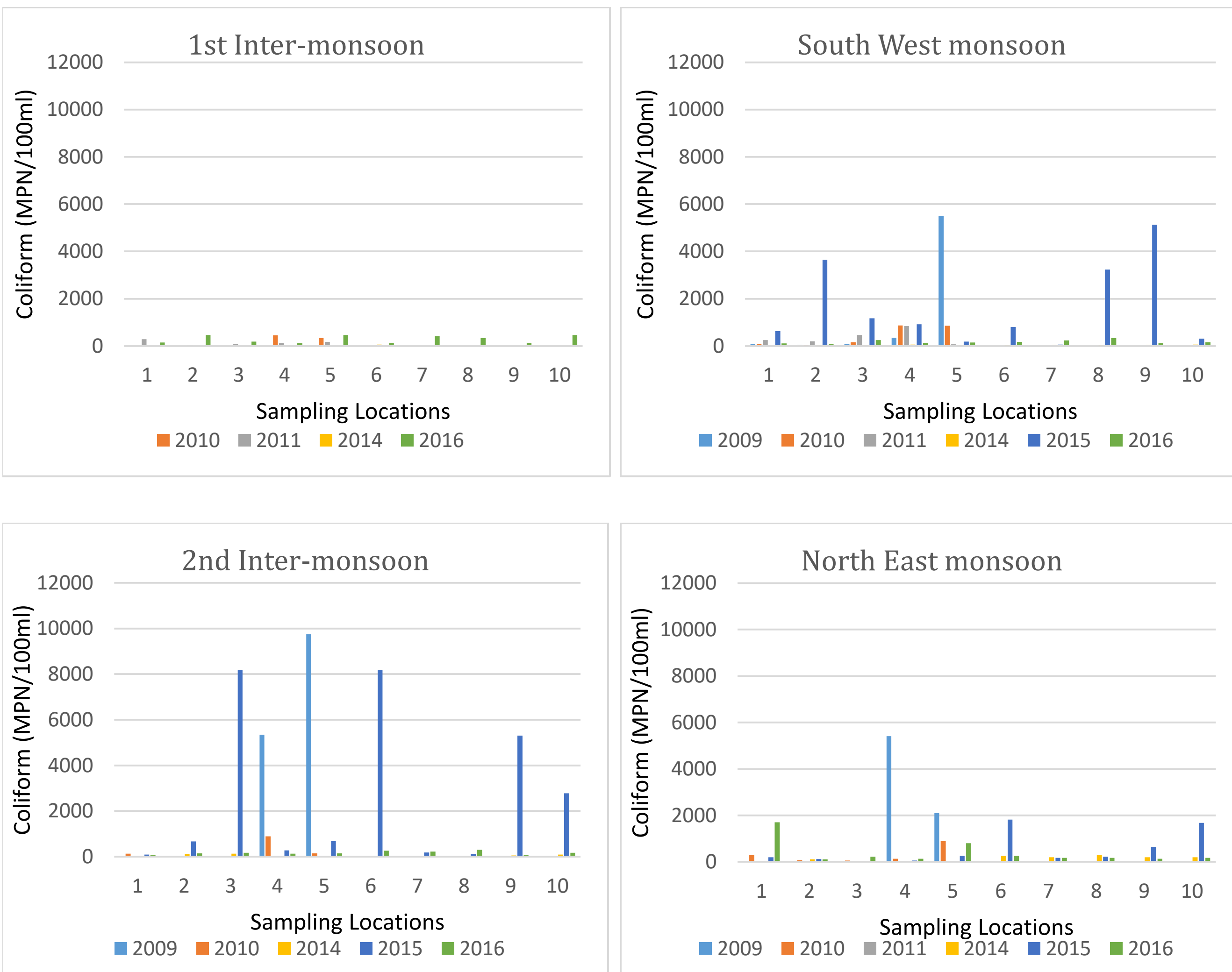



**Figure 2.45:** Seasonal variation of faecal coliform at Polhena

A trend could not be seen in faecal coliform concentrations at Polhena with respect to monsoons. However, lower values were recorded during the 1st Inter-monsoon. Few locations have shown higher values during the other monsoons.

## 6. Hikkaduwa

Hikkaduwa beach is located in the South coast of Sri Lanka, about 17 km North West of Galle and 98 km South of Colombo. It is a well-known international recreational and holiday destination for board-surfing. Hikkaduwa coral reef is one the most beautiful coral reefs found in Sri Lanka and the first coral reef to be declared as a marine national park in the country. Coral Reefs plays an important role in protecting the beach. Because of the coral reef the Hikkaduwa area was one of the least affected areas when tsunami waves hit the country though some of the reef was destroyed due to tsunami hit. But the biggest threat to the reef is from humans who collect corals and capture various fish types to be sold in the commercial market. Hikkaduwa is one of two marine reserves in Sri Lanka and one that is constantly under threat due to human activities. Undoubtedly water quality would have a great impact on the livelihood of coral reef. Monitoring of water quality parameters such as pH, DO, and temperature would be required to safeguard and assess the status of this natural habitat.

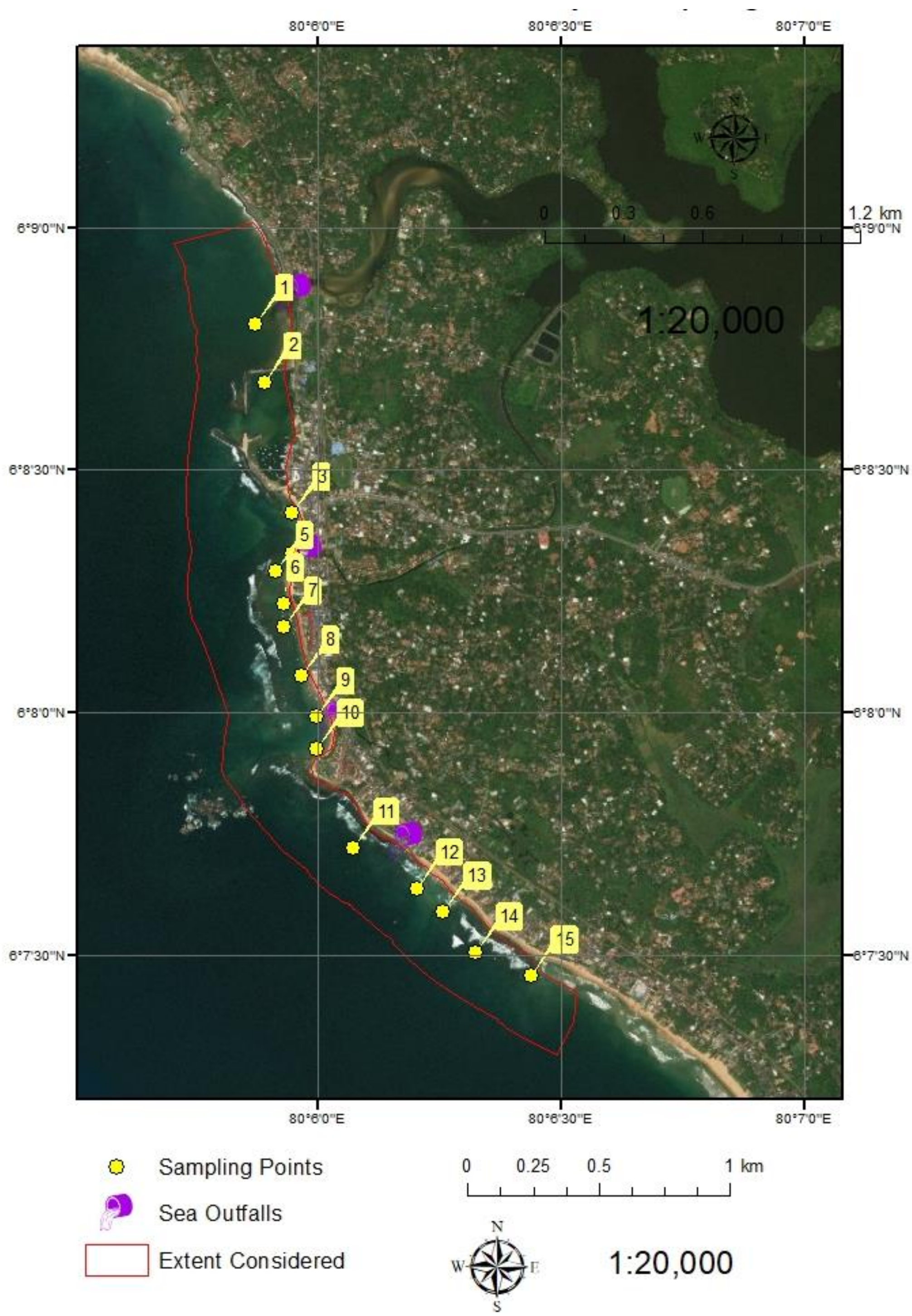



**Figure 2.46:** Sampling locations at Hikkaduwa Beach

## pH Profiles

In this analysis, the variation of pH with time and the monsoons were studied. Table 2.42 shows the summary of mean pH data with associated standard deviations from 2009 to 2016. The mean pH values are within the range of 7.36 to 8.07. Figure 2.47 shows the impact of monsoons with respect to pH in the given location

**Table 2.42:** Comparison of mean pH values at Hikkaduwa Beach

| Year | pH |
|---|---|
| 2009 | 8.07 (±0.17) |
| 2010 | 7.36 (±1.44) |
| 2014 | 7.59 (±0.42) |
| 2015 | 7.92 (±0.49) |
| 2016 | 7.94 (±0.09) |

It was noted that pH had not been varied throughout the monitoring period with time. When considering the variation with monsoons, a visible variation could not observed with respect to monsoons. However, unusual values were obtained for pH in 2010 during the $2^{nd}$ Inter-monsoon except at $7^{th}$, $12^{th}$, $13^{th}$, $14^{th}$ and $15^{th}$ locations.

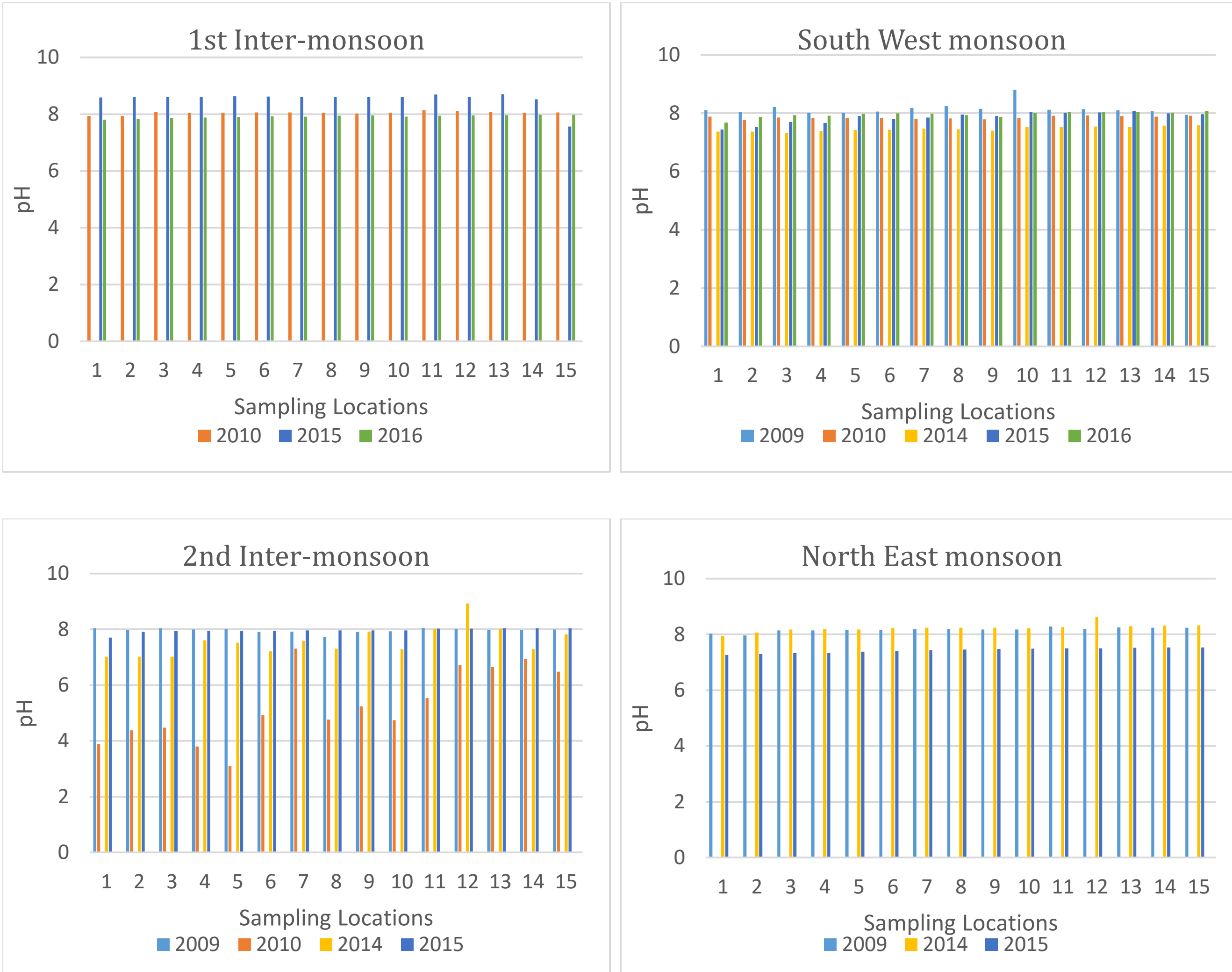



**Figure 2.47:** Seasonal variation of pH at Hikkaduwa

## DO Profiles

Mean DO values are varied between 6.67 mg/L and 8.06 mg/L as shown in Table 2.43. A clear trend could not be seen during the monitoring period from 2009 to 2016. The variation of DO with respect to monsoons are illustrated in Figure 2.48.

No visible trend in DO could be seen with respect to monsoons. The higher values were recorded at 12th location during the 1st and 2nd Inter-monsoons in 2010 and 2014 respectively. However, relatively lower values were observed at first six locations (1-6) during the 2nd Inter-monsoon in 2015 and 8th location in 2010.

**Table 2.43:** Comparison of mean DO values at Hikkaduwa Beach

| Year | DO (mg/L) |
|---|---|
| 2009 | 8.06 (±0.32) |
| 2010 | 7.54 (±1.04) |
| 2014 | 7.52 (±0.71) |
| 2015 | 6.67 (±0.43) |
| 2016 | 7.72 (±0.26) |

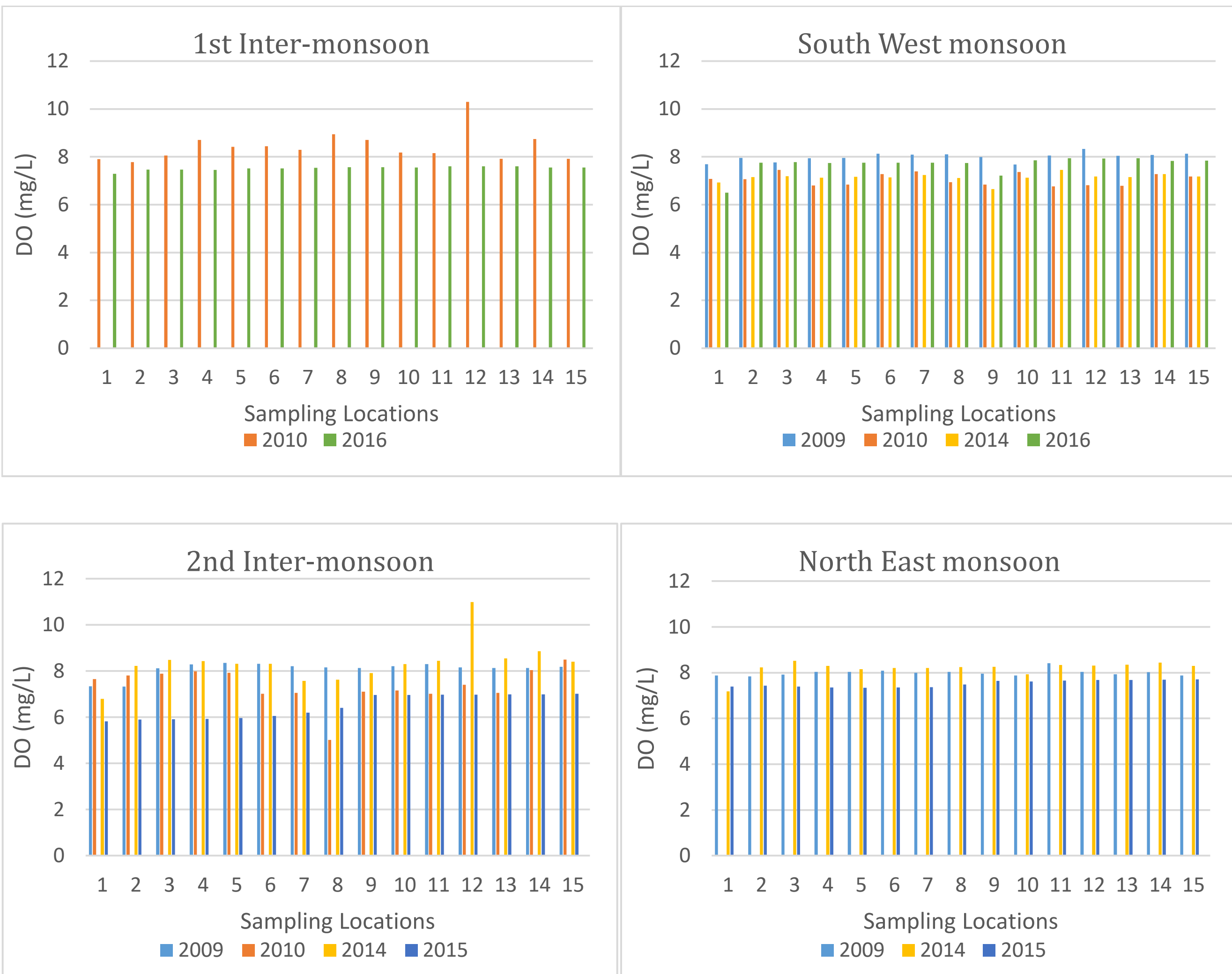



**Figure 2.48:** Seasonal variation of DO at Hikkaduwa

## EC Profiles

Mean EC values are within the range of 50.83 mS/cm to 57.55 mS/cm as shown in Table 2.44. A large variation of EC could not be seen from 2009 to 2016. Figure 2.49 shows the impact of monsoons with respect to EC in the given location.

**Table 2.44:** Comparison of mean EC values at Hikkaduwa Beach

| Year | EC (mS/cm) |
|---|---|
| 2009 | 50.83 (±8.84) |
| 2010 | 52.72 (±1.49) |
| 2014 | 54.51 (±7.33) |
| 2015 | 53.88 (±2.09) |
| 2016 | 57.55 (±4.96) |

EC has increased with respect to time during the 1st Inter-monsoon and North East monsoon. A clear trend could not be seen during the South West monsoon and 2nd Inter-monsoon. Nevertheless, large decrease of EC could be seen at first two locations (1-2) during the 2nd Inter-monsoon in 2014.

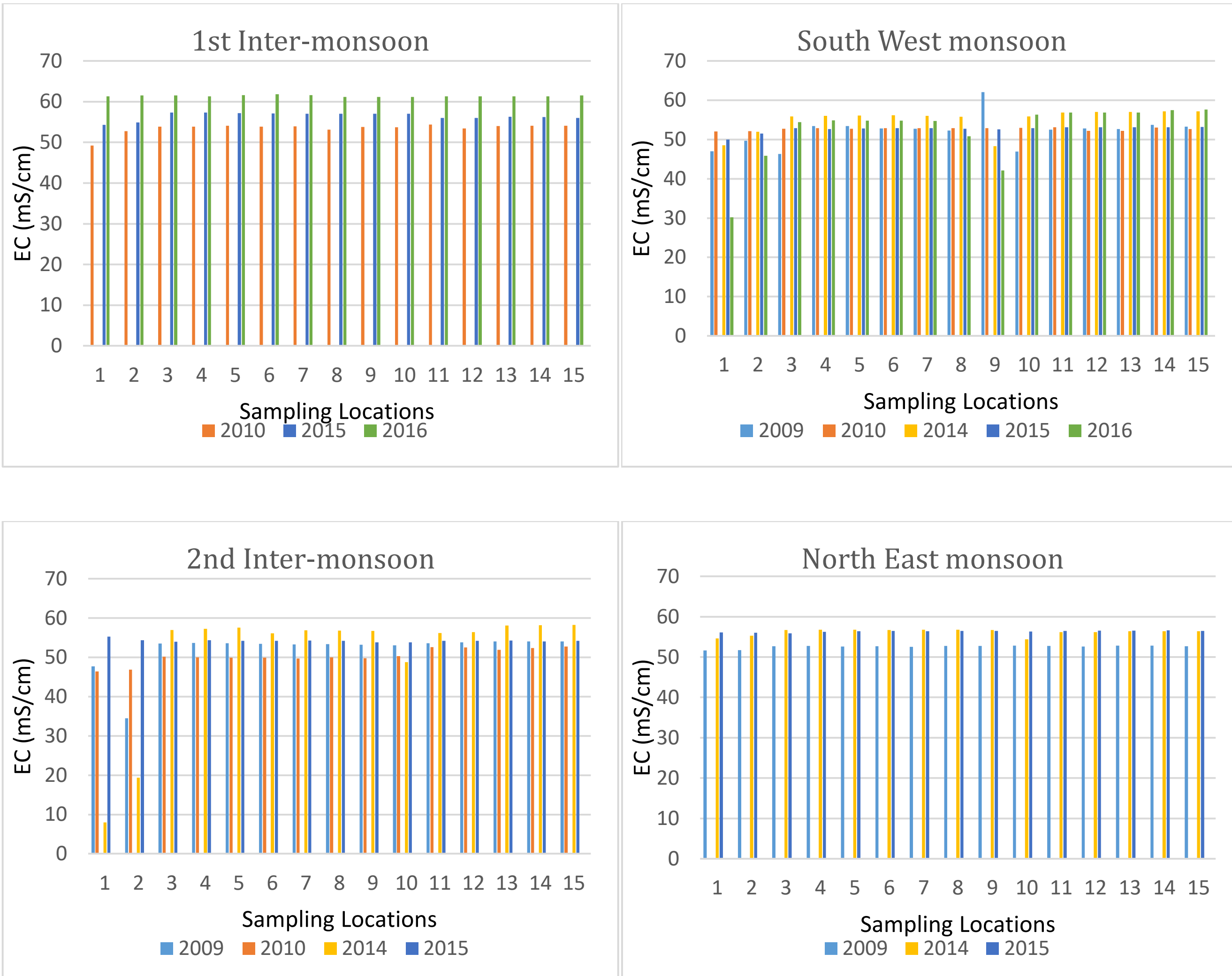



**Figure 2.49:** Seasonal variation of EC at Hikkaduwa

## Salinity Profiles

Mean salinity values are varied within the range of 29.15 % to 35.29 % as shown in Table 2.45. It can be seen a slight increase of temperature from 2009 to 2016.

The variation with respect to monsoons are presented in Figure 2.50. Salinity has increased with the time during the 1st Inter-monsoon and North East monsoon as observed in EC at Hikkaduwa. This variation can be accepted since salinity has a correlation with EC. And also this could be identified as a common fact which applied for all the locations (i.e. - Arugambay, Mt. Lavinia etc.). No trends could be clearly identified during the South West and 2nd Inter-monsoon. The lowest salinity values were recorded at 1st and 2nd locations during the 2nd Inter-monsoon.

**Table 2.45:** Comparison of mean salinity values at Hikkaduwa Beach

| Year | Salinity (%) |
|---|---|
| 2009 | 29.15 (±4.28) |
| 2010 | 31.84 (±22.94) |
| 2014 | 33.18 (±5.19) |
| 2015 | 34.09 (±4.61) |
| 2016 | 35.29 (±3.26) |


**Figure 2.50:** Seasonal variation of salinity at Hikkaduwa

## TDS Profiles

Mean TDS values are presented in Table 2.46. It varied between 51.98 g/L and 52.88 g/L. The variation respect to monsoons are illustrated in Figure 2.51.

**Table 2.46:** Comparison of mean TDS values at Hikkaduwa Beach

| Year | TDS (g/L) |
|---|---|
| 2009 | 51.98 (±7.13) |
| 2010 | 52.88 (±6.05) |

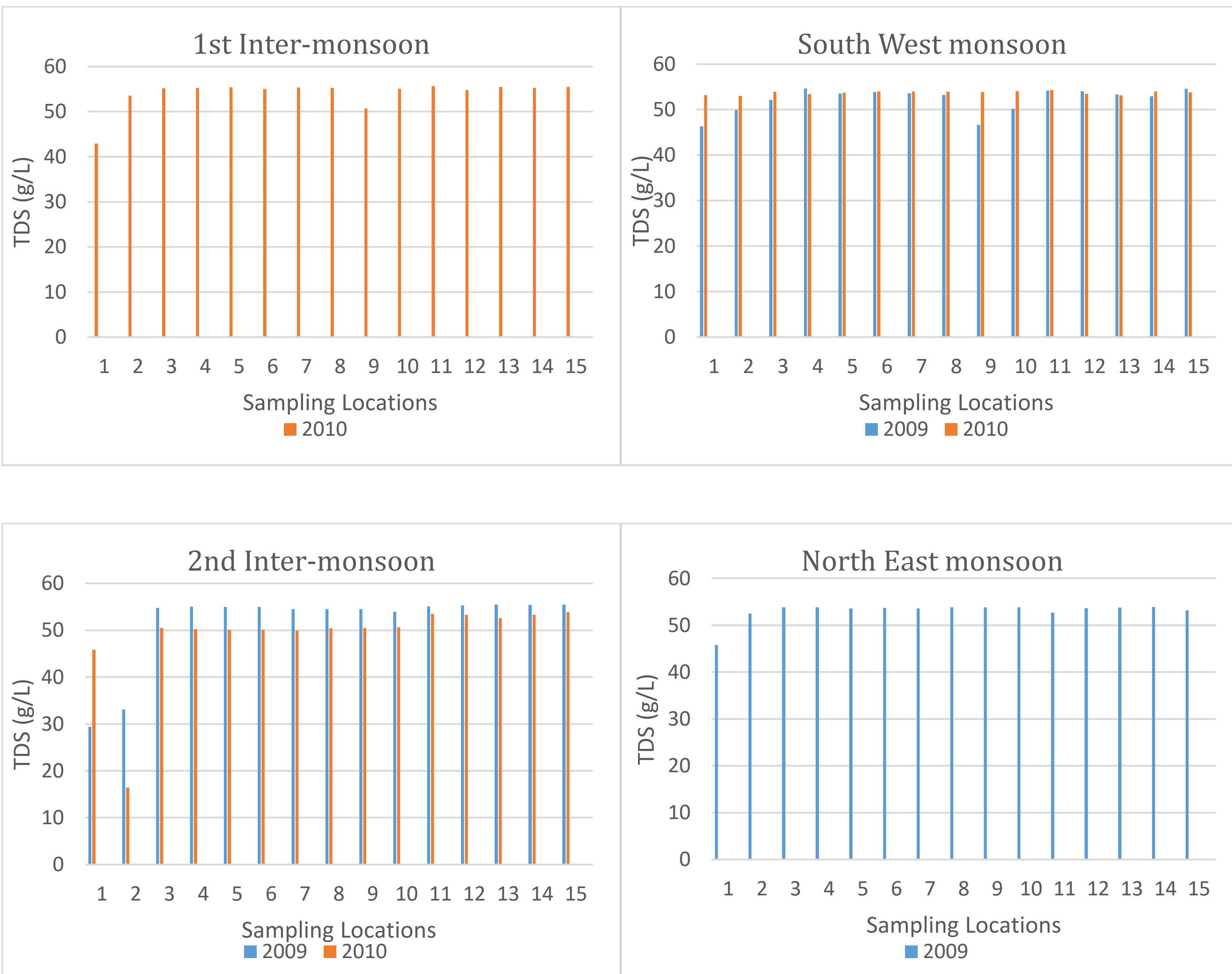



**Figure 2.51:** Seasonal variation of TDS at Hikkaduwa

## Turbidity Profiles

Mean turbidity values are varied between 24.33 NTU and 28.99 NTU from 2009 to 2010 as shown in Table 2.47.

**Table 2.47:** Comparison of mean turbidity values at Hikkaduwa Beach

| Year | Turbidity (NTU) |
|---|---|
| 2009 | 24.33 (±46.60) |
| 2010 | 28.99 (±54.69) |

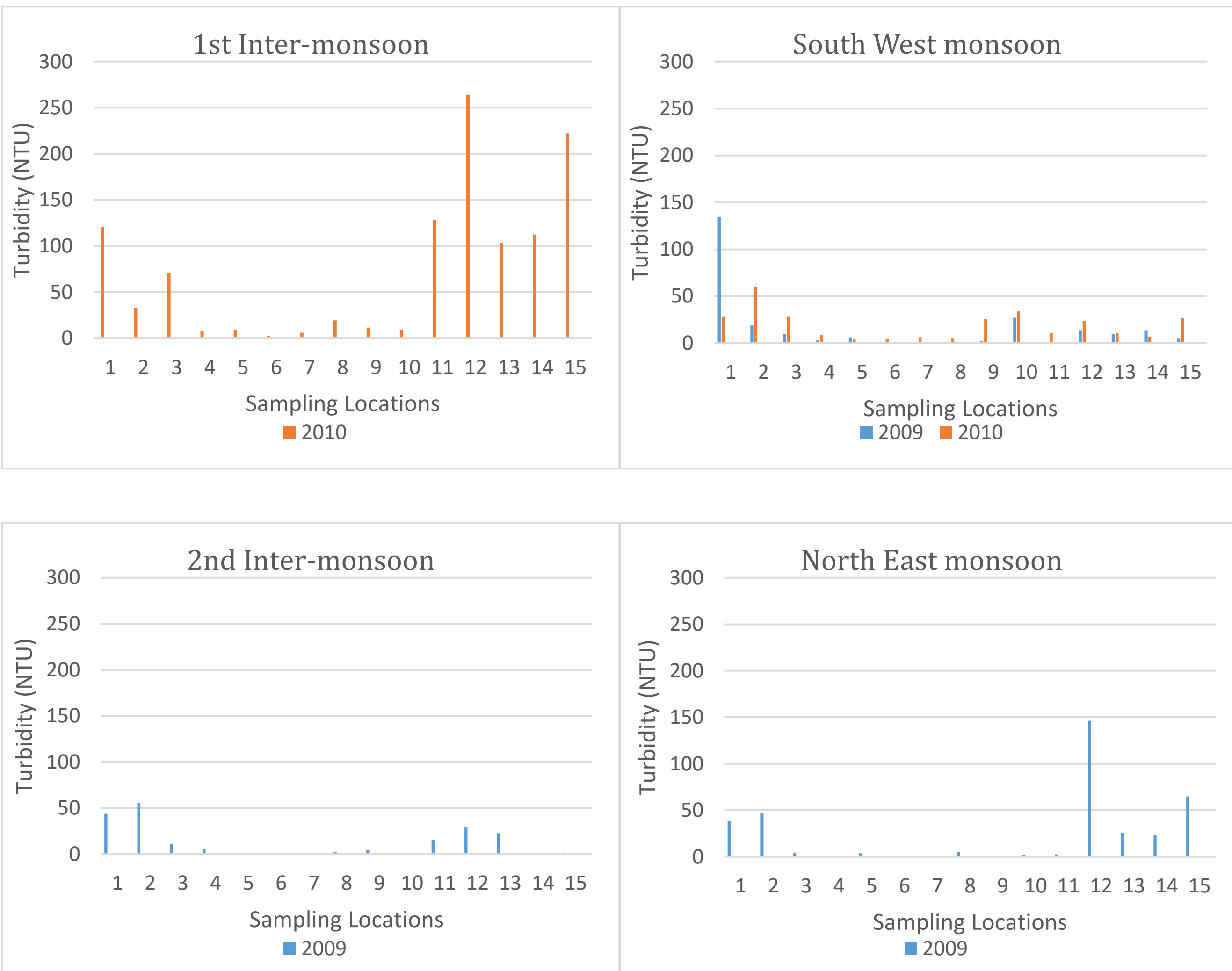



**Figure 2.52:** Seasonal variation of turbidity at Hikkaduwa

All the locations showed lower turbidity values than 150 NTU during all the monsoons except for 12th and 15th locations during the 1st Inter-monsoon in 2010.

## Temperature Profiles

Mean temperature values varied from 28.54 °C to 29.06 °C where a trend could not be seen with respect to time. The mean temperature values with their standard deviations are presented in Table 2.48.

**Table 2.48:** Comparison of mean temperature values at Hikkaduwa Beach

| Year | Temperature (°C) |
|---|---|
| 2009 | 28.54 (±1.00) |
| 2010 | 28.74 (±1.15) |
| 2014 | 29.03 (±0.50) |
| 2015 | 28.71 (±2.31) |
| 2016 | 29.06 (±1.78) |

The variation of temperature with respect to monsoons are illustrated in Figure 2.53. A clear trend could not be perceived with monsoons and it seemed to be constant.

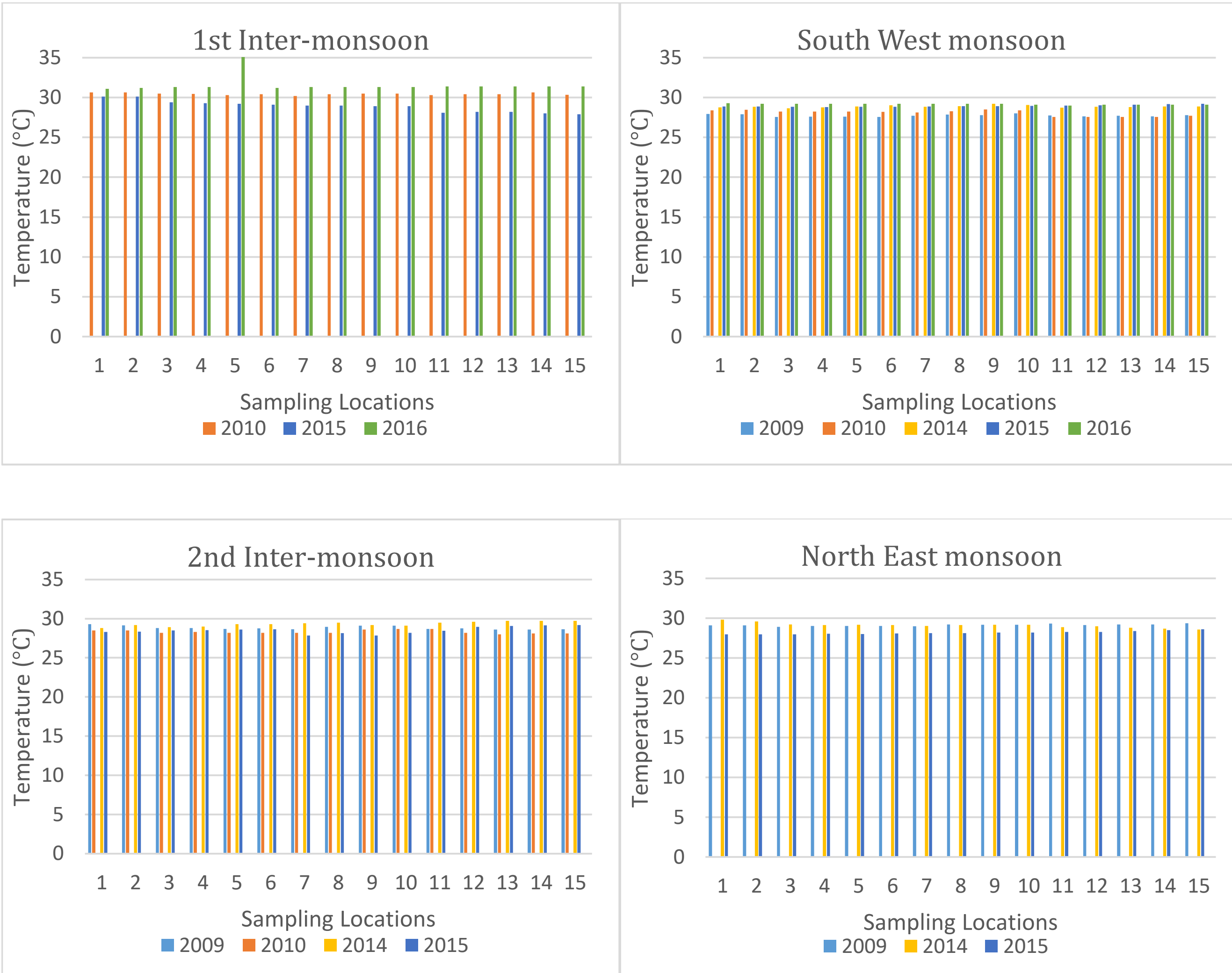



**Figure 2.53:** Seasonal variation of temperature at Hikkaduwa

## Faecal Coliform Profiles

Mean faecal coliform concentration values are varied within the range from 50.26 MPN/100 ml to 943.21 MPN/100 ml as shown in Table 2.49. A regular pattern of varying could not be observed in coliform count with respect to time. The variation of coliform count with respect to monsoons are presented in Figure 2.54.

**Table 2.49:** Comparison of mean faecal coliform values at Hikkaduwa Beach

| Year | Coliform (MPN/100ml) |
| --- | --- |
| 2009 | 607.12 (±2390) |
| 2010 | 172.90 (±426.1) |
| 2011 | 188.90 (±430) |
| 2014 | 50.26 (±73.76) |
| 2015 | 943.21 (±5017) |
| 2016 | 112.58 (±451.9) |

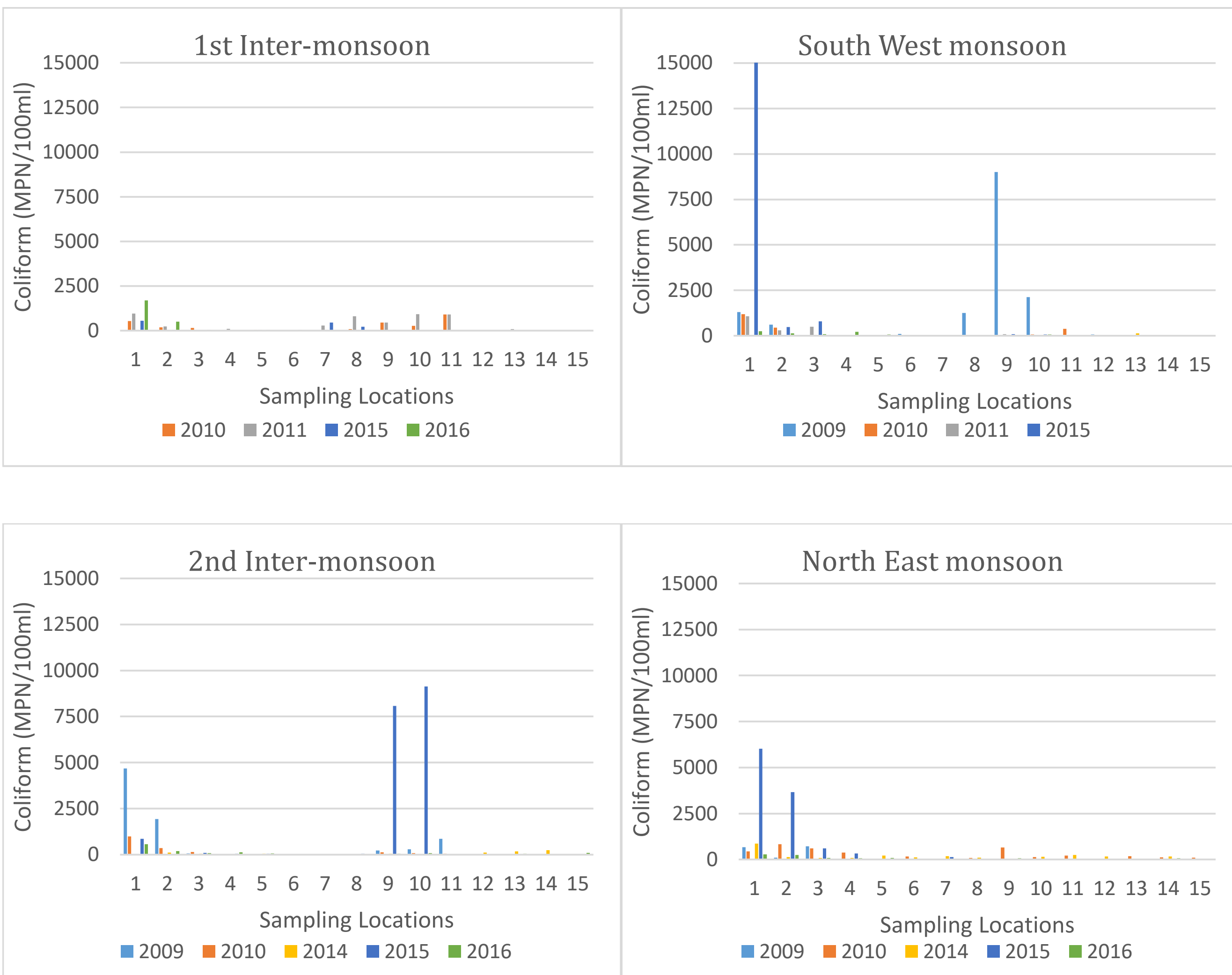



**Figure 2.54:** Seasonal variation of faecal coliform at Hikkaduwa

When considering the $1^{st}$ Inter-monsoon, all the locations had lower values than 2500 MPN/100 ml. The highest coliform count was recorded at $1^{st}$ location in 2015 during the South West monsoon. All the locations except for $1^{st}$, $9^{th}$ and $10^{th}$ locations, have showed lower values during the $2^{nd}$ Inter-monsoon. A visible trend with respect to monsoons could not be seen at Hikkaduwa.

# GIS DATA ANALYSIS

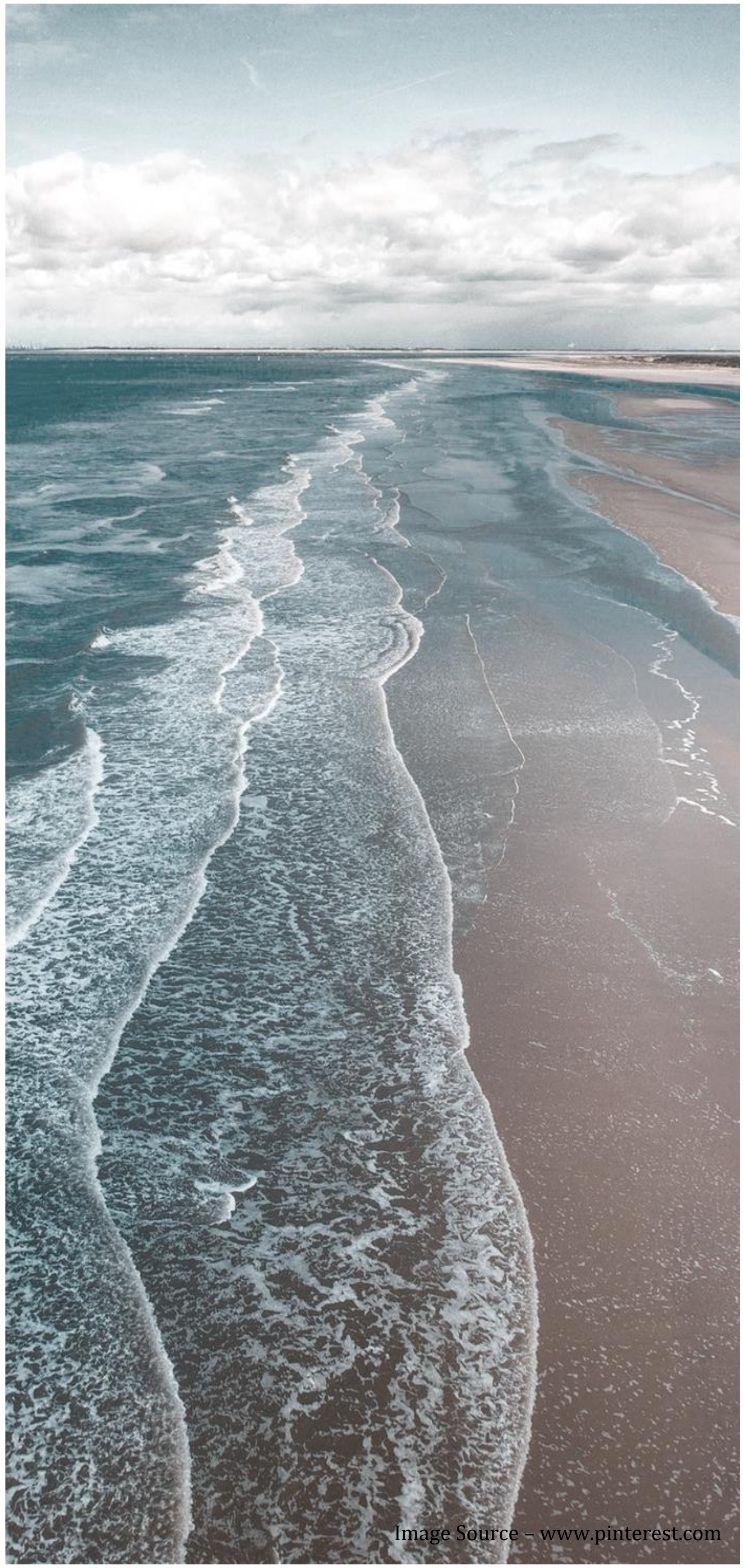


Image Source – www.pinterest.com

# GIS Data Analysis 3

## 3.1 Introduction

Geographic Information Systems (GIS) are increasingly used as a support tool that allows accessing data, generating thematic cartography, and performing spatial and geostatistical analysis. In this project different maps can be prepared for various analyses for the parameters measured depending upon the level of difference between measured parameter of the points.

## 3.2 Methodology

The maps were created for each location using coordinates of the data collection points. However, GIS is not a good tool to show the variation of parameters with time since it will create countless maps. It can be proposed that the statistical details such as mean and trends at a point be mapped. After mapping these details, they had to be distributed spatially using interpolation techniques available in GIS applications. Several methods are available in GIS environment to distribute the parameters spatially, such as Kriging, Inverse Distance Weight (IDW), Spline and Trend.

The most adopted method of interpolation in coastal water quality parameters is Kriging according to Sahlin *et al.*, (2016), Huang *et al.*, (2016) and Elumalai *et al.*, (2017).

Kriging, is used to distribute the data spatially considering the range of data sets and the shape of the area concerned. However, there are several approaches involved in Kriging method such as the ordinary/ universal and search radius, which need to be investigated and calibrate. In the present analysis the ordinary method with linear semivariogram model is used with search radius of 3 points. Note that, validation is not conducted due to lack of points available. Note that, validation has not been conducted as the number of points available is inadequate.

## 3.3 Results

Figure 3.1 shows the location map of all the sites where the various parameters were measured. The details of each site such as locations of sampling points, locations of sea outfalls (including locations where streams and rivers entered the sea), and the area considered for the analysis were presented in the previous chapter.

Maps were created for the various parameters and for the various seasons in the years investigated. The seasons considered were the 1st Inter-monsoon (March/April), South West monsoon (May to September), 2nd Inter-monsoon (October/November), and North East monsoon (December to February). Depending upon data availability, the distribution of measured parameters in each season of a year would then be presented in the maps. Figures 3.2 to 3.6 show the maps of spatial data distribution of coliform at Arugambay beach for the seasons in the years investigated. Maps of spatial data distribution of coliform at the other five locations are attached in Appendix II.

The difference between the other measured parameters at sampling points are not significant enough to present the variations on a map and most of them are within the limits (NHMRC, 2008). The Coliform presence is categories according to the NHMRC, (2008) in the maps as presented in Table 3.1.

**Table 3.1:** Sanitary Inspection Microbial Assessment Category

| **Coliform Count/100 mL** | ≤ 40 | 41-200 | 201-500 | >500 |
|---|---|---|---|---|
| Sanitary Inspection Microbial Assessment Category | Good | Fair | Poor | Very Poor |

## 3.4 Future directions

The locations at a given area are not sufficient to represent the distribution of a given parameter sufficiently. Some of the points are too close while some are further apart. Therefore, the number of locations should be increased at the sites with regular intervals.

Two or more sets of sites further away from the beach also should be included to study the variation of parameter towards the sea.

During the Site visits it was noted that pollution is related to the sea outfalls whether it is a stream or a canal. At Some places local vendors of the area used to block them during the dry season. However, during the rainy season all these canals and streams are used to open up polluting the beach. Figure 3.7 shows the blocked canal at Unawatuna. Figure 3.8 shows some of the canals which are not flowing to the sea during the dry season.

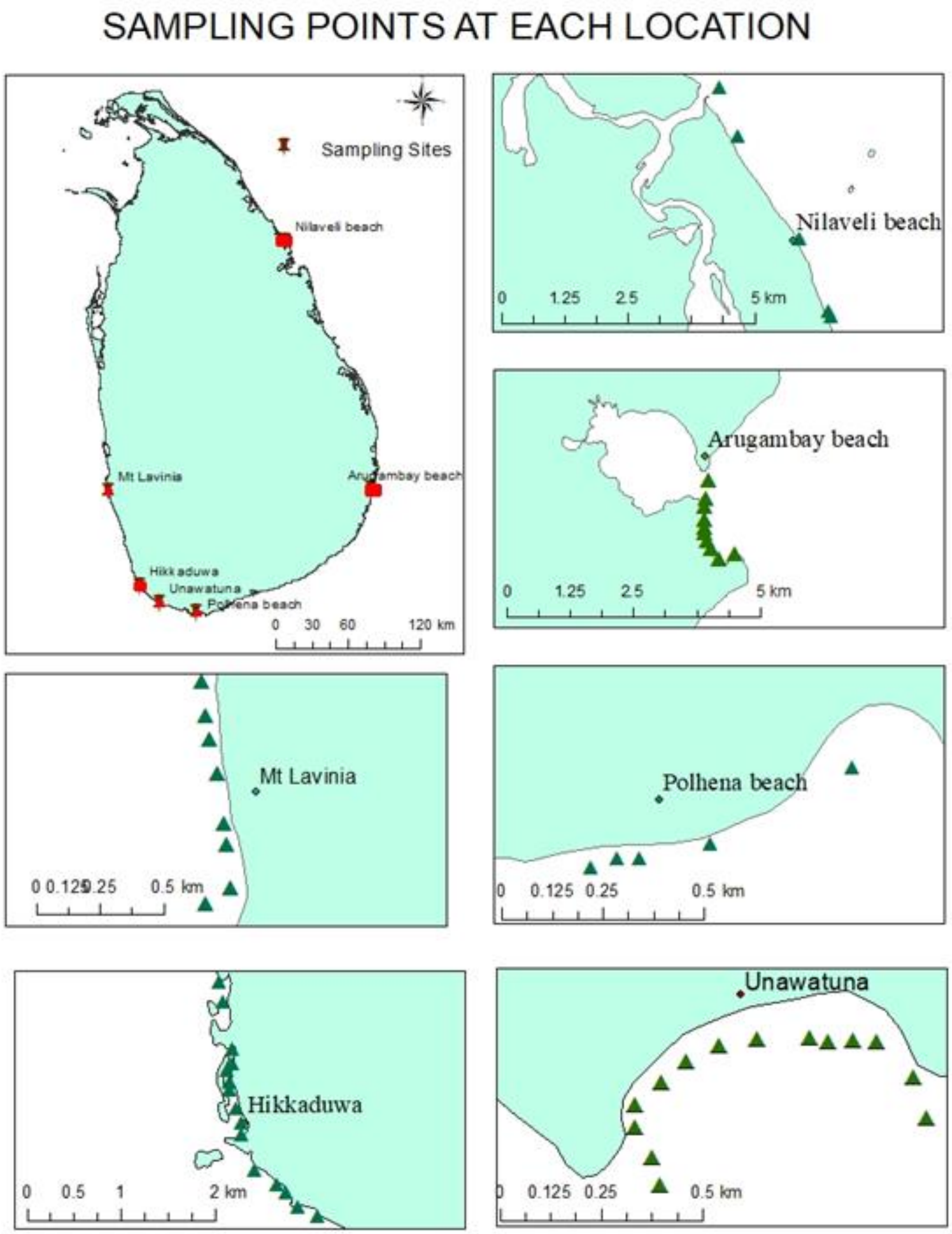



**Figure 3.1:** Map of the monitoring locations

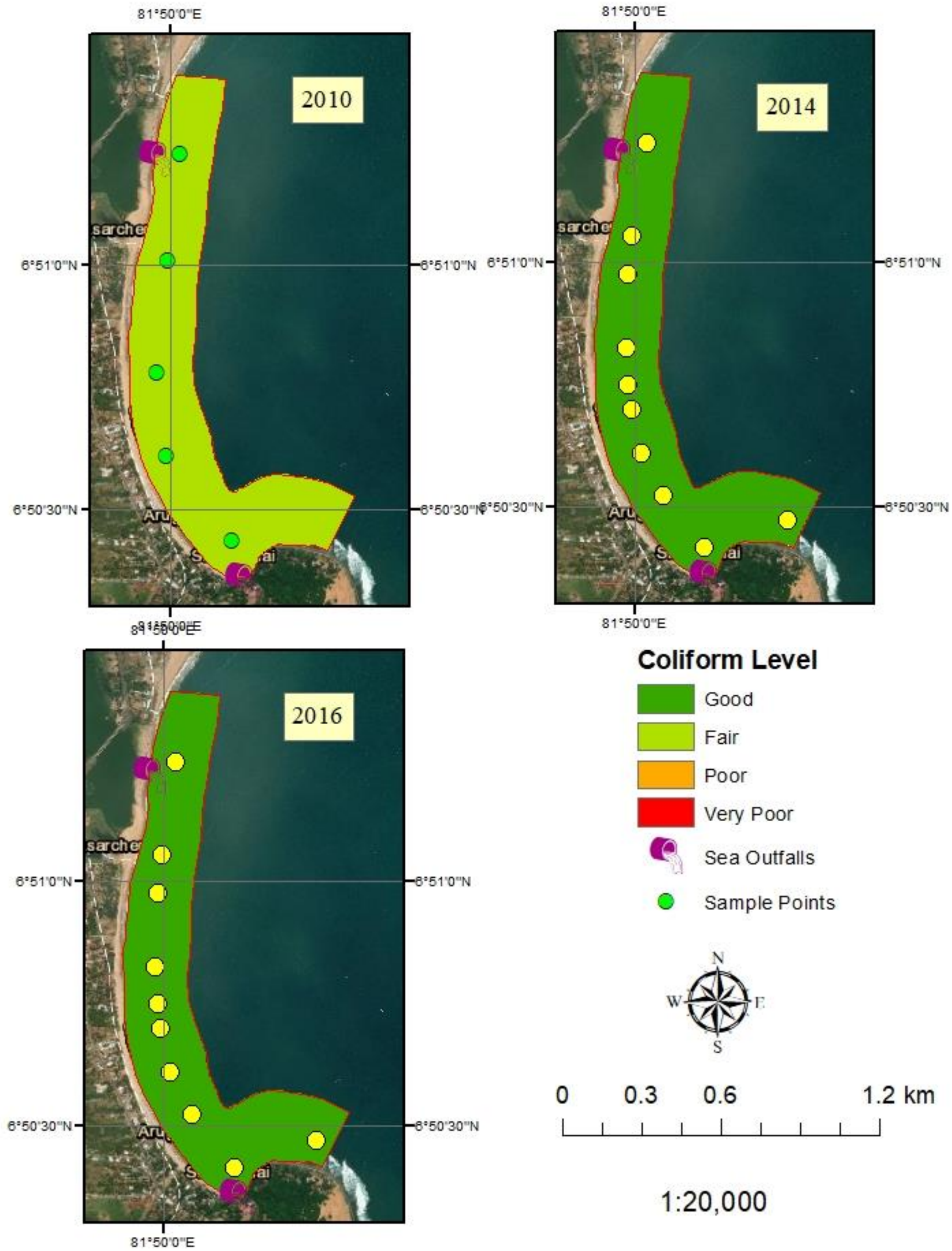



**Figure 3.2:** Faecal Coliform distribution at Arugambay-First Inter-monsoon (2010, 2014, 2016)

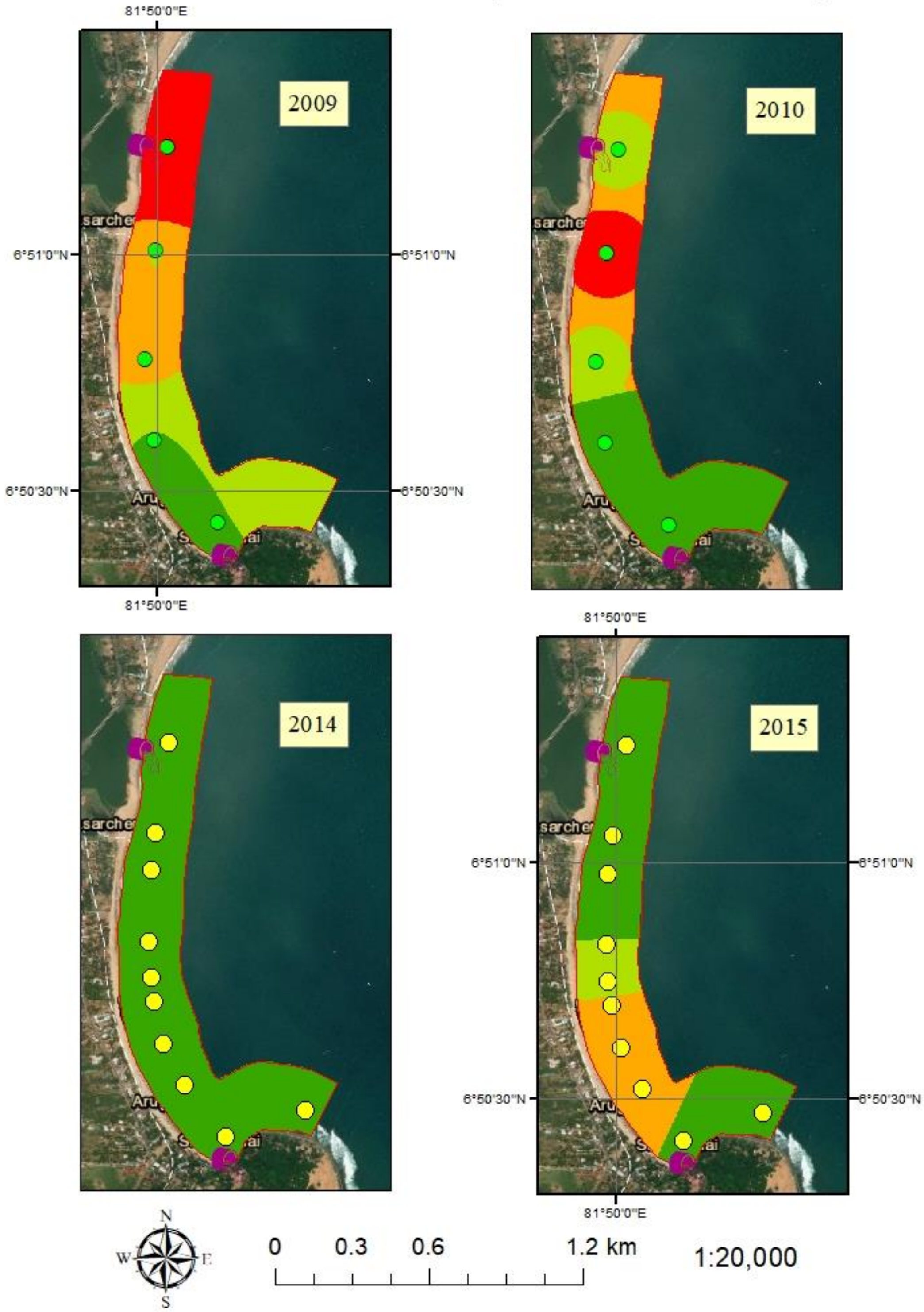



**Figure 3.3:** Faecal Coliform distribution at
Arugambay-Second Inter-monsoon (2009, 2010, 2014, 2015)

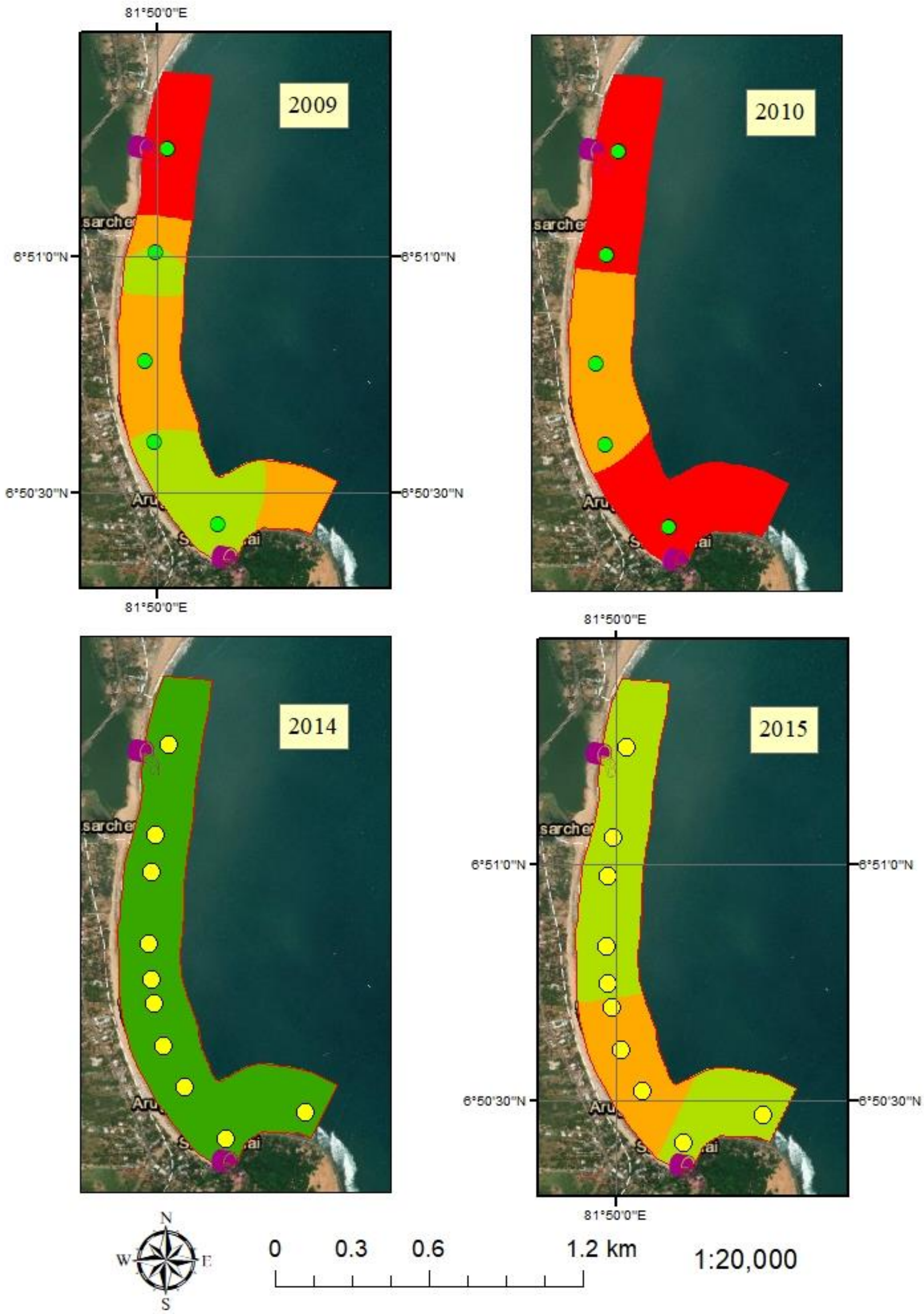



**Figure 3.4:** Faecal Coliform distribution at
Arugambay-North East monsoon (2009, 2010, 2014, 2015)

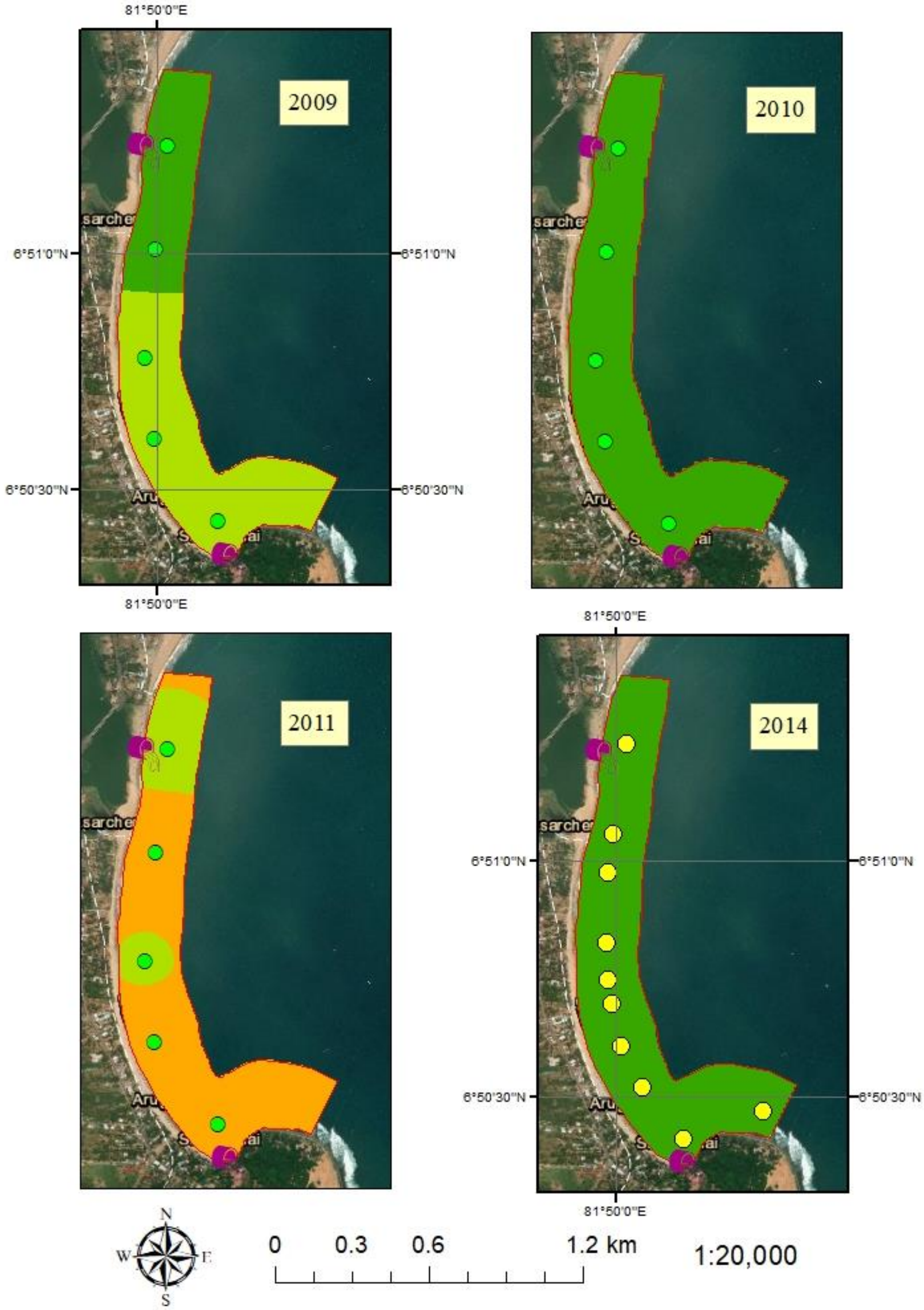



**Figure 3.5:** Faecal Coliform distribution at
Arugambay-South West monsoon (2009, 2010, 2011, 2014)

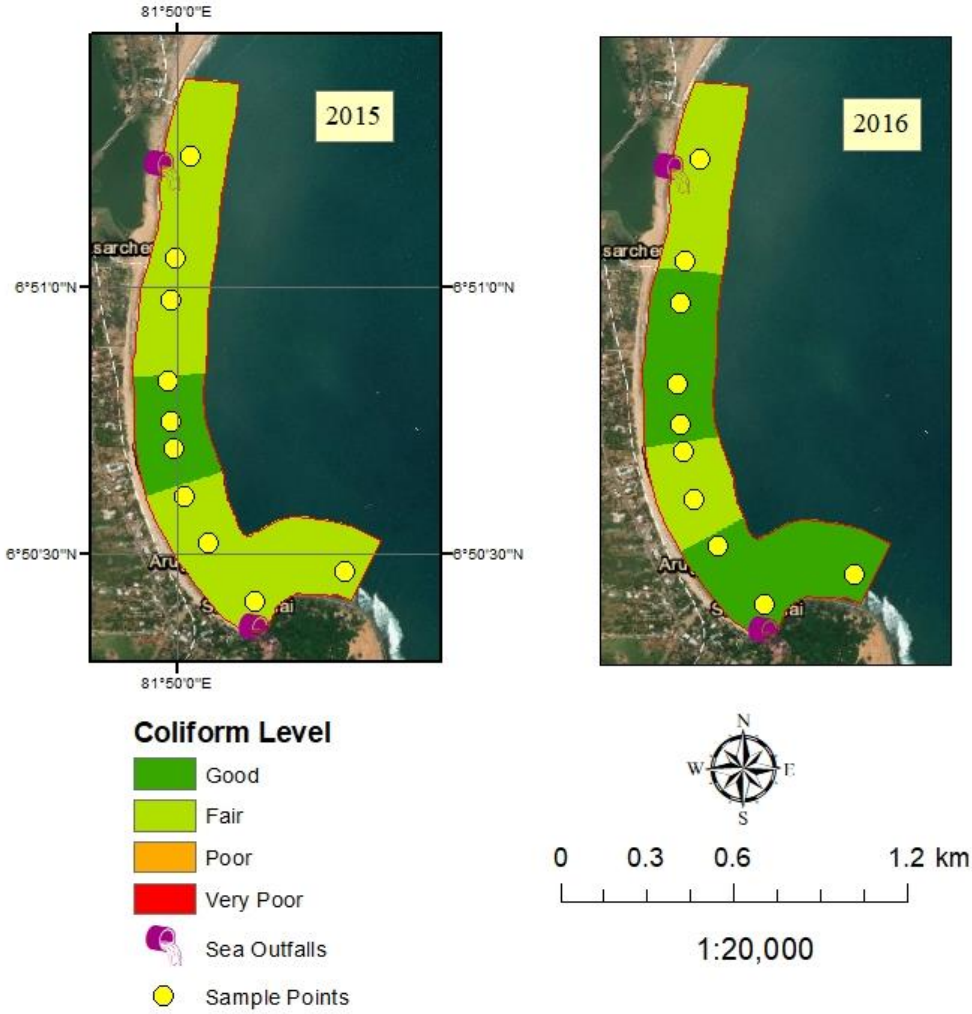



**Figure 3.6:** Faecal Coliform distribution at Arugambay-South West monsoon (2015, 2016)

## 3.5 Effect of Morphology and Hydrodynamics on Water Quality

### 3.5.1 Arugambay

Literature has reported disturbed water can have higher total faecal coliform and E. coli counts compared to samples taken from the overlying water column. This would then suggest where there is anthropogenic activity which disturbed the water, higher values of faecal coliform can be expected compared to undisturbed waters which may show relatively low faecal coliform counts. At the Arugambay site a similar phenomenon could be observed where the narrow stretch between the two land masses in which waves could be subjected to local acceleration and so facilitating substantial mixing than at the other locations. Sampling locations such as 8, 9, and 10 show lower coliform counts because the land morphology did not enhance mixing. This suggested the importance of understanding the wave regime at a particular location so that data could be better understood.

The regions with higher coliforms also showed higher turbidity. The latter would be an indication of the dynamic movement of sediments and could have included resuspension. Such sediment movement could also lead to sediment accumulation on the sea side and/or land side. A consequence of such accumulation may be increased incidence and severity of floods and ebb tidal deltas.

DO values were higher at locations 8, 9, and 10 compared to the other sampling points. Water absorbs oxygen and other gasses from the atmosphere until it reaches equilibrium at complete saturation. This process is accelerated by turbulence and wave action (Miller et al, 1988). Though information on the wave regime in the region was not gathered, visual observation onsite would suggest significant wave action. The solubility of oxygen decreases as temperature increases (Wetzel, 2001). This implies the regions with higher temperatures could have lower DO values, all other factors being equal. Assessment of temperature variations in the region indicate the contrary – i.e. sites with higher temperature showed higher DO values. This would indicate other factors have impacted on the DO. These factors could have included benthic vegetation (either photosynthetic or respiratory) and sediment movement releasing oxygen-demanding substances. Salinity affects oxygen solubility. The higher the salinity, the lower the dissolved oxygen concentration though this did not follow with the data – again suggesting other factors have influenced the DO. Sampling locations 7, 8, 9, and 10 showed the highest salinity (and hence the highest conductivity values) and it was noted these locations had calmer waters and were less exposed incoming freshwater streams.

### 3.5.2 Hikkaduwa

The unique land form at Hikkaduwa is the barrier islands. These islands can potentially influence the circulation patterns and consequently sediment movement as the impact of ocean swells and other extreme coastal events would be reduced.

The region behind the barrier islands show low coliform counts due to the reduced turbulence and hence lower mixing compared with the other regions. The lowest observed coliform counts were noted on the sheltered side behind the barrier islands. Where higher coliform counts occurred, these regions were associated with higher turbidities - similar to most other beaches. Thus turbidity can be a quick indicator of possible issues with coliform counts.

Further that should be noted the barrier islands are facilitating accumulation and settlement of salt particles compared to other regions and lower mixing in the area has caused this observed higher salinities and corresponding conductivities.

When it comes to the temperature variation it is worth to note that barrier islands are ideal locations for the development of coastal vegetation. The temperature of coastal vegetation is highly variable. Since they are generally shallow, particularly at low tide, water temperature varies mainly with air temperature. Hence monitoring the air temperature in an adjacent site would be beneficial to get an insight over the marine temperature fluctuations. Tidal measurements would be supportive further for the decision making. Average temperature resulted in the region is about 28 $^{0}$C and higher temperature regions are observed to carry lower DO as expected (DiPietro, 2013).

TDS are higher sampling locations 11-15 and it supports to predict a dominant alongshore drift directing towards that direction, which is one of the key attributes that alters the TDS in the coastal regions. Yet there aren't any provided documents to prove such details, it is recommended to monitor the directional currents and in these sites of interests to get a clear picture about the setup. Further anthropogenic influences magnify the TDS counts and such inputs should also be monitored to get a vivid insight about such sensitive parameters.

### 3.5.3 Mount Lavinia

At the Mount Lavinia site unique morphological feature to be observed is an extruded spit though it is difficult to verify whether its composition is entirely fluvial sediment. The significance of this bed form would be its influence for altering the current pattern in the vicinity compared to the adjacent ocean stretch. This bed form then would directly influence the circulation pattern of the region which affects the measured water quality parameters at the site. Additionally, being densely populated coastal belt in the country the significance of anthropogenic activities should be high compared to other sites. But the non- availability of such pertinent data drags it out of making firm conclusions. Lowest coliform count and TDS, highest EC, temperature variation, salinity, pH and turbidity values are resulted near this sand spit.

As this region doesn’t entertain much mixing and inherently adjusted for the water accumulation and instantaneous stagnations, it could be verified the observations related with lowest coliform counts, high salinity and related conductivity and the turbidity. pH values mostly resembles neutral nature with a resulted growing trends towards basis region.

Higher the TDS, higher the conductivity and lower the pH leading towards the acidity, though such trend could not be observed in the vicinity of this spit. This may be caused due to alongshore currents (those are not traced in the study) that could have locally governed the mixing and particle movements.

Though it is expected a lower DO levels at the places near the sand spit where it records highest temperature values, DO claim to have intermediate figures, which is difficult to elaborate with the established knowledge. It is noted that none of these parameters and processes are solely depend on a single process and govern by few factors, as pelagic environments are inherently complex and maintained with the support of numerous hydrodynamic, morphodynamics and anthropogenic processes.

### 3.5.4 Nilaweli

In the context of dispersion of the sampling points Nilaweli shows the highest dispersion that made it difficult to capture the variation of parameters compared to the other sites. At Nilaweli site that has been noted lagoon type morphology with a narrow opening to the ocean making this site unique compared to the other sites. Along with the seaward capturing of the parameters that could have been focused on monitoring the in lagoon parameters as well since mixing of two distinct water body takes place at the opening, which significantly alters the monitored parameters at this environment.

Abiding the observed correlation, mouth of the lagoon observed to have the highest resulted temperature and lowest DO, even though it is expected much disturbances at the mouth compared to the surrounding.

Usually at the mouth of the lagoons waves may subject to local acceleration that disturbs the deposited sediments at the mouth. Naturally this morphology facilitates for the evolution of flood and ebb tidal deltas due to the sand accumulation at the mount during flooding and ebbing cycles. This should be leading to higher turbidity, TDS, salinity and resulted conductivity. But in the particular site mouth of the lagoon claims to have the lowest turbidity and an average salinity. This might be due to the untraced phenomenon such as current movements and influence from the anthropogenic activities those are not properly observed and recorded in this process.

Considering the uniqueness of this site monitoring the parameters within the lagoon itself also would have been important to trap the real variations of the parameters and the correlation between lagoon and coastal water qualities since both are interdependent. Further that could have been placed additional sampling points at this site since the morphology of this site may trigger fluctuations in the water quality parameters compared to the other sites.

### 3.5.5 Polhena

Inadequacy of the sampling points could be noted in this site as well. That has not been observed any unique morphology in this site other than an extrusion of the land towards the ocean at one point between sampling points 1 and 2. This point may be important in the context of current movement and the sediment transport. Hence that would have been located a sampling point right in front of this particular point to trace any variations in the parameters.

Further an existence of such morphology may lead to create an instantaneous stagnation of the waves, which might facilitate an accumulation of TDS. Further, undisturbed water is an indication of lower level of coliform, which is evident with the observed results at this site as well.

Unlike the other sites the region with the highest temperature doesn't claim for the lowest DO in this site. Lowest EC coincides with the sites shows the lowest salinity though it doesn't obey for the vice versa. There is a contradictory in the behaviors of turbidity, salinity and TDS. Regions resemble the higher turbidity show a lower salinity and TDS. This might be resulted due to the current movement in this site, which should be critically considered in the future monitoring processes.

### 3.5.6 Unawatuna

The average pH levels in Unawatuna beach have shown fluctuations in seasonal and inter annual time scales as it is observed in Coastal environments under the influence of tidal fluctuations and having bay type coastal morphologies in the world (Baumann et al., 2015) These fluctuations could have been triggered due to the acidic and hypoxic conditions occurred during the low tide periods (Baumann *et al*.,2015), anthropogenic activities originated waste, mixed and modulated by the bay and spit type morphologies observed in this coastal site.

Temperature in this region has been fluctuated in the range of 26-32 °C and this would have been resulted due to the wind effect as large open water bodies have a fast cooling rate with respect to wind direction and this results in colder water during the rainy season, and warmer water during dry periods (Theeuwes *et al.,*2013).

Conductivity and salinity values for sea water are 55 mS/cm, 35000-40000 mg/L (Malmberg, 1965). Salinity and conductivity values observed in this site are apparently abide by the standard figures, though there are sudden deviated observations at some instances. This would have been resulted due to the sea-surface slope and input of freshwater and mixing due to strong wind greatly disturbed the circulation inside and outside of the bay, making the salt exchange between the land and coastal ocean very different from that under normal conditions (Du & Park, 2019).

DO fluctuates due to the temperature, altitude of the sea level and influence of marine ecology. For an instance sea level (1 atm or 760 mmHg) and 4°C (39°F), 100% air-saturated water would hold 10.92 mg/L of dissolved oxygen. But if the temperature were raised to room temperature, 21°C (70°F), there would only be 8.68 mg/L DO at 100% air saturation. At Unawatuna site, resulted DO levels are in acceptable range, even though the measured temperature is in high side. This would have been supported by the marine ecology in the region and the suspended sediment movement triggered by wave, current actions that has positively affected the turbidity thereby the DO levels (You & Chen, 2019).

**Figure 3.7:** Blocked canal at Unawatuna Beach by local vendors

**Figure 3.8:** Some of the sea out falls

# CONCLUSIONS
# &
# RECOMMENDATIONS

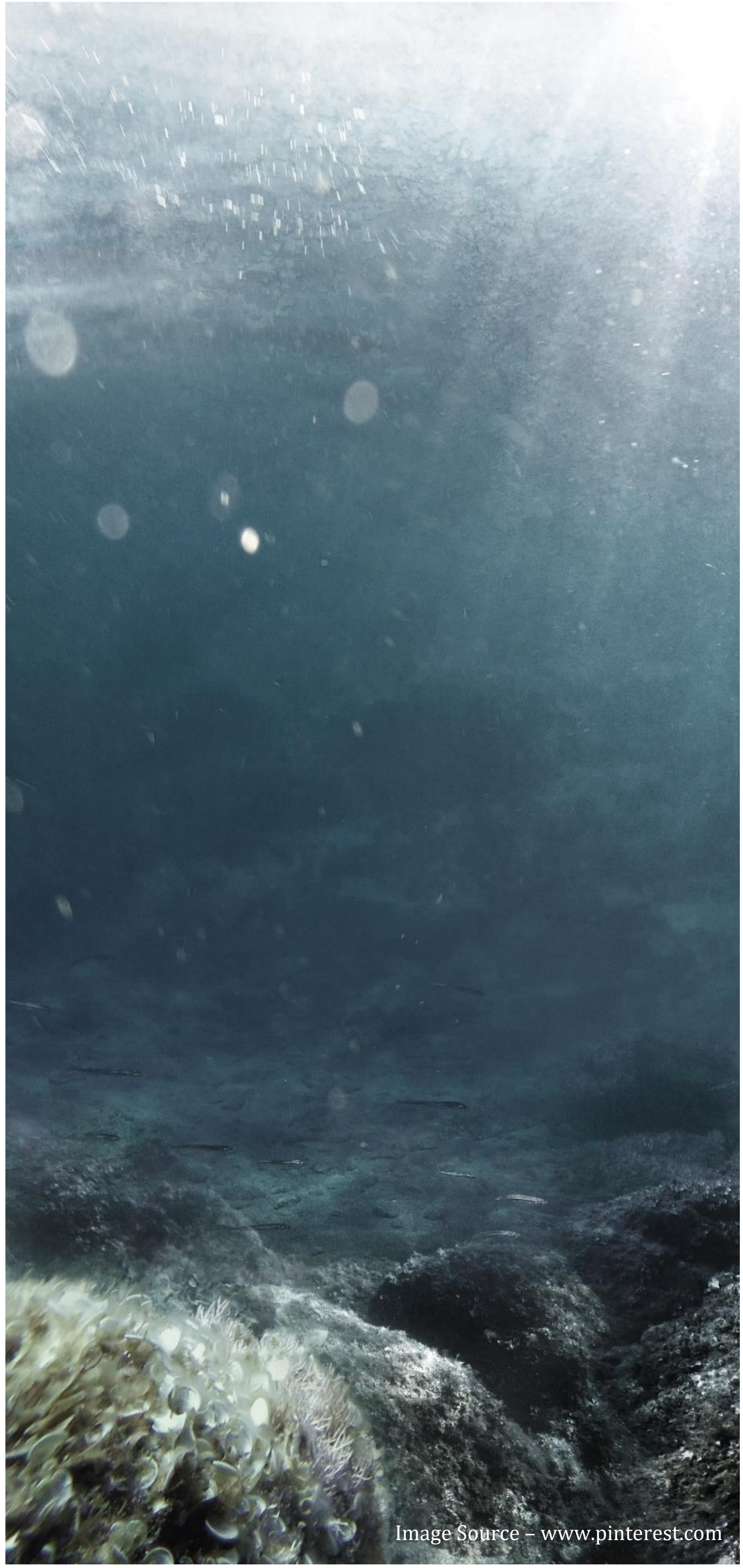


Image Source – www.pinterest.com

# Conclusions & Recommendations 4

## 4.1 Background

Coastal water quality plays an important role not only for human habitats along the coastal stretch around Sri Lanka, but also for protection of the rich biodiversity (*flora and fauna*) in the marine eco-system. Deterioration of this ecosystem can lead to both direct (e.g. loss of breeding grounds, coral reefs) and indirect consequences (e.g. tourism industry). Therefore, the Government of Sri Lanka has developed a number of mechanisms to safeguard human habitats, and flora and fauna on the coastal belt via policy interventions, acts, and laws related to these areas since the introduction of the Coast Conservation Act, No 57 of 1981. However, the importance of evidence-based policy formulations and interventions, and subsequent enforcement of the regulatory frameworks/laws cannot be overstated and this has to be coupled with periodic reviews. This is because the coastal belt is a dynamic system impacted by anthropogenic activities (e.g. constructions, discharge of waste and wastewater) and natural events (changing sea level, tsunamis) leading to changes in the coastal morphology and land use patterns, and thereby sediment transport and coastal water quality.

Sri Lanka has a coastal belt of 1,600 km (Senevirathna *et al*., 2018) comprising natural and man-made harbours, environmentally sensitive areas such as coral reefs and marine parks (Hikkaduwa and Pigeon Island), recreational beaches (Arugambay, Mount Lavinia, Nilaweli, Polhena, Unawatuna), and highly congested areas with hotels and tourism industry related establishments in addition to the local human settlements. The coastal area is densely populated with more than 65 per cent of the country's total population and urban centres such as the capital city of Colombo and several other large cities. The total population in this area was estimated at 8.4 million (about 38 % of the total population) in 2010 (Senevirathna *et al*., 2018). Therefore, socio-economic activities in these areas are very high and anthropogenic influence on coastal water quality significant.

According to the ASEAN (Association of South-East Asian Nations) Environmental Monitoring Recommendations, long-term monitoring is essential to determine baselines, measure change and assess overall ecosystem health. Effective monitoring programmes will improve the management and protection of marine resources. Development of an integrated coastal water quality monitoring framework that encompasses estuarine, coastal (including river mouths, bays and lagoons) and offshore waters allow documentation of status change, and allow for informed management decisions for sustainable coastal resource utilization and management. The elements in a coastal inventory can include environmentally highly sensitive areas (e.g. coral reefs, mangroves, and coastal wetlands), pollutants (solid and liquids including hazardous waste) and their sources, industrial activities (e.g. power generation, salterns, fishing and commercial harbors), commercial activities (e.g. tourism and hotels) and human settlements.

## 4.2 Indications on the Current Status based on Data Collected

A summary of the coastal water quality monitored at the 5 sites monitored by the Coast Conservation and Coastal Resource Management Department of Sri Lanka (CC&CRMD) from 2011 – 2016, is shown in Table 4.1 below.

**Table 4.1:** Salient Features of Data Collected from 6 Sites

| **No.** | **Site/Description** | **pH** Min/Max | **DO** Min/Max (mg/l) | **Electrical Conductivity** Min/Max (mS/cm) | **Salinity** Min/Max (%) | **Faecal Coli Form** Min/Max (MPN/100ml) |
|---|---|---|---|---|---|---|
| 1 | Arugambay | 7.8/8.1 | 6.1/7.9 | 3.6/56.2 | 2.1/35.2 | 71.8/463.5 |
| 2 | Hikkaduwa | 7.4/8.1 | 6.7/8.1 | 50.8/57.6 | 29.2/35.3 | 50.3/943.2 |
| 3 | Mount Lavinia | 7.4/8.1 | 7.6/8.3 | 49.5/57.4 | 29.3/36.5 | 202.7/3143.4 |
| 4 | Nilaweli | 6.5/8.0 | 6.9/8.2 | 48.9/56.1 | 29.4/35.5 | 9.9/721.5 |
| 5 | Polhena | 7.6/8.0 | 7.8/8.5 | 49.0/53.3 | 28.4/35.5 | 32.6/1949.8 |
| 6 | Unawatuna | 7.0/8.1 | 7.4/8.4 | 52.2/56.8 | 30.4/36.2 | 49.9/3306.6 |
| 7 | CEA Limit | 5.5/9.0 | | | | |
| 8 | ASEAN | | 4 | | | 100 |

The data shows water quality has largely met with the compliance limits during the monitoring period except for faecal coliform counts at all sites. These values exceeded the standard set by ASEAN (100 MPN/ 100ml) by a large margin. Thus, it is clear human faecal contamination was an issue in coastal waters. This can have a significant impact on human health and hence the tourism industry since these areas are used for recreational purposes. Given the importance of the tourism industry and its sensitivity to public health issues, the indicator of human waste pollution must be taken to signal need for regular monitoring and implementation of upstream mitigation measures.

## 4.3 The Way Forward

Inadequate information on the execution of the monitoring programme by the CC&RMD has resulted in difficulty in interpreting the data provided and in attempts to compare the data and interpretations with international standards. The gaps in the data provided may suggest constraints in resource availability (manpower, equipment and operational budget) at the CC&RMD for implementation of a more comprehensive monitoring programme.

The Coast Conservation Act (Amendment) No 49 of 2011 requires developing a Coastal Zone and Coastal Resource Management Plan, in which coastal water quality is considered as one of the key aspects. Therefore, data collection, analysis and interpretation of coastal water quality should have support from other government agencies and institutions. These can include regulatory bodies (e.g. CEA, MEPA), R&D institutions (e.g. NARA, ITI) and universities, to supplement the CC&RMD's resources. Box 4.1 shows some of the activities that can be carried out for creating clean and safe coastal zones and sustainable coastal resource management in Sri Lanka.

| **Box 4.1:** Some interventions for developing National Coastal Water Quality Monitoring Programme (NCWQMP). |
| --- |
| • Calling for a multi-stakeholder meeting/forum/workshop for selection of appropriate coastal water quality parameters and development of monitoring programme in accordance with the government regulations and international signatory agreements, where these are applicable. |

- Carrying out a baseline survey in accordance with internationally accepted norms/standards and leveraging on resources from among the relevant stakeholders (e.g. Consortium of public institutions such as CEA, MEPA, NARA, and universities, headed and coordinated by the CC&RMD).
- Conducting an Annual National Expert Panel Conference on Coast Conservation and Costal Resource Management (ANC$^3$&CRM) by inviting researchers from regulatory agencies, R&D institutions, universities and other public/private institutions to present their research findings and discuss future policy directions for sustainable coast conservation and resource management coordinated and chaired by the CC&RMD.
- Executing a public awareness campaign on the importance of protecting coastal recreational areas with the help of public and private media institutions.
- Empowering local communities for **C**itizen-based **E**nvironmental **M**onitoring targeting schools (e.g. selected technology laboratories located along the coastal line)/technical colleges using open-source hardware/software to monitor and report status of coastal water quality on a public web portal apart from the main monitoring programme of the CC&RMD.
- Introducing suitable recognition scheme (e.g. Annual National Best Beach Award) to encourage public/private stakeholders (LGs bodies, hotels and other service providers, community-based organisations, NGOs ) for active participation in keeping clean and safe recreational areas and branding such places among locals and internationals (e.g. Trip Advisor, Lonely Planet, Booking.com ).
- Developing National Coastal Water Quality Index (CWQI), National Beach Grading Scheme (NBGS) and displaying the prevailing status, and encouraging all stakeholders to contribute to reaching the target status (e.g. Blue Flag Beaches) at prominent places (e.g. recreational areas).

### 4.3.1 Coastal Water Quality Parameter Selection for Monitoring

**STEP 1:** Define the purpose and the scope for Coastal Water Quality Monitoring Plan

The basis and purpose of coastal water quality monitoring can be categorized into the following:

- assessment of status or condition, often across a specified spatial area;
- assessment of temporal trends;
- assessment of the impact of legislation and implemented measures; and
- compliance with various national regulatory requirements and/or international agreements

The following general definitions were proposed by Quevauviller (2016) for various monitoring requirements and substances of concern related to different regulatory frameworks (e.g. The Coast Conservation Act) and/or international conventions.

**Monitoring:** Long-term, standardized measurement, observation, evaluation and reporting of the coastal environment in order to define status and trends.

**Survey:** A finite duration, intensive program to measure, evaluate and report the quality of the coastal environment for a specific purpose.

**Surveillance:** Continuous, specific measurement, observation and reporting for the purpose of water quality management and operational activities.

Apart from the above, the following definitions can also be used to define the scope of the monitoring and measurement plans.

**Trend monitoring:** Measurements are made at regular, well-spaced time intervals in order to determine the long-term measurement in a particular parameter.

**Baseline monitoring:** Used to characterize existing water quality conditions and establish a database for planning or future comparisons.

**Implementation monitoring**: Used to assess whether activities have been carried out as per the plan.

**Effectiveness monitoring**: Used to evaluate whether the specified activities had the desired effect.

**Project monitoring**: Assesses the impact of a particular activity or project.

**Validation monitoring**: Deals with the quantitative evaluation of a proposed water quality model to predict a particular water quality parameter.

**Compliance monitoring**: Used to determine whether specified water quality criteria are met.

It can be concluded that any methodology adopted must be "fit for the purpose". This means providing data that are interpretable such that it helps to conclude the status and trends of the coastal water quality of Sri Lanka (See **Box 4.2**: Case Study of WFD of EU).

| **Box 4.2:** Case Study of Water Framework Directive (WFD) of EU (Quevauviller, 2016) |
|---|
| According to Water Framework Directive (WFD) of EU, the member states are mandatory to implement surveillance monitoring, operational monitoring and investigative monitoring. The objective of the **surveillance monitoring** is to provide information on long-term changes in natural conditions and those resulting from widespread anthropogenic activity as well as providing information on the design of future monitoring programs.<br><br>**Operational monitoring** is undertaken to establish the status of water bodies that have been identified as being at risk of failing to meet their environmental objectives and to assess the changes in status of those water bodies as a result of programs and measures. |

Finally, **investigative monitoring** is carried out to ascertain the cause and effects of a failure when either the reason for exceedance is unknown or the magnitude of accidental pollution is unknown.

Therefore, future monitoring programs will be a mixture of classical chemical monitoring, in situ monitoring and biological effect determinations in coastal waters. However, the challenge will be integrating those different methodologies to provide truly holistic assessments, and allocate and manage resources demand for the collection of data as shown in Table 4.2 below.

**Table 4.2:** Various Methodologies and Their Attributes for Developing Coastal Water Quality Monitoring Plan (Source: Quevauviller, 2016).

| **Characteristic** | **Classical chemical Monitoring** | **In-situ chemical monitoring** | **Biological effects monitoring** |
|---|---|---|---|
| **Type of Sampling** | Spot sampling, often from a ship | Single site using Smart Buoy | Spot sampling, often from a ship or 30 min trawl |
| **Frequency of Sampling** | Medium (weekly) or low (monthly or annual) | Very high (15 min) or high (hourly) | Low (monthly or annual) |
| **Spatial Coverage** | Good | Limited by the availability of in situ monitoring devices | Good |
| **Temporal Resolution** | Limited | Good | Limited |
| **Components** | Water, sediment, biota | Water | Biota |
| **Analytes** | Hazardous substances, nutrients, salinity, chlorophyll, biotoxins | Nutrients, salinity, chlorophyll | Indicators of exposure to hazardous substances, e.g. tributyltin (TBT) |
| **Benefit** | ▪ Large number of analytes in water, sediment and biota<br>▪ Technical guidelines available<br>▪ Well established methodologies and quality assurance<br>▪ Assessment criteria available for many analytes | High frequency of monitoring giving excellent temporal resolution | ▪ Can provide information on exposure to a specific contaminant (e.g. TBT)<br>▪ Provides information on the impact of exposure to the environment in which the animal lives<br>▪ Takes account of what is bioavailable |

| | | | |
|---|---|---|---|
| **Limitation /problems** | ▪ Single compound or group of compounds<br>▪ Limited temporal resolution<br>▪ Requires a sampling platform, often a ship | ▪ Analytes currently limited to nutrients, salinity and chlorophyll<br>▪ Subject to biofouling that limits operation<br>▪ Limited spatial resolution | ▪ Many techniques still being developed<br>▪ Limited number of assessment criteria available<br>▪ Cause and effect can be unclear |

| **RECOMMENDATION 1:** Set up a Multidisciplinary Steering Committee |
|---|
| Due to the complexity of requirements by various regulatory agencies such as CEA, NARA, MEPA and CC&RMD and to avoid the repetitive work by these agencies, it is proposed a multidisciplinary and multi-agency steering committee comprising authorized representatives from the above agencies be set up to define the scope and objectives of a coastal water quality monitoring plan. This shall be contingent on agreeing to the principle of resource and data sharing. This steering committee may include a water quality expert, a marine biologist, an analytical chemist, a sociologist, and a policy and planning expert from national R&D intuitions and universities. |

**STEP 2:** Identify National Coastal Water Quality Criteria

Identification of necessary coastal water quality parameters, and prioritizing them if required based on technological and economical capabilities, is very critical for its success in implementation of the National Coastal Water Quality Plan (NCWQP). However, in order to compare the current status of coastal water quality related standards of Sri Lanka with international standards, it is imperative to consider the local regulatory provisions along with the international conventions. Therefore, Table 4.3 shows some of the local and international legal frameworks, which will be appropriate to consider developing the National Coastal Water Quality Criteria. The list is not exhaustive but the authors of this report would argue these frameworks make appropriate starting points based on their scopes and purposes.

**Table 4.3:** National and International Regulatory Requirements/Frameworks Associated with setting up of Coastal/Marine Water Quality Standards/Criteria

| Local Acts and Regulations | International Conventions |
|---|---|
| ▪ The National Environmental Act No. 47 of 1980 and subsequent amendments | ▪ Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (LC), 1972 (and the 1996 London Protocol) |
| ▪ The Marine Pollution Prevention Act No. 59 of 1981 and subsequent amendments | ▪ International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto and by the Protocol of 1997 |
| ▪ The Coast Conservation Act No. 57 of 1981 and subsequent amendments | ▪ International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC), 1990 |
| ▪ The Fisheries and Aquatic Resources Act No. 2 of 1996 | ▪ Protocol on Preparedness, Response and Co-operation to pollution Incidents by Hazardous and Noxious Substances, 2000 (OPRC-HNS Protocol) |
| ▪ The National Aquaculture Development Authority of Sri Lanka Act. No.53 of 1998 | ▪ International Convention on the Control of Harmful Anti-fouling Systems on Ships (AFS), 2001 |
| ▪ The Fauna and Flora Protection Ordinance No. 2 of 1937 and subsequent amendments | ▪ International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 |

**Table 4.3:** National and International Regulatory Requirements/Frameworks Associated with setting up of Coastal/Marine Water Quality Standards/Criteria (Cont'd)

| Local Acts and Regulations | International Conventions |
|---|---|
| ▪ The Industry Development Act 1969 and subsequent amendments | ▪ International Convention on Civil Liability for Oil Pollution Damage (CLC), 1969 |
| ▪ The Control of Pesticides Act 1980 and subsequent amendments | ▪ 1992 Protocol to the International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (FUND 1992) |
| ▪ The National Environment Conservation Act 1989 | ▪ Convention relating to Civil Liability in the Field of Maritime Carriage of Nuclear Material(NUCLEAR), 1971 |

| | |
|---|---|
| ▪ The Chemical Weapons Convention Act 2007 | ▪ International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea (HNS), 1996 (and its 2010 Protocol) |
| ▪ The Factory Ordinance 1942 and subsequent amendments | ▪ International Convention on Civil Liability for Bunker Oil Pollution Damage, 2001 |
| ▪ | ▪ Nairobi International Convention on the Removal of Wrecks, 2007 |
| ▪ | ▪ The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal |

Apart from the above regulatory requirements, it is needed to consider similar practices around the world (ASEAN, UNEP) for setting up the criteria for coastal/marine water quality, which can be used as templates by revising them appropriately.

A study done by AusAID (2008) identified seventeen (17) parameters related to marine water quality as agreed by ASEAN Ministerial Meeting on 20$^{th}$ November 2002 in Vietnam. Considering the similarities in the challenges faced in coastal water quality in ASEAN countries and Sri Lanka (e.g. protecting marine life, harvesting of seafood, high tourism activities) appropriateness of these parameters is strongly likely. These are:

- Sixteen parameters for aquatic life protection (ammonia, cadmium, hexavalent chromium, copper, lead, mercury, cyanide, total phenol, tributyltin, nitrate, nitrite, phosphate, temperature, dissolved oxygen, oil and grease, and total suspended solids); and
- One parameter for human health protection (i.e. bacteria)

Table 4.4 shows the ASEAN marine water quality criteria for protection of aquatic life and human health.

**Table 4.4:** ASEAN Marine Water Quality Criteria for Protection of Aquatic Life and Human Health (Source: AMWQC, 2008)

| Parameter | Criterion for Protection of Aquatic Life | Criteria for Protection of Human Health | |
|---|---|---|---|
| | | Seafood Consumption | Recreational Activities |
| Ammonia (unionized) | 70 µg/L $NH_3$-N | Not applicable | Not applicable |
| Arsenic | 120 µg/L As | 3.0 µg/L As | 60 µg/L As |
| Bacteria[1] | Not applicable | 70 FC/100 mL | 100 FC/100 mL;<br>35 enterococci/100 mL |
| Cadmium | 10.0 µg/L Cd | 23 µg/L Cd | 35.7 µg/L Cd |
| Chromium (VI) | 48 µg/L Cr | Not derived | Not derived |
| Copper | 2.9 µg/L Cu | Not applicable | 500 µg/L Cu |
| Cyanide | 7.0 µg/L | 32 mg/L | 1.5 mg/L |
| Dissolved Oxygen | 4.0 mg/L | Not applicable | Not applicable |
| Lead | 8.5 µg/L Pb | Not derived | Not applicable |
| Mercury | 0.16 µg/L Hg | 0.04 µg/L Hg | 21 µg/L Hg |
| Nitrite/Nitrate | 55 µg/L $NO_2$-N<br>60 µg/L $NO_3$-N | Not applicable | Not applicable |
| Oil and Grease | 0.14 mg/L (WSF)[1] | Not derived | Not derived |
| Phenol | 0.12 mg/L | 23.8 mg/L | 30 mg/L |
| Phosphate | 45 µg/L (estuaries)<br>15 µg/L (coastal) | Not applicable | Not applicable |
| Temperature | ≤2°C increase over maximum ambient | Not applicable | Not applicable |
| Tributyltin (TBT) | 0.010 µg/L TBT | Not derived | Not derived |
| TSS | ≤10% increase over seasonal average | Not applicable | ≤10% increase over seasonal average |
| Zinc | 50 µg/L Zn | Not applicable | 1,250 µg/L Zn |

These 17 parameters are known as the ASEAN Marine Water Quality Criteria (AMWQC) and set values to guide concerted national level action to protect the shared marine waters of ASEAN. However, the monitoring programme in this study had focused only on pH, DO, Salinity, Electrical Conductivity and Faecal Coliform, and TDS at some places. Therefore, there is need to review the monitoring parameters according to internationally accepted standards.

| **RECOMMENDATION 2:** Identify National Coastal Water Quality Criteria |
|---|
| It would be appropriate to consult various stakeholders involved in water quality monitoring, policy planning and implementation in government agencies to reach consensus on the water quality parameters required by the various regulatory |

frameworks, in accordance with prevailing and anticipated future legal scenarios, by considering both local and international conventions. The following short, medium and long term monitoring parameters can be considered. These are based on ASEAN standards and may require review and appropriate modification during formulation of the National Coastal water Quality Criteria.

**Short-term:** A subset of the ASEAN guidelines can be used to establish the status of coastal water quality with minimum resources. This can include parameters such as BOD, COD, Ammonia, Nitrate, Phosphate, DO, Oil & Grease, Total Suspended Solids (TSS), Fecal Coliform, DO and Temperature.

**Medium-term:** This can include metals as indicated in the ASAEN guidelines such as Cd, $Cr^{6+}$, Cu, Pb, Hg, and Tributyltin (anti-fouling agent) in addition to the short-term list.

**Long-term:** Real-time monitoring coupled to GIS based system can be developed. This will require considerable investment. However, limitations of reliable sensing systems for parameters listed in short and medium terms should be considered carefully. Remote sensing and image analysis techniques may be an alternative approach instead of expensive instrumentation systems for various water quality parameters (Chang *et al.*, 2015).

**Other Supporting Infrastructure:** Low-cost, yet reliable weather stations can be set up close to monitoring stations in order to capture micro-climatic conditions. This will be useful when interpreting the data with respect to rainfall and changes in the water quality parameters close to sea outfalls.

**STEP 3:** Setting up of Infrastructure and Execution of Monitoring Plan

Based on the agreed National Coastal Water Quality Parameters, setting up of infrastructure and monitoring plan execution should be carried out. Initially offline analyses of selected parameters would be appropriate due to the high initial cost for real-time monitoring infrastructure. However, a conceptual framework can be set up as shown in Figure 4.1 in anticipation of development of new technologies and improved affordability. These automated systems may improve monitoring consistency, help developing predictive models using the recorded data for easier and quicker decision making, support for policy formulation and implementation.

Sampling, sample storage, transportation, and onsite/offsite analyses of water quality parameters (chemical/physical/biological) should be carried out in consistent manner irrespective of the person, location, equipment and laboratory in which required analyses are done to avoid random and systematic biases.

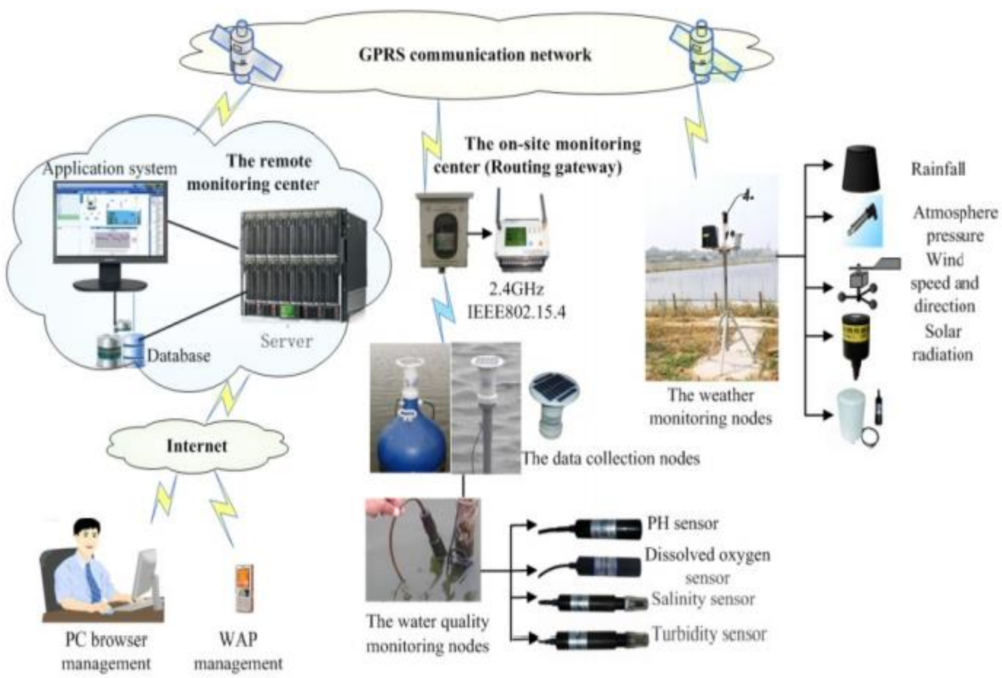



**Figure 4.1:** Digital Remote Wireless Monitoring System (Mukhopadhyay et al., 2013)

| **RECOMMENDATION 3:** Develop a Protocol Manual based on Standard Operating Procedures for Sampling, Sample Storage, Transportation and Analyses |
|---|
| A protocol manual which is easy to refer to and yet information rich can be developed and provided for the field officers and analysts to maintain consistency from sampling to results interpretation. The manual can be based the standards practices used by organizations such as the USEPA/ISO/BS for the selected water quality parameters. This |

will be very useful for interpreting the data obtained from the field work by various/changing field officers. It would be appropriate to set up/use regional resource centers/universities to reduce the cost of manpower, sample storage time, sample transportation due to the geographical distribution of monitoring locations, and logistics required for transporting them to a central lab. However, an appropriate mechanism is needed to coordinate with local/regional resource centers.

### 4.3.2 Data Collection, Analysis and Result Interpretation

The AMWQC (2008) stated that the correct statistical analysis of the data collected in a monitoring program is essential to fully utilise all available information and to provide adequate, confident direction in the outcomes of the program. Further it need be mentioned that before starting any monitoring program, the following decisions are required:

- Whether data is collected for estimates or comparisons
- The desired precision for estimates
- The specifications of direction of change for comparisons
- The probability of acceptance of a difference
- The probability that the test will detect a difference

These decisions will have been a consideration when designing the monitoring program, in the context of the system model (AMWQC, 2008).

### A Road Map for Developing National Coastal Water Quality Monitoring Framework

Table 4.5 shows a tentative roadmap to match the international requirements for monitoring coastal water quality. This can be implemented phase-wise as it needs significant resources to realise set objectives. In developing this, it can be used the current monitoring infrastructure and identify gaps required to match the international standards.

**Table 4.5:** Development of National Coastal Water Quality Monitoring Programme

| Phase | Goals/Activities | Resources Required/Key Players | KPIs and Time Frame |
|---|---|---|---|
| **Phase 1** | **Goal 1.1:** Critical Review of Current Status of Coastal Water Quality in Sri Lanka<br>• Analysis of data collected from 2009 to 2016<br>• Trends analysis and comparison with other sources on current standards measurements to evaluate the true status of the coastal water quality<br>• Identification potential root-causes<br><br>**Goal 1.2**: Identification of Future Directions and Strategies for Sustainable Coastal Water Quality Monitoring Programme<br>• Legal framework and analysis of current recommendations on coastal water quality<br>• Comparison of similar exercise used regionally and internationally<br>• Identification of international compliance, bilateral and multilateral agreements on marine water pollution considering global trends | **Resources:**<br>• Existing laboratory facilities<br>• Technical personnel within CC&CRMD<br>• Compiled collected data by various agencies from various sources<br>• Potential partner institutions from public and private sectors<br><br>**Key Players:**<br>CC&CRMD, CEA, MEPA, NARA, Planning Ministry, National R&D Institutions/ Universities | **KPIs:**<br>• Declared current coastal water quality status as safe (**Green**), gradual deteriorating (**Amber**), dangerous (**Red**) or no sufficient data/information to make a decision (**Black**)<br><br>• Identified measurement gaps and improvement requirements<br><br>• Benchmarked coastal water quality considering environmental, economic and social aspects<br><br>• Identified future directions and strategies for sustainable coastal water quality monitoring<br><br>**Time Frame:** 6 Months |

**Table 4.5:** Development of National Coastal Water Quality Monitoring Programme (Cont'd)

| Phase | Goals/Activities | Resources Required/Key Players | KPIs and Time Frame |
|---|---|---|---|
| **Phase II** | **Goal 2.1:** Planning and Development of Sustainable Coastal Water Quality Monitoring Programme<br>• Consultation with public/private organization for developing coastal water quality monitoring<br>• Identification minimum criteria required for national/regional and international compliance<br>• Extraction/modification of standards procedures/protocols for monitoring of coastal water quality<br>• Identification technical specifications for measurement instruments and technologies<br>• Proposal development for potential funding agencies<br>• Procurement of necessary equipment and setting infrastructure in-place.<br><br>**Goal 2.2:** Implementation of National Coastal Water Quality Monitoring Programme<br>• Identification of vulnerable locations in terms of the highest impact on coastal water quality<br>• Mobilization of resources in identified monitoring sites | **Resources:**<br>• Literature survey<br>• Local acts, laws and other related information sources<br><br>**Key Players:** CC&CRMD, MEPA, CEA, NARA, R&D Institutions/ Universities | **KPIs:**<br>• Implementable plan with identified resources and budget<br>• Availability of finance and implementation infrastructure<br>• Well-defined monitoring protocols<br><br>**Time Frame:** 12 Months |

# Appendix I

1. **Graphs of Arugambay**

2. **Graphs of Mt. Lavinia**

3. **Graphs of Polhena**

4. **Graphs of Hikkaduwa**

5. **Graphs of Nilaweli**

6. **Graphs of Unawatuna**

# Appendix II

1. **Maps of Mt. Lavinia**
2. **Maps of Polhena**
3. **Maps of Hikkaduwa**
4. **Maps of Nilaweli**
5. **Maps of Unawatuna**

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