Optimization and Computational Case Studies in Civil Engineering

K. Jagannadha Rao
Angshuman Das
Editors

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Optimization and Computational Case Studies in Civil Engineering

K. Jagannadha Rao, Angshuman Das, editors (Chaitanya Bharathi Institute of Technology (A), Hyderabad, India)

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Preface

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In the dynamic realm of civil engineering, ongoing research endeavours strive to enhance safety, sustainability, and efficiency in urban areas and construction projects. Optimization techniques and statistical analyses have emerged as indispensable tools, facilitating data-driven decision-making and fostering advancements in the discipline. This book has addressed various pressing issues prevalent in developing urban areas, emphasizing the potential of statistical and optimization techniques to deliver economic and effective solutions.

The research presented in the first chapter is based on developing flood inundation maps in one of the main rivers of Bangladesh named "Buriganga". The main purpose of these inundation maps is to depict the degree of flood damage based on flood depth classification. The inundation maps are based on different administrative Upazila. ArcGIS (Aeronautical Reconnaissance Coverage Geographic Information System) has been used for developing flood inundation maps. Results were obtained from the simulation of 1D/2D coupled hydrodynamic model in HEC-RAS (Hydrologic Engineering Center River Analysis System). Results acquired from the simulation were maximum flood depth, maximum flood flow velocity, and maximum inundation area for different historical flood events and return periods. Second chapter is presented to utilize the Soil and Water Assessment Tool to simulate streamflow in this basin via a watershed model called ArcSWAT. The outcomes of this study found helpful in water resource management and mitigation of flood in this basin. This chapter includes Sequential Uncertainty Fitting technique, which was applied for analysis of the data and allowed for calibration and global sensitivity using the SWAT-Calibration and Uncertainty Program (SWAT-CUP). The feasibility of this model was reported on the basis of R2 and NSE (Nash Sutcliffe efficiency).

Next chapter has explored several insights on settling phenomenon of particulate matter in ambient air. These insights are completely new or newly explained to the study. However, to narrate such several insights, the study has applied the subjective interpretation, combined with logical motions and innovation.Fourth chapter presents the evaluation of project cost management and cost trend analysis using qualitative and quantitative methods, survey will be distributed with engineers and interview with industry experts. The expected results are used to evaluate and analyse the factors that affect project costs, and how to maintain the budget. Also, to understand the importance of cost trend analysis.

The last chapter presents an integrated approach for investigating surface water quality for drinking purposes and applying it to the Mahanadi River in Odisha using Information entropy, geographic information systems (GIS), and an examined of the use of TOPSIS and ELECTRE as multi-objective decision-making tools.

With a collective focus on addressing real issues in developing urban areas, the book aims to provide practical and effective solutions, facilitating progress and sustainability in civil engineering practices. All chapters were subjected to double blind peer-review process.

At this stage, we wish to thank all authors who have contributed for this book and confirmed their willingness to pursue the publication despite the unusual boundary conditions.

1

Flood Inundation Mapping of Buriganga River Floodplain using HEC-RAS 1D/2D Coupled Model

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Abstract

Bangladesh, as a low-lying country, is prone to flooding. Flooding has adverse effects on many social and economic aspects. This research has been constructed based on developing flood inundation maps in one of the main rivers of Bangladesh named "Buriganga". The main purpose of these inundation maps is to depict the degree of flood damage based on flood depth classification. The inundation maps are based on different administrative Upazila. ArcGIS (Aeronautical Reconnaissance Coverage Geographic Information System) has been used for developing flood inundation maps. Results were obtained from the simulation of 1D/2D coupled hydrodynamic model in HEC-RAS (Hydrologic Engineering Center River Analysis System). Results acquired from the simulation were maximum flood depth, maximum flood flow velocity, and maximum inundation area for different historical flood events and return periods. The findings of the analysis showed that among all historical flood events, the event of 1988 was disastrous in nature. In 1988, the most and least affected areas during maximum inundation were Kadamtali Thana and Serajdikhan Thana. This study will aid in providing an overview of the degree of flood damage that has already occurred. Thus, it will help in planning different mitigation measures and managing future aspects of socio-economic vulnerability.

Keywords

ArcGIS, Flood Inundation Map, HEC-RAS

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1. Introduction

Bangladesh has two major distinctive features which are: a vast deltaic plain that is contingent to excessive flooding due to intense precipitation events in the monsoon season; and a small hilly region in the southeast and the northeast parts crossed by high-velocity rivers, carrying water all the way down to the Bay of Bengals, and depositing sediment throughout the river area [1]. The location of Bangladesh is on the Brahmaputra River Delta, also known as the Ganges Delta. Ganges delta is the largest river delta in the world which carries the combined water of several river streams, mainly the Brahmaputra River and the Ganges River [2]. In the Brahmaputra River, the greatest release happens during early rain events in June and July, though within the Ganges River, the most extreme release happens in August and September [3].

"The Buriganga River is the main river in Dhaka, the capital of Bangladesh. Old Dhaka was established as a provincial capital by the Mughal rulers on the northeastern bank of the Buriganga River during 1608-10" [4]. So, studying the characteristics of flood inundation in the Buriganga River is essential.

The objective of our research is to study how much area will be flooded and other flood analyses due to a given discharge and water level. For the very first time, HEC-RAS (Hydrologic Engineering Center River Analysis System) has been used employing a sophisticated 1D/2D coupled hydrodynamic model for the flood inundation analysis. Flood frequency analysis has been done for 30-, 50- and 100-year return periods, utilizing the Gumbel Distribution method. The fabrication of flood inundation maps for selected well-known historical flood events as well as for diverse future return periods has been studied. This research exclusively focuses on the Buriganga River's floodplain, encompassing the regions of Dhaka, Narayanganj, and Munshiganj districts.

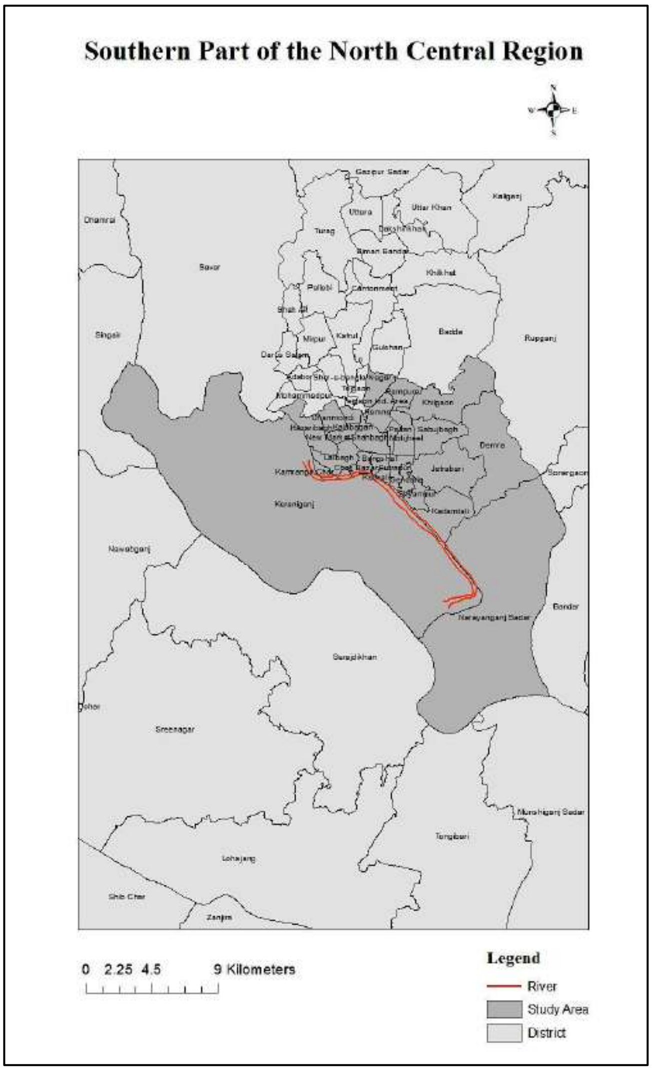

Fig. 1. Buriganga river system near Dhaka, Narayanganj, and Munshiganj districts of Bangladesh

2. Methodology

2.1 Study Area

The Buriganga river catchment, located between 23̊38′ N latitude and 90̊26′ E longitude, is used for this study. The boundary of the Buriganga River is considered from Bosila (where the river Turag ends at a distance of about 11 km downstream from Aminbazar bridge at Mirpur) to Hariharpara (where Buriganga meets with Dhaleswari downstream). This section of the river covers a distance of 16.5 km. Buriganga river has been chosen for developing flood inundation maps to develop an advanced alert system due to frequent flooding in this area. The hydrodynamic characteristics of the Buriganga River are influenced by the tropical changes in various climatic types prevalent in the study area. The time-dependent changes in various meteorological aspects such as rainfall level, time span, ambient temperature, atmospheric moisture, vapor release, and wind speed affect the discharge levels along the hydrological pathways. These changes ultimately have an impact on the quality of water in the river [5]. Fig. 1 depicts the study area of this research.

2.2 Data Collection

The study area's cross-sectional, water-depth, discharge, and landscape profile data were acquired in accordance with the hydrodynamic and flood model specifications. Discharge records from 2005-2020 and water-level data from 1985-2020 were obtained from BWDB (Bangladesh Water Development Board) for stations of Mirpur, Dhaka Mil Barac and Hariharpara. Cross-section data (2019) of Buriganga River (RMBG1-RMBG6) was also collected from BWDB. The corresponding data of the digital Elevation Model (2021) and satellite images for the Southern portion of the North Central Region of Bangladesh (2021) were gathered from USGS/ Earth Explorer. For topography, Shuttle Radar Topography Mission (SRTM) data was used.

2.3 Data Map Preparation and Model Development

A stream centerline layer of Buriganga river reach was created first, and later riverbanks were defined. Flow paths from upstream to downstream were defined and digitized for left riverbank, central channel, and right riverbank. The Cross-section Cut Line theme represents the location, position and size of cross-sections. Cross Section Cut Line themes were extracted and later digitized using ArcGIS and HEC-RAS.

After exporting the data, the one-dimensional hydrodynamic model of the study area was developed. Around twenty-two numbers of river cross-sections were integrated for the development of the model. As a boundary condition, the stage hydrograph was considered for both upstream and downstream calculations.

2.4 Model Performance Evaluation

It is essential to conduct tests to determine the level of precision with which the model reproduces river processes. Mirpur was considered as the upstream station and Hariharpara as the downstream station. Dhaka Mill Barrack was considered to be an intermediate hydrologic station. Calibration was done in this study using Hariharpara. Later the Model data was tested with the observed data set. Validation was done in this study using the Hariharpara station. For calibration and validation, the 2016 and 2018 dataset was used respectively.

In this research, recognized quantitative statistical performance metrics, including Coefficient of Determination (R^2), Coefficient of Nash-Sutcliffe Efficiency (NSE), Percent BIAS (PBIAS), and RMSE-Observations Standard Deviation Ratio (RSR), were employed to evaluate the performance of the developed 1D/2D coupled hydrodynamic model for the Buriganga River. These metrics facilitated the comparison between simulated results and observed data.

2.5 Layering and Modification of Terrain Data

After connecting the terrain model with geometry and plan, it is possible to perform layering in RAS Mapper. The floodplain geometry can be visualized using this terrain. As a result, to capture the terrain's features accurately, the size of each grid cell must be sufficiently small. Previously, a digital terrain model of the research region was created using a new layer tool. This terrain model was employed to preprocess data for 2D flow regions, enabling computation of flood depths and inundation extents according to simulation outcomes. The BTM (Bangladesh Transverse Mercator) projection was adopted as an ESRI file to develop the terrain layer. All of the data were projected into the chosen coordinate system until projection was included. The initial terrain model insufficiently represented the ground surface. So, a new terrain in RAS-MAPPER was formed to improve the terrain data. The resample to the single terrain option was used to generate a single RAS terrain at the specified cell size. After that, cross-sections were used to create an interpolation surface terrain. "Merge input terrains to single raster" was used to bring in multiple tiles that are of the same cell size resolution to create a single continuous surface.

2.6 2D Flow Area Computational Mesh and Lateral Structure

A 300 m × 300 m grid resolution polygon boundary was defined for the 2D flow area (regions where flow occurs on both sides of the Buriganga River). A Finite Volume solution scheme was used in the HEC-RAS 2D modeling capability.

Three lateral structures on both sides of the Buriganga River were included on the upstream and downstream portions. In this model, a close equivalent elevation was maintained for both bank elevation and levee height.

2.7 1D and 2D Coupled Model Generation

Stage hydrograph was used as a boundary condition. Calibrating the 2D flow domain for unsteady flow simulations included implementing boundary conditions using different time series datasets. Later, water surface profiles were generated for the year 1988. These data were exported in Geographic Information System (GIS) format data to create a floodplain map and the depth of the flooding map. The main focus of this study involves the development of a 1D/2D coupled model for the Buriganga River floodplain, utilizing HEC-RAS 5.0.7., a software developed by the United States of Army Corps of Engineers (USACE). The equations employed for this coupled modeling are presented below. The 2D Saint-Venant equation was effectively employed to solve HEC-RAS 5.0.7 [6].

$$\frac{\partial \zeta}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=0 \tag{1}$$

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)=-\frac{n^2 pg\sqrt{p^2+q^2}}{h^2}-gh\frac{\partial \xi}{\partial x}+pf+\frac{\partial}{\rho\partial x}\left(h\tau_{xx}\right)+\frac{\partial}{\rho\partial y}\left(h\tau_{xy}\right) \tag{2}$$

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)=-\frac{n^2 qg\sqrt{p^2+q^2}}{h^2}-gh\frac{\partial \xi}{\partial x}+qf+\frac{\partial}{\rho\partial x}\left(h\tau_{yy}\right)+\frac{\partial}{\rho\partial y}\left(h\tau_{xy}\right) \tag{3}$$

Where h is the water depth (m), p and q are the specific flow in the x and y direction (m^2s^{-1}), ζ is the surface elevation (m), g is the acceleration due to gravity (ms^{-2}), n is the Manning resistance, ρ is the water density (kgm^{-3}), τ_{xx}, τ_{xy}, and τ_{yy} are the components of the effective shear stress and f is the Coriolis (s^1) [7].

2.8 Flood Inundation and Flood Flow Velocity

Flood inundation depths were within the study region sorted into five tires: F_0 (0-0.3 m), F_1 (0.3-0.9 m), F_2 (0.9-1.8 m), F_3 (1.8-3.6 m), and F_4 (> 3.6 m). Additionally, flood flow velocities were grouped into five categories: V_0 (0-0.15 ms^{-1}), V_1 (0.15-0.3 ms^{-1}), V_2 (0.3-0.45 ms^{-1}), V_3 (0.45-0.60 ms^{-1}), and V_4 (> 0.6 ms^{-1}) [8].

3. Results and Discussion

The model is calibrated using the 2016 dataset, and the model is validated using the 2018 dataset. As a boundary parameter, stage hydrographs were used. For both calibration and validation, the observed station's daily average water level data is compared to the model’s simulated performance. Fig. 2 and Fig. 3 depict the stage hydrograph for Hariharpara station, which displays a comparison between the observed and simulated performances based on Manning’s ‘n’ value of 0.027 for the main channel.

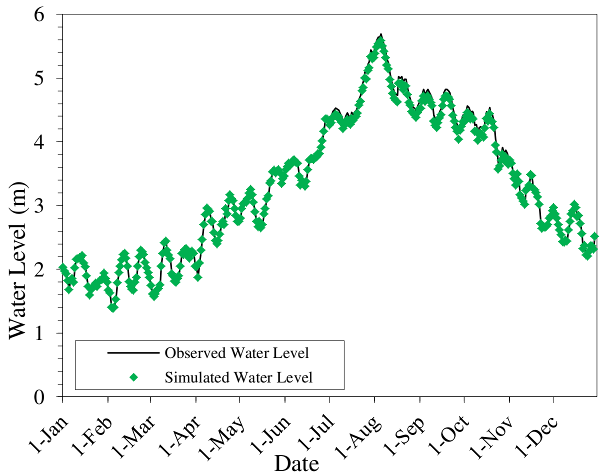

Fig. 2. Calibration hydrograph

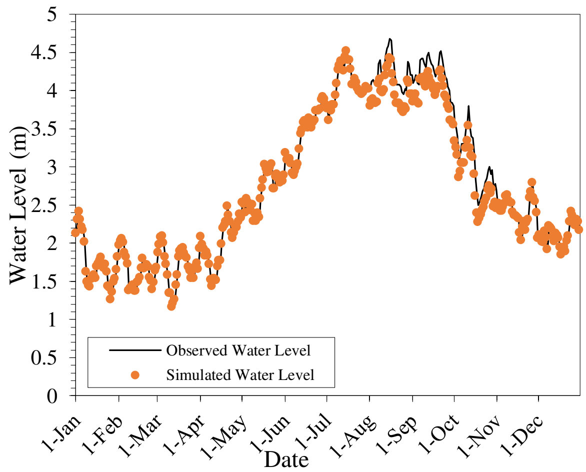

Fig. 3. Validation hydrograph

Fig. 4. Inundation area map 10 August 1988

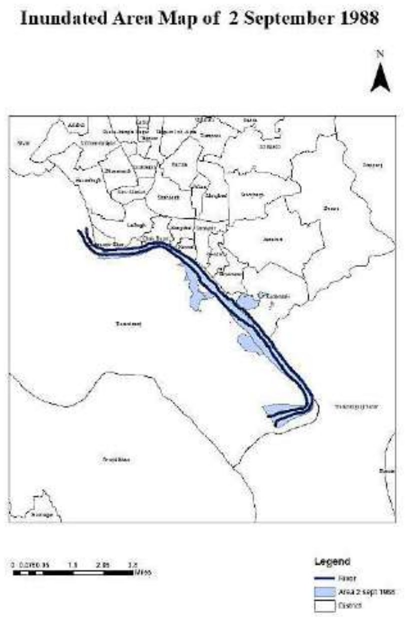

Fig. 5. Inundation area map 2 September 1988

In unsteady calibration, the coefficients of determination R^2, PBIAS, and Nash Sutcliffe Efficiency (NSE) were determined to be 0.94, 2.5, and 0.87, respectively. These values indicate that the simulated value closely resembles the observed value. The coefficients of determination R^2, PBIAS, and Nash and Sutcliffe

Efficiency (NSE) have been found 0.89, 2.8, and 0.85, respectively, in unsteady validation, suggesting that the validated value is similar to the observed value.

3.1. Flood Inundation Map and Area Analysis

HEC-RAS conducts flood model simulations and displays them using RAS-Mapper without reliance on GIS assistance. Multiple shapefiles representing different flood extents were generated for various time periods. Subsequently, the exported shapefile in GIS facilitated the assessment of the inundated area, encompassing the main channel, for flood inundation evaluation. The computation of each flood depth class area aided in defining the categorization of flood depths.

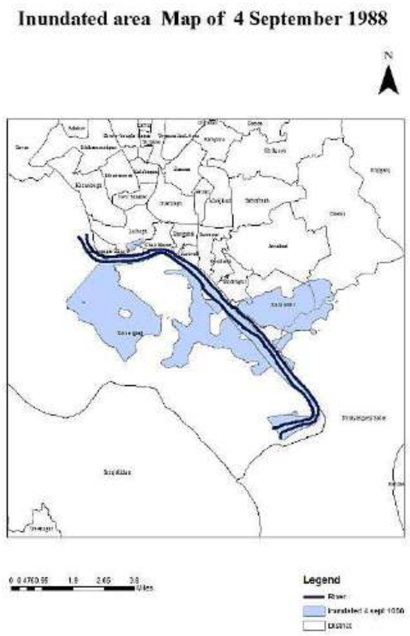

Fig. 6. Inundation area map 4 September 1988

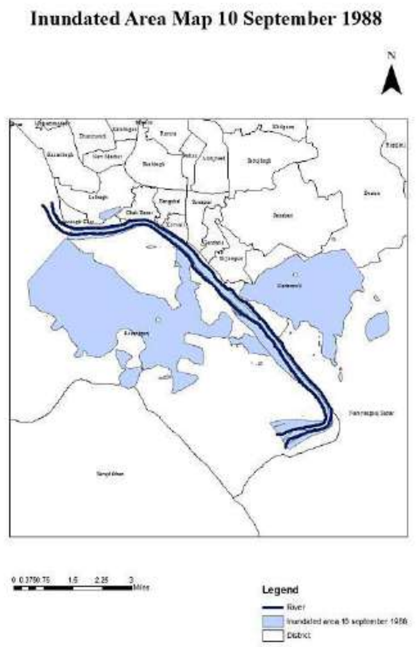

Fig. 7. Inundation area map 10 September 1988

Table 1. Inundation area of 10 August 1988

District Name	Thana Name	Land Type	Area (m^2)	Inundated Area (m^2)	%
Dhaka	Chak Bazar	Land	1633734.8	59512.7	3.64
Dhaka	Kadamtali	Land	8878120.3	333607.8	3.76
Dhaka	Kamrangir Char	Land	1610062.3	393245.1	24.42
Dhaka	Keraniganj	Land	190677011.9	4606361.6	2.42
Narayanganj	Narayanganj Sadar	Land	99854101.3	246414.2	0.25

Table 2. Inundation area of 2 September 1988

District Name	Thana Name	Land Type	Area (m^2)	Inundated Area (m^2)	%
Dhaka	Chak Bazar	Land	1633734.83	82645.09	5.06
Dhaka	Kadamtali	Land	8878120.28	1033962.51	11.65
Dhaka	Kamrangir Char	Land	1610062.33	454299.50	28.22
Dhaka	Keraniganj	Land	190677011.86	8645965.83	4.53
Dhaka	Shyampur	Land	2293924.06	33679.84	1.47
Narayanganj	Narayanganj Sadar	Land	99854101.29	268688.34	0.27

In 1988, four consecutive days were observed in the study region for the review of inundation scenarios from May to September. 10 August, 2 September, 4 September, and 10 September are the dates for observation. Fig. 4 – Fig. 7 display a model-simulated inundation flood map for those precise dates, and Table 1 – Table 4 indicate the amount of inundation areas. On 10 August, the maximum and minimum inundation area percentages were approximately 24.42 percent and 0.25 percent, 28.22 percent and 0.27 percent on 2 September, 61.95 percent and 0.41 percent on 4 September, 64.95 percent and 0.02 percent on 10 September and 59.38 percent and 0.02 percent on 13 September.

Table 3. Inundation area of 4 September 1988

District Name	Thana Name	Land Type	Area (m^2)	Inundated Area (m^2)	%
Dhaka	Chak Bazar	Land	1633734.83	83268.33	5.10
Dhaka	Demra	Land	22376005.78	1069371.50	4.7/
Dhaka	Jatrabari	Land	12264492.94	50097.36	0.41
Dhaka	Kadamtali	Land	8878120.28	5499970.38	61.9497
Dhaka	Kamrangir Char	Land	1610062.33	501412.77	31.14
Dhaka	Keraniganj	Land	190677011.90	26545358.24	13.92
Dhaka	Lalbagh	Land	4256260.10	196271.60	4.61
Dhaka	Shyampur	Land	2293924.06	100300.23	4.37
Narayanganj	Narayanganj Sadar	Land	99854101.29	2330552.31	2.33

Table 4. Inundation area of 10 September 1988

District Name	Thana Name	Land Type	Area (m^2)	Inundated Area (m^2)	%
Dhaka	Chak Bazar	Land	1633734.83	81337.26	4.98
Dhaka	Demra	Land	22376005.78	1634737.67	6.86
Dhaka	Jatrabari	Land	12264492.94	110919.90	0.90
Dhaka	Kadamtali	Land	8878120.28	5766192.29	64.95
Dhaka	Kamrangir Char	Land	1610062.33	487638.70	30.29
Dhaka	Keraniganj	Land	190677011.9	30892845.32	16.20
Dhaka	Lalbagh	Land	4256260.1	224400.07	4.80
Dhaka	Shyampur	Land	2293924.06	23973.05	1.05
Munshiganj	Seajdikhan	Land	173749913.96	36967.77	0.02
Narayanganj	Narayanganj Sadar	Land	99854101.29	5575465.08	5.58

3.2. Flood Inundation Depth Analysis

Fig. 8 – Fig. 11 show the flood inundation depth of the study region in 1988 (10 August, 2 September, 4 September, and 10 September). RAS-Mapper has been used to build the depth map, which is then exported as raster files into GIS.

These Figures reveal that the F_1 flood depth zone exhibits significantly greater coverage compared to other depth categories during the Monsoon periods. Conversely, the F_4 flood depth class had a smaller area. Each of the flood depth categories, including F_1, F_2, F_3, and F_4, have also been observed to increase with the passage of time until September.

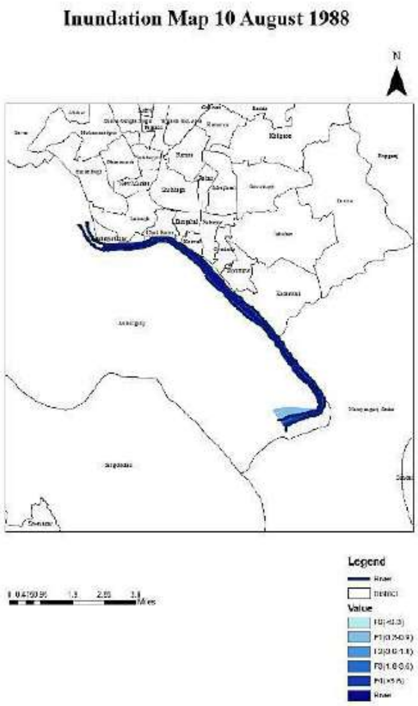

Fig. 8. Inundation depth map 10 August 1988

Fig. 9. Inundation depth map 2 September 1988

Fig. 10. Inundation depth map 4 September 1988

Fig. 11. Inundation depth map 10 September 1988

3.3. Flood Inundation Velocity Analysis

The flood velocity data for the studied region was exported as a RASTER format and subsequently underwent additional processing to generate maps that visually depict the geographical change in flood flow rate across the overall study area. The flood depth is classified into five classes denoted as V_0, V_1, V_2, V_3, and V_4, each representing defined intervals: 0-0.15 ms^{-1}, 0.15-0.30 ms^{-1}, 0.30-0.45 ms^{-1}, 0.45-0.60 ms^{-1}, and >0.60 ms^{-1}, respectively. Fig. 12 shows a map depicting the spatial variation of flood flow velocities for the highest inundation conditions in 1988.

3.4. Analysis of Future Flood Inundation Depth

Fig. 13 – Fig. 16 display flood inundation maps for the base time, 2047s, 2067s, and 2117s. Flood depths are categorized into five groups in these inundation maps as adapted for historical flood depth mapping. When comparing flood depth maps from various time periods, it reveals a notable escalation in flood depth, evolving from the initial reference point to the year 2117. This transition is visually depicted by the increasing intensity of the blue shades in the flood depth mapping, signifying the progressive nature of this change over time.

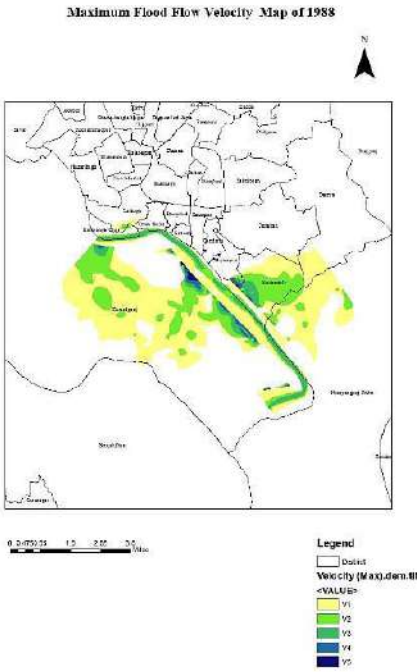

Fig. 12. Maximum flood flow velocity map of 1988

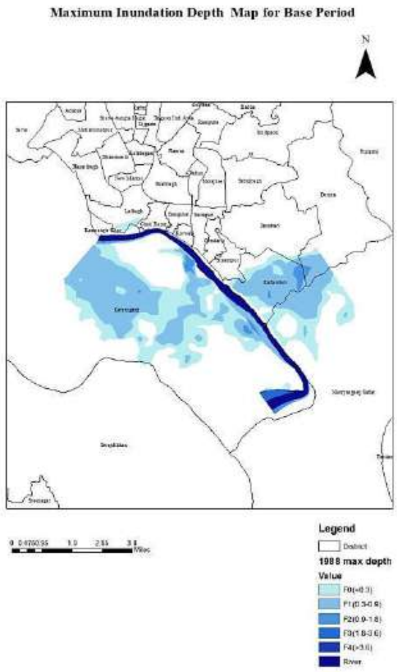

Fig. 13. Maximum inundation depth map for base period

Fig. 14. Maximum inundation map for 30 years return period

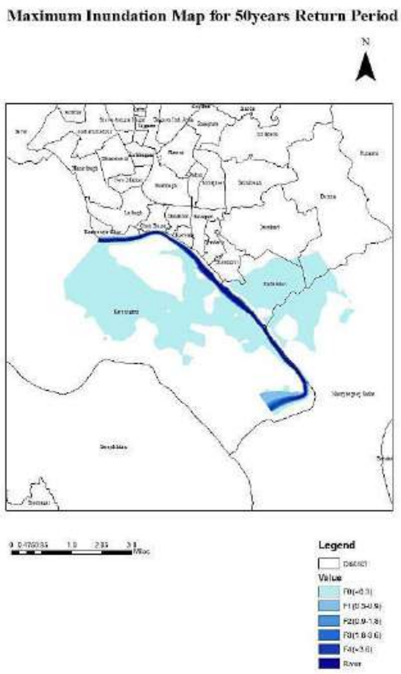

Fig. 15. Maximum inundation map for 50 years return period

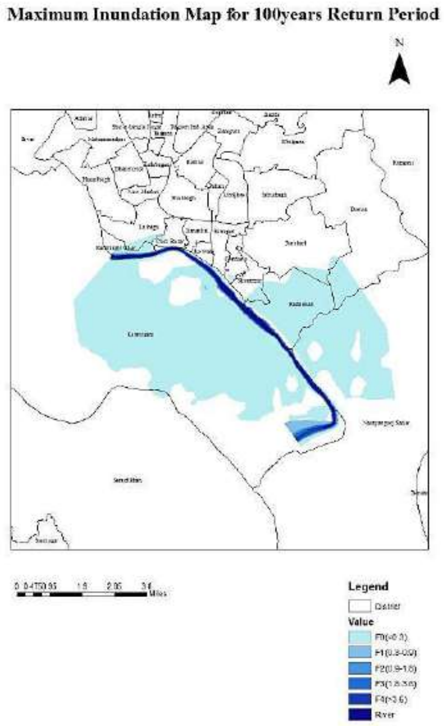

Fig. 16. Maximum inundation map for 100 years return period

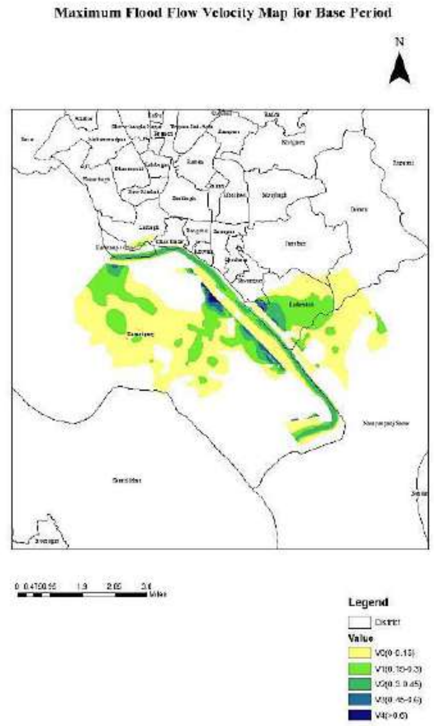

Fig. 17. Maximum flood flow velocity map for base period

3.5. Analysis of Future Flow Velocity

The RASTER file containing flood flow velocity data from the study region was processed further to generate maps that depict the spatial distribution of flood flow velocity across the floodplain. These maps cover the base time as well as the years 2047, 2067, and 2117.

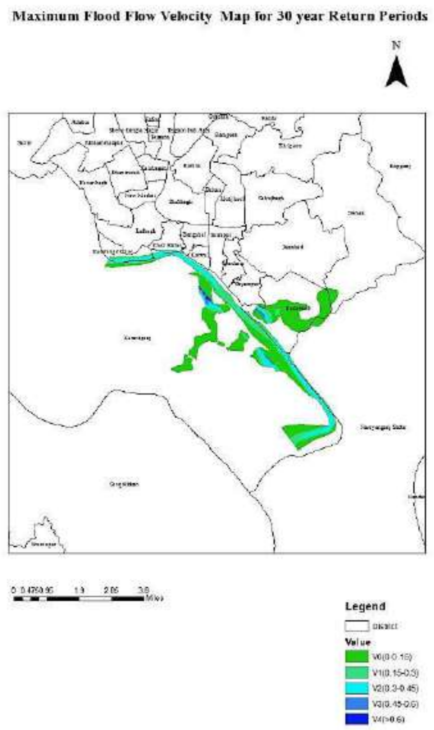

Fig. 18. Maximum flood flow velocity map for 30 years return period

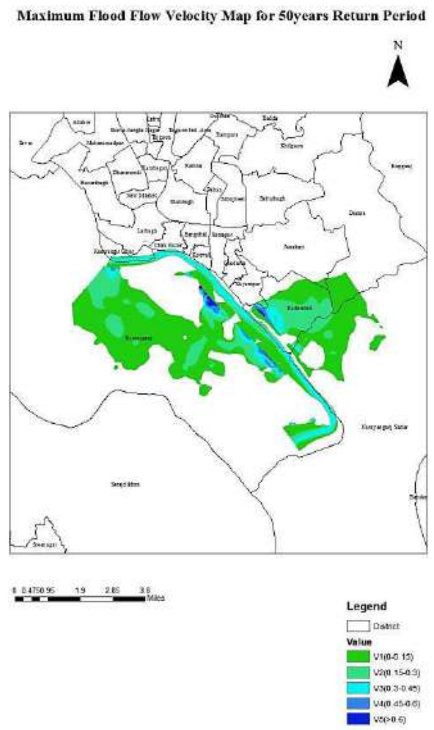

Fig. 19. Maximum flood flow velocity map for 50 years return period

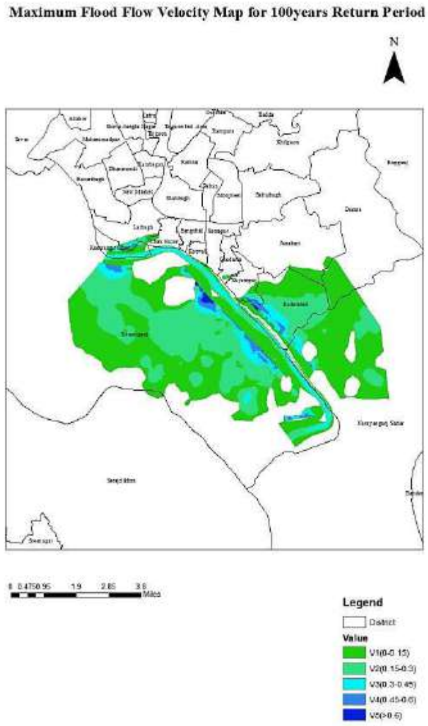

Fig. 20. Maximum flood flow velocity map for 100 years return period

Fig. 21. Flood inundated area of 30 years return period

3.6. Analysis of Future Flood Inundated Area

The figures represented in Fig. 21 – Fig. 23 illustrate the maps displaying the extent of flood inundation for both base and projected future time periods. The potential percentage of inundated area is shown in Table 5 – Table 7. In the 2047s, 2067s, and 2117s, the highest inundated area percentages are about 38.99 percent, 76.25 percent, and 90.05 percent, respectively.

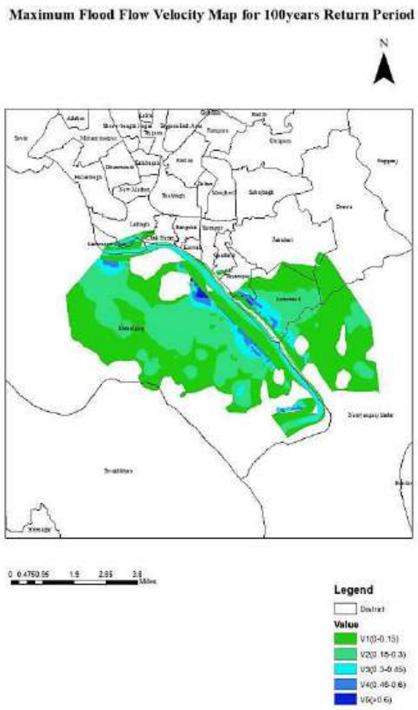

Fig. 22. Flood inundated area of 50 years return period

Fig. 23. Flood inundated area of 100 years return period

Table 5. Maximum inundated area for 30 years return period

District Name	Thana Name	Land Type	Area (m^2)	Inundated Area (m^2)	%
Dhaka	Chak Bazar	Land	1633734.83	82560.65	5.05
Dhaka	Demra	Land	22376005.78	256342.98	1.15
Dhaka	Jatrabari	Land	12264492.94	2623.34	0.02
Dhaka	Kadamtali	Land	8878120.28	3461392.42	38.99
Dhaka	Kamrangir Char	Land	1610062.33	454075.82	28.20
Dhaka	Keraniganj	Land	190677011.90	11030041.75	5.79
Dhaka	Shyampur	Land	2293924.06	51045.68	2.23
Narayanganj	Narayanganj Sadar	Land	99854101.29	538445.54	0.54

Table 6. Maximum inundated area for 50 years return period

District Name	Thana Name	Land Type	Area (m^2)	Inundated Area (m^2)	%
Dhaka	Chak Bazar	Land	1633734.83	83241.33	5.10
Dhaka	Demra	Land	22376005.78	1615985.79	7.22
Dhaka	Jatrabari	Land	12264492.94	158910.37	1.30
Dhaka	Kadamtali	Land	8878120.28	6769489.87	76.25
Dhaka	Kamrangir Char	Land	1610062.33	461336.21	28.65
Dhaka	Keraniganj	Land	190677011.90	32973878.80	17.30
Dhaka	Lalbagh	Land	4256260.10	7264.85	0.17
Dhaka	Shyampur	Land	2293924.06	115466.33	5.03
Narayanganj	Narayanganj Sadar	Land	99854101.29	6718774.90	6.73

Table 7. Maximum inundated area for 100 years return period

District Name	Thana Name	Land Type	Area (m^2)	Inundated Area (m^2)	%
Dhaka	Chak Bazar	Land	1633734.83	83622.70	13.04
Dhaka	Demra	Land	22376005.78	1675398.43	8.64
Dhaka	Gendaria	Land	1547054.48	68436.63	4.42
Dhaka	Jatrabari	Land	12264492.94	763556.87	6.23
Dhaka	Kadamtali	Land	8878120.28	7995446.73	90.05
Dhaka	Kamrangir Char	Land	1610062.33	923697.88	57.37
Dhaka	Keraniganj	Land	190677011.90	52013832.73	27.28
Dhaka	Kotwali	Land	760703.07	16618.75	2.18
Dhaka	Lalbagh	Land	4256260.10	475507.42	11.17
Dhaka	Shyampur	Land	2293924.06	526527.97	22.95
Dhaka	Sutrapur	Land	2191581.00	670038.00	0.31
Munshiganj	Seajdikhan	Land	173749913.96	210958.37	0.12
Narayanganj	Narayanganj Sadar	Land	99854101.29	14425796.06	14.45

4. Conclusion

In this study, a thorough analysis portrays the severe impacts of the highest flood depth, flow rate, flood inundation area, and percentage of Upazila inundated for each Upazila within the studied area. The development of a Buriganga River floodplain inundation model employed a 1D/2D couple approach. For 2D flood areas, floodplains have been considered, and the flow conditions of Buriganga River have been considered as 1D flow. Calibration and validation utilized the water-level data from the upstream station

(Dhaka Mill Barrack). Results exhibited strong agreement between observed and simulated water-level data, employing a Manning's roughness coefficient '*n*' value of 0.027, yielding correlation coefficients R^2 of 0.94 and 0.89, respectively. From these maps, it has been found that during maximum inundation, Kadamtali Thana was the most affected, with 79.65% affected area, and Serajdikhan Thana was least affected, with 0.033%. Maybe because of the higher elevation, Serajdikhan Thana was the least affected. By the Gumbel Distribution method, flood frequency analysis was done for 30-, 50- and 100-year return periods. Notably, the inundation mapping in this study specifically addresses the water overtopping, excluding flooding due to embankment breaches or other factors, which could be explored in further studies.

This flood inundation modeling process can reliably be used as a helpful tool for managing risks of floods, future assessment of socio-economic vulnerability, and for decision making as well for future development within the floodplain of the Buriganga river basin.

However, this study has some limitations which can be addressed in our future research. The resolution of the digital spatial database can be increased for the real replication of the topography and better performance of the model. The flood hazard maps can be studied by this model. A comprehensive evaluation of the socio-economic, natural, physical, and institutional vulnerability would offer a more rational assessment of the study area's sensitivity, adaptability, and exposure. Notably, this study overlooks factors like rainfall, evaporation, and percolation, which can be integrated into subsequent research. Furthermore, for future research, the inclusion of risk assessment based on hazard and vulnerability indexes could provide valuable insights.

Acknowledgment

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2

Hydrological Modeling of Bhagirathi River Basin Up to Tehri Dam Using ArcSWAT

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Abstract

The river Bhagirathi comes from Gaumukh Glacier and merges with Alaknanda before flowing for about 193km to form River Ganga at Devprayag. Due to the intensity of the flooding in this area, the Bhagirathi watershed basin, one of the most significant basins in Northern India, necessitates aggressive water resource management. There are no significant studies available for Bhagirathi basin of northern India. The study is an attempt to utilize the Soil and Water Assessment Tool to simulate streamflow in this basin via a watershed model called ArcSWAT. The outcomes of this study will be helpful in water resource management and mitigation of flood in this basin. This study includes Sequential Uncertainty Fitting technique, which was applied for analysis of the data and allowed for calibration and global sensitivity using the SWAT-Calibration and Uncertainty Program (SWAT-CUP). The feasibility of this model was reported on the basis of R^2 and NSE (Nash Sutcliffe efficiency). Together, these variables show how well the SWAT model's calibration-uncertainty analysis has been done. After the calibration and validation, a global sensitivity analysis was conducted to identify the parameters in the basin that were the most sensitive. Results shows the GW_DELAY (Ground Water Delay) was found most sensitive parameter. The results of this study can be utilised efficaciously in the Bhagirathi basin to mitigate floods, manage droughts, water resource management, and prepare for hydraulic structures, according to the statistical parameters of this study.

Keywords

Hydrological modelling, calibration, validation, watershed

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1. Introduction

One of the most important natural resources is water; because entire life system depends on it. Water resources on earth cannot be altered, but it can be regulated. The impacts and distribution of water issues may be minimized by handling supplies in two ways: by increasing the available supply and reducing the excessive demands and eliminating the losses. But this control isn't as simple as it seems and involves numerous factors together with environment (temperature, precipitation), population, settlements, use, economic factors and much more. From a hydrological viewpoint, the various stages of the hydrological cycle in the river basin/watershed depend on the various natural factors and human influences.

Most of the ancient civilizations were often found along the river side, demonstrating the value of water as a tool for domestic necessities including food production, transportation, and recreation. Some of these historical locations also saw significant human habitation over time, developing into megacities and modern communities. Many water issues are now plaguing these cities as a result of the significant population movement to these towns. Depending on its climatic, topographical, geological, and socioeconomic circumstances, each place has unique challenges with water quality and quantity. The potential impacts of climate change and global warming on weather patterns worldwide are significant. Studies conducted on modeling projections for the 2050s have suggested that the global freshwater flow may undergo a fundamental transformation [1] [2] [3]. Both surface water and groundwater are essential sources of water storage, but their overuse has resulted in resource depletion. Meeting the demand for high-quality water while ensuring a balance between supply and demand is a major challenge nowadays. If there are no measures taken to stop the overuse of the resource, the growing demand for water could have a significant impact on future supply [4] [5]. In order to preserve the ideal balance of sustainable advantages for current generations and societies, water resource management is crucial for integrating all environmental, economic and social problems within the river basin [6].

To efficiently manage water resources in the river basin, it is crucial to have an understanding of the hydrological cycle. This cycle describes how water moves between the hydrosphere, biosphere, atmosphere, and lithosphere. Processes like condensation, evaporation, rainfall, absorption, drainage, sublimation, transpiration, melting, infiltration, and groundwater movement all play a role in carry water from one source to another [7]. Around 91% of the water that evaporates from the oceans returns through precipitation, with the remaining 9% falling on landmasses due to climatic situations [8]. India has 16% of the world's population and occupies around 2% of the planet's surface area, yet it only possesses 4% of the world's total water supply. India has a total surface water availability of 2309 and 1902 m^3 per person in 1991 and 2001, respectively [9]. However, it has been predicted that between the years 2025 and 2050, the amount of surface water available per person would likely decrease much more, to 1401 m^3 and 1140 m^3, respectively. The per capita availability of water in 2010 was 1545 m^3 when compared to the 6042 m^3 available in 1951 [10] [6].

1.1 Need of the Study

Besides being a hydrological unit, a river basin or watershed is also a socio-political-ecological unit that plays a critical role in determining rural citizens' health, social, and economic well-being [11]. Bhagirathi basin is one of the most significant river basins of northern India. It directly affects 5 states of the northern India. There are no significant studies and data available of this river basin. Therefore, Bhagirathi basin was selected for this study. This paper aims to provide a SWAT model which will contribute in mitigation of flood and water resource management in this river basin [12] [13] [6]. For the parameter analysis and calibration watershed was divided into small units. The impacts of natural climate variability, anthropogenic climate change, and human activities on the underlying surface on the hydrology of a basin were then discussed through basin hydrological simulation and future runoff prediction.

2. Material and methods

2.1 The Description of the study area

Gaumukh Glacier is the source of the Bhagirathi River, which joins the Alaknanda River near Devprayag in Garhwal and becomes the Ganges. It is 205 kilometers long and located in Uttarakhand. Before entering the Alaknanda at Devprayag, it travels 193 kilometers. The basin is located between latitudes 30° 43' and 31° 47' north and longitudes 78° 28' to 78° 98' east. The watershed covers 2514.254 km^2 in total. The Gangotri Glacier and the Khatling Glacier in the Garhwal, Himalaya, at an altitude of 3892 meters above mean sea level, are the sources of the Bhagirathi River's headwaters. Jadh Ganga at Bhaironghati, Kedar Ganga at Gangotri Siyan Gad near Jhala, Asi Ganga near Uttarkashi, Kakora Gad and Jalandhari Gad near Harshil, and Bhilangna River close to Old Tehri are some of the tributaries that enter the Bhagirathi River. The basin is located on the Himalayan Mountain range's southern flank. While the southern portion of the basin is heavily wooded and ranges in height from 3700m to 4100m, The Greater Himalayan mountains, also known as Himadri, which is covered with high Himalayan peaks and glaciers, make up part of the basin's northern region. At 3892 m is the elevation of the region where Bhagirathi rises.

2.2 Description of SWAT model

The SWAT model, a physically based, semi-distributed catchment (river basin) model that simulates evapotranspiration, plant growth, infiltration, percolation, runoff and nutrient loads, and erosion, was developed to assess the effects of land management methods on surface waters. This model is skilled at performing simulations indefinitely. The SWAT model distinguishes between two distinct phases of catchment processes [14] [12]. The first phase, known as the land phase, focuses on the transportation of water, sediment, nutrients, and pesticides from all sub basins to a major channel [15] [16] [17] [18] [19]. The second phase, known as the water routing phase, is concerned with processes that occur in the main channel leading to the catchment outlet [20]. A "catchment" under SWAT is further subdivided into "hydrologic response units" and "sub-basins" (HRUs). HRU are special assemblages of slope, soil, and land use. In the current study, modelling was done using SWAT 2012 [21] [22]. SWAT has two ways for figuring the surface runoff: the Green-Ampt infiltration method and the Modified SCS curve number (CN). In this work, the surface runoff volume was estimated using the SCS-CN approach. SWAT primarily uses the Priestley-Taylor, Penman-Monteith (PM), and Hargreaves methods to determine potential evapotranspiration. For determining evapotranspiration, we applied the Hargreaves approach the kinematic storage model was utilized to simulate lateral flow, while return flow was estimated by creating a shallow aquifer [23]. The hydrological balance is governed by the water balance equation, which is expressed as [24] [20].

$$SW_t = SW_0 + \sum_{i=1} \left(R_{day} - Q_{surf} - E_a - W_{sweep} - W_{gw}\right)$$

Where:

- The final water content of the soil on day i (SWt) is measured in mm
- The initial water content of the soil on the same day (SW0) is also measured in mm
- The amount of rainfall on day i (Rday) is measured in mm
- Q_{surf} is the amount of surface runoff on day i (mm)
- The amount of evapotranspiration on day i (Ea) is also measured in mm
- W_{seep} is the volume of water entering the vadose zone from the soil profile on day i (mm)
- Q_{gw} represents the return flow on day i (mm)

The following equation describes the SCS curve number:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Where:

- Q represents the runoff depth in (mm)
- P represents effective precipitation in (mm)
- I_a represents the initial abstraction of water in (mm),
- S represents maximum potential retention.
- Initial abstraction of water I_a is the function of maximum potential retention S.

Therefore,
$I_a = \lambda S$
Where:
λ=0.2. Therefore, I_a =0.2 S
By integrating both Equations we have;

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

When P is more than 0.5 S, runoff processes occur. Due to the influence of catchment slope, soil type, and land use management, the potential retention parameter exhibits variability. The following equation correlates the dimensionless parameter CN with potential maximum retention of S.

$$S = 25.4\left(\frac{1000}{CN} - 10\right)$$

The SCS curve number (CN) is impacted by various factors such as soil permeability, land use, infiltration, and soil water conditions (CN). It is possible to determine the CN value using three conditions: dry, average moist, and wet. The SWAT model has been developed and validated to generate several outputs, including evapotranspiration, surface runoff, stream flow, interception storage, deep aquifer, infiltration, and reservoir water balance.

2.3 Methodology and Swat Input

The SWAT model necessitates four primary types of data, including a digital elevation model (DEM) of the study area, information on land use and land cover, soil data, and a database of weather and hydrology. All of these data are utilized to develop the SWAT model. After the SWAT model was successfully used, SWAT-CUP was used to calibrate and validate the model.

2.4 Input Data

The stage of data collection is regarded as crucial in hydrological modeling because of the substantial amount of data needed. The selection of the study area was based on data availability to guarantee that adequate information was obtainable for the modeling process.

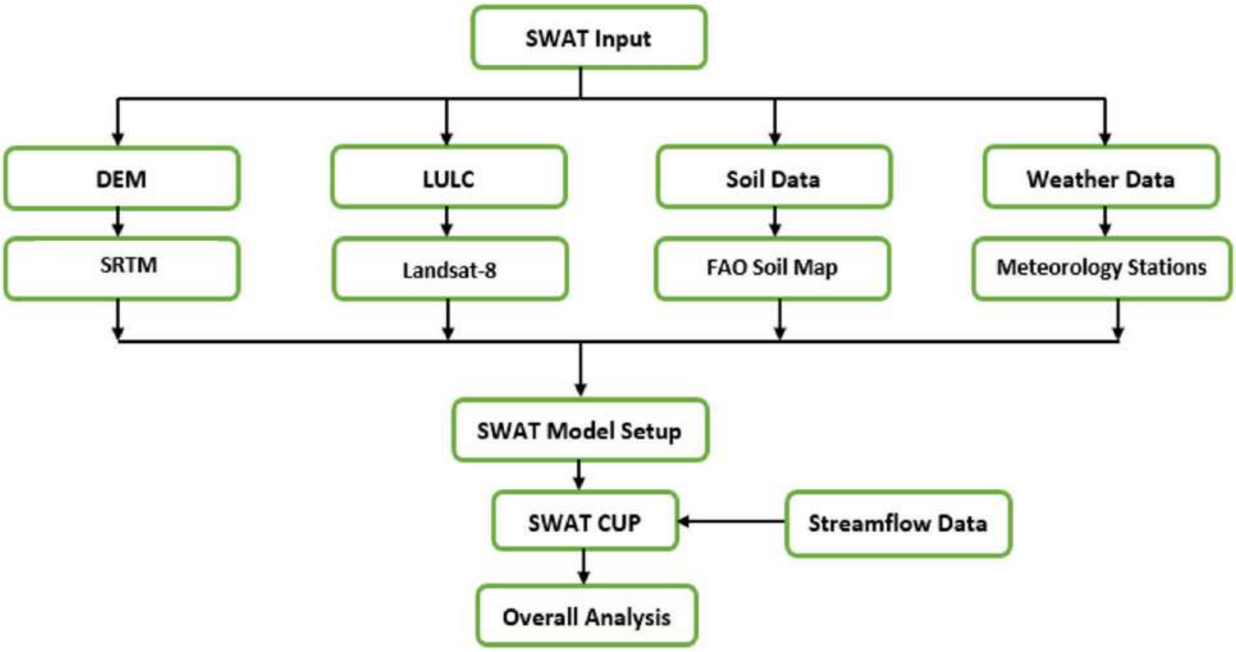


Fig. 1. Project Methodology

2.4.1 Digital Elevation Model (DEM)

A digital elevation model (DEM) is a raster dataset that comprises an array of cells or pixels that contain information about the elevation. To define the topography of the basin, a DEM was used to determine the elevation of each point in a given area at a specific spatial resolution Figure 2 shows the 90 m x 90 m resolution DEM that was obtained for the current investigation from the SRTM (Shuttle Radar Topography Mission). To create the necessary basin DEM, ArcGIS is used to process it and project it to the coordinate system (WGS 1984 UTM Zone 43 N). The stream streams, sub-basins, and other features like the slope map for HRUs are often delineated using DEM.

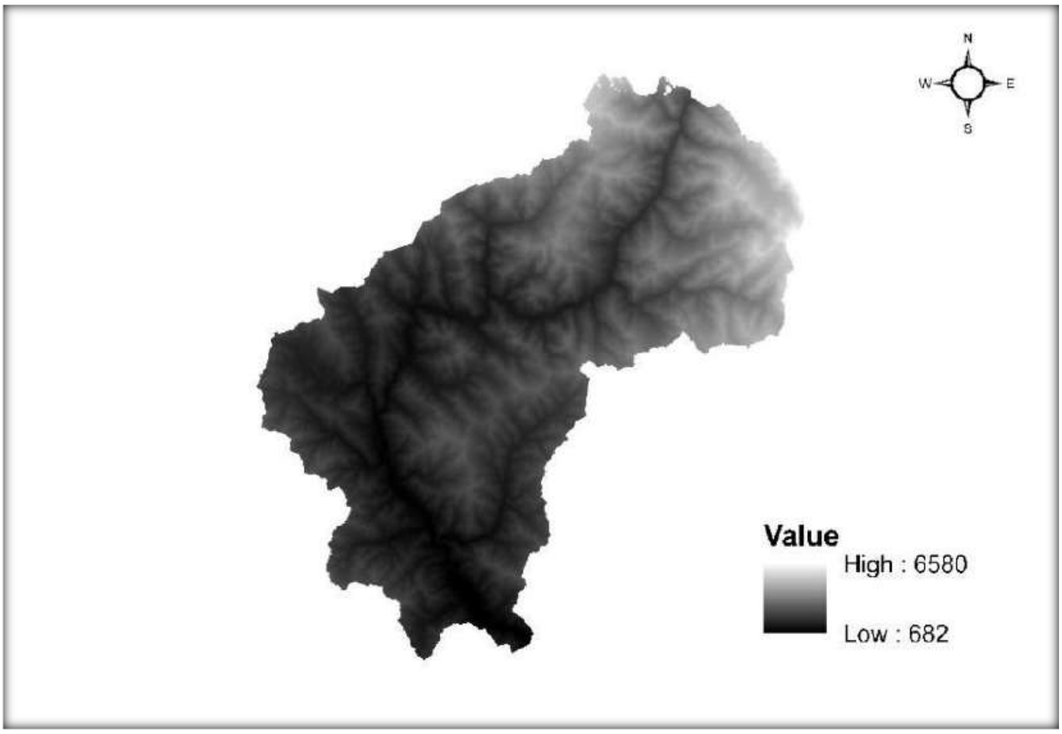


Fig. 2. Digital Elevation Model of Study Area

2.4.2 Land use/land cover (LULC)

Two of the most significant factors affecting runoff, surface erosion, and evapotranspiration in a watershed area are land use and land cover. ArcMap, which has a spatial resolution of 30 meters, is used to process Landsat 8 photographs 2020 to create the Land use land cover map. To reclassify the area's land use, the unsupervised categorization is completed and shown in Fig.3 Snow cover, mixed-cover forests, barren ground, low-density built-up areas, and water bodies were identified and classed to fit the SWAT LULC database.

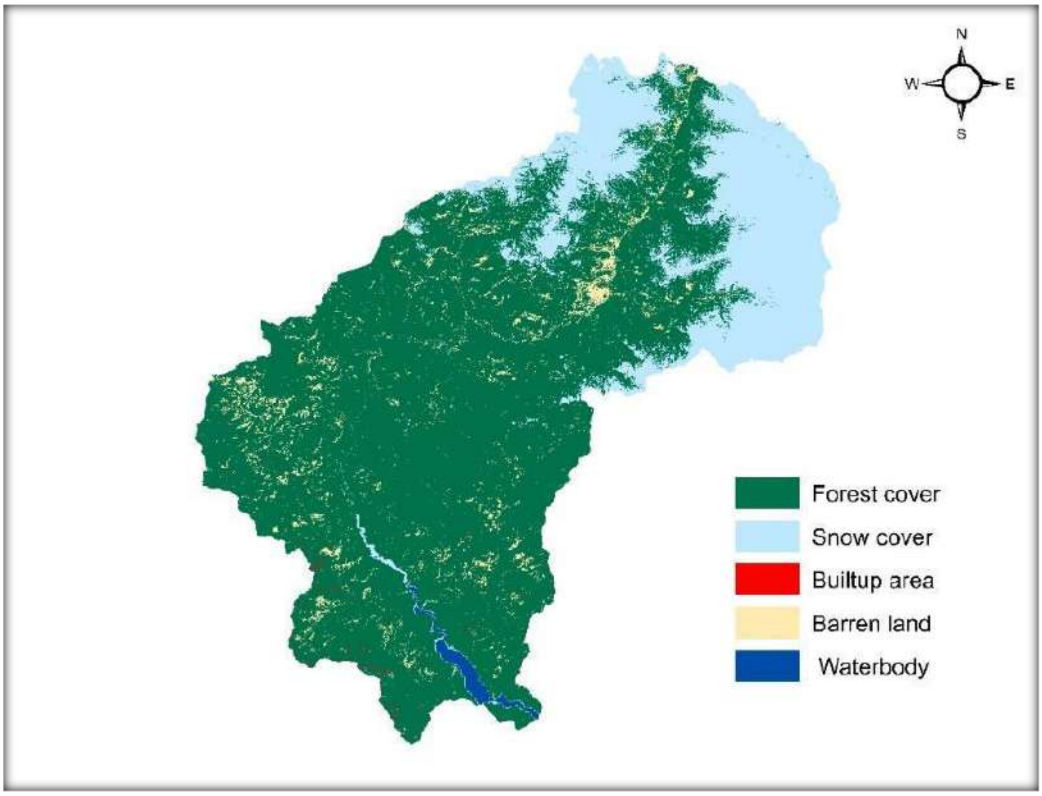


Fig. 3. LULC Map of Study Area

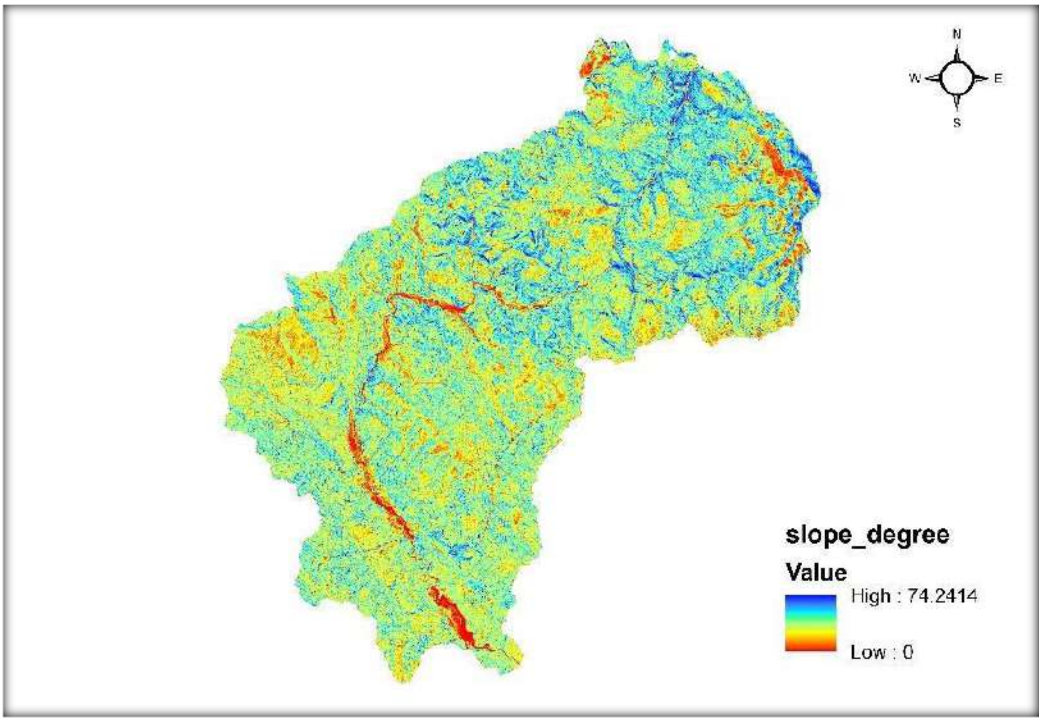


Fig. 4. Slope Map of Study Area

2.4.3 Soil data

The World Soil Database created by the Food and Agriculture Organization of the United Nations served as the primary source for the soil map of the basin (FAO-UN). This database offers a map of the world's soils. The study area's soil map was processed and trimmed. According to Fig. 3.44, two distinct soil classes have been identified in this study area.

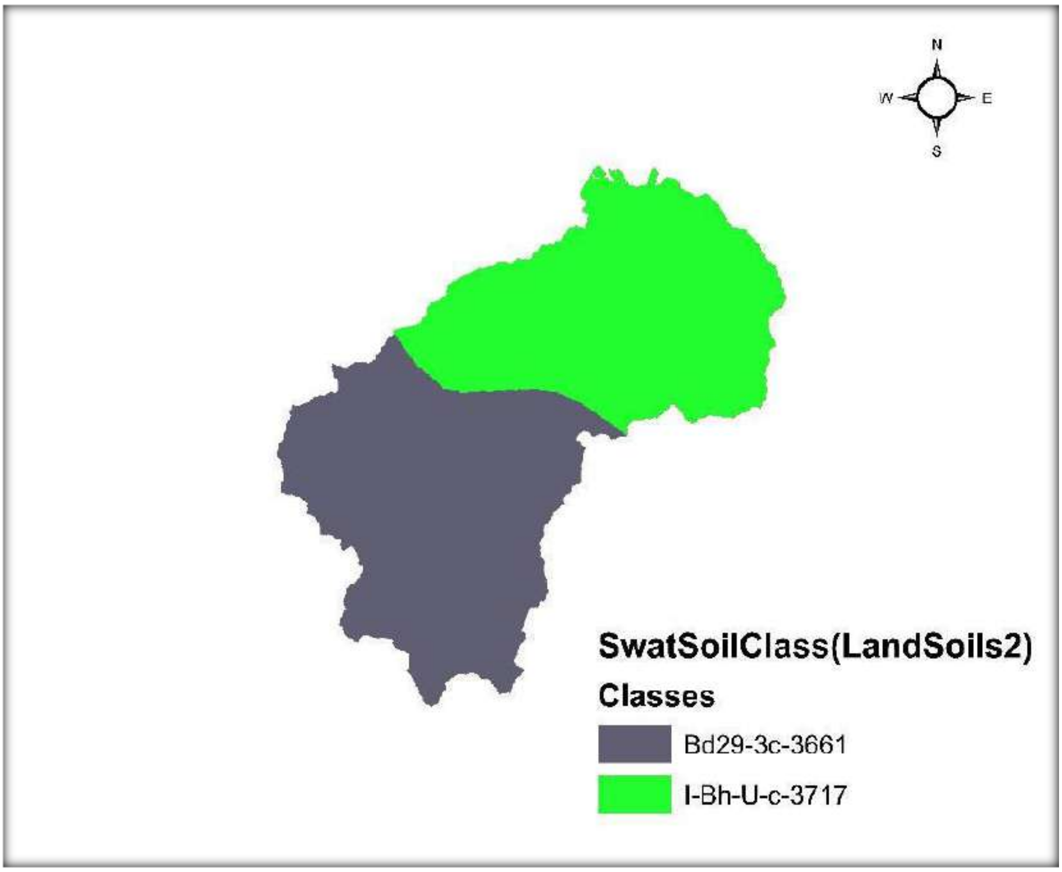


Fig. 5. Soil Map of Study Area

2.4.4 Weather data

SWAT requires daily and monthly meteorological data, which can be found in observed data sets or generated by weather generator models. Precipitation, minimum and maximum temperatures, relative humidity, wind speed, and solar radiation are among the climate factors taken into account in this study during the period 2000–2014. This information was all gathered from the Climate Forecast System Reanalysis (CFSR) website maintained by the National Centers for Environmental Prediction (NCEP). (referred "CFSR weather") (https://globalweather.tamu.edu/#pubs).

Table 1. Watershed weather station information

Station	Longitude	Latitude	Elevation	From	To	Frequency
Tehri	78.4375	30.4423008	762	1979	2014	Daily
Sangrali	78.4375	30.75449944	1664	1979	2014	Daily
Sarun May Bandiyar	78.75	30.4423008	1929	1979	2014	Daily
Uttarkashi	78.75	30.75449944	3550	1979	2014	Daily
Gangotri	78.75	31.06679916	3714	1979	2014	Daily
Sankari Range	78.4375	31.06679916	4144	1979	2014	Daily

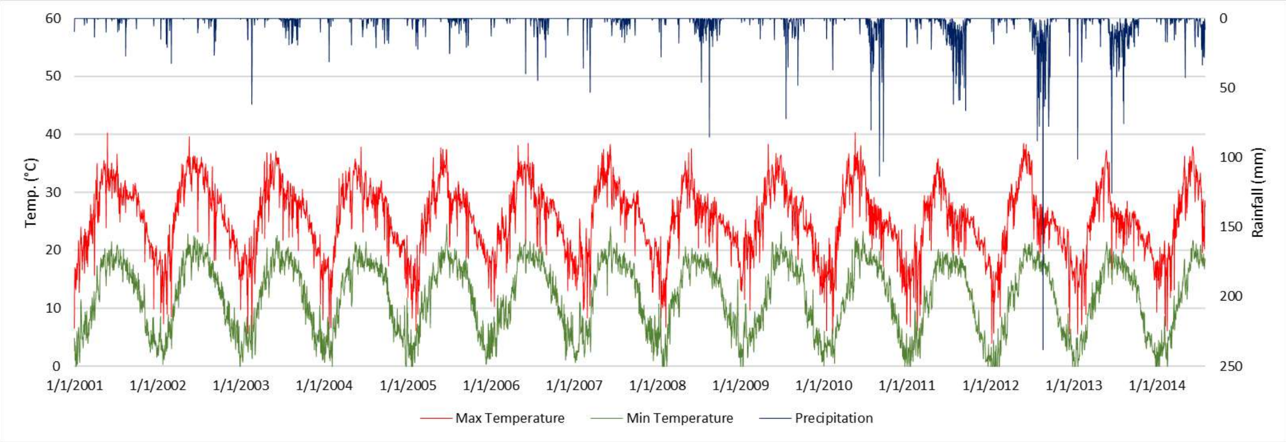


Fig. 6. Daily variation of Temperature and Rainfall at Tehri Station

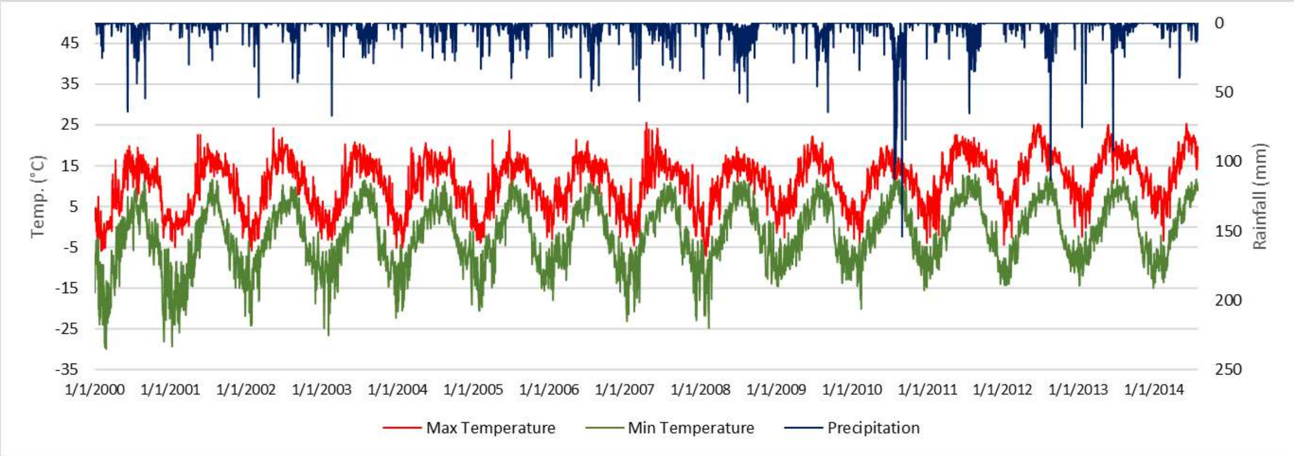


Fig. 7. Daily variation of Temperature and Rainfall at Uttarkashi Station

3. Results and Discussion

3.1. Standard SWAT Output

A watershed's average annual information, which includes a number of hydrological and water quality metrics, is provided via standard SWAT output. Table 2 lists several significant basin characteristics.

Table 2. Watershed Characteristics

Characteristics	Bhagirathi River Basin	
Land use/land cover	**LULC Classes**	**Area coverage (%)**
	Forest-Mixed (FRST)	73.19
	Water (WATR)	22.38
	Residential-Low Density (URLD)	0.12
	Spring Barley (BARL)	4.31
Soil Classification	**Soil Type**	**Area coverage (%)**
	Bd29-3c-3661	52.53
	I-Bh-U-c-3717	47.47
Slope Distribution	**Slope class limit (%)**	**Area coverage (%)**
	0-25	9.11
	25-50	32.27
	50-9999	58.62
Total Area (ha)	**251425**	

3.2. Validation and Calibration of SWAT Output

The calibration process assesses the suitability of a hydrological model for use. For the Bhagirathi River basin, the SWAT CUP calibration was performed for the years 2000-2010. The model was established in the initial two years (2000 and 2001) by accurately defining the internal hydrological compartments' conditions such as soil moisture content, groundwater store, etc. The input variables utilized for model calibration were CN, ALPHA BF, GW DELAY, and GW QMN. The SCS curve number is a significant determinant of soil permeability, soil moisture, and land use. It has been found that raising CN raises hydrograph spikes by decreasing infiltration and base flow. A clear indicator of how groundwater flow responds to variations in recharge is the base flow recession constant (ALPHA BF). The groundwater delay time is the period of time between water evaporating from the soil profile and entering the shallow aquifer (GW DELAY). The groundwater and vadose zones' hydraulic properties as well as the depth of the water table determine it.

The calibration findings reported in Figure 24 demonstrated that the observed peak value in years 2008 and 2010 differed significantly from the simulated peak value. The over prediction seen during these years could be attributed to the fact that SWAT is unable to simulate extreme events accurately and over predicts or under predicts large flows in the basin [25]. Past studies have also related over predictions and under predictions to spatial variability within a watershed [26] [18]. Results of the validation periods are shown in Figure 8. As was designated above, SWAT was unable to forecast extreme events during the calibration phase, which lasted from 2011 to 2013. This is also true of the validation phase, except that simulation is well synchronized with the measured values.

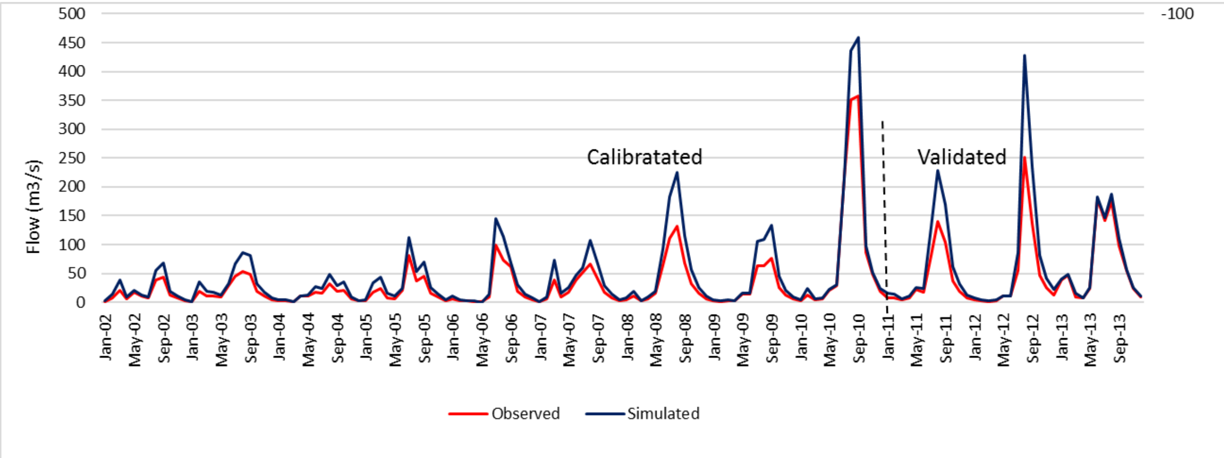


Fig. 8. Observed and Simulated Flow for Calibrated and Validated Period

Figure 9 portrays the graph comparing observed and simulated values against precipitation, indicating that the rainfall peaks closely correspond to both actual and modeled values. Figures 10 illustrate the linear regression graph between observed and simulated streamflow values during the calibration and validation periods, with R^2 values of 0.87 and 0.76, respectively. The SWAT simulations accurately reflect the peak-flows as well. This validates the SWAT model over the watershed for modeling discharge, which is also evident from the effectiveness measurements. The effectiveness measurements, R^2 and NSE values, are discovered to be 0.76 and 0.71, respectively, on a monthly timeframe. As a result, the model may be used to simulate discharge over the basin and evaluate how climate change would affect the hydrology of the watershed.

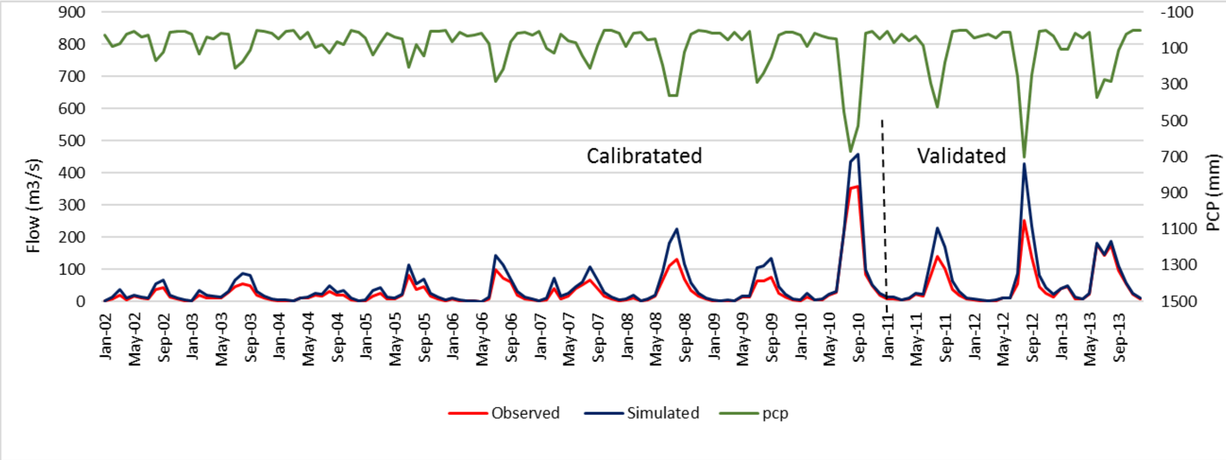
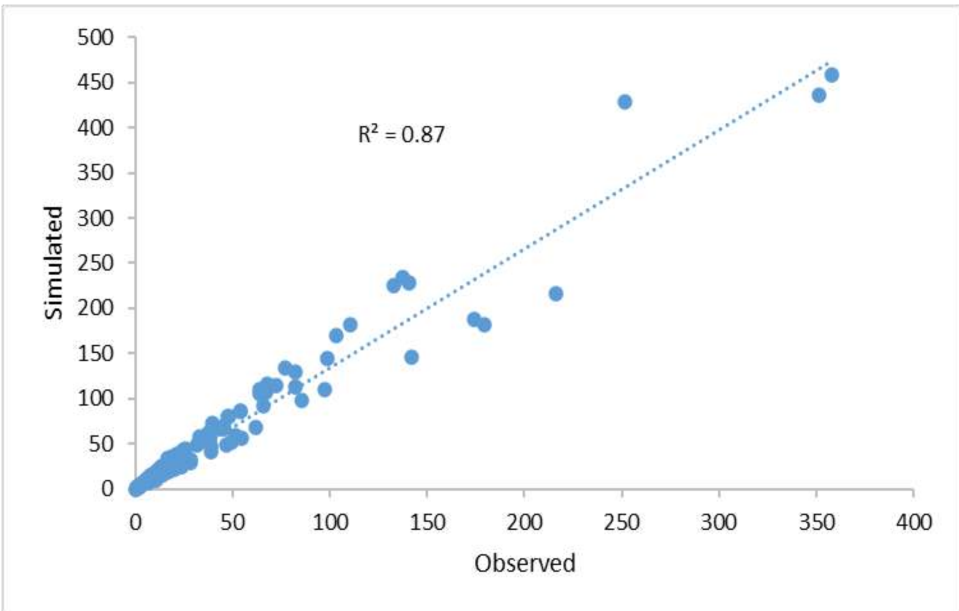


Fig. 9. Observed and Simulated Flow including Precipitation for Calibrated and Validated Period



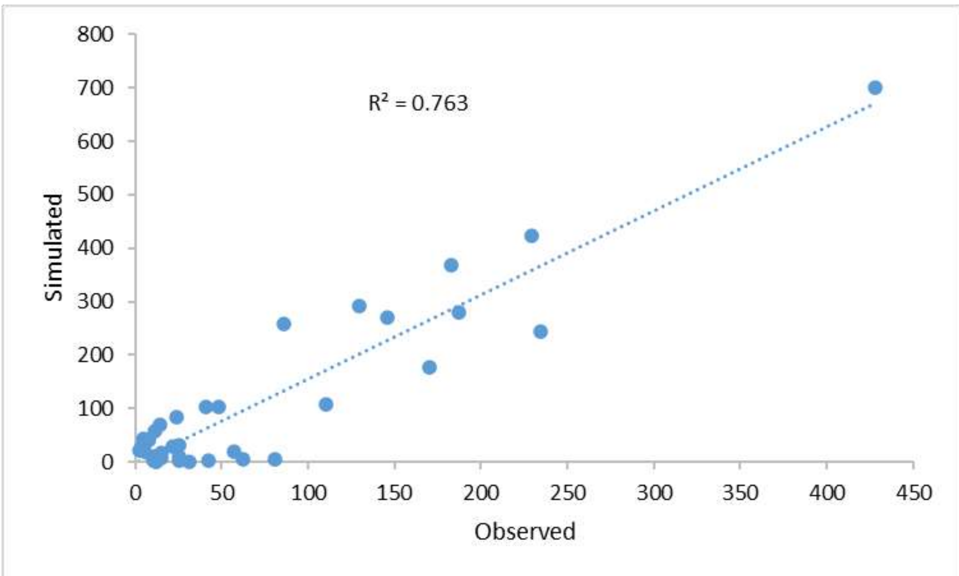


Fig. 10. R^2 values of calibration and validation period

Following calibration and validation, it was found that the R^2 value was, respectively, 0.87 and 0.76 for the calibration and validation periods. This suggests that the observed and simulated streamflow data show a very significant connection. It has a lower NSE value than R^2, but it is more than adequate, according to Moriasi et al., 2007 (NSE > 0.50). NSE (Nash Sutcliffe efficiency) was 0.83 and 0.71 for calibration and validation period respectively. Less NSE value than R^2 but it is more than satisfactory [27]. Lesser NSE value indicates that because it was considered as the main objective function during the simulation of observed data, whereas high R^2 implies that both are strongly correlated, while their magnitudes that varies greatly [28].

The percent of bias (PBIAS) calculated for calibration and validation was 6.4 and -15.7, respectively. The PBIAS value indicates that the calibration period was less overestimated than validation period, and both values are falls within satisfactory limits (PBIAS <20) [20]. The statistical significance of the NSE, R^2, PBIAS p-factor, and mean values are shown in Table 3. Due to the shorter duration of the validation period, the results show that the calibration period had less uncertainty than the validation period. For the calibration and validation period, the SWAT model's overall prediction of monthly surface runoff was exceptional.

Table 3. Model Performance Statistics Results

S.No.	Statistical parameters	Calibration (2000-2010)	Validation (2011-13)
1	R^2	0.87	0.76
2	p-factor	0.88	0.68
3	NSE	0.83	0.71
4	PBAIS	6.4	15.7
5	Mean (Simulated)	33.01	42.60
6	Mean (Observed)	35.26	50.56

Table 4. Statistics of Sensitivity Analysis

S.No.	Parameter	Description	Fitted Value	Min. value	Max. value
1	CN2.mgt	Curve number	-0.17	-0.2	0.2
2	ALPHA_BF.gw	Base flow alpha factor	0.125	0	1
3	GW_DELAY.gw	Ground water delay time	355.5	30	450
4	GWQMN.gw	A threshold minimum depth of water in the shallow evaporation coefficient	1.45	0	2

Table 5. Ranking of Most Sensitive Parameters

Rank	Parameter Name	P-Value	t-Stat
1	GW_DELAY.gw	0.072	-1.9315
2	ALPHA_BF.gw	0.2	-2.3398
3	GWQMN.gw	0.624	-0.4998
4	CN2.mgt	0.672	0.4315

After the successful calibration and validation, a global sensitivity analysis was conducted. Table 4 lists the sensitivity parameters taken into consideration and their fitted values. Table 5 displays the findings of the sensitivity analysis. GW DELAY, ALPHA BF, GWQMN, and CN2 were the most streamflow-sensitive parameters, with corresponding p-values of 0.072, 0.2, 0.624, and 0.672. More sensitivity is indicated by a p-value that is closer to 0. The quick changes in land use classifications are shown by GW DELAY's sensitivity. It results from the basin's seasonal change and snowfall. According to the sensitivity of ALPHA BF, infiltration, percolation, and baseflow are believed to be the main sources of water flow in this lowland region because of the shallow groundwater. The sensitivity of ALPHA BF suggests a prompt response and movement to groundwater replenishment because the basin is situated in a mountainous area. While CN2.mgt has a p-value of about 1, which means that it is not significantly different from zero.

4. Conclusions

This study's objective was to use ArcSWAT to create a hydrological model that would simulate the streamflow for the Bhagirathi River basin up to the Tehri dam. The effectiveness measurements ($R^2 = 0.76$, NSE = 0.71) taken throughout the validation period show that the model performed superbly in simulating streamflow. The calibrated and validated model will be helpful for the Bhagirathi River basin catchment's water resource planning and management. The data presented in this work; high-resolution remotely sensed data is useful for hydrological modeling across Bhagirathi River basin catchment. The study can be concluded in the following ways based on observations:

1. For the Bhagirathi River basin, it is revealed that the parameters GW DELAY, ALPHA BF, GWQMN, and CN2 are the sensitive parameters. Out of which, GW_DELAY is the most sensitive parameters.
2. The model worked well, as evidenced by the R^2 values of 0.76 during validation and 0.83 during calibration. Interesting, the NSE values for calibration and validation were 0.83 and 0.71, respectively, which is once more a good indicator for the applicability of the model.
3. The SWAT model gives strong simulation results of daily and monthly time steps despite data ambiguity, which is helpful for the basin's water resources management. Additionally, the modeling may be used to plan future dam building and manage flood disaster risk, which will help with the management of water resources in the Bhagirathi River basin and benefit the nation's sustainable development.
4. The SWAT model is adequate for streamflow prediction in the Bhagirathi River basin, according to the results of the SUFI-2 global sensitivity analysis.

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3

Airborne Particulate Distribution and Removal (Settling) by Statistics Interest and Physicalness

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Abstract

Although it's not new to describe airborne particulate settling by nature of statistics or probability frequency distribution (PFD), but this present study would enrich the subject of aerosol science and its behavioural analysis. This study has explored several insights on settling phenomenon of particulate matter in ambient air. These insights are completely new or newly explained to the study. However, to narrate such several insights, the study has applied the subjective interpretation, combined with logical motions and innovation. Three-dimensional visions on particulate settling and its behavioural characters has been applied and PM10 is kept at point of limelight in the study. Totally, this paper is going to be highly interesting alongwith various research scopes. Specifically, built-up environment and its concern to climate-change abatement would get new-age cutting-edges by innovation and creative designs, by the study. Readers would find this study useful with theirs' own enrichment of subjective knowledge-depths surely and out-the-most a satisfaction to become a seer to the new theory of various dimensions evolve.

Keywords

Aerosol, Impending tubule, Probability frequency distribution, Settling innovation, Settling by statistics, Settling trajectory.

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1. Introduction

"Settling of clouds of pollution is the demand and clouds to be made up by statistics, for a city (to) clean"- with this theme the study of airborne particulate setting is to be best expressed by. With upgrowing urbanization, most of cities all around world are re-thinking again and again (many a times!) to how to provide serviceability standard of better degree to its peoples [1], [2]. On this vision, upgrading versions in the definition of a city (and its standard) are used to come in views and news always. For name of a few it may include definition like smart city, ultra city, modelled city or hybrid city model [3], [4], [5]. On many of its directions, this is going to be an unending subject of future civil engineering where multi-variable aspects are to be thought of and provided with serviceability standards to its nation [6]. In recent updation, various ratings (like LEED certification - Leadership in Energy and Environmental Design that is a building certification) have come up in our new-age urbanization to be an indicator of energy-efficient building structure and this present study could be useful to that also [7], [8].

Understanding of behaviour of airborne particulate in their settling or dispersion or distribution character has been going on in the field of air pollution or aerosol science and engineering[9], [10]. Various studies have been done onto knowing how particulate (especially PM10) settling occurs in ambient atmosphere [11]. While this present study delivers the explanation of settling character enhanced by statistical analyses (especially, standard normal distribution, or, probability frequency distribution (PFD)), theoretically, the proclamation as an objective would be not at all away from the study itself. The study has expanded the proclamation onto highlighting further research extractions (on knowing particulate settling character by statistics' way) by its own way of analytical methodology with rational feasibility. The study has followed basic fundamentals of aerosol settling and interpreted the characters of settling through exploration of research insights, subjectively. Such insights are hereby said to be newer ones. Entire study is theoretical and of academic interests. Such a study as explained herein could explore out various insight-making pathways to understand and propagate with to discover many other exploitable knowledge/area that's not yet discovered. The study hopes that it would make a progress onto the thought or perspective of the subject as well, to go furtherance through the given platform of knowledge perceptions, as provided in it.

It is always a complex task to tackle pollution at source and find their source apportionment clearly. For airborne particulate pollution, re-suspension of road-dusts might often cause ambiguity or errors in their right (righteous!) estimation or finding [12], [13]. For sake of air pollution measurement or anticipation, stability or correct acquaintances of (prevalent) atmosphere along with various others at a location is the utmost thing to take care of[14], [15]. In fact, if these are possible then human activities (from road-side tea-stalls to new car/engine innovations) might resemble as secondary or non-influencing object to "particulate" air pollution. So, it all-in-all needs landscaping (i.e., land use "effectiveness" of built-up environment) alongwith correct anticipation of particulate pollution by its movement in the air.

Particulates are necessarily air-borne in ambient atmosphere [1]. This study explains settling of particulates by way (theoretical) of statistical distribution [16], [17], [18]. In addition, there are various statistical modelling taken into consideration of settling study or analysis like [19], [20] and many more. This present study is theoretical totally and explained by keeping up the background of conventional fundamental of statistical distribution on the settling.

Figure 1 shows an illustrative layout of formation, distribution, transportation and settling of particulates from a given source. Though it's an elevation view but it also depicts two zones of settling (PM10 and PM2.5) horizontally along a given road. PM10 is, comparatively, known as higher sizes than PM2.5. The study is about determining profile nature of PM10 ONLY and various approaches or innovations made up to bring down limit of concentration (of PM10) well below permissible value. In the study, PM10 and PM2.5 settling is termed by 10 settling and 2.5 settling respectively.

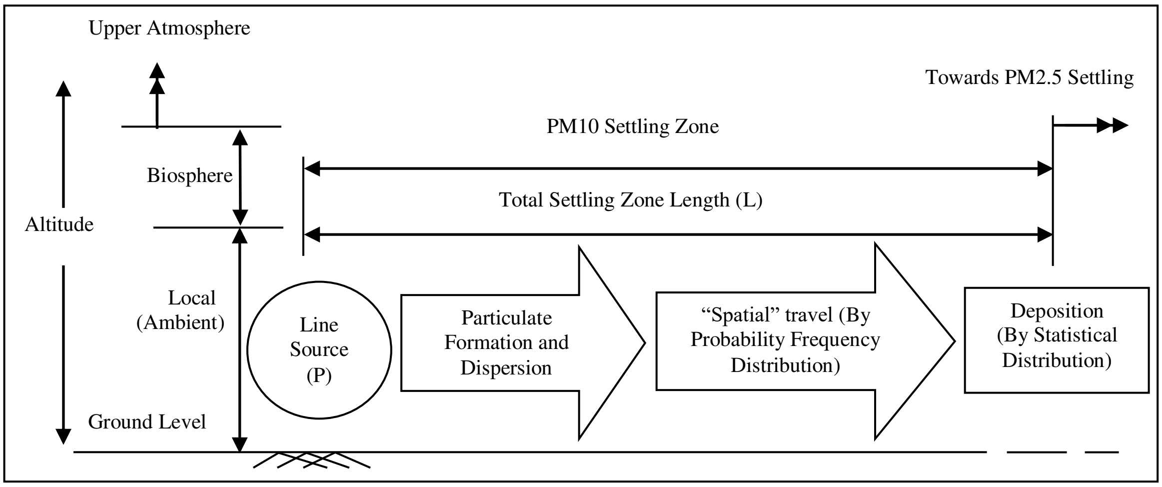


Fig. 1. Settling Zones (Elevation View)

As mentioned by Figure 1 itself, there should be an assumption to consider propagation of distribution of PM10 by a statistical way which shall be discussed afterwards. Table 1 gives the basics of airborne particulate; their behaviour and mechanism of settling. It is mentioned that the study would be applicable to any roadway/location subjected to any atmosphere/weather/climate or surrounding objects (please see Table 2, given afterwards).

Table 1. PM10 settling (some key points)

Source type	Air medium	Distribution	Settling mechanism	Atmosphere nature	Pervading settling criteria
Basics					
Vehicular	Ambient	Both horizontal and vertical	Impaction, interception, sedimentation	Prevalent	Dispersion, Distribution and Statistics

Entire study is theoretical, academic and interesting to research point of interests. It unfolds a visionary thought led by scientific finding.

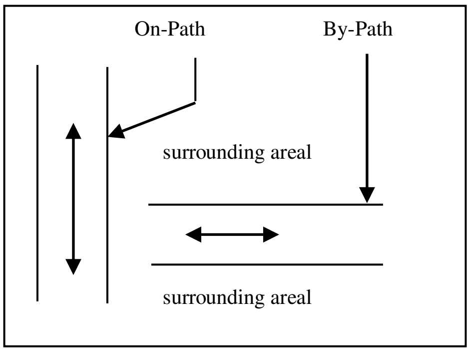


Fig. 2. Plan Layout

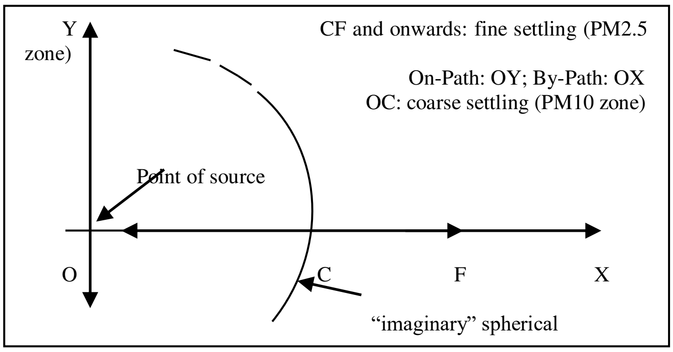


Fig. 3. 10 settling zone and imaginary sphere

1.1. Background of the study

For a given location, there should be position of main road and its bifurcated one as shown by Figure 2 (plan view). Features resting over the place that might be termed as surrounding areal should govern the nature of distribution and settling of particulates generating from source which is necessarily on the main

road (On-Path). As the study discusses kind of statistics involved in a particular settling phenomenon of particulate (PM10 only), the study considers an assumed zone within which such settling must happen in all respects. Such a zone termed by the study as PM10 settling or 10 settling zone simply can be assumed to be looking as spherical in shape (in plan-view). In an axial system, Figure 3 shows such an imaginary zone which is, later by explanation, shown with scientific reasons to justify and confirm it with realism/reality. Subjectively, OC is to be in By-Path as it is evident that OX and OY is On-Path and By-Path respectively (Figure 3). So, it is now quite clear that the study is going to narrate out settling phenomenon on By-Path by On-Path which is acting as source of PM10 pollution.
[Note: Imaginary spherical zone of PM10 can be a full sphere, all around, about its centre.]

Table 2. Basic kinetics of study

Sl.	Kinds of road-way or path	Feature	Pollution Modelling	NWZ Approach (applicable yes/no)
1	On-Path	It is main road	On-Path Modelling (OPM)	Yes
2	By-Path	It is branch (horizontal) roadway, placed at 90 degree or else, to On-Path.	By-Path Modelling (BPM)	Yes

Lots of study by their experimental data and analysis, like the ones as [21], [22], [23] and [24], show that 10 settling should happen only after PM10 has travelled down a few distance away from its source; although, distance where most concentration (PM10) is found is most important. Based on such finding, a schematic layout diagram could be drawn which provides an idea of how such settling happens (Figure 4).

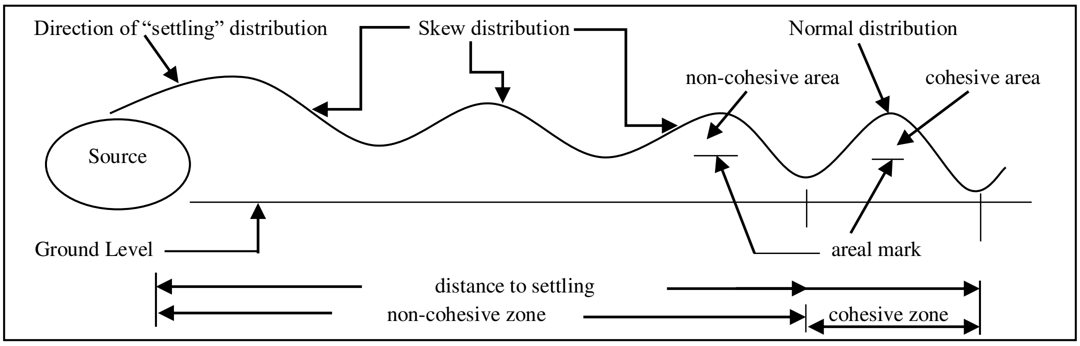
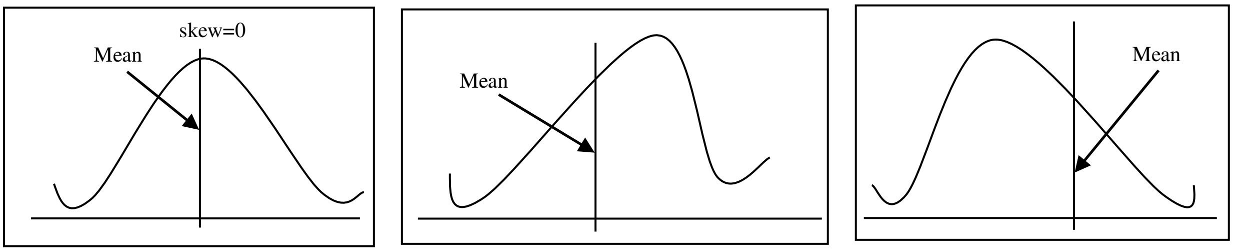


Fig. 4. Variations of statistical distribution of particles to 10 settling

All experimental data, like [25], [26], [27] and [28] including previous ones given earlier, has claimed that 10 settling should always happen by a statistical way of journey. Since PM10 liberates out through its formation in air and back by its source or else (like re-suspension etc), all kinds of statistical distribution should definitely take place [1] and final or ultimate settling could occur either by skew or normal distribution or in a combination of statistics interest[29], [30]. It is assumed that an ideal settling should happen and occur by normal frequency distribution only.

Figure 4 shows the layout perspective of settling by distinguishing two kinds of frequency distribution. The study for better understanding entire settling zone has divided into two - cohesive and non-cohesive settling zone respectively meaning to normal and skew distribution. Term "cohesive" is literally valid in the study, so as to define settling potential or assertive condition to setting of particulate pollution. And, term "areal mark", shown by Figure 4, is added to indicate the planar surface area which may, as shown, be equally meaningful to location area as well as hypothetical study-area of concern to the study.



5.1: P.F.D (normal) 5.2: P.F.D (skew to right) 5.3: P.F.D (skew to left)

Fig. 5. Various kinds of probability frequency distribution (P.F.D)

Figure 5 gives various kinds of probability frequency distribution (PFD), as an assumption of the study, that may take place in a given settling (10 settling) phenomenon; for normal PFD, skewness is equal to zero. Followings shall be considered as assumption of the study:

- The study has not mentioned an ideal settling ambience or ideal atmosphere. Instead, entire ambience is divided into ambience of cohesive and non-cohesive settling. Term “ambience” refers to an ambient atmosphere, which is from (at or near) ground-level to an ambient level of atmosphere. Thereby, an ambience is nothing but a spatial zone or area surrounding a considered or given point on ground-level.
- Cohesive settling (zone) happens in cohesive ambience that occurs only in normal PFD (Figure 5.1) and non-cohesive settling in non-cohesive ambience which is characterized by skew PFD (Figure 5.2, 5.3).
- As long as skew distribution continues, PM10 settling can never be said “happening” or “starting”. Conversely, whenever settling (of PM10) happens, it should be said that there is only normal PFD happening or prevailing. So, rational settling (of PM10) is nothing but a normal PFD which is practically possible to be set or happening at an atmospheric (biosphere) ambience.
- There should not be co-existence of above two kinds of settling ambience (of particulates), at a given time. There may be a series of such two kinds (of settling criteria/ambience) alternatively and repetitively along a settling trajectory/path of particles.

At a given location, nature of atmosphere is not so unknown, especially at ground level. This confidence is due to identity of location over natural atmosphere by primary and secondary data. Such identity is variability of the location with regard to atmosphere and its various agents like temperature, humidity, wind speed, rainfall, solar radiation, wind direction, etc etc. Subjectively, the location must be in coherence to settling privilege, which defines setting up of built up environment. So, characterization of nature of “airborne” 10 settling zone at a location or place is easily possible to have as information or guide to particulate research.

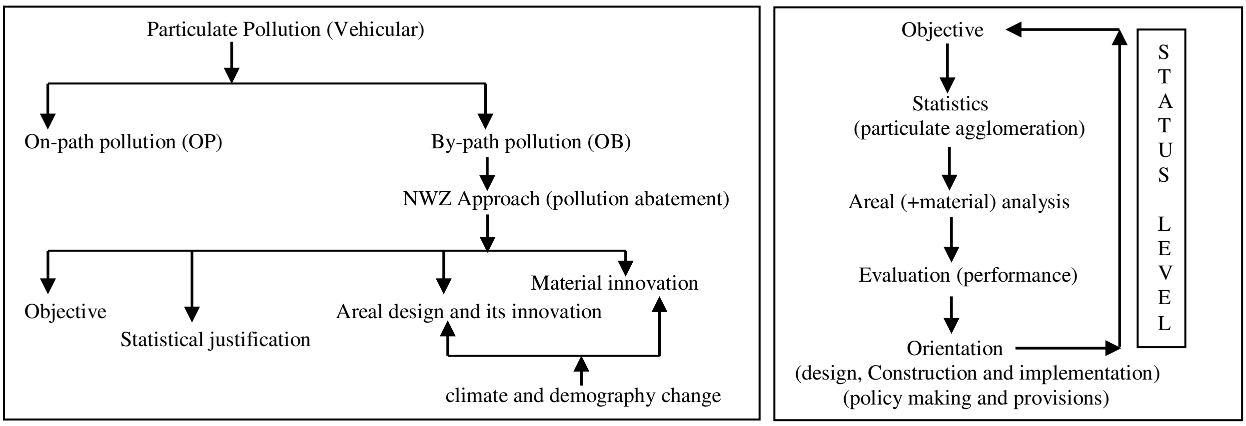
As shown by Figure 1, local (ambient) atmosphere is the concern here within which particulate settling is hereby considered to happen, occur and set in. Above or beyond this local altitude, zone called as biosphere is normally turbulent in nature and that is not usually considered in settling of particulate so far as their contribution, to its lower zone “Local”, does affect on. Above biosphere, there is the huge space which is upward and also by similar emphasis as like as biosphere onto local. So, a local “ambient” environment is to be within a human’s hand reach or a few distances that may range from human’s normal or average height to well upto five-storied building height (1.5 to 15 metre). This “above” guideline is only for a consideration of the study only, and it may well vary also.

[Note: Entire study is meant for local (ambient) zone only (10 settling) that may be subjection of other zones as well as explained.]

1.1 Methodological Initiations

In order to have a well-constructive settling zone all over at ground-level, a source (line) must be in good proportion (of volume of pollution liberation) with built-up environment and thickness of surrounding areal. Such proportion as “good” nature may often be discriminated by PM10 and PM2.5 settling zones. So, a 10settling zone (that is PM10 zone) must be studied well to know and demarcate the furtherance settling which is PM2.5 settling, and surrounding “areal” must be ordained with in accordance with this. With this, a design is consequently made up for the location of interest subjected by line source of vehicular pollution.

An approach, called by NWZ (narrow wide zone), has been applied as methodology of the study into making a cohesive nature of settling zone that would not only cause PM10 to settle but also not disturb PM2.5 settling. In applying NWZ approach, a management needs to be followed and it is also described by the study.



6.1: Methodological particulate removals (10 settling) NWZ management

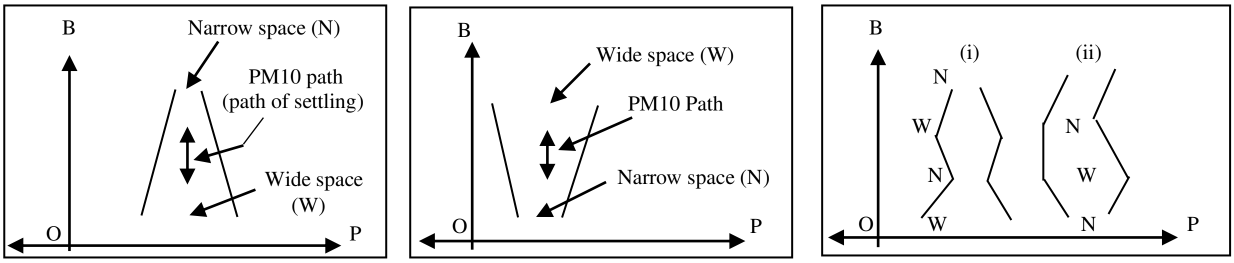
Fig. 6. 10 settling and creative NWZ management

Figure 6.1 gives entire layout of methodology and Figure 6.2 shows how management of NWZ approach should work. Both the figures are self-expressive and self-explanatory to the explanation.

Table 3. Theme components of study

Sl.	Methodology (alongwith NWZ)	Background (Perspective)
1	Statistics implication of interests	Objective, Vision, Mission
2	Material innovation and design	
3	Orientation (such as Policy, People awareness, Norms/acts/rules/laws, Vehicular upgradation, Fuel quality and its combustion effectiveness, Tail-end concerns, Ecology balance enhancement, Built-up envelope and environment, Waste-to-recycle initiative and Consumption lifestyle etc)	

Table 3 gives quite a detailing of what orientations could be made up and associated perspectives to draw out such an approach and its corresponding management. It is thereby clear that NWZ reveals a “pollution” status of a location with respect to particulate pollution (PM10) abatement. Entire study has been explained with basic aim to define and create a local ambience (at ground level) cohesive enough to particulate settling, of PM10 interest preferably. So, an ambience defined by cohesive nature of particulate (PM10 preferably) settling is hereby termed as cohesive areal modelling or CAM simply; methodology of the study explains how a surrounding area should be given a CAM to particulate pollution removal. Subjectively, CAM should also hold creativity like NWZ (Figure 7) as a part of it or the study as well.



7.1: W to N Kind 7.2: N to W Kind 7.3: Zig-zag Kind

Fig. 7. NWZ and its various kinds (along OB only)

Short note on NWZ: It is an aerial outlook (plan view). It is with an aim of creating an area of better spread-ability concern. As OB path is the pathway of our study, so the creation is to be on OB path. An area of concern can be armoured with or adorned by various covering by plantation or roofing etc so as to settle down the particulate matter like PM10 of flowing air within not very long reaches. Figure 7 has shown it. Using components of space-provisions like N, W as delineated by the figure, there could be three possibility to have such a creativity or aerial arrangement which is termed by the study as NWZ. Detail of NWZ is given against Table 6 afterwards, in methodology section. Such arrangement would be helpful not only to spread the pollutant-laden ambient air within the kind but also to settle them within shorter length in/for any kind of NWZ. Each of kinds has unique nature of feature and functions (see Table 6).

The study observes entire discussion on NWZ approaches. This means it assumes that an ambience is subjected to NWZ by a kind usually (Figure 7) and each such kind must be able to deliver cohesive settling in particular (Figure 4, 5). Again mentioned that cohesive settling is assumed to be happened by Figure 5.1 only while other than cohesive one is the state wherein all particles are in suspension with haphazard/non-settling movement as described by Figure 5.2, 5.3 earlier. So, a physical location with NWZ preparation/arrangement by built-up environment is hereby said to be under a management usually which is termed in the study as NWZ management that always enhances a cohesive than non-cohesive settling, of ambience, on human respiration concern. Subjectively, NWZ location is so designed or made up of that it propels a settling ambience to cohesive kind, on entire batch of (in-coming) particulates to it. Figure 7 has shown such a bringing on with respect to OB's starting from a given OP. Please see Table 6 for further explanations of NWZ.

1.2 Mini-Recap

Several questions that may come to behind such cohesiveness formation in atmosphere close to ground level -

- How is cohesive settling to be created?
- How far is its range (of dominance)?
- What is physicalness for it to be materialized?
- What are various fundamental theories pertinent to it, providing the confidence?

At any ground-level location, there are basically two kinds of distribution simultaneously, namely horizontal and vertical distribution or settling. Each of these distributions can be distinctly defined for a given and prevalent winds flow and other atmospheric agents/variables (like relative humidity, solar radiation, temperature, rainfall, etc) including locational features. These variables have their own concern to affect a settling, over horizontal or vertical distribution.

[Note: The study considers only horizontal distribution of particulate settling as it explains settling of particulates along a horizontal plane (OB).]

Originating from source, particulates flow and get spread over by pfd distribution which can be represented by statistical measures (Figure 5) - already it's assumed by the study also. As said by this present study, this pfd distribution can be set up to proclaim an ambience as a pre-determined or presuming nature (for a given atmosphere and its pervading location) to PM10 settling by NWZ and its management. This means a particular nature of settling (normal or skew pfd) can be thought of, accounted with and estimated based on locational feature, behaviour of its atmosphere at ambience level and concentration of "particulate" pollution.

As the present study focuses to particulate matter and its settling only, the study has assumed that particulate distribution would accumulate, spread and settle down (by gravity) by statistical distribution of probability frequency distribution function (pfd). This is interesting and objective part in the concern. This propagation upon research knowledge of statistical particulate distribution is at core of the study.

Such a statistical distribution, on horizontal settling, is highly possible at any given location or environment. So far given up by various reviews and studies (by bibliography), it might need or demand suitable and accustoming built-environment and suitable use of atmospheric agents to form a "desired" settling trend by statistics. It would enhance any locality or city to grow up to higher version of modification. This is not only to a higher version but also to be to the environmental dominance by mankind, towards creating a greener, pollution free habitation. Such an environment may be called as design environment than calling it as only built-up environment. However, such kind of design environment is irrespective of any locality of any built-up nature; it can easily be applied into rural places/locations, if not thought of them yet in this study. So, the design environment enhances landscaping, orientation, use of vegetation cover to channelize atmosphere (agents), suitable plantation (by kind also), pollution measures, policy, etc. etc.

At end of the study, the research attracts several research scopes to attain at best design environment. It is broad, engulfing by nature and seeks expertise (visionary). Such would bring in new structuring and innovation besides having an upgraded environment to the facility to human service. After all, city-life experience would be flowing through a different life-style and visionary service which is only now a thought of realization at perception level but it all in all pursuits to the new higher version of a city's grade of living.

Following are the literature surveys done and found relevant in pursuit of the study as well,

Michael L. Larsen et al. Study (2003) [31]

This is a work stating a debating research on whether rationality matches with stochastic experiment or not. The study has shown applicability of Poisson's probability distribution function and validity of it to describe correlation of dispersion in atmosphere, by it. The study has initiated three simulations – negatively correlated, positively correlated and purely random base. This simulation concept has been further justified and supported by time-scale experiments of correlation residency. Ultimate finding of the study is that it enhanced random dispersion more than implicitly independent concept of dispersion of aerosols in atmosphere.

This literature study would help find out basis of spread or distribution of PM10 aerosols where atmospheric elements are always at the variable concern as to any practical situation, in order to throw limelight on arriving at the study's objective.

Hamid Taheri Shahraiyni and Sahar Sodoudi Study (2016) [32]

It is a study which has demonstrated all previous works involved in prediction of PM10. Various studies of temporal, spatial and spatio-temporal prediction (as approaches) of PM10 are reviewed and discussed in it. It showed relative relevance to urban area application based on variety of prediction approaches. As stated by the study, Vector Machines, Artificial Neural Networks and hybrid techniques show promise for suitable temporal PM10 prediction. It summarized the approaches which has potential to the applicability of suitable approach.

The study would be suitable for horizontal transportation and settling of PM10 along a By-path road in response to On-path busy road serving as pollution source.

Jan Bitta, Irena Pavlíková, Vladislav Svozilík and Petr Jančík Study (2018) [33]

This study explained why Land Use Regression (LUR) modelling is better than Gaussian Model. The study also showed a combination (LUR-Gaussian) would be more convenient and better to serve at obtaining precision results given the fact of accessibility of more factors inclusions feasibility. LUR is hoped with to be more useful in coming years ahead in the research area to fulfill a researcher's desired pursuits.

The study is a specific to advancement possibility over core objective of spatial analysis and feasibility. There are lots of variables, some of them need to be taken care of more vibrantly and some of them as negligible ones, but conventionality should be get accepted to be changed or altered with suitable demands or initiations. This review study is one of a kind.

Objectives of the Study

Following are the targets of the study entirely,

- To draw out and explain kinetics involved in spatial distribution by PFD of PM10 on By-Path.
- To determine an approach called in the study as NWZ approach.
- To establish PM10 regime by PFD by physical happening as it occurs to.
- To bring in various scopes of research and ranges of possibility to make PM10 free areal, at a given locality.
- To provide insights to alternative ways to find out pollution concentration on By-Path.
- To explain various physical way-outs to PM10 removal.

2. Methodology

While it's discussion of natural or artificial "design" settling (of airborne particulates) in laboratory or else, there are certain things in common between the twos and that are their model forming assumptions. These assumptions do circumscribe entire functioning of the model and its principles. It might be said also that an artificial settling in natural atmosphere by naturalness could be more complex and of a hardwork, than doing the same thing in laboratory. This present research has attempted to understand settling by statistics with its intrigued approach-cum-methodology besides making artificiality in air medium in naturalness to cause settling and consequent freeness of pollutant from ambient air (subject to permissible limit!).

In the parlance by the study's interest, Table 4 gives an illustrative understanding of what statistical settling distribution can be defined over conventional finding so far in the research of particulate distribution. Table 5 provides basic fundamental ways of settling, by statistics or knowledge of statistics.

Table 4. Contrast between conventional and statistical finding@

Post since source^	1	2	3	4	5	**Kind of finding, fundamental**
Distance, meter	at source	100	200	300	400	
Pollution level and settling kind	Highest (no settling possible)	Coarse particulate zone (High PM10 settling)	High medium particulate zone	Low medium particulate zone	Fine particulate zone (PM2.5)	Conventional finding
Distance, meter	at source	50	100	150	200	Statistical finding
Pollution level and settling kind	Highest (no settling possible)	Skew distribution	Normal distribution for higher PM10 only	Normal distribution for lower PM10 only	Dispersed distribution	

@please compare with Figure 4; numerical values are illustrative and might be comparable or competitive.
^to be pointed along By-path (assumed).

As got from earlier discussion, settling of airborne particulate by statistical inference always resembles an evidence of probability frequency by normal or skew distribution. If it is not, even then it should be considered that there must be a possibility of getting it to be realized and happened in the air medium that the statistical settling does cause particulates to settle by normal distribution preferably or other modes of settling of statistics interests.

Table 5. Various (particulate) settling provisions

Settling criteria by PFD statistics		
PFD		**Hypothesis**
Normal PFD distribution	**Skew PFD distribution**	
Highly feasible for PM10 as settling by it is valid for first some meters of distance from source.	It occurs from source till normal distribution settling happens. It has been assumed that removal of particulate never happens if skew is not transformed to normal distribution. It is of two kinds - left and right skew.	It measures degree of possibility of settling (over by-path distances). It can determine settling quality at any distances.

Also, it might be an assumption of the study itself that there must be a focus of all components (inert, living things etc of surroundings at any place or location) to respond (together) in a particular definition or degree, to particulates settling mechanism by the statistics settling by PFD distribution. So, settling of particulates that are formed and spread by vehicular pollution as a source can be thought of a best combination of features of statistics and surrounding objects at a location. Such settling is termed in the study as **settling mechanism by *statistics*** or particulates removal by statistics or simply, ***statistics settling***. So, there are two unique features that must be initiated with and these include –

- areal design and material innovation
- statistics analysis

Entire methodology is hereby determined by following twos to arrive at CAM -

I. Approach to modelling – NWZ (background of CAM).
II. An application - Statistics implications (functionality of CAM).

[Note: Above second one is part of NWZ and is not vice-versa (please see Figure 6.2).]

2.1 Approach to modelling – NWZ Approach

This is a methodological initiation given in this research paper. This approach provides distinctively a particular regime of particulates to settle within 10 settling zone. There are three kinds of such distinctive "settling" regimes. However the regimes are -

- Shorter settling
- Longer settling
- Zig-zag settling

Each must be equipped with objective and others as provided by Table 6 which gives meaning and description of each one of above threes. So, this NWZ approach provides a distributional concept in above three ways where each of the ways is able to happen, create and establish 10 settling zone, rationally. It is again mentioned that each settling regime is required to be provided with other criterion (as given by Table 6) described in the following (dots shown in row 3 in Table 6, in kinds of zig-zag settling, define the continuation of such alternation or repetition, as suitably applicable).

2.1.1 NWZ Management

It comprises of various steps of working as needed into making NWZ approach a rational one. Figure 6.2 shows the schematic layout.

I. Objective

This is the item that demarcates limitations and boundary of using NWZ to further steps to use and apply modelling CAM. There must be philosophical and physical expectations from a basis of modelling application that what should be fulfilled and what should be not. This is a kind of strategy that is to be taken care of prior to further initiations to take place.

II. Statistical justification

Whatsoever locational features surrounding a By-path including atmospheric is existing, there must be a statistical distribution for particulate to follow. Settling down by such distribution is to be by normal distribution of probability frequency distribution.

Table 6. Basis of By-path pollution analysis

Sl.	NWZ Approach (Kinds)	What is it?^	Description	How to operate NWZ Approach?
1	Shorter settling NWZ	Narrow to wide (Narrow-Wide)	Narrowness is at source and wideness at distances away from the source. So, the passage on By-path resembles as narrow to wide shape of path configuration that enhances settling at shorter lengths from source.	NWZ Management
2	Longer settling NWZ	Wide to narrow (Wide-Narrow)	It is opposite of shorter settling as given above. Here, for a given settling, particulates get settled down at longer lengths as wideness enhances skewness to disperse more onto the wideness.	
3	Zig-zag settling NWZ	Narrow-Wide-Narrow-... Wide-Narrow-Wide-... Narrow-Narrow-Wide-... Wide-Wide-Narrow-... Narrow-Wide-Narrow-...	It is combination of above twos. Suitably, a better settling zone can be created that results to a zig-zag path and settling occurs accordingly at points of settling.	

^it is by line source of air pollution as it occurs spread from OP (to OB); each approach is unique and not given in a ranking.

Normal distribution should usually become feasible and rationally happening only after a certain distance away from the source of pollution, for PM10 settling. So, there should always be a skew (non-normal) distribution first and then only the normal kind in sequence, with respect to the pollution source point at any given location. Thereforth, the finding of PFD should be studied very well so that a particular location
can be assessed as accurately as possible with respect of distribution of normal and skew kind of it, that is, probability frequency.

III. Areal design and its innovation - Climate and demography change

This is the step usually to be followed after above steps like statistics, NWZ kind, and others. At this step, surrounding areal is required to be arranged, prepared of and oriented in such a way that should support cohesive settling in the zone concerned. So, it's a part of planning and design of location. Also, it should not forget, ignore or neglect valuable criteria such as sustainability, resilience, efficacy etc. including climate and demography changes while designing the location and its various features.

IV. Material innovation- climate and demography change

It should be the last step which can be thought of in simultaneous rhythm with above step of areal design. In this, various research and developmental works are encouraged to bring in innovations that are completely able to sustain the areal design to facilitate particulate settling and removal. It is such a step where imagination or virtuality becomes to a rational entity, resembling to be purposeful, working and useful.

V. Evaluation

Earlier steps must be checked to the desired objective so as to mention their success. Objective limits must be followed always.

VI. Orientation

This is the step of making locational features oriented to the evaluation standards of implementing the differential (that is, performance metric which may be equal to difference between desired and available measures). Also, various policies have to be initiated with alongwith provisions, at this step, to give a higher level of amelioration to a location status of city/town.

VII. Level of status

As shown by Figure 6.2, a better status can be achieved if more and more recycling is done, as continuously and repetitively, from objective to orientation. Subjectively, this status is for air quality (by particulate concentration). A better level in the quality is thus hereby said to be attained by NWZ management as explained in the study. So, Figure 6.2 is a layout only to illustrate how NWZ could be tken care of, to fulfil the study's objectives.

2.2 An application - Statistics implications to particulate (PM10) removal

Basic objective of the study is to determine a modelling on the basis of assumption-like consideration of settling of PM10 by statistics interest. This modelling, called in the study as CAM, is theoretical, constructive and of academic interest.

Settling of particulate by statistics' view-point of interest is very comprehensive and well applicable. Knowing behaviour of particulate ontowards settling mechanism by concept of probability frequency distribution (PFD) is naturally highly possible and can be set to an artificial built-up areal also. Such possibility has already been discussed in literature review and in the foregoing description the study explains what physical phenomena should happen on such possibility. It should be taken care of NWZ always into all those phenomena in order to make them proper in making an areal or built-up envelope free from PM10 or such control.

Already explained, on any given location a By-Path should experience settling phenomenon in sequential phases of PFD as shown by Figure 4. There could be possibility of variety settling by kinds of PFDs as given in Figure 5, but target should always be to make an areal location to normal PFD than skew one to as much as possible. Because, location or areal under normal PFD should provide better settling condition and fast removal of PM10 from prevalent air medium. This enhancement is highly required to any encroachment including By-Path of interest. Visuals like Figure 3 then might come into perspective so as to ordain an areal on likeable standard to pollution removal. Above discussion has been enveloped by one single term which is CAM (Figure 8) that is needed in taking care of an areal location competent enough to combat and dominate over air pollution dispersion. In the study, NWZ is methodology, one of the kind, given as a new one (Figure 6.2) which should be kept at core of CAM.

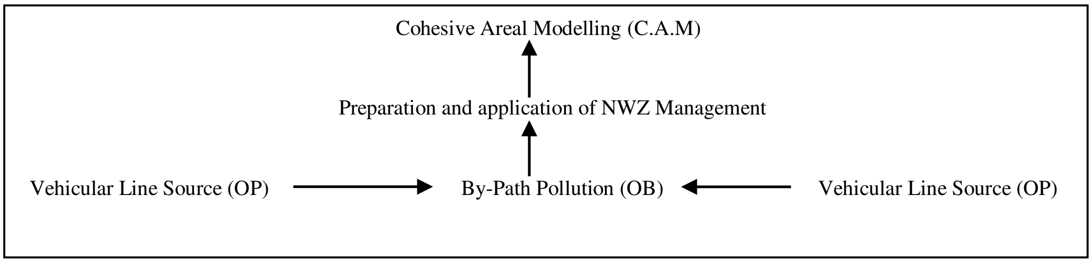


Fig. 8. CAM Layout

Usually, there are three kinds of settling mechanism of particulate. These are - inertial, impaction and sedimentation. All these threes are hereby considered to be prevailed by PFD in the study. PFD should thereby act as backbone of the three settling mechanisms. More cohesive a PFD, more degree of settling an areal location to be having - this should be made up of and is considered in the study as its prime objective. Question may be to what cohesiveness a PFD should have to be having with to govern and accomplish particulate settling! This is already explained earlier in "introduction" and again it is mentioned that simultaneous presence of skew and normal PFD would be answer of this, that is, condition of "ambient" air medium (Figure 1) may create or result to unique normal or skew PFD merely, but it should make the settling happening independent of unique presence of any one of normal and skew PFD (Figure 5). It is thereforth considered that presence of both kinds of PFD simultaneously could be also be a gateway to say that happening of settling is 100% uniquely possible for normal PFD but such is also possible owing to applicability of term "cohesive" into the study.
Note:

- For any given batch of particulates, settling transforms from skew to normal pfd, under NWZ.

- Cohesive settling can happen anywhere within a kind of NWZ. This means there could be a series of non-cohesive pfd's prior to cohesive pfd or settling.
- NWZ should assume settling of PM10 and PM2.5 both and cohesive settling should only assume settling of PM10 only (see Figure 3).
- CAM would explore out several zones of settling within OB or NWZ kinds. All such zones (like Z1, Z2 shown afterwards in Figure 15) are at a lapse over horizontal movement of particulate. Subjectively, these lapses are at change of trajectory along the horizontal movement of particulates.
- CAM would not only be deemed to be of cohesive settling only but also to enhance skew pfd to transform into normal pfd. It is all about to make a turn-on over existing skew pfd's in a given location so as to cause or happen or formulate into cohesive settling, positively and rightly.
- It is always an attempt in any built-up environment or civil engineering project to make its (project) ambience a cohesive one or transformable to cohesive one.
- CAM is a name only given to represent entire explanations by one singular terminology.
- A place or project fulfilled by CAM can be called as CAM project or CAM place.
-

I. Trajectory profile of particulate (elevation profile)

Altitude versus elevation profile of particulate concentration (on ambient level) on horizontal variability is visualized and given in Figure 9. The visualization so given by Figure 9 is completely based on rational history that what it should be and the profile would be the one like it.

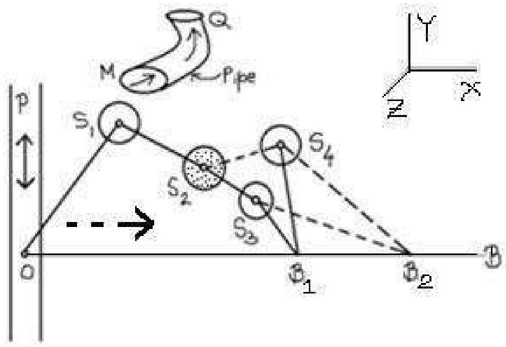


Fig. 9. Particulate settling with controlling centroid (sectional elevation; profile view)

In the figure, there are some points (in sphere) shown like S1, S2 and so on. Each point indicates the particulate concentration over its corresponding "co-ordinate" position on altitude versus horizontal distance profile as shown by the figure itself (Figure 9). The position of S2 should be at higher level as it is nearest to the pollution source and affected most by "prevailing" environmental conditions such as turbulence, fluctuations, entry or exit losses or gains, etc etc. The position of line source is O and position of settling of particulate on horizontal By-path (OB) is denoted by B1 and B2 which also signify alternative positions of settling on the path. Actually, the settling caused by statistics (normal or skew) is shown by trajectory profile in the figure by line S1-S2-S3-B1 orS1-S2-S4-B1 or S1-S2-S3-B2 or S1-S2-S4-B2. So, for a given point (B1, B2, so on) of settling at ground-level, there should be number of trajectories which might be studied as the alternative paths to settling. Another factual should be on each point that a number of points against any given point on trajectory profile should exist until finalization. For example, before going to point S3, final position of S2 at S2 should experience a number of positions around the point (S2) itself, resulting to variations in the trajectory's nature and profile. Several dots shown inside sphere of S2 indicate such points of variability that a finalization is done over all such possible dots before moving to succeeding point, S3. This emphasis of several variations over finalization of a point's position on the trajectory is denoted by encircling all those points (shown by dots) which results to resemble each point as a sphere itself. This is important so as to have the concept of variability phenomenon against each trajectory point. It reflects that what would have been done on finalization. However, it is upto this quite clear that profile nature or concentration profiles can be shown via trajectory nature of trend or pattern that should be like the one as shown and it gives the concept of variability over “horizontal” settling of particulate.

[Note:

- Change in gradient of trajectory profile does take place due to change in PFD (from non-cohesive to cohesive or vice-versa as applicable).
- It’s an assumption by the study itself that only a cohesive nature of PFD does make settling to happen along horizontal By-Path.
- The study has shown by its ownness the distance of settling along By-Path by settling length, L (of PM10) in Figure 1, by length OC in Figure 3 and by PFD by Figure 4. All these should hold equal correspondence.
- Direction of particulate settling is shown in Figure 9 by arrow mark (rightward from O to B).]

Significance of arrows (Figure 9):

- Dotted arrow from O to B indicates direction of (horizontal) movement of ambient air. As it goes forward (from O), several points S1, S2, etc do take place in the profile or pattern.
- Both-sided arrow mark indicates the roadway OP which is regarded in the study as pollutant generating source.
- A pipe MQ with inner arrow marks shown above the profile has been explained afterwards.

II. Distribution of PFD

As each of points S1, S2, etc are spatial or spatially variable, their positions should be of a number variety. On projecting of sectional profile view (Figure 9) by horizontal plane, three kinds of views are obtained and shown in Figure 10. These views depict the possibility of formation of points, S1, S2, S3 etc. on spatial interest of areal. The three kinds are as follows –

- Collinear (where all points lie on a single line; Figure 10.1).
- Zig-zag (where all points lie in an alternative way; Figure 10.2).
- Mixed (where a mix of above twos are present; Figure 10.3).

Each above variety can be called as kind of distribution of PFD. Term “distribution” of PFD is applied to indicate and define how statistical distribution (PFD) is dispersed or distributed on spatial arena, to particulate settling.

[Note:

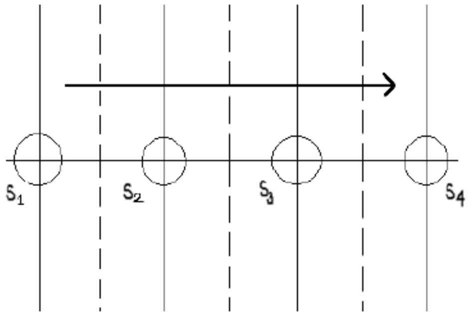
- All kinds are subject to equi- and non-equi-spaced.
- Vertical dotted line shows boundary.
- Vertical firm line shows settling point (S1, S2 etc) at intersection with horizontal line; it also indicates transverse direction.
- Horizontal line shows reference line or By-Path or like that can act as to define settling by spatial character as it belongs to.
- Direction of settling is essential to be shown and have in information to analyse always. All kinds should be under a specified settling direction of particulate (shown by arrows in Figure 10).
- All kinds should be under cohesive settling with respect to settling objective.]

III. PFD Classification To Statistically Distributed Pollution

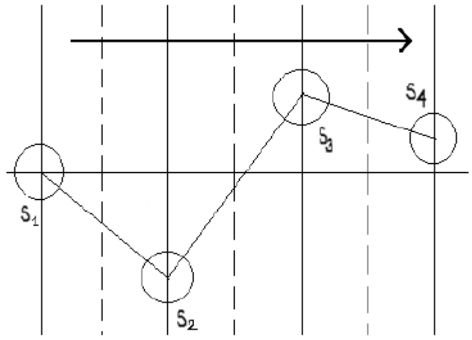
Here is the classified kinds of the particulates distribution on spatial interest (shown by Figure 10 which is in relation to Figure 9) described in this section by the following.

Collinear distribution of PFD

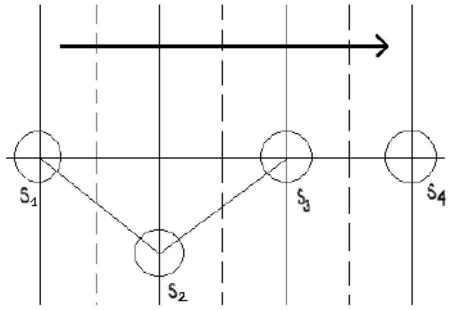
It is the kind signifying residing of all settling points (defined by PFD) on similar "horizontal" line.



10.1: Collinear distribution



10.2: Zig-zag distribution



10.3: Mixed distribution

Fig. 10. PFD distribution (plan view)

Zig-zag distribution of PFD

It is the kind signifying residing of all settling points (defined by PFD) not on similar "horizontal" line, but on different position as applicable by spatial movement of settling. Points of settling (S1, S2, etc) lying on this distribution may not necessarily lie on similar (horizontal) line.

Mixed distribution of PFD

It is the kind signifying residing of all settling points (defined by PFD) on a mix up of collinear and zig-zag distribution together.

IV. Area of influence

This is marked by dotted (vertical) line. For a given point, there should an area on both side of it which should be under maximum influence for the point itself. This influence is about settling intensity or areal settling about concerned point. It indicates the area (or volume) responsible enough for determining a settling point. An influence area does have only one point of settling on its adjacent (transverse) line. Figure 10 shows it.

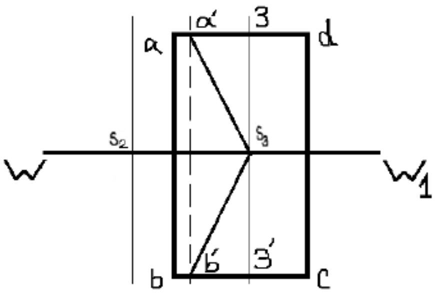
[Note:

- An influence area is formed once a succeeding settling direction is achieved or started with respect to the area itself.
- Each point of settling should have influence area on both side of it (Figure 10).]

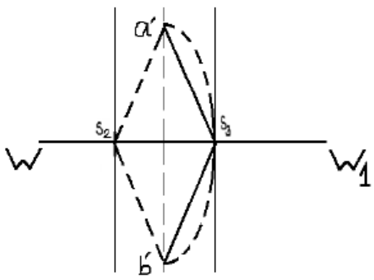
V. Curvature of arc of settling

It is an assumption by the study itself that distribution of PFD at any instance of time does take place about a centre over horizontal projection (of Figure 9) or areal region. Such distribution is hereby visualized as a curvature of circular arc as periphery of the distribution itself. For example, for S2 there is a curvature with a centre at S2 forming succeeding point S3. So, area enclosed by peripheral arc with radii at centre S2 is to be an influence area within which PFD is getting distributed (over its best potential).

For a given area or volume of settling of particulate by PFD, there should be movement of settling along resultant path (assumed) shown by Figure 11. Example, for a given area (or volume of particulates, rather than air medium) of abcd or specifically area a′b′3′3 (Figure 11.1), settling should occur along a resultant path (assumed) which is a′S3 that is obtained by resolving horizontal (a′3) and vertical (a′b′) component. Point a′ is to be taken from line (dotted) marked for influence area. Similarly, b′S3 resultant should be found. In this way, one side against a given point (for example S3 here) is obtained with the resultant lines forming a tripod whose three sides are a′S3, b′S3 and S2S3. Such tripod should be achieved on other side of the point S3 similarly. So, line 3-S3-3′ should act as mirror to be giving another tripod on the side. Keeping changing concerns depending on kind of PFD distribution as explained by Figure 10, the point S3 should have to be determined (as a part of tripod) on best application of knowledge and suitability.



11.1: Tripod determination by resultant



11.2: Initiation of arc and centre

Fig. 11. Birth of curvature of arc

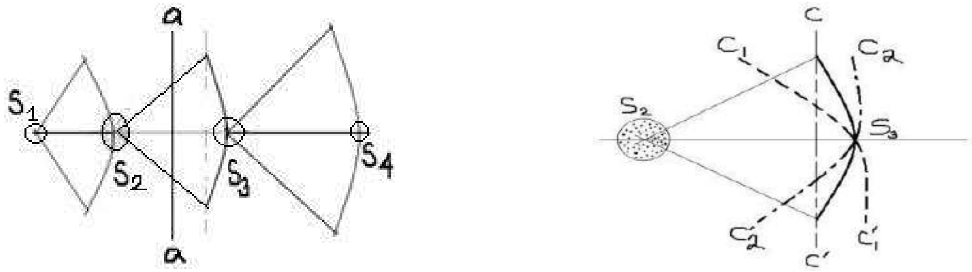
Circular arc can be drawn with the resultants on each side of the concerned point (say, S3) on settling trajectory. Through point a′, S3 and b′, an arc is hereby plotted with centre at S2 (Figure 11.2). This centre point may be elsewhere apart from S2 for given curvature. The study has explained its all discussions based on S2 as the centre point of curvature of arc. This curvature or arc should have several research scopes to proceed with find out further fundamentals on the research.

[Note:

- Horizontal line (WW1 in Figure 11) should be preferably a kind of “reference” line and position of points S1, S2, etc should not necessarily coincide with a “reference” definition of the (horizontal) line WW1. This would be found true for zig-zag and mixed PFD distribution apart from collinear distribution only.

- For a mass or batch of particulates, it is assumed that settling or transformation to cohesive settling should follow a resultant path. Thus, a'S3 or b'S3 is obtained.]

Sectoral forming by curvature of arc with a chosen centre point (say S2 for arc at S3) should represent concentration areal given by a given distribution of PFD. Figure 12.1 is thereby modification over Figure 9 in place of Figure 10. However as said above or earlier that a centre-point location may be elsewhere apart from chosen S2 for explanation purpose here and there should lots of several other points (shown by dots inside S2) that could have formed prior to finalization for point S2 at S2. Again it's thereforth mentioned that presentation of point (say S2) by encircling all the dots by a big sphere is only for understanding purpose of one point to be in the concern out of several points shown by dots. In this way, curvature-cum-sectoral alongwith a single point (S1, S2) out of all dots against the point itself is obtained to define how and what should the pollution distribution and consequent settling for a given PFD distribution.



12.1: Settling zones (with tripod and arc) 12.2: Variability in settling zone

Fig. 12. Planar view of settling zone

Figure 12.2 shows how curvature would look like if its centre-position is changed instead of point S2. In the figure, curvature cc′ is only for point S2 as its centre point and similarly curvature c1c1′ and c2c2′ is respectively for centre-positions other than S2 point or position, keeping in view of concept of line WW1 as given earlier. Also, it's not necessary to intersect all the changing curvatures through one singular point S3 as shown in the figure which is instead should change as applicable. With all these variations and possibility, the explanation of Figure 9 is hereby achieved by the concept of what should be a PFD distribution should be having with while settling happens or particulates move through airs of By-path. Also noted, sectoral formation may be given by concept other than "resultant" interest.

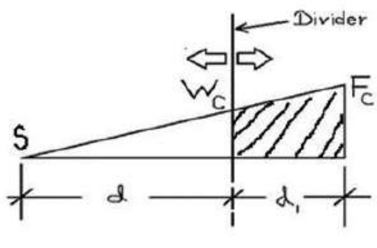


Fig. 13. Concentration triangle profile (section a-a)

Now, if a section a-a of sectoral formation (shown by Figure 12.1) is taken then sectional elevation would be one shown in Figure 13. By equating similar triangle application of geometry, we get,

Wc/d=Fc/(d+d1) . . . (Eq. 1)

where,

S=S2 point of settling (it may be S1, S2, S3, etc as considered).

Wc, Fc=pollution removal status or concentration of pollutant or percentage of distribution of PFD at d and d1 respectively.

d=length of non-cohesive zone=distance of non-settling zone.

d1= length of cohesive zone=distance of (cohesive) settling zone.

Furthering Eq.1, we get,
Wc/Fc=d/(d+d1)
Fc/Wc=(d+d1)/d=1+(d1/d)

Again, Fc=(Wc)[1+(d1/d)]
Or, Wc=(Fc)/[1+(d/d1)] . . . (Eq.2)
Thereby, unknown variable can be suitably determined on given known ones by Eq. 2 using Figure 13. Furthermore, research scopes may increase to more dimensions of finding if three-dimensional features of "elemental" nature are taken care of as shown in Figure 14 by considering thickness (t) or such. So, transverse contribution of PFD distribution (with respect of By-path) may be future scope of research which could be solved and explained by this study.
[Note: L (as shown in Figure 1)=d+d1=settling zones length (total); Wc/d=Fc/L (by using Eq.1); please see Figure 21 also, shown afterward]

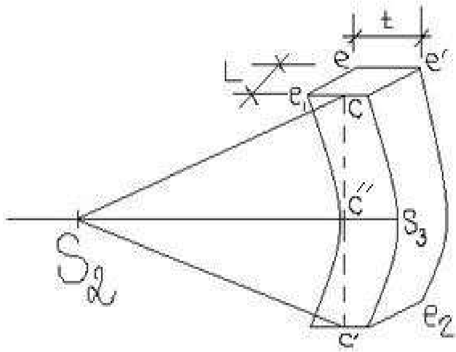


Fig. 14. Dimensional view of area of settling (elemental)

By superimposition of concept of curvature of arc and elevation profile of concentration of PM10, we hereby get the profile view shown in Figure 15 in which settling points S1, S2, etc should form their own settling "horizontal" length such as Z1, Z2 etc – as always in the study, it's just an illustration though but it should find the place while modelling on the study.

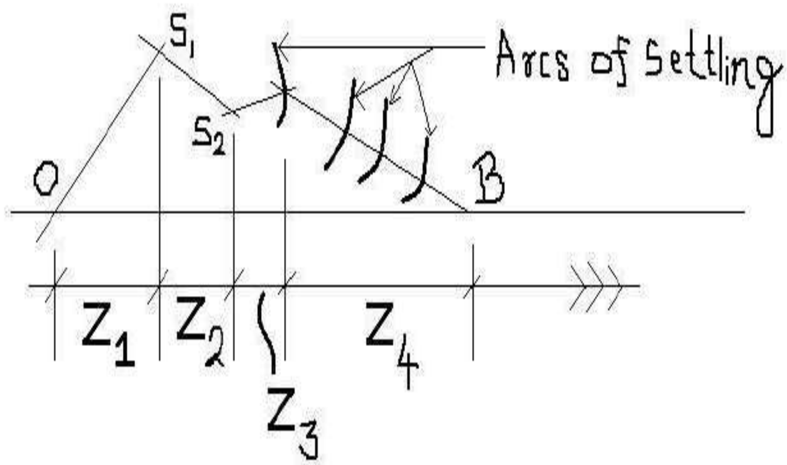


Fig. 15. Various kinetics under superimposition of arc and elevation profile

It is now clear that considered path of settling as resultant one as explained by a′S3 or b′S3 (Figure 11.1) should undergo the travelling of particulate or trajectory, by PFD distribution for settling as suitable out of normal or skew ones (shown in Figure 5). Finally, determination of points S1, S2, S3 etc should be obtained by "resultant" concept which may also be otherwise for point of interest of research.

VI. Concentration cylinder

This is an outcome of the study based on its explanations. A small curvature of arc is a part of full complete sphere. With respect of each settling point S1, S2, S3 etc we can thus have number of full spheres resting in consequence or sequence. One such view is shown in Figure 16. Irrespective size of sphere, it should resemble as a cylinder on elevation projection for a given elevation or altitude. Height of cylinder should be the height PFD has undergone or experienced during settling journey along the trajectory. This means the height of falling of settling through its various possible settling distributions of PFDs. This concept of cylinder formation should thereby be visualized as resting on connecting lines in between two points of settling successively or in a sequential manner in the consequence. Such cylinder is hereby termed as ***concentration cylinder***. So, against each point of settling there should be a cylinder consisting of number of circular plates resembling as one full cylinder entirely. Let's call each plate in circular shape by term ***"planar plate"*** (or ***settling sphere***) of concentration cylinder. Its size or dimension is of variable nature, depending on (horizontal) range within which cohesive settling does occur. In a setting of urban's built-up, such a cylinder would behave like an indication of a pollution/particulate free zone instead. As said always, NWZ management would constitute such a cylinder to process through to make an ambience pollution free. In order to ensure such a cylindrical concept, various pollution measuring experiments (for PM10 or PM2.5) can be carried through which are beyond the scope of this present study as well. Furthermore, this study can be thought of for constructing various other pollutants, be it gaseous or particulates.
[Note:

- Hatch portion shown in plan-view of Figure 16 is the areal formed by curvature of arc (that is tripod) which may extend to any extent (included angle (say at S2 for S3) should vary from zero to 360 degree) as explained in Figure 11.1.
- Shapes of planar plates may vary, to other geometrical shapes as well.]

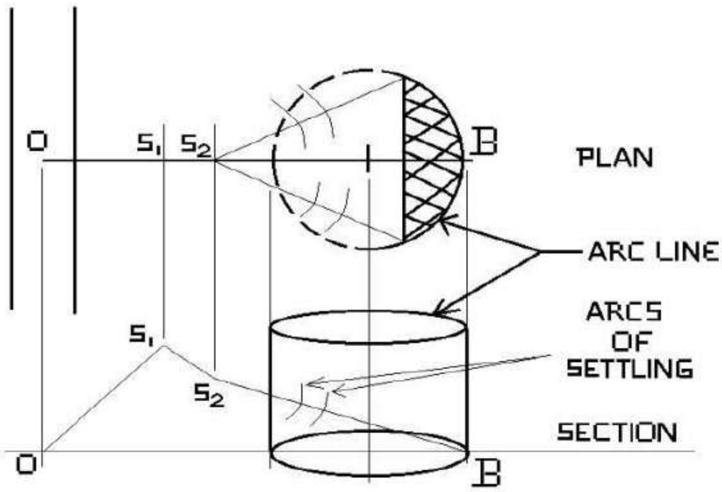


Fig. 16. Projected views with perspective of (planar) settling – concentration cylinder

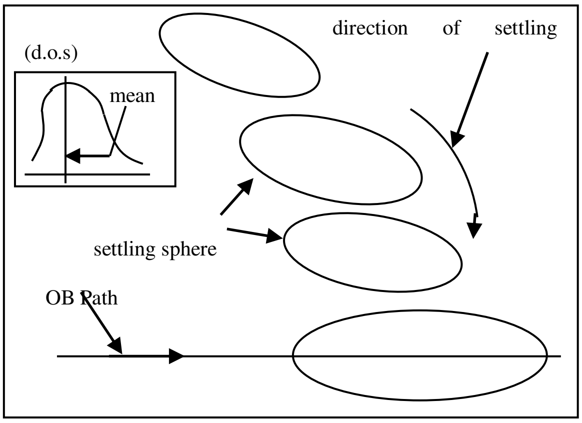
A perspective view to justify above concept of cylinder formation is hereby given as follows –
Apart from normal PFD, for two kinds of skew condition in PFD there should be different phenomenon into particulate setting by nature. For left-sided skew whose PFD is shown in inside box of Figure 17.1, each circular plate (planar plate), comprising of distribution of PFD indeed, may keep falling alongside by keeping its balance over its "left-sided" skewness of PFD. Tendency to opposite side (that is rightwards) is due to making a normalcy in the PFD distribution. Moment is also thereon acting on such rightward settling of left-sided skew and that should be clockwise (upside convex). It is shown in Figure 17.1. For right-sided

skew, phenomenon would be opposite as normalcy is on left side and skew is to rightward (Figure 17.2) and in this case ***"direction of settling"*** (d.o.s) should be clockwise with upside concave as shown. This is only an illustrative explanation delineated for understanding of the concept for the study.
[Note: Depending on prevalent ambient atmosphere and others, direction may be clockwise or anti-clockwise (not in sameness but also in opposite manner) and criteria or concave or convex may also change accordingly.]

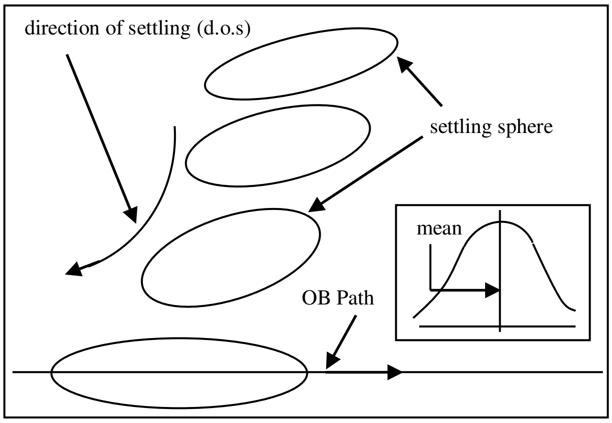
Now, we can also imagine that such falling of settling spheres may occur through a channel based on the skew that holds (Figure 17.3). And, finally the cylinder consisting of plates is formed at the point of settling at ground-level which is shown in Figure 17.4. It may be infinitesimal by nature but it's the research concept for understanding. In this way, the justification of formation of concentration cylinders is explained to defend such determination by resultant concept of tripod and curvature of arc earlier as given by Figure 16.

VII. Concept of transverse settling and settling field

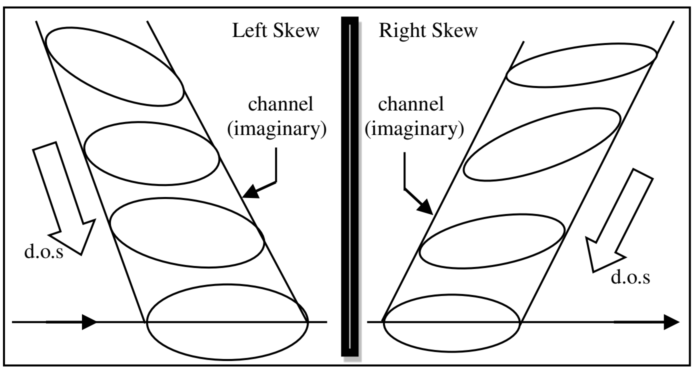
It is noteworthy to imagine an areal surrounding by the concepts discussed earlier in this study and it should provide idea of settling character of PM10 interest.



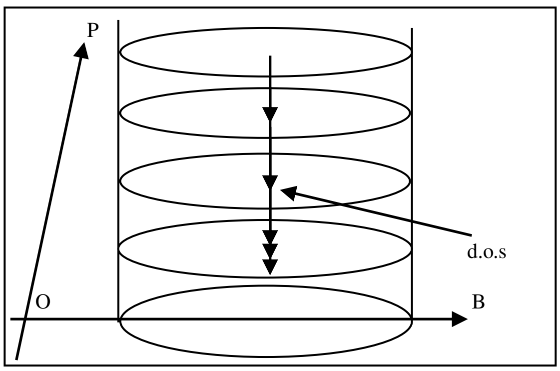
17.1 Settling by skewness to the left (clockwise)



17.2 Settling by skewness to the right (anti-clockwise)



17.3: Skew and planar plates



17.4: Concentration cylinder with beads

Fig. 17. Evolution of concentration cylinder (in particulate pollution removal)

Transverse settling

It's already got indication in explanations of settling kinetics given earlier. For an areal surrounding, settling of PM10 is completely possible to at any desired location along By-path away from On-path provided a design scenario is made by policy and etc (Table 3). The study so far explained can be easily put on in any given By-path locations irrespective geography and demography. However, a simple plan view can show how a transverse variation could be formed using the study's concept. It is shown in Figure 18.1 where a number of curvatures are possible and to be considered for the analysis, subject to any required changes if necessary.

PM10 free field

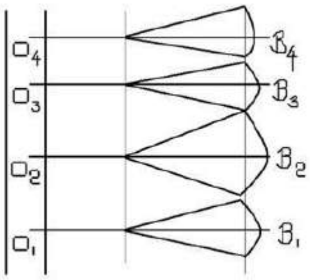
It is customary to have a field once more than one number of By-path meet at a single point together. Figure 18.2 shows it for such four in number. Enclosed area formed by several curvature of arc together, on outside of each By-path, as shown by the figure is hereby called as ***10 settling free field*** or ***PM10 free field***. The field which is formed on outside of each By-path in a set of number of By-paths meeting together may be in subjection of either or both of following twos –

- PM2.5 zone.
- Zone free from PM10.

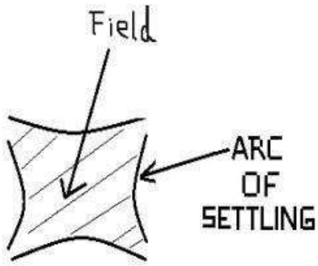
Such field having PM10 free definition may have several following benefits –

- A field from PM10 may be suitable for hospital, hermit, crèche, heritage building, parks etc.
- Dedicated built-up envelopes may be given on the field for removal of PM2.5 interest.

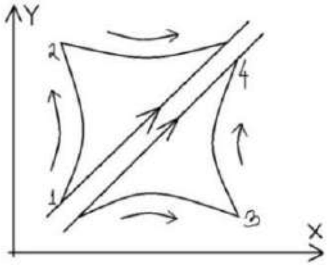
[Note: Term "envelope" defines to ambient stability in response to prevalent atmosphere.]



18.1: Arcs forming "sectoral" (plan view)



18.2: A 10 settling free field



18.3: Vectorial presence in the field

Fig. 18. Transverse sectoral and peripheral boundary of settling surrounding a field

"Singular" field direction (of pollution flow)

A field of settling is defined as, settling field at a given locality=sum of (multiple settling zones).
It is possible to determine a direction of pollution flows for the field stated above. By vectorial application simply, all sides by defining or representing as vectors direction of "resultant" can be obtained which should be the direction (of pollution-flows) of the entire field.

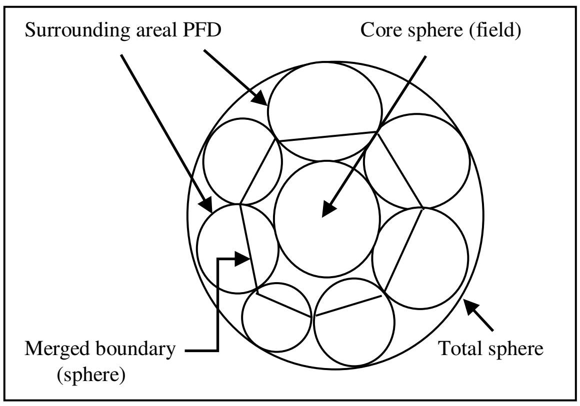


Fig. 19. Merging with adjacent spheres

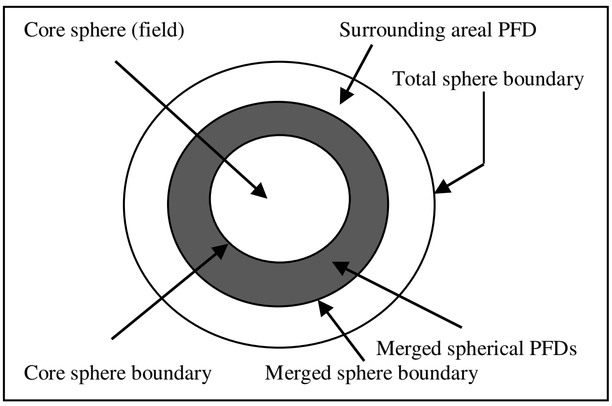


Fig. 20. Evolution by clarity between core and merging

Figure 18.3 depicts it and resultant direction is shown By-path 1-4 (here it's assumed as 1 to 4, for both the triangles, which may be otherwise depending on given conditions) for given vector triangles 1-2-4 and 1-3-4. This is completely illustrative and all directions are given for understanding purpose for given finding by vector analysis so shown in the figure. So, this may be the way of determination of direction of flow of entire field.

[Note:

- Above summing is subject to variability and its viability to function as a singular field.
- "Field" is defined in this study as PM10 free zone.]

Total "field" sphere and its boundary

This concept can be made in either way of inside to outside or outside to inside at a given locality of settling consideration. As envisaged in previous delineation of forming up a ***"singular"*** field, there should be a development of several number of settling zones joining together in any way (along tangent of "settling zone" sphere or else) resulting to appearance of number of spheres connecting one by one on a spherical field. Figure 19 shows it where number of spheres concerning to their PM10 settling zones should be found together for a given locality or surrounding areal. If periphery or circumferences are joined by a straight line or sphere there should be two spheres, one on inside and other on the outside, For such a figurative understanding, we should get an easy deliverance about phenomenon happening at locality where number of By-paths may be analysed together which are considered to be such as shown in the figure. Outside sphere which is called as total sphere should be an extreme boundary of settling zones and analysis, whereas inside sphere that is termed by core sphere should be treated as the field explained by above segment (also please see Figure 20).

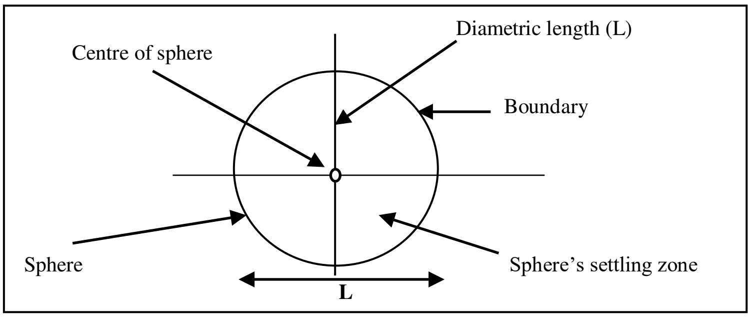


Fig. 21. A typical "settling zone" sphere (plan view) of diametric length L

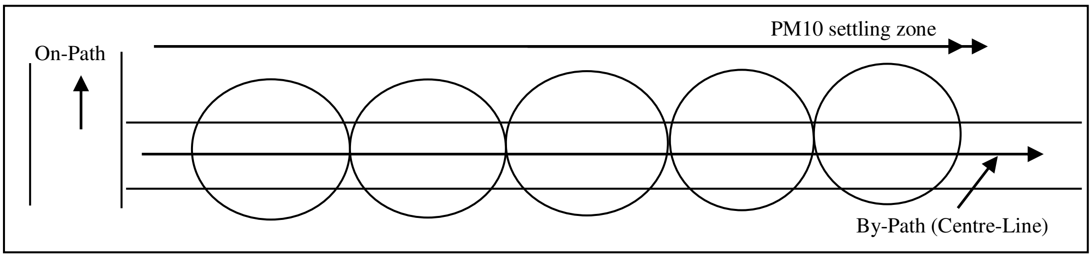


Fig. 22. Ideal network of spheres

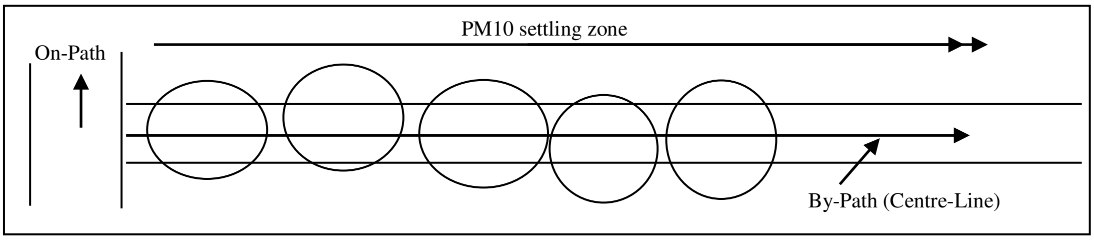


Fig. 23. Real network of spheres

It is quite well known that every consideration where a circular or curvature of arc has been initiated with in this study can be also analysed by straight line initiation. Merged sphere zone which is between total sphere and core sphere zone can also be found by curvature of arc or curvature simply instead of straight-line initiation as shown by Figure 19 and Figure 20.

As all geometrical shapes are shown in the study not to scale so areas coming out from related analyses or figures should be considered as relevant to rational happening as there is no defined geometrical consideration that can be put on in the study as of now.

Figure 21 shows what elements of geometry one sphere of settling zone interest must be having with by keeping all considerations as changeably constant as always in the study.

PM10 Settling Length

It is the distance from source where PM10 is considered to be get settled down at ground-level (Figure 1). A typical settling zone should have its settling trajectory over several spheres of "considered" PFDs. Such spheres may be imagined as shown in Figure 22 and Figure 23 in their plan-view of formation for an ideal and rational perspective respectively. So, it is at well disposition of knowledge that all these spheres which represent various forms of settling by PFDs could be represented by a single or big sphere (Figure 21) in which all those several spheres might be situating as well.

VIII. Pollution physicalness abatement (Impending Tubule)

It is observed from the study itself that there should be an outset of innovation above a certain height from ground-level to reduce ambient PM10 concentration. With this purview, a tunnel or pipe could be kept at an altitude to attract and drag out PM10 from ambient air to outer atmosphere). Figure 24 shows kinds of pipes that can meet the criteria by their shape as required (H1=height above ground-level; H2=height of pollution removal, that is, height within which the pipes would be kept or spread). For relevance, Figure 1 can be compared here.

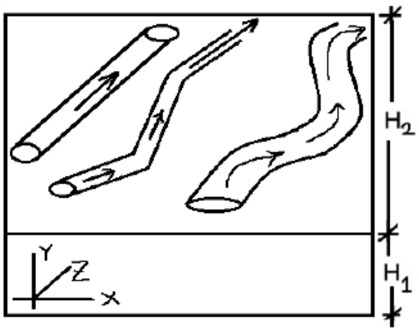


Fig. 24. Different impending pipes in the height

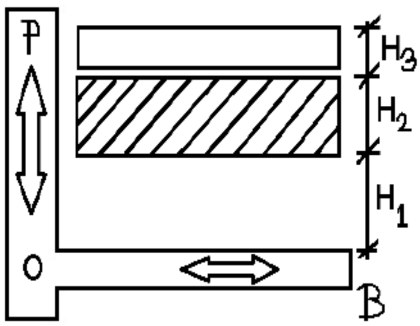


Fig. 25. Impending heights (3-dimensional)

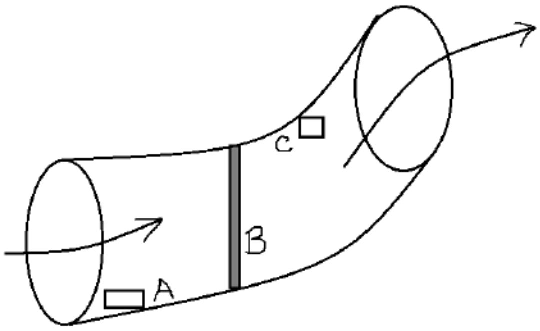


Fig. 26. Impending Tubule or Pipe

(air-flow direction into pipe by arrow: left side: entry; right side: exit)

Figure 25 is hereby given for having a distribution of heights for laying the pipes. H3=height of biosphere as suggested by this study whereas H2 should be given for giving the pipes' laying and H1 to be a (clear) height above ground-level. Such innovation is termed here by "impending pipe or tubule".
Figure 25 is hereby given for having a distribution of heights for laying the pipes. H3=height of biosphere as suggested by this study whereas H2 should be given for giving the pipes' laying and H1 to be a (clear) height above ground-level. Such innovation is termed here by "impending pipe or tubule".

Figure 26 gives an internal layout component to delineate functional working. A=motor (battery/solar/electrically operated); B=filter membrane; C=exhaust or exit fan. Impending tubule which should be kept at a suitable inclination should be operated by motor to channelize ambient air (pollutant) into its own internal path or bends through suitable filter medium to separate out PM10 and finally release out PM10 free air with an enhancement of exit fan.
[Note:

- Subjectively, Figure 9 is also shown with an arrangement of such tubule (MQ pipe) just above the profile variation.
- Heights, H1, H2, H3 are research points of interest.]

IX. Physicalness preparation (on transformation of non-cohesive to cohesive settling)

There should be possible to design a built-up envelope in an areal surrounding (termed in the study as surrounding areal) concerned By-path and to do this, Table 7 is hereby provided to define how such an approach could be done to make and prevail a certain level or status of PFD by implying emphasis on associated attributes of possibility.

Table 7. Innovation provisions to cohesive areal modelling^

Sl.	The study	Modelling's theme steps	Physicalness provisions on statistics conversion	
			From	To
			Skew or non-cohesive distribution	Normal or cohesive distribution
1	CAM Modelling	Areal design (anticipating)	Orientation (building, road, drain, boundary wall, etc.)	
2			Landscape design	
3			Cohesiveness (Atmosphere)	
4			Hollow passage (hot air path/layers surrounded by cold airs)	
5		Provisions and Preventive	Colder passages or bushes at ground-level or at altitude as suitable	
6			Sticky smooth, glassy or wet surfaces	

7		Materials	Wind velocity reducers (obstruction, barriers, curtains, shrubs, cripple plants)
8			Altitude pipes and glossy (Figure 26)
9			Anti-reflective material (absorbers/adsorbents)

^with NWZ planation and many others of innovation interest and creativity.

2.3 Assumptions of C.A.M

- Settling is best possible and accomplished by normal distribution of statistical probability frequency function.
- Source of pollution is vehicular of On-path and settling of the pollution (particulate only; PM10) on or along By-path is the subjective interest if research and discussion.
- Particulate of interest is PM10 only.
- Boundary of settling is circular by shape. This means each settling zone is of shape of sphere or circular sector or area under circular arc.
- Area under settling is assumed as an imaginary sphere which may or may not have equal settling condition in all its directions So, it's only a sphere presented by a settling arc in the settling zone.
- Settling zone is called for settling on By-path only.
- It is considered that coarser particles (PM10) would settle first and then finer ones as we go away from source location of On-path.
- By-Path's particulate settling of PM10 (not PM2.5) is only the study point of interest in this study.
- It is considered that origination of settling condition shall take some time or distance to settle or removal finally; removal means removal from atmosphere. This means that there must be a distance or time interval between origination of settling condition and its final settling in a particulate removal process of By-path. This is one of reasons behind settling arc or arc nature or shape of settling boundary.
- There may be a distance in between two settling arcs. This enhances study of lateral distribution of particulate settling.
- Negligibility can be assumed as applicable to anywhere as suitable validly.

3. Results and Discussions

- Dispersion or distribution of particulate (PM10) is discussed with sharing of particulate between By-path and On-path respectively acting in the study as affected by pollution and source of pollution (vehicular line source).
- Entire study is explained in limelight of horizontal distribution of particulate.
- Distribution by PFD is already an established fundamental. The study has explained its various insights on physical and perspective ground.
- By magnitude, d and d1 can have three possibilities and these are as per Eq.2 and as obtained as follows (please see Figure 13) -
  - d=d1
  - d>d1
  - d<d1
- NWZ approach is one of the innovations the study's given in the pursuit.
- There are various scopes of materials innovation of application which should include -
  - Impending Tubules or Pipes (with motorized arrangements; Figure 26)
  - Sticky Bars (curtains/pads/sprays) – the location's surrounding objects to be covered by glue-like matter that can easily attract and stick up PM10 particulate.
  - NWZ Plantations – greenery can be put on by NWZ definition at the location of By-Path site.

- More understanding and further research is possible over explanations of the study so made.
- The study's claimed that normal PFD is possible to create or prevail but more of it, "cohesive" should be the term to express the functional purpose of that.

4. Conclusions

- Initiations of several new approaches have been provided in the study.
- The study, by its entirety, could be resembled as a modification over inclusion of various perspective based concepts subject to rational validity.
- From curvature of arc to concept of field and its direction is a completely new part of the study as well.
- Furthermore, cylindrical settling areas should excel more other research pursuits with respect to "changeable" creativity or further new parts of the study.
- With entire explanation so found out, the subject of particulate settling could find broader dimensions ever.
- Several physical measures could be provided to abate particulate pollution and this includes PM10 post marking, PM10 Impending Pipe, NWZ Plantation, human awareness to use mask always etc etc.
- It is possible to make demarcation of PM10 settling at ground-level. Figure 27 shows a layout to showcase total or final settling point (T) of PM10 to define an entire settling zone of PM10 for the given source O as shown.

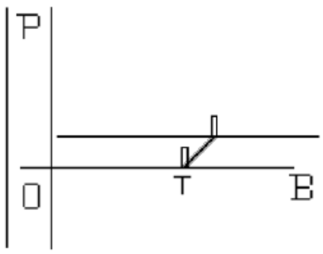


Fig. 27. PM10 post (T) on By-path

- A sketch of NWZ and its various kinds has been shown in Figure 7. Arrangement of N or W should be made within a settling zone not necessarily defined for PM10 only. However, cohesive settling zone for PM10 marked by OT of Figure 27 indicates PM10 free zone to TB. This kind of showcase shall have various implications on beneficial ground and those might include as,
    - Social and health awareness.
    - Value or status of the location.
    - Implications of engineering and science.
    - Correlative effect with involved structural or environmental components (such as drains, vegetation covers, boundary wall if any etc.).
    - A field of importance.
- The study proclaims that instead of normal distribution only a combination of all PFDs (which is termed by cohesive zone of settling) could be the best spatial distribution of PM10 in ambient atmosphere.
- Other introspections should include -
    - Basic precautions, like [34], [35] and [36], must be attained at while creating modelling on the study as explained.
    - In another perspective, approach like [37], [38], [39] etc may give spatial variability to understand.

- The study is equally applicable and quite of highly enhancing also for the study like [40] and scale-based barriers must be always in great concern like [41].
- The study could vary or modify available practices of greenery in and along road-side pollution concern as studied for [42] and [43].

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4

Evaluation of Project Cost Management and Cost Trend Analysis

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Abstract

Construction projects are the most complex, with no certainty of the exact cost or time to completion. According to the records, it is uncommon for construction projects completed without contract variation, due to the nature of construction projects; it involves many stakeholders, making them more complex and distinct from other sectors. Project variations have had an impact on construction projects all over the world. Both contracting parties acknowledge the situation and work hard to keep it to a minimum. The main objective of this study is the evaluation of project cost management and cost trend analysis. The methodologies of this study are qualitative and quantitative methods, survey will be distributed with engineers and interview with industry experts. The expected results for this study are to evaluate and analyse the factors that affect project costs, and how to maintain the budget. Also, to understand the importance of cost trend analysis.

Keywords

Trend analysis, Project Management, Cost and Budget

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1. Introduction

The construction industry is one of the most important indicators of a country's economic growth. Because construction projects are very complicated, it is very common to find projects completed far beyond the original schedule and cost [1]. A change order is any request to change or modify an approved design, including an increase or decrease in quantity, specifications and standards, and quality [2].

The most common issues in the construction industry are cost and time overruns. These two factors are regarded as the most important parameters in construction project management. Cost and time overruns are the primary causes of construction project failures. Project cost management and cost trend analysis are mathematical techniques that use previously published data and results to forecast possible future outcomes. This is usually accomplished by closely monitoring cost and performance variances. Cost trend analysis and project cost management are critical tools in project management and quality control [3].

The practice of collecting information about an organization and identifying the pattern in which it moves is known as trend analysis. This is mostly used to predict the future, but it can also be used to estimate uncertain past events. Trend analysis employs cost estimation techniques to comprehend and maintain a project's scope. Scopes of work frequently shift and vary during a construction project [4]. Thus, trend analysis is a continuous process that is carried out with reference to previous estimates. Cost is typically represented graphically. The data quality within an organization is calculated using this type of trend chart representation [5].

The construction industry happens to be one of the most important factors of economic growth of a country and construction projects are very complicated in nature. The main issues faced in a construction project are cost and time overruns [6]. These two factors are regarded as the most important parameters in managing a construction project. Project cost overruns and unable to finish the task within the given time are the factors in the failure of a project. Cost trend analysis and project cost management are two very critical tools in project management. This is the practice of collecting information about an organization and identifying the pattern of profit or loss also known as trend analysis. In a construction project scope of work constantly shifts and varies. Therefore, cost trend analysis is a continuous process [7]. In a construction project, the project scope and quality must be integrated with time. This is the fundamental concept of cost management, and this helps ensure the success of a project. Some of the most important factors to be considered are project investments, economic evaluation & cost forecasting. The combination of these forms the foundation for cost trend analysis. It is often noted that a place/ organization follows a particular pattern.

Trend analysis examines these patterns to make future predictions. This helps in making the best decisions financially and examines the monetary arrangement of an organization. Cost trend analysis predicts what may lead to profit and what maybe a loss. It indicates where a market is headed.

1.1. Project Cost Management

Budgeting, estimating, and controlling expenses throughout the life of a project are all aspects of project cost management. This is done to keep the budget within the approved limits. This is critical to the success of any project.

The following must be noted for a project's success:

- It meets or exceeds the standards and scope
- It is executed to a high standard
- It is completed on time and under budget

As a result, one of the most important pillars of project management is project cost management, which applies to every industry, including manufacturing, retail, technology, and construction. It contributes to the establishment of a financial baseline against which project managers can assess the current state of their project costs and, if necessary, realign the project's course [8]. Cost management is self-evidently important.

If you want to build a house, for example, you must first establish a budget. Once you know how much you want to spend on the project, you can break down the high-level budget into expenses for sub-tasks and smaller line items. The budget will determine critical decisions such as: which designer to hire—a high-end one who will build and deliver the project from start to finish, or someone who can assist with a few elements and work on a smaller budget? How many stories should the house have? What kind of material should be used?

It is impossible to answer these questions without a budget, and it is also impossible to determine whether you are on track once the project is underway. Because of the concurrent running of multiple projects, changes in initial assumptions, and the addition of unexpected costs, the scale of this problem is magnified in large organizations. This is where budgeting comes into play. Project managers can use efficient cost management practices to:

- Set clear expectations with stakeholders.
- Control scope creep due to transparency established with the customer.
- Track progress and respond with corrective action at a rapid pace.
- Maintain expected margin, increase ROI, and avoid losing money on the project; and
- Generate data to benchmark for future projects and track long-term cost trends.

Cost management and control are critical for most projects, but project scope and cost overruns are common all over the world. This is largely due to ineffective approaches to identifying, managing, and controlling client needs, project scope, and project cost. Numerous cost overruns on major projects worldwide in the hundreds of millions and billions of dollars have piqued the interest and concern of people at all levels of society [8]. The process of planning, organizing, directing, and controlling a project is known as project management. Control over company resources for a relatively short-term goal formed to achieve specific goals and objectives. One of the key resources in the above definition, according to the project management overview in the diagram below, is cost.

Fig. 1. Overview of Project management

2. Methodology

The orderly and hypothetical technique used for investigation for achieving the goals of the analysis is the most important strategy used. The methodology used includes a hypothetical analysis to provide an understanding of the investigation. In this research, a quantitative approach was adopted to achieve the primary goals. Along with this, a qualitative analysis was also adopted.

The qualitative method examined the experiences of experts and specialists' experiences, using their opinions, words, and information to collect data based on real-world insight. The subjective strategy is more concerned with organizing information in a different way by using an interview [10]. The raw data was extracted and discussed to develop the general framework. The quantitative research strategy relied on the data collected through a questionnaire, which was further investigated. Where people are selected based on relevant knowledge or records that can help with the topic and analysed by SPSS -V25.

3. Results and Discussion

Semi-structured interview questionnaires and interviews are the primary data collection tools. The questionnaire's goal was to identify the primary causes and effects of various policies on a specific project or organization. The questionnaire was divided into three parts, 1st part for general demographic information, 2nd part for the causes and 3rd was for effects. Questionnaire Respondents come from a wide range of industries and organizational structures. It was discovered that 78.4% of respondents were male and only 21.6% were female. Omani participants made up 14.9% of the total, while non-Omanis made up 85.1%. Out of the 74 responses, 59.5% were engineers, most of who worked in the construction industry. Non-engineers made up 20.3% of the total, with the remainder coming from a variety of other occupations. 45.9% have 0 to 5 years of experience. This is followed by respondents with more than 17 years of experience, who account for 41.9% of the total. 6.8% have 11 to 16 years of experience. 45.4% have 6 to 10 years of experience. The majority of the participants were either new professionals or experienced professionals. Participants were from different age groups as mentioned; It was 45.9% for those aged 25 to 30 years, 43.2% for those aged 41+, and 40.7% for those aged 36 to 40 years. 40.5% of the 74 total respondents were from the construction industry.

Table 1. Frequency Statistics

Variables	**Category**	**Results**	
		F	**%**
Gender	Male	58	78.4
	Female	16	21.6
Nationality	Omani	11	14.9
	Non-Omani	63	85.1
Designation	Engineer	44	59.5
	Non- Engineer	15	20.3
	Other	15	20.2
Experience	0-5 Years	34	45.9
	6- 10 years	4	5.4
	11-16 years	5	6.8
	More than 17 years	31	41.9
Age group	25-30 years old	34	45.9
	31-35years old	5	6.8
	36-40years old	3	4.1
	More than 40	32	43.2
Sector of work	Construction	30	40.5
	Non construction	27	36.5
	Other	17	23

Pearson's coefficient was computed and found to be N=74. The cost means score (M = 1.945, SD = 0.719) indicates that cost overruns and cost management are common issues in construction projects. A correlation test was performed, and the results are as mentioned, p = 0.744, the two variables are related and have a strong relationship. r = 0.01 in this study, indicating that the relationship between cost and trend is moderately strong and the study is significant.

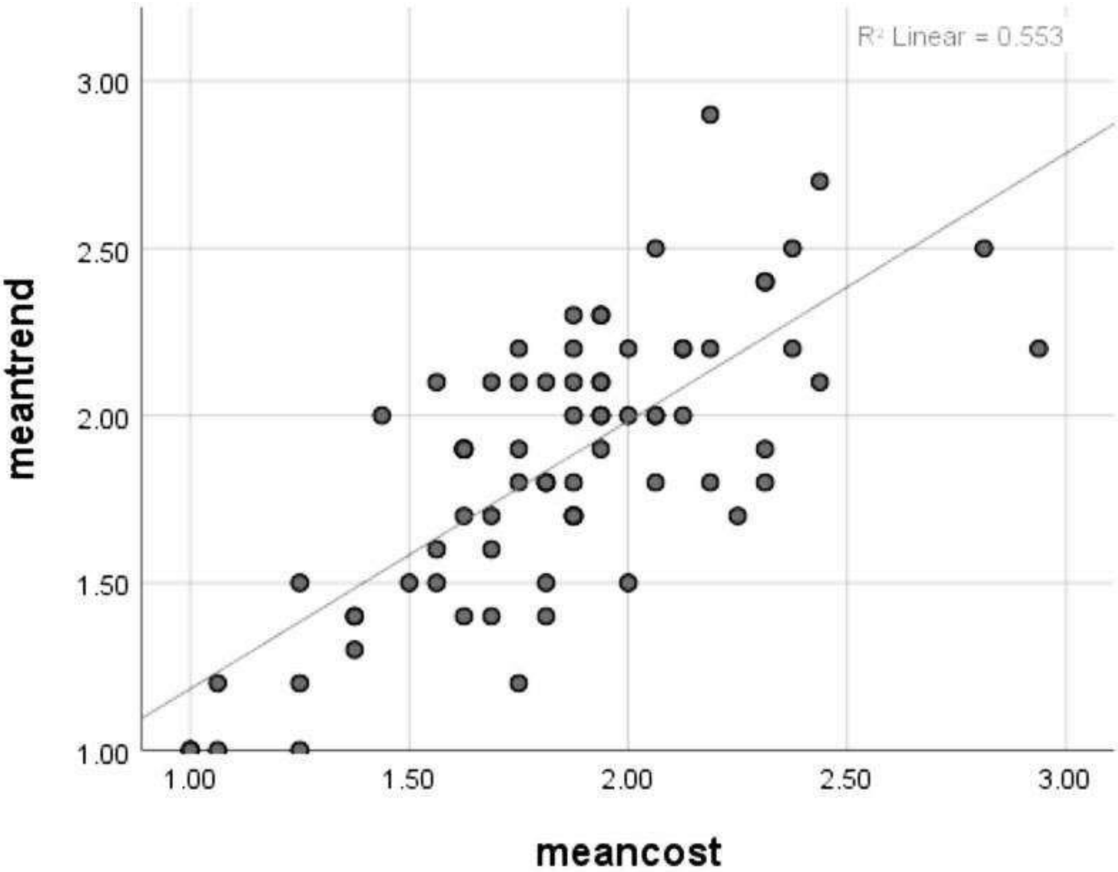

Fig. 2. The positive correlation between mean cost and mean trend

Also, there is a positive relationship between mean cost and mean trend. A null hypothesis test was performed on the sample data collected and the following were the results. The hypothesis test has a 95% confidence interval of difference and t =41.637, df = 73, and mean difference = 1.847. This indicates that the study is important. A crosstab analysis was done to analyse categorical data; crosstab testing is used as a nominal measurement scale. It demonstrates that the relationship between cost management and the trend is very important in construction projects. A rank analysis was also performed to check the significance and the study found no significant differences between the responses collected.

3.1.Qualitative Data Results

The interviews focused on three types of contracting parties: the client, the contractor, and the consultant. Three construction interviewees were chosen from various categories, including senior project manager (contractor), contract manager (consultant), and senior engineering manager (client). The interviewees all agreed that the main driving forces behind project cost management challenges are new requirements and ongoing changes from the client's perspective. The interview also revealed that poor design, unfavourable site conditions, inconsistent contract documents, and a lack of a project database are the main concerns with project costs in the construction industry. The contracting process, particularly in pre-tenders, requires modification. According to the interviewees, there should be a system in place to select the right contractor based on their level of technical expertise. During the interview, six main open-ended questions were discussed. The interviewees all concur that new requirements and ongoing changes from the client's perspective are the main driving forces behind challenges related to managing project costs. However, an interview also revealed that the main concerns with project costs in the construction industry are poor design, unfavourable site conditions, inconsistent contract documents, and a lack of project database. According to observations, the contracting process, particularly in pre-tenders, needs to be adjusted to each project's specific requirements. As a result, choosing the lowest bidder for the A Despite its technical suitability, a contract typically results in numerous extra and additional costs during the execution stage. The interviewees argued that there needs to be a system in place to choose the right contractor by considering their level of technical expertise.

The interview revealed that work completion delays are the most common problem faced in a project in the construction industry, followed by project cost overruns (out of budget) and, to a lesser extent, rework, or demolition. Finally, the interviewees largely agree on the proposed set of strategies to manage projects and related costs in a more effective way. However, interviewees A and B were slightly opposed to the strategy of daily reporting. As a result, in their opinion, it will complicate the requested verification process while also being time consuming, potentially delaying the approval process even further.

4. Conclusion

The main focus of this study was to find and analyse the factors that affect project costs, estimations, and how to maintain the budget. Also, yet another aim was to understand the importance of cost trend analysis. Based on the questionnaire responses and their analysis, it can be concluded that: The cost planning factors included in the project cost plan are as follows, beginning with the one deemed most important:

- Project requirements
- Work statement (brief)
- Structures of work breakdown
- Timetables for major milestones

Milestone schedules are thought to be the least important cost planning factor. As a result, if not monitored, it can be one of the causes of indirect costs, leading to cost overruns on a project. This hypothesis is supported by the analysis and interpretation of the research findings on cost planning techniques. This is because, while cost planning factors were included in the cost plan, they were ineffective because the statement of work (scope) and project specifications were not complete when the cost plan was determined. The study revealed that the cost analysis of the variations was done mostly when the contract variations were executed / or after they were executed, and the employer was notified afterwards. It is reasonable to conclude that cost analysis was performed when it was too late to make decisions on alternatives.

Future project costs are not adequately analysed and reported, resulting in ineffective cost- cutting measures. This hypothesis is supported to a large extent by the research findings and analysis. This is because future costs were not calculated before they occurred, but only after they occurred. As a result, instead of cost control, what was done on projects was cost monitoring and simple bookkeeping of performance in terms of costs. A project's financial completion entails settling contractual claims and agreeing on final accounts. Based on the research findings and analysis, it is possible to conclude that. Following the completion of the project, final cost reports were prepared. The project cost management system can be tailored to specific projects, resulting in successful financial project management and completion. The project cost management system can be tailored to specific projects, resulting in successful financial project management and completion.

4.1. Recommendations

- The recommendations below would improve the effectiveness of project cost management in construction projects.
- A detailed brief and project specifications should be provided for all projects. These should be clear and concise in order to confirm the project requirements, particularly since most construction projects are standardized. This will reduce the cost variances caused by an inadequate statement of work (scope) and specifications.
- More emphasis should be placed on milestone schedules as a cost planning factor. This is due to the fact that this time parameter has indirect cost implications that should be considered, especially when changes are made.
- Cost variance approval by the client or contractor should be encouraged. However, this should be done before the changes are implemented so that the employer can make decisions and consider alternatives.
- In terms of cost reporting, there is a need for a standard format for presenting project cost reports. It should outline the report's contents, requirements, and presentation style. The report should include graphs so that the employer can easily understand the project status and make decisions.
- According to the current procurement system, the lead consultant should oversee project cost reporting. The report should be compiled by a quantity surveyor (cost expert) with assistance from other consultants.
- Contractual claims and final accounts should be settled and agreed upon as soon as they arise or are specified in the contract. In most contracts, the period of final measurement and final accounting conclusions is no more than six months after the practical completion of a project.
- Final project cost reports should always be compiled and reported in their entirety, including cost variances, analysis, and comments (Earned value format is recommended). Following this report, a post-mortem investigation should be carried out to compare the actual expenditure with the original estimate, which will aid in identifying mistakes to avoid when estimating or executing future projects.

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5

Identification of Surface Water Contamination Zones and its Sources on Mahanadi River, Odisha Using Entropy-Based WQI and MCDM Techniques

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Abstract

Information entropy, geographic information systems (GIS), and an examination of the use of TOPSIS and ELECTRE as multi-objective decision-making tools, this study demonstrates an integrated approach to investigating surface water quality for drinking purposes and applying it to the Mahanadi River in Odisha. 19 distinct locations and 20 physicochemical factors were examined for this aim over a 7-year period (2016-2023). EWQI's classification depicts 84.21% of the samples belongs to good category, 10.53% falls under the poor group, and eventually, 5.26% belongs to extremely poor class. To classify different levels of pollution, multivariate statistical analysis framework namely, Principal Component Analysis (PCA), Cluster Analysis (CA) and Discriminant Analysis (DA) were implemented in the on-going work. In case of CA, the results suggests that by separating the locations into three major groupings, such as relatively more polluting, medium-polluted, and less polluted locations, it depicts site similarity. Also, DA analysis highlights the linkages between the stations. PC could provide a good explanation for 93.92 % total fluctuation in the water quality. In addition, this study clearly justifies the effectiveness of all finding's outcomes discussed above by the application of TOPSIS and ELECTRE in prioritizing decisions, based on their comparative levels of pollution. Spatial variation maps of all water quality parameters and all methods illustrated above specify that St. (8), (9) and (19) have poor water quality. Leaching, organic, and natural pollutants, industrial and home waste water, soil erosion and weathering, have all been identified as major contributors to river water pollution.

Keywords

Information entropy, GIS, ELECTRE, Mahanadi River, Multivariate analysis, TOPSIS

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1. Introduction

The most significant freshwater sources that are readily usable by humans are rivers [1]. Additionally, it serves as a landfill for industrial and human garbage [2]. This led to river contamination, which has elevated it to the top of the environmental worries list [3]. Despite the fact that this resource can be replenished, rapid grow of commercial institutions, rise in population and industrialization that creates tremendous pressure on the water supply [4]. Among the most fundamental sources of water on the globe is surface water, which is used for essential purposes like drinking, agriculture, and industry [5]. In addition, the quality has declined due to the overuse of water resources and the exponential growth in population [6]. Unregulated household, agricultural, and industrial activity pollution exists in developing nations [7]. In light of this, it is crucial to evaluate and keep track of the water quality of the accessible resources, which are mostly used for drinking [8]. Too far, a variety of methods and criteria have been generated to provide water quality metrics. All agree that the Water Quality Index (WQI) is an important strategy for categorizing and regulating the aquatic environment [9]. Recently, methods for measuring water quality indexes have been devised and hence, it is a crucial component in the grading and maintenance of surface water quality [10]. Entropy WQI's representation of water quality enables a better assessment of the circumstances of water quality in various locations and, as a result, a better allocation of resources to the areas that need them the most [11]. Entropy theory has been utilized frequently over the past ten years to analyze water quality and has been found to be more accurate than other indexing techniques [12]. The literature shows that the entropy weighted method has been frequently used [13]. Geographical Information System (GIS) is a crucial tool for mapping the quality of surface water nowadays [14]. These programs include geographical analysis and its capabilities, that can handle massive amounts of data [15]. Numerous research has been carried out to evaluate water quality utilizing WQI within a GIS framework [16]. Additionally, GIS-based mapping and IDW are crucial for resource management that is sustainable [17]. An effective method for analyzing the characteristics of physicochemical parameters and figuring out how they relate to one another is multivariate statistical analysis (MSA) [18, 19]. A robust data mining approach called hierarchical cluster analysis (HCA) is applied to categorize elements are that are grouped based on the degree to which their qualities resemble one another [20]. The statistical method known as discriminant analysis (DA), which is based on regression, that enables us to create discriminant functions and it’s expressed in the form of DFs [21]. It is observed that a linear mixture of unrelated variables called a DF makes a distinction between different dependent variable categories [22]. A helpful method for clarifying large data sets in complex formats and minimizing process distortion is principal component analysis (PCA). It also motivates us to be alert to factors that could lead to pollution or have an impact on the quality of the water [23]. Recently, models using multi-criteria decision-making techniques and growing computer technology have been created and used to create programs for rehabilitation and damage analyses in wastewater systems [24]. For multi-criteria analysis, a most prominent method termed as “Elimination and Choice Expressing Reality (ELECTRE)”, which is referred to be called as outranking method, is an appropriate way for selecting between choices [25]. One of the most effective and precise models of multi-index decision making used by planners is referred as “Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)” [26]. These two techniques are predicated on the assumption that the chosen alternative must be as near to the most ideal positive value, which considered as the best option and in second case, it is as far away from the most unfavorable solution i.e., the worst option [27]. As far as the author is aware, no single study evaluates the quality of drinking water using an integrated strategy based on WQI, multivariate, and MCDM techniques for the river basin. Therefore, the key objective of the current research is to assess the topographic water quality in Mahanadi River Basin (MRB), to provide a realistic perspective and understanding of the overall water quality in this region.

2. Study Area

It is widely believed that the "Mahanadi River" is one of the pivotal rivers that flow from west to east before emptying into the Bay of Bengal. Generally, the basin lies encompassed within the geographical coordinates of 80°30’ to 86°50’ East longitudes and 19°20’ to 23°35’ latitudes. The river empties into a region of 141600 km^2 which pertains to 4% of the total geographical area of the country [28]. Out of its total length of 851 km, 494 km of it runs primarily in the State of Odisha. The drainage basin has an average elevation of 426 m, a high elevation of 877 m, and a minimum height of 193 m. It is seen that the average annual rainfall is 1572 mm, of which the southeast monsoon, which lasts from mid-June to mid-October, contributes 70% of the total. A tropical monsoon climate with average annual temperatures ranging from 15.8°C to 28.7°C is evident from the river basin. The river experiences cyclonic storms and seasonal rainfall because it flows through a tropical zone. Red, yellow, mixed red & laterite soils are the two main types of soil in the basin [29]. Agriculture is evidently the backbone of the basin's economy and a necessity for human survival. Rice, oilseed, and sugarcane are the three main crops connected to this river. During the southwest monsoon season, it refers mostly to a coast that is wave-dominated, whereas during the non-monsoon season, it is mixed wave and tide-dominated. Locations and layout of the 19 quality monitoring points can be found in Figure 1.

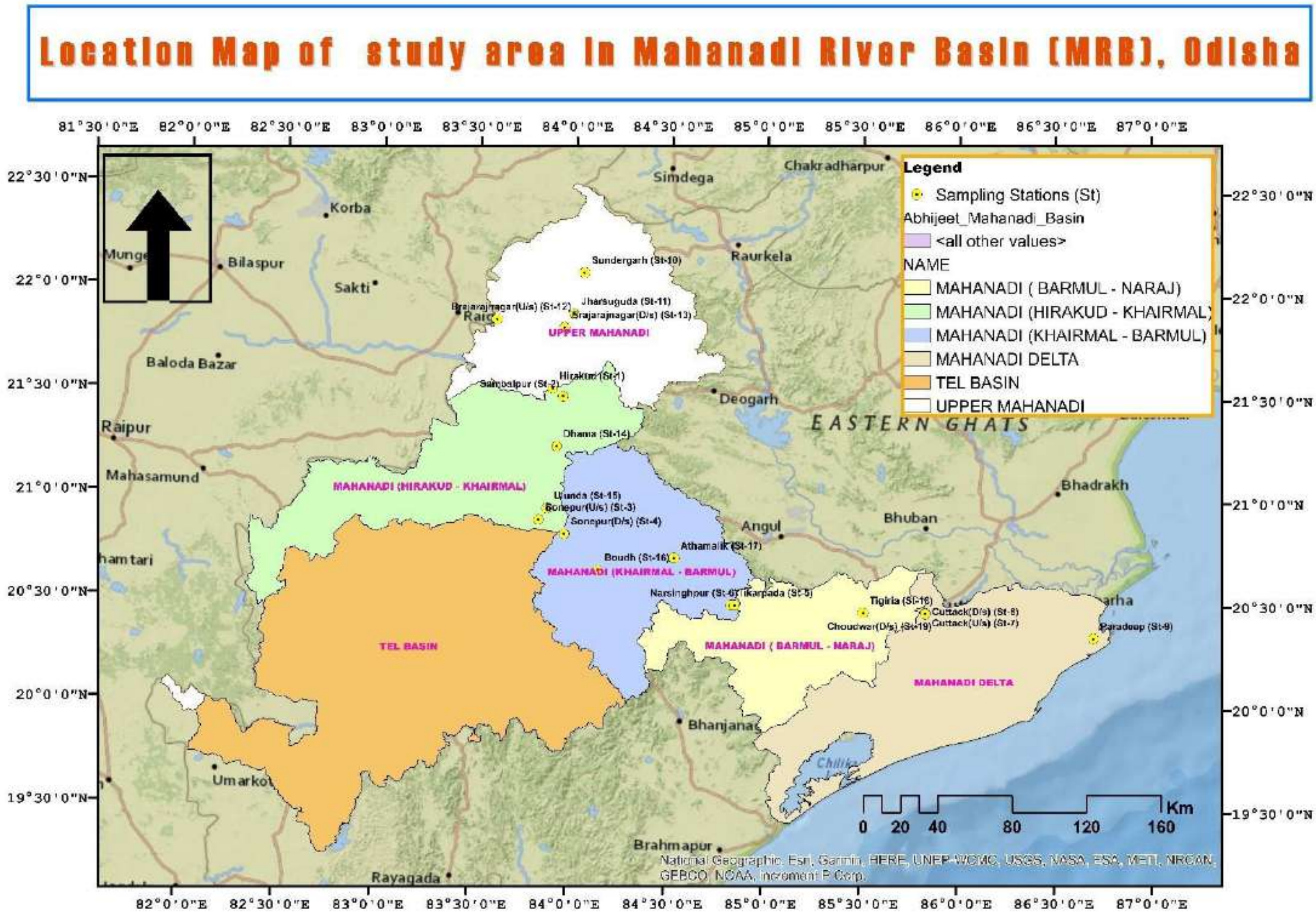


Fig. 1. Location of the study area, Mahanadi watershed of Odisha, India

3. Sampling Methodology

Grab samples were taken at a depth of around 0.3 meters below the surface of the river from the Mahanadi basin and its tributaries. To track the places designated for water quality evaluation, the State

Pollution Control Board, Odisha, are used for collecting water quality data. 19 monitoring sites were used as the reference sample in these tests of quality assessment, which were conducted on a regular basis from 2016 to 2023. Using the standard methods for analyzing water and wastewater, water quality samples and analysis were carried out at every point along the river as per [29]. The sites were picked in order to evaluate the effects on water of household, industrial, and mining operations in the basin. Prior to use, high density polyethylene sample bottles were repeatedly rinsed with double distilled water after being immersed in % HNO_3 for 24 hours. 20 water quality parameters namely boron (B^+), biochemical oxygen demand (BOD), total coliform (TC), sodium adsorption ratio (SAR), chloride (Cl^-), ammoniacal nitrogen (NH_3-N), iron (Fe^{2+}), nitrate (NO_3^-), fluoride (F^-), sulphate (SO_4^{2-}), total suspended solids (TSS), free ammonia (free-NH_3), total dissolved solids (TDS), pH, dissolved oxygen (DO), total hardness (TH), electrical conductivity (EC) alkalinity (Al), chemical oxygen demand (COD), and Total Kjeldahl nitrogen (TKN) were used in this investigation. Following sample collection, the onboard measurements of pH and EC as well as fixation of DO were performed. Other parameters other than pH, EC, and DO were analyzed in accordance with accepted practices [29]. Using Winkler's technique, DO and BOD were measured. Through thorough standardization, procedural blank measurements, spiked samples, and duplicate samples, the analytical data quality was guaranteed. The dilutions were performed using deionized water. The standards-based methodologies' recommendations for quality control were followed. Standard reference materials (SRM) evaluated the precision and consistency of the procedure. In addition, the data accuracy was verified by the charge balance error (CBE) of the major ions in all samples, falling within ± 10% and the following formula given as,

$$CBE = \{\Sigma \text{ Cations} - \Sigma \text{ Anions} / \Sigma \text{ Cations} + \Sigma \text{ Anions}\} \times 100.$$

4. Methodology

Multiple surface water quality assessment techniques have been widely employed by researchers in the literature [30]. A scientific method that also takes into account the unpredictability of water quality measures is entropy weight [1]. As a result, it is a useful method of presenting uncertainty and probability. Entropy water quality indexes is an enhancement in compared to traditional WQIs, that exhibits on assigning weights to characteristics, based on subjective evaluations and professional opinion [31]. The higher the score, the more each type of pollution or component contributed, and the poorer the water quality was [32]. The following steps are used to calculate entropy weights: Data Normalization is calculated from the following Eqn. (1)

$$v_{ij} = a_{ij} / a_{1j} + \ldots\ldots + a_{mj} \quad (1)$$

for all j belongs to {1, …., c}, where a_{ij} talks about concentration of j^{th} parameter at i^{th} sampling period and ‘c’ stands to be total number of parameters. Furthermore, total number of sampling periods is expressed as ‘m’. Information entropy is suggested by [1], and it is given in Eqn. (2).

$$E_j = -(1/\ln m) \times \Sigma\, v_{ij} \times \ln v_{ij} \quad (2)$$

Weight determination expressed as (w_j) is calculated by Eqn. (3) as

$$w_j = d_j / (d_1 + \ldots. + d_c) \quad (3)$$

where, $d_j = 1-E_j$. In case of Quality rating scale, each parameter has given the following Eqn. (4) as

$$Q_j = (C_j/S_i) \times 100 \quad (4)$$

where C_j = measured concentration of the parameter. Thus, EWQI was calculated by Eqn. (5).

$$EWQI = \Sigma\, w_j \times Q_j \quad (5)$$

Following this, its classification is differentiated into five classes, namely, a EWQI value <50, referred as excellent <50, score between 50 and 100, signifies good class, average class varied in a range of 100 to 150, value in a range of 150-200, classify poor water, and finally, >200 graded as extremely poor water [33, 34].

[35] proposed and created the multi-criteria decision-making process known as TOPSIS. It serves as a useful tool for selecting a variety of options by calculating the Euclidean distances between a desired ideal best and an undesirable ideal worst. Based on entropy weights and user-defined criteria, TOPSIS computes a weighted normalized matrix in the presence of uncertainty [35]. It is possible to obtain the normalized decision matrix (NDM), presented in Eqn. (6), which represents the relative performance of the alternatives.

$$NDM = R_{ij} = a_{ij} / (\Sigma\, a_{ij}^{2})^{1/2} \qquad (6)$$

The ideal best (IB) and the ideal worst (IW) of the alternatives were estimated in Eqn. (7)

$$IB = A_{+} = \{V_1 +, V_2 + \ldots, V_n^{+}\} \text{ and,}$$

$$IW = A_{-} = \{V_1 -, V_2 - \ldots\ldots, V_n^{-}\} \qquad (7)$$

The distance between the positive (d_i^{+}) and negative (d_i^{-}) ideal alternatives is represented in Eqn. (8) as follows:

$$d_i^{+} = \{\Sigma\, (v_{ij} - v_j^{+})^2\}^{1/2} \text{ and } d_i^{-} = \{\Sigma\, (v_{ij} - v_j^{-})^2\}^{1/2} \qquad (8)$$

The closeness coefficient (CC) of each alternative was computed as follows in Eqn. (9):

$$CC_i^{+} = d_i^{-} / (d_i^{-} + d_i^{+}) \qquad (9)$$

Finally, the possibilities were ordered by their closeness coefficients.

Another approach namely, ELECTRE is software for making multi-criteria decisions that enables the best ranking to be made by fusing the weight of a criterion with data, both numerical and subjective [36]. The initial matrix, containing the alternative data, was built and expressed as a normalized decision matrix (X_{ij}). The Eqn. (10) containing weighted normalized decision matrix (V) given as

$$V = R \times W = \begin{matrix} V11 \ldots\ldots & V1n \\ V1m \ldots.. & Vmn \end{matrix} \qquad (10)$$

It is created by multiplying the component parts of the decision matrix normalized by the constants of the weight of the factor [37]. However, these weights and rankings are compared to determine the superior and inferior sets, which are determined using the equations suggested by [38]. The links between alternatives' relative distances in Eqn. (11), can be enhanced through calculation by the net superior (C_{net}) and inferior (D_{net}) indices for each alternative

where,

$$C_{net} = \Sigma\, C_{pq} - \Sigma\, C_{qp} \text{ and } D_{net} = \Sigma\, D_{pq} - \Sigma\, D_{qp} \qquad (11)$$

The correlational analysis (CA), principal component analysis (PCA), and hierarchical cluster analysis (HCA) techniques were also used in the current work in addition to the aforementioned methods. These strategies encourage the use of powerful data classification tools and practical visualization techniques to locate the source of pollution in surface water [1]. To investigate the spatial heterogeneity, HCA was used to group together similar sampling sites based on correlation coefficients as indicators of similarity [39]. It employs Ward's approach as a linkage algorithm and Euclidean distance as ‘a measure of similarity’. The Euclidean distance calculates how far apart two observations are geometrically. However, Ward's technique was used to standardize the data before creating the 2-D dendrogram diagram [40]. The main goal of DA is to create discriminant functions, which are nothing more than a linear combination of discriminating factors that allow for the best possible discrimination between the categories of the dependent variable. If the DA is trustworthy for the given set of data, a classification table that is both accurately and erroneously calculated will produce a high accuracy percentage. For each group, the DA approach creates a discriminant function that operates depending on the original data as indicated in equation, which is represented in Eqn. (12) as

$$f(G_i) = k_i + \Sigma\, w_j \times p_j \qquad (12)$$

The term ‘i’ refers to ‘various groups i.e., G’, while k_i stands for ‘constant inherent to each group’, n depicts to ‘pertinent parameters’ and finally, w_j is said to be the ‘weight coefficient’. PCA has the advantage of reducing the number of variables to a smaller number of factors, which can then be used to sort variables and clusters of data based on these factors. The parts that make up the principal components (PCs) are arranged in a descending order and contribute less to the total variability [41]. The primary variables influencing water quality are identified using the weighted correlation coefficient. Liu et al. (2003) categorizes factor loadings as strong, moderate and weak according to the total values of >0.75, 0.75-0.50 and 0.50-0.30 respectively [42]. The computations were finally performed using the correlation matrix of the rearranged chemical components. These statistical methods support effective data classification tools and practical visualization strategies for locating the source of pollution in surface water.

5. Results and Discussions

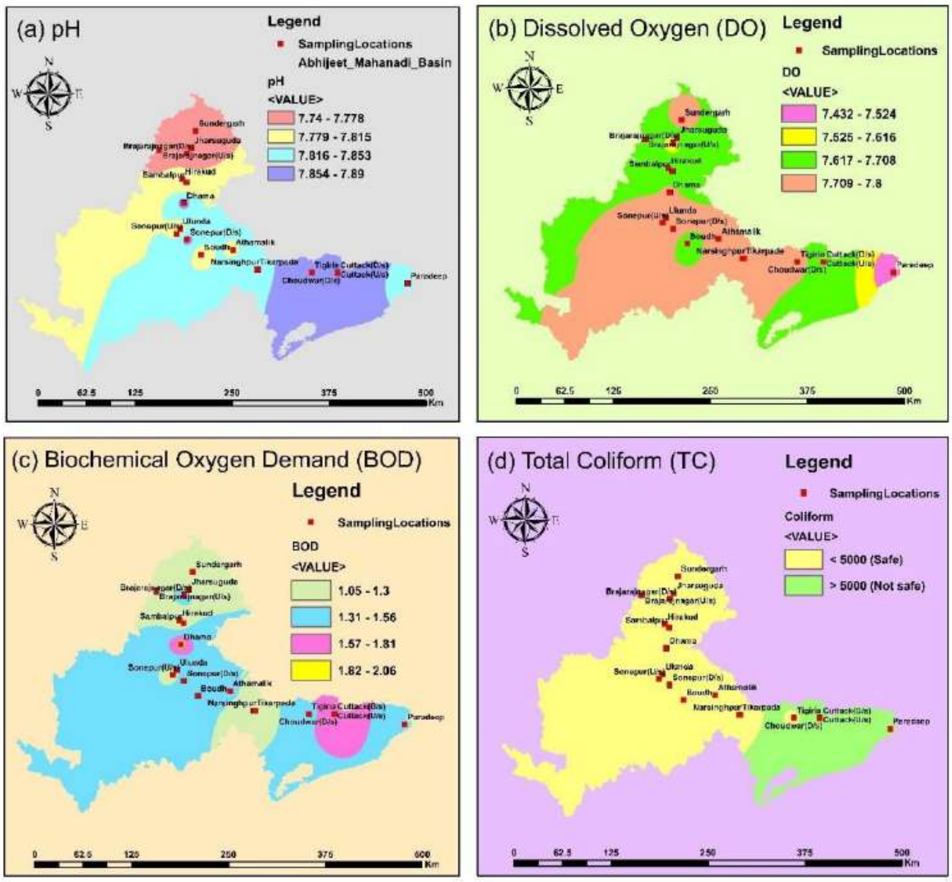
In Table 1, the descriptive statics of the monitored physicochemical parameters at a total of nineteen sampling sites of the Mahanadi River are displayed.

Table 1. The values of the parameters analyzed by sampling the stations

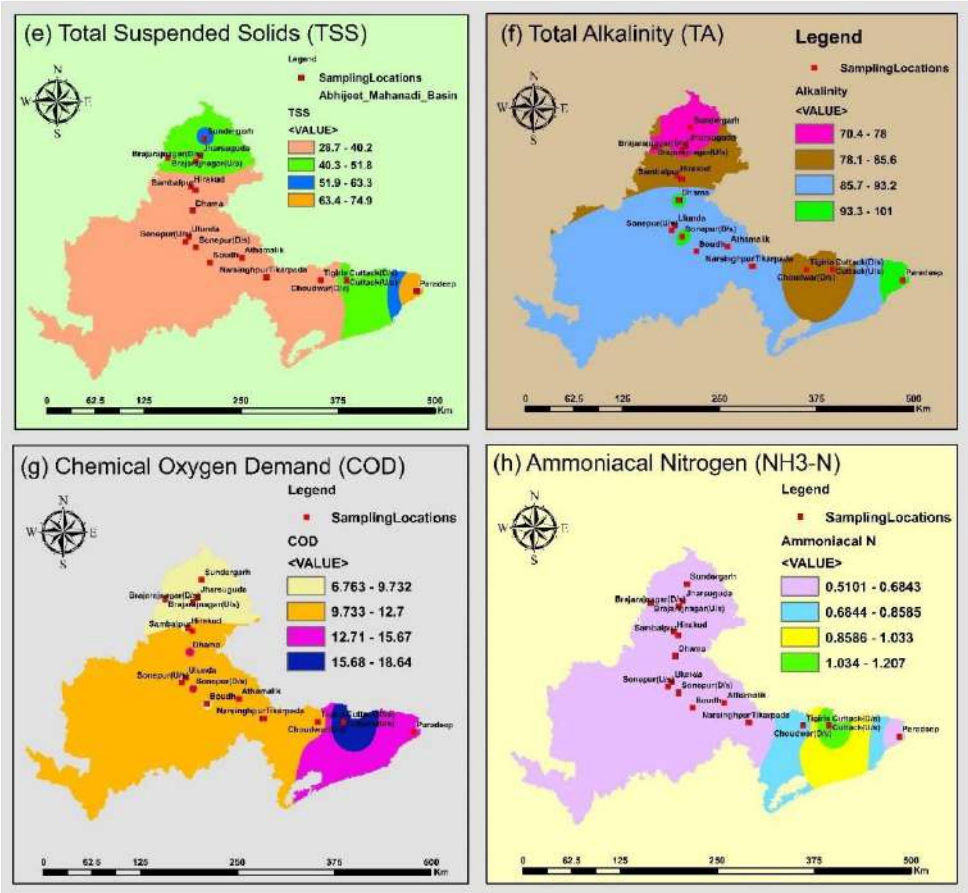
Parameters	Range (Minimum-Maximum)	Standard Deviation (SD)
pH	7.7-7.9	0.05
DO	7.2-7.8	0.14
BOD	1.05- 2.4	0.34
TC	1212.4-42529.20	9193.97
TSS	28.6-74.9	11.56
Alkalinity	70.4-100.9	8.24
COD	6.7-21.8	3.96
NH_3-N	0.5-1.9	0.31
Free NH_3	0.02-0.06	0.01
TKN	3.2-11.8	2.07
EC	138.1-7779.3	1743.33
SAR	0.4-16.5	3.69
B	0.03-0.5	0.12
TDS	82.3-13230.6	3007.19
TH	51.2-2195.2	486.60
Cl^-	9.6-4904.9	1122.58
SO_4^{2-}	4.9-376.0	84.68
F^-	0.26-1	0.17
NO_3^-	1.2-2.7	0.41
Fe^{2+}	0.6-2.6	0.46

The nutritional absorption and bioavailability of nutrients and toxic metals, are generally determined by the water's pH. [43]. The pH of the river (7.7–7.9) was found to be within the range of 6.5–8.5 recommended by [44]. Another crucial metric that reveals the health of an aquatic habitat is DO. The river water's DO concentration (7.2–7.8) during the sampling period was higher than 6.0 mg/. Due to the river's ability to purify itself, reaeration occurs along its length, which can be used to support the growth in DO levels [45]. The amount of organic contamination brought on by an overabundance of organic materials has historically been gauged by the BOD levels of rivers. The majority of the locations' readings (1.0–2.4) were found to be within the WHO-threshold limit of 5 mg/l, which is the acceptable limit (2012). The existence of more coliforms in water is typically a result of water contamination. Its value in the current study is provided in MPN/100 ml and ranges from 1212-42529. The acceptable upper limit is 5000 MPN/100 ml. According to reports, waste waters close to industry, municipal sewage systems, or hospitals are to account for the greatest levels of this group of bacteria detected in St-8, 9 and 10. The TSS result was within the range of (28.6-74.9 mg/l), which is the threshold value. It has an impact on aquatic life. Clay and silts, as well as biological solids like bacteria and algae cells, were the main sources of TSS. Alkalinity is the water's ability to buffer acids and keep the pH level steady. Alkalinity is a term used to describe a solution's ability to react with a solute and neutralize an acid [46]. Hence, as per [44], this parameter established an acceptable limit of 200 mg/l. The results in the samples that were taken ranged from 70.4 to 100.9 mg/l. Aquatic ecosystem resources are evaluated using COD as a main criterion since it shows the quantity of organic contaminants that deplete oxygen in the water body [47]. The value in the study region varied from 6.7 to 21.88 mg/l, satisfying the WHO's 30 mg/l threshold. NH_3-N is a signal for residential sewage and mineral composition pollution. The value was between 0.5 to 1.93 mg/l, which is well within the 2 mg/l WHO standards. Free NH_3 reveals that home sewage and hydrochemistry associated with minerals were the main sources of the contamination, primarily from the outflow of waste water from Pulping processes, household waste, and metal manufacturing waste crossing the river near the coastline. The sampling sites' free NH_3 concentrations span between 0.02-0.06 mg/l. The threshold value is 2 mg/l. The origin of indicator i.e., TKN often denotes incomplete organic matter degradation processes and is a reliable sign of river contamination from urban effluents [48]. The TKN ranged from 3.28 to 11.80 mg/l. As per [44], it suggests that the threshold value is taken as 5 mg/l. Ammonium ion species were found in the water in St-8 and St-9 (areas with higher TKN values), which were attributed to the nitrogen cycle, domestic effluents (urea), and urban runoff [49]. EC denotes the total ions in dissolved form that are present in the water and are affected by different effluent discharges into the river [50]. Along the locations, conductivity varied between 138.1 and 7779.3 µS/cm. Higher levels were seen in St-9, which could be attributed to port operations, shipping, and agricultural practices. The amount of salt absorbed by soil and the SAR of irrigation water are significantly correlated. High levels of Na^+ salts in soil damage its physical state and texture, making it difficult to cultivate [51]. SAR levels were determined to be 0.41–16.59, which meets the WHO threshold of 20 meq/l. Therefore, irrigation is feasible at all places. At low concentrations, boron is a necessary element for plant growth; but, at greater amounts, boron becomes harmful. Boron concentrations ranged from 0.03-0.55 mg/l, indicating that the water is suitable for irrigation and drinking. TDS may be caused by rainfall, surface runoff, river water flow, and bank and riverbed erosion, according to observations. Its values fluctuated in the current work, is around a range between 82 and 13230 mg/l. All samples belong to freshwater category as per [44] i.e., 100 mg/l except St-9. The addition of ions from the source rocks and also the longer residence time of surface water in contact with the aquifer system are responsible for the greater TDS in St-9. The maximum permitted level of TH is 600 mg/l, and the ideal level for consumption is around 300 mg/l, according to WHO guidelines. Throughout the investigation period, it varied between 51.2-295.2 mg/l. The hard water found in St-9 is to blame for aesthetic concerns because it has a disagreeable taste and makes soap less effective at producing scale on plumbing fixtures and in pipes [52].

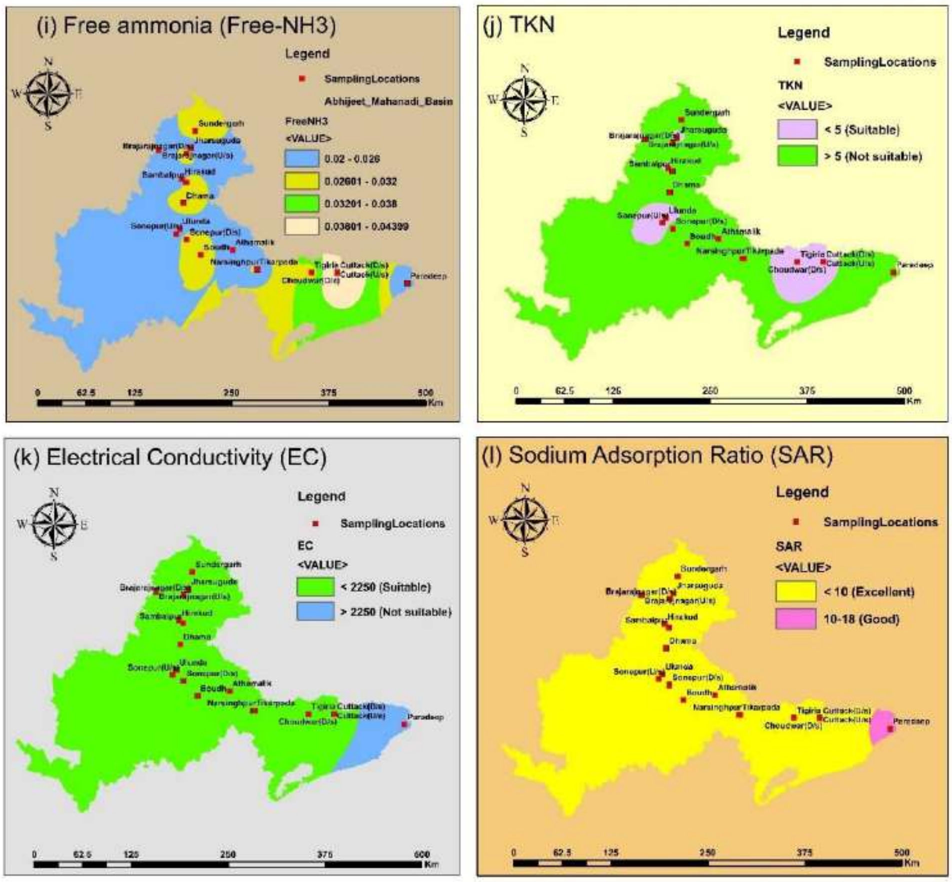
Cl- is used in the treatment of water to eliminate bacteria, parasites, viruses, and microorganisms by neutralizing and oxidizing them [1]. Except for the St-9 location, all of the water samples included in this investigation has Cl- concentrations below the permissible limit of 250 mg/l. The key factor at the St-9 site is efficient leaching from the topsoil caused by domestic and industrial activity, as well as dry temperatures [53]. For surface water, however, the quantities of SO_4^{2-} that we have measured range from 4.97 to 376.07 mg/l. Accordingly, we may consider the current levels to be safe for use based on the WHO's 200 mg/l standard. Due to industrial Sulphur gas emissions, which oxidize and enter the aquifer matrix after precipitation, SO_4^{2-} levels are greater in St-9 [54]. The earth's crust contains the naturally occurring element F^-, which is extremely hazardous to freshwater aquatic life. According to reports, industrial sites like brick kilns and fertilizer are potential sources of F^- near the surface. The maximum permitted level is 1 mg/l. The magnitude of the measurement was 0.26 to 1.0 mg/l, indicating that all sampling points are within the acceptable range. Natural ions called NO_3^- play a vital role in the nitrogen cycle. However, because it causes methemoglobinemia in infants under 6 months of age, the ion in surface water is undesirable [54]. Surface water has a NO_3^- concentration that ranges from 1.29 to 2.70 mg/l. The recommended limit for drinking water is 45 mg/l, according to [44]. Since Fe^{2+} helps in blood flow, it is not thought that the concentration found poses a health risk. It aids in the blood's ability to carry oxygen. According to WHO recommendations, the ideal level of Fe^{2+} is 3 mg/l. The research area's Fe^{2+} concentration was 0.6-2.61 mg/l, which is below the threshold criteria. The determining factor in the study area's cation dominance hierarchy is $Fe^{2+} > B^+$, whereas the anions is $Cl^- > SO_4^{2-} > NO_3^- > F^-$. Figures 2a–t shows the results of the spatial map display of all parameters using IDW interpolation in ArcGIS 10.5.



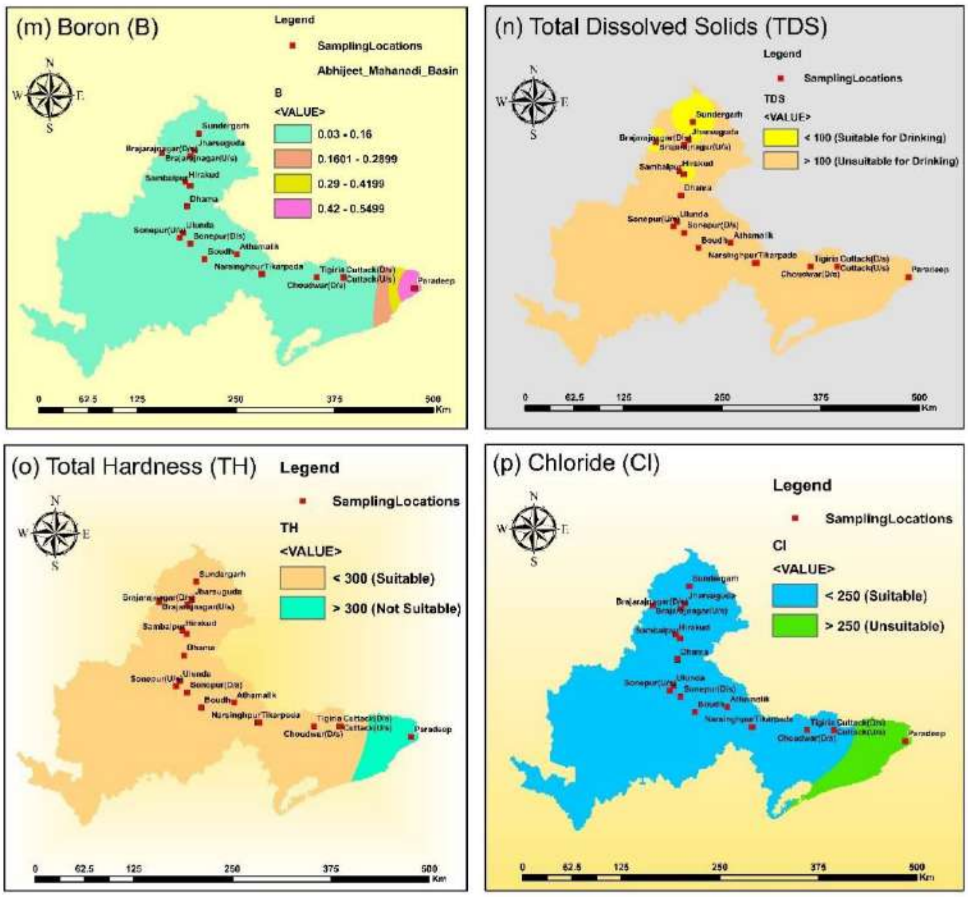
(a) pH, (b) DO, (c) BOD and (d) TC



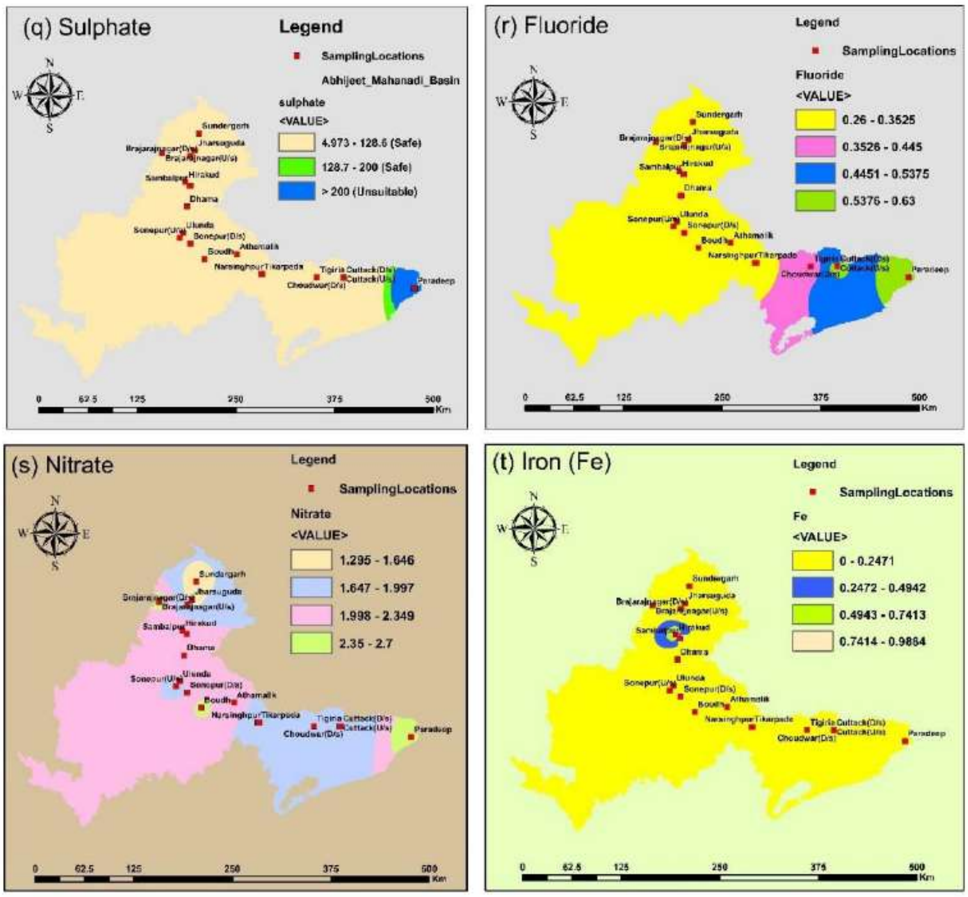
(e) TSS, (f) TA, (g) COD and (h) NH_3-N



(i) Free-NH_3, (j) TKN, (k) EC and (l) SAR



(m) Boron, (n) TDS, (o) TH and (p) Cl^-



(q) SO_4^{2-}, (r) F^-, (s) NO_3^- and (t) Fe^{2+}

Fig. 2. Distribution of spatial maps

The methodology section of this research provides a detailed explanation of the EWQI calculation. The EWQI ranged from 14.6 to 1065.2 in the research area, which represents excellent to extremely poor categories. However, in the upstream portions close to the sample sites, the water quality improved. The St-(9), (19) and (8) sample sites consistently displayed unsatisfactory water quality. A little over 84.21 % locations show good conditions, 10.53 % showed poor conditions and 5.26 % locations (1 place) showed extremely poor water conditions. The higher values of EWQI at site 9 were attributed to Cl^-, SAR, TH, EC, TKN, TDS, TC and SO_4^{2-}. This shows about detrimental effect on human activity towards the quality of potable water. Table 2 displays the EWQI values for each sample based on the WHO drinking water quality standard. Figure 3 illustrates how the severely contaminated areas were generally visualized using 3D spatial analysis. Weights, on the other hand, are the results of data normalization in MCDMs. Priority ranks of the relevant sampling locations were established using ELECTRE and TOPSIS, and their findings were compared (Dell' Aira et al. 2021). This was done after calculating the factor weight coefficients from the EWQI. All of the physical and chemical water quality characteristics were subjected to each methodology in order to create overall rankings, with the highest rank for each time denoting the most polluting sampling point. The priority ranks as well as performance score (PS) are shown in Table 2. The results in case of both methods, the station 9 is placed in the category of most polluted site with the rank of 1 on account of greater value containing TH, SAR, Cl^-, TDS, SO_4^{2-}, TKN, EC, and TC, which were also higher than their desirable concentration and highest among all the locations. Furthermore, it was clear that the locations 8 and 19 had poor water quality because they had the second and third highest EWQI scores. High TKN and EC levels were also present. The cause could be the subsequent release of pollution in the river's downstream zone as a result of sewage, agricultural, and leachate drainage systems (Islam et al. 2020). Figures 4 and 5 display the created interpolated map. Therefore, using MCDMs like TOPSIS and ELECTRE showed effective in prioritizing sampling locations based on their degree of pollution/contamination levels and in calculating current ranks with high accuracy for samples.

Table 2. Suitability of surface water for drinking needs based on entropy WQI, TOPSIS and ELECTRE

Sample No	EWQI	Rank	Water type	TOPSIS (PS/P_i^*)	Rank	ELECTRE (PS/C_a)	Rank
St-1	15.7	16	Excellent	0.006	18	0.025	16
St-2	18.4	9	Excellent	0.013	6	0.030	9
St-3	16.2	15	Excellent	0.005	19	0.025	15
St-4	19.9	5	Excellent	0.011	10	0.031	6
St-5	18.6	8	Excellent	0.010	11	0.029	11
St-6	19.5	6	Excellent	0.012	9	0.029	10
St-7	17.6	12	Excellent	0.009	14	0.028	12
St-8	196.0	2	Poor	0.132	2	0.074	2
St-9	1065.2	1	Extremely Poor	0.887	1	0.959	1
St-10	15.0	18	Excellent	0.008	15	0.025	17
St-11	15.1	17	Excellent	0.007	16	0.024	19
St-12	14.6	19	Excellent	0.006	17	0.025	18
St-13	16.9	13	Excellent	0.009	12	0.027	13
St-14	20.0	4	Excellent	0.012	8	0.030	7
St-15	16.3	14	Excellent	0.009	13	0.027	14
St-16	18.4	10	Excellent	0.016	4	0.031	4
St-17	19.5	7	Excellent	0.013	7	0.030	8
St-18	17.9	11	Excellent	0.014	5	0.031	5
St-19	152.0	3	Poor	0.034	3	0.046	3

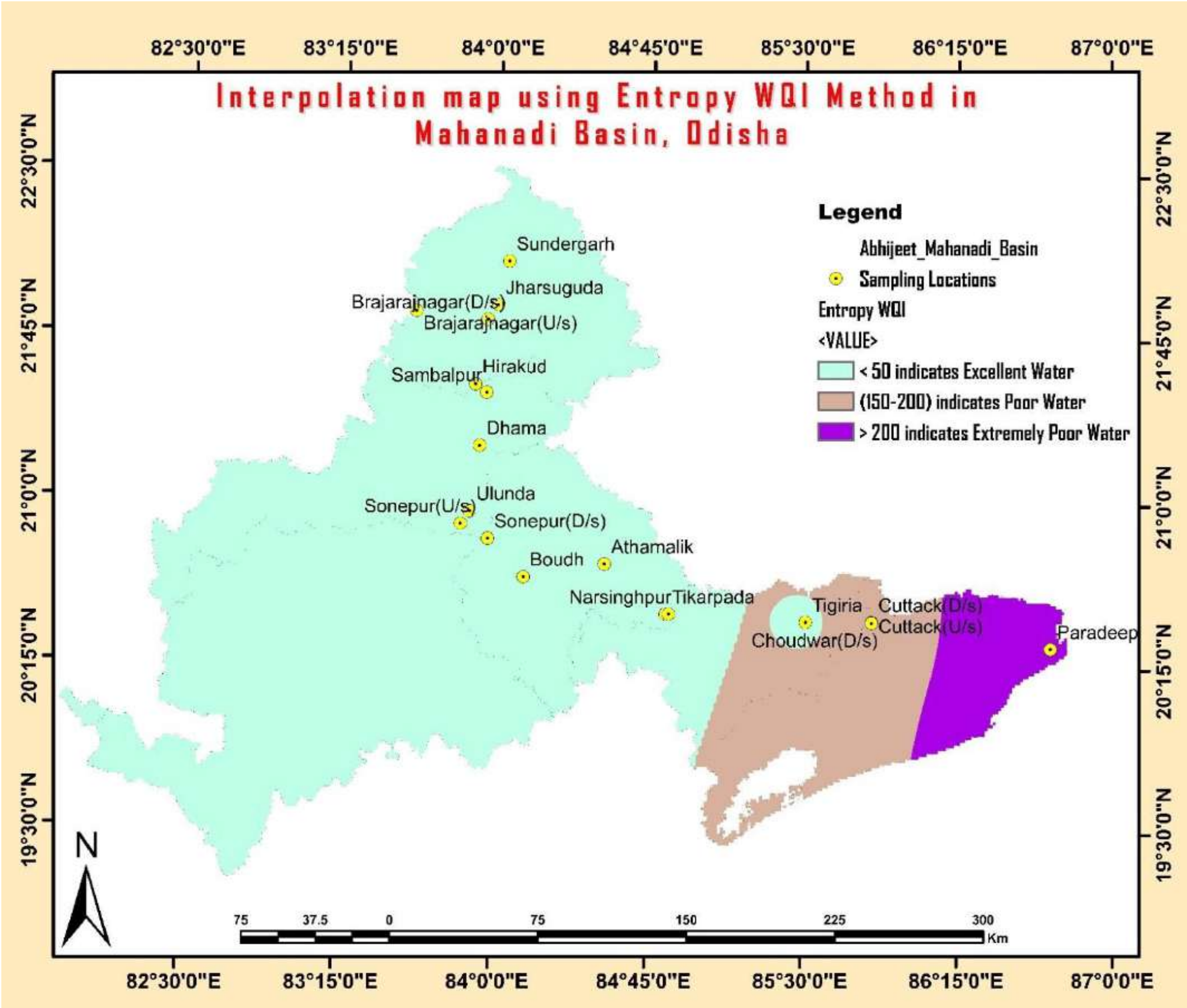


Fig. 3. EWQI map of surface water sample points at the study area

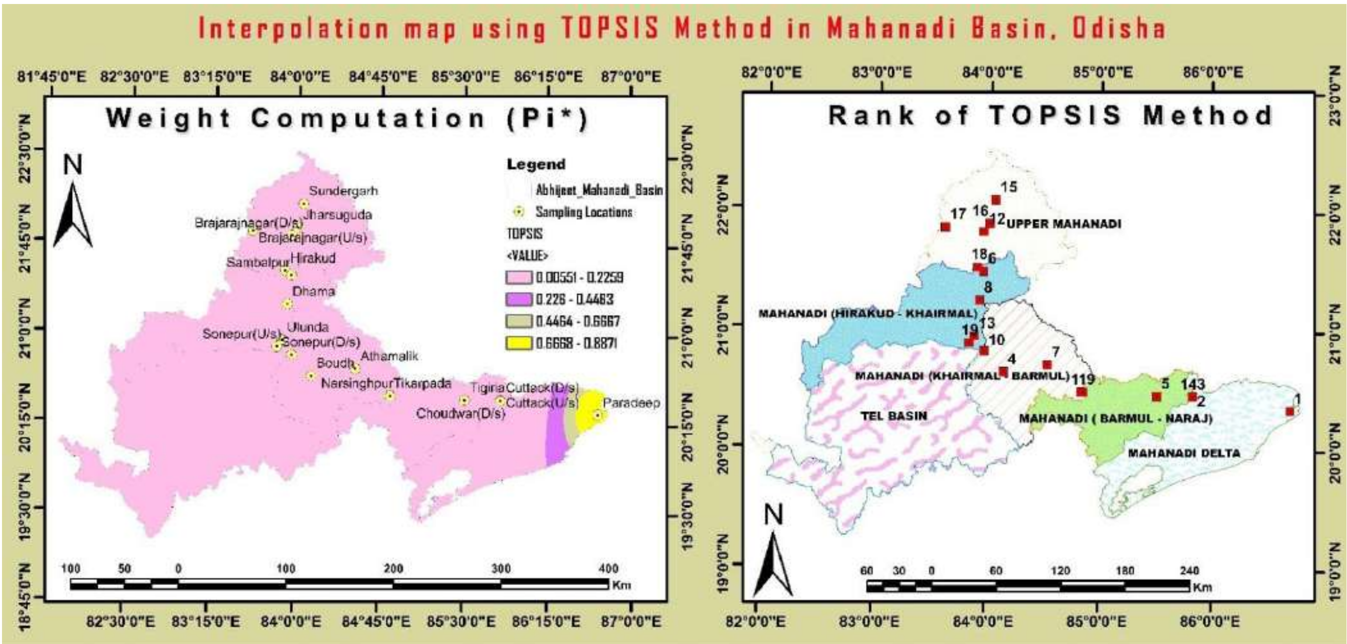


Fig. 4. TOPSIS map of surface water sample points at the study area

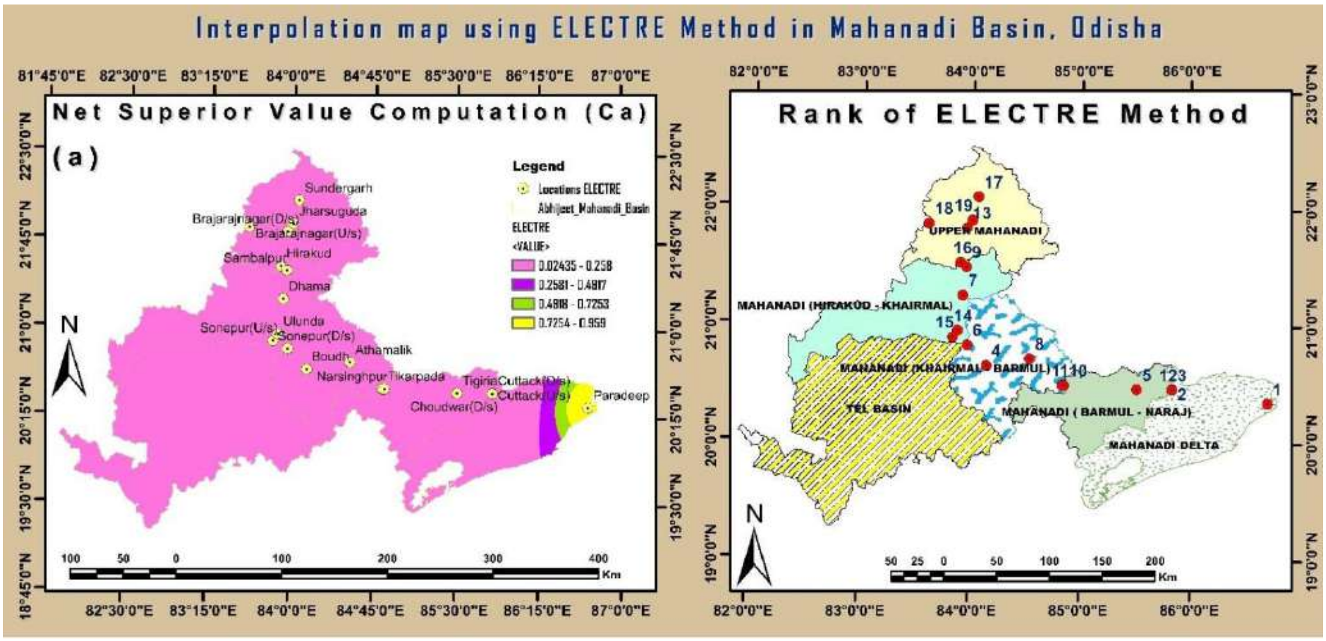
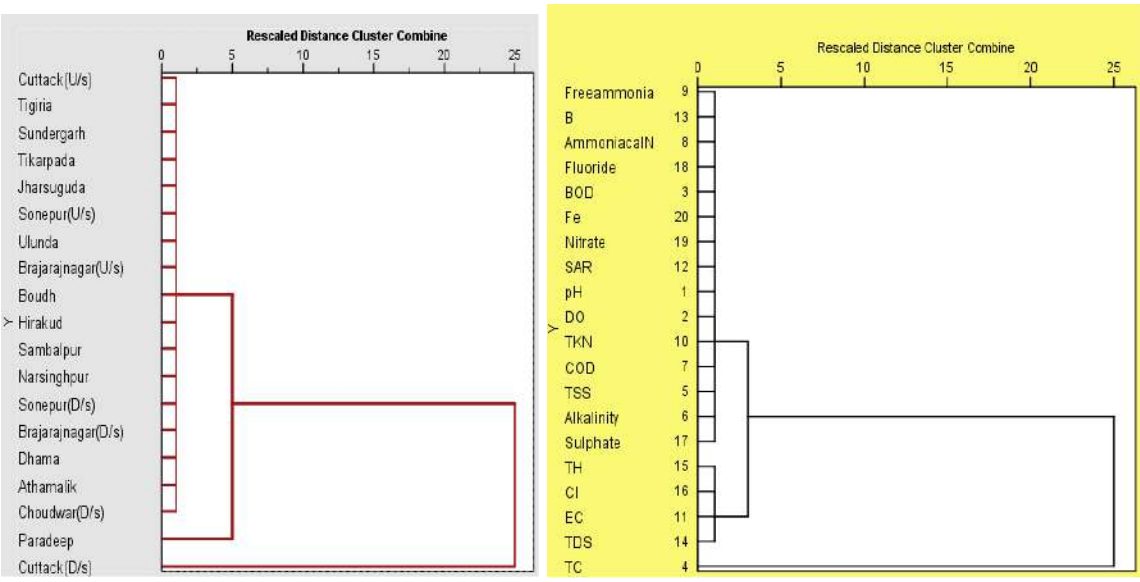
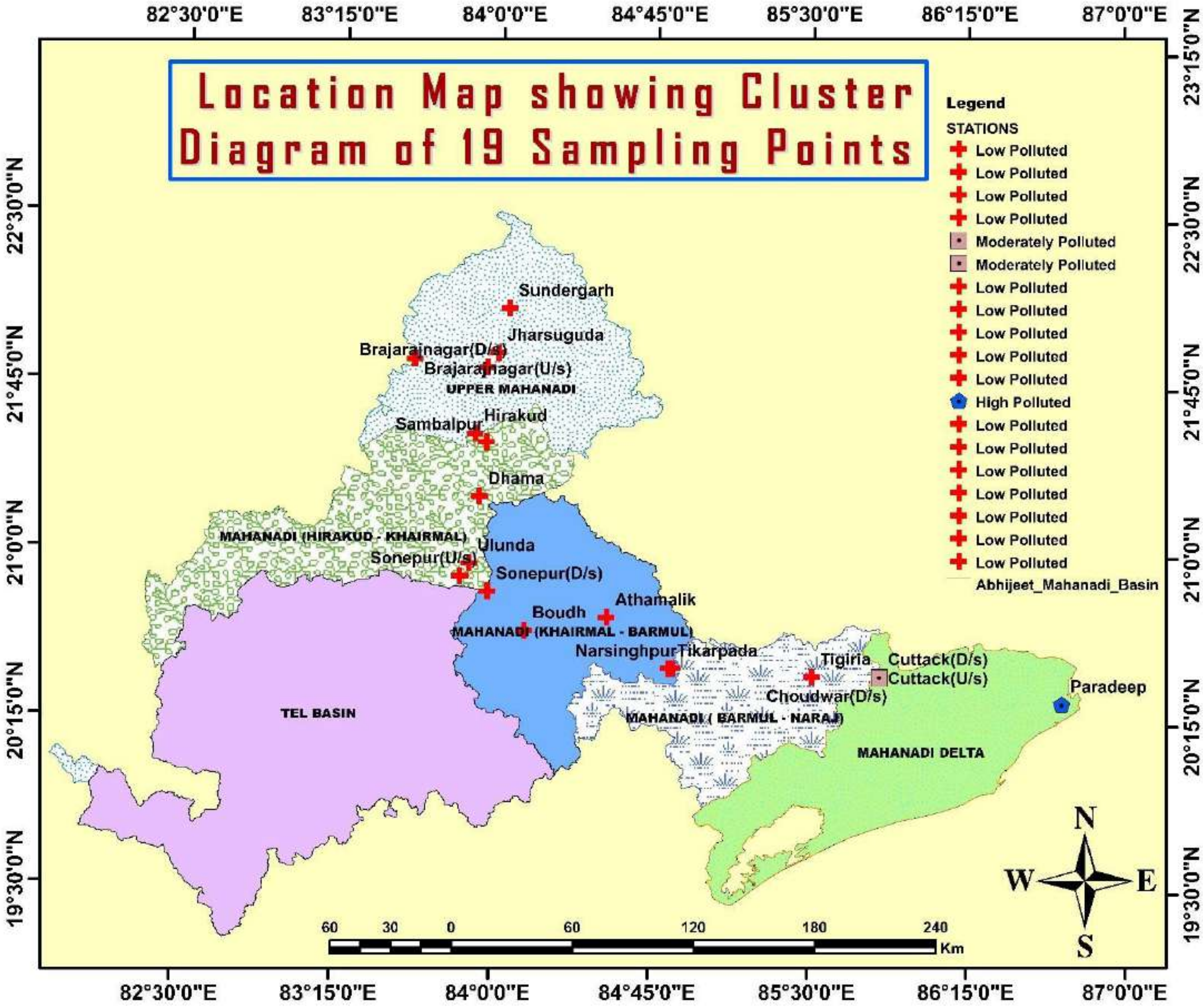


Fig. 5. ELECTRE map of surface water sample points at the study area

Using MATLAB software, the data matrix was once more examined using Cluster Analysis (Hierarchical Tree Clustering, Rescaled distance cluster combine analysis). HCA was applied to the 19 sampling sites using 20 variables [55]. As a result of the dominating ions and sites existing in the research region, three separate clusters or groupings of the data were found and categorized as dendrograms in Figures 6(a), (b), and (c). In the present investigation, Cluster 3 includes EC, TDS, TH and Cl^-. It is affected mainly by salinity factor due to mineral dissolution. TC is the only parameter that covered by Cluster 2, includes toxic anthropogenic fecal coliform bacteria. Coliform is a good sign of fecal pollution when found in water bodies [56]. The Cluster 1 consists of further 15 variables, which probably derived from anthropogenic activities. Following this, dendrogram view of all sites represents, that shows Cluster 1 comprises of 16 testing places, in which all sites belong to 'excellent-good water' quality. Hence, this cluster is categorized as 'low polluted zone'. However, cluster 2 consisting of two sample sites namely St-(19) and (8). These samples depict 'poor water' status. So, this group of objects is known as 'moderately polluted' zone. St-(9) points towards Cluster 3. This cluster illustrates very poor water because of higher concentration of SO_4^{2-}, TH, TKN, Cl^-, and TC. Hence, it is known as high polluted zone. This demonstrates that the surface water chemistry in the examined area is controlled by a combination of human operations, leakage, and dissolution [57].



(a) (b)



(c)

Fig. 6. Dendrogram showing results (a) Sampling Sites, (b) Physicochemical parameters and (c) Spatial distributions of HCA for 19 sampling points

DA was carried out with the constraint that it would be useful in identifying naturally banded or clustered water sample sites. The clusters based on CA were used to examine the variation. Two modes—Standard mode and Stepwise mode—are used to carry out this technique in the current investigation. For the creation of discriminating functions, standard mode incorporates all the predictive factors (DFs). When there are numerous predicting variables, the stepwise approach is useful. These two modes were employed in the construction of discriminant functions (DFs), and Tables 3, 4, and 5 shows the classification outcomes as a result, in this ongoing research. Wilk's Lambda (λ) indicates the case-by-case grouping function's capacity for discrimination. λ equals to 1 signifies equal group means. On the other hand, a small λ demonstrates that group means appear to be different and that within-group variability is minimal compared to overall variability. The values of each discriminant function's i.e., 'Wilk's lambda' and 'Chi-Square' ranged from 0.063-0.33 and 63.01-286.33, respectively, demonstrating the validity and reliability of the spatial discriminant technique. Additionally, the p-level value was less than 0.01, demonstrating the validity and efficacy of the time DA. Using 20 and 10 factors, respectively, standard mode and stepwise mode were able to reach discriminant accuracy rates of 100 and 97.92%. The final outcomes suggests that 10 indicators namely (EC, SAR, TKN, TDS, TH, TC, Cl^-, SO_4^{2-} and Fe^{2+}) were shown to be the most effective discriminant (predictive) variables for describing the variation in water quality in three groups. These indicators are regarded as crucial differentiating factors that explain the regional variance in water quality. Since TC in water is caused by sanitary contamination, it should be protected at these locations by taking steps to lessen or eliminate the causes of pollution. It is evident that there is a large excess in values virtually everywhere throughout the course of the river. High concentrations of TKN, which strongly depart from the threshold values, are commonly obtained from fertilizers or waste water leaks in water sources. The areas with the highest levels of pollution (St-8, 9 & 19) are those that are most influenced by point source pollution releases, which make the pollution there worse than it is elsewhere. As a result, DA reduced the vast data's dimensionality and defined a small number of indicator variables responsible for fluctuation in water quality. Figure 7 displays the values of the discriminant scores.

Table 3. Results of spatial-DA for spatial variation

Mode	DFs	Canonical Relation (R)	Eigen value	Wilk's lambda	Chi-square	P-value (sig)
Standard	1	0.99	2.156	0.063	286.33	0
	2	0.98	2.143	0.328	73.612	0
Stepwise	1	0.95	2.121	0.064	280.116	0
	2	0.91	2.099	0.33	63.012	0

Table 4. Description of Classification functions (CFs)

Indicator	Standard Mode			Stepwise Mode		
	LP	MP	HP	LP	MP	HP
pH	269.1000	265.7000	261.0000			
DO	17.0000	16.3000	17.3000			
BOD	23.1320	21.7800	21.8910			
TC	7.2100	2.1920	1.5670	7.876	3.111	3.234
TSS	-51.2300	-42.1230	-8.6780			
Alkalinity	-0.0310	-0.0430	-0.0330			
COD	1.1000	1.0000	0.8000			
NH_3-N	21.5000	21.3000	21.0000			
Free NH_3	-1.2100	-3.3320	-5.6780			
TKN	6.8910	21.3410	21.8910	-6.6660	15.4230	46.5670
EC	0.8790	2.1230	4.3450	-33.2110	-28.9810	4.1110
SAR	-6.2310	-6.5670	-6.5450	0.3230	-0.5554	-0.9800
B						
TDS	-2.4560	-2.1230	-1.2340	-2.0090	-4.3450	-7.6780
TH	-6.3450	-6.3320	-2.1230	-0.0050	-0.0120	-0.0110
Cl^-	-0.0800	-0.0100	-0.0110	-0.8760	-0.7760	0.4320
SO_4^{2-}	-2.3410	-2.3210	-0.9980	-3.2220	-2.1110	-0.7760
F	6.7860	4.2340	1.2350			
NO_3^-	-0.9230	-16.2310	-41.2100			
Fe^{2+}	-0.4230	-0.3330	-0.4110	-0.4560	-0.5550	-0.6640
(Constant)	-42.31	-56.87	-81.39	-28.56	-55.31	-88.61

Table 5. Classification matrix for discriminant analysis of spatial variation

Pre-identified Clusters	% Count	LP	MP	HP
Standard mode				
LP	100.00	16	0	0
MP	100.00	0	2	0
HP	100.00	0	0	1
Total	100.00	16	2	1
Stepwise mode				
LP	93.75	15	1	0
MP	100.00	0	2	0
HP	100.00	0	0	1
Total	97.92	15	3	1

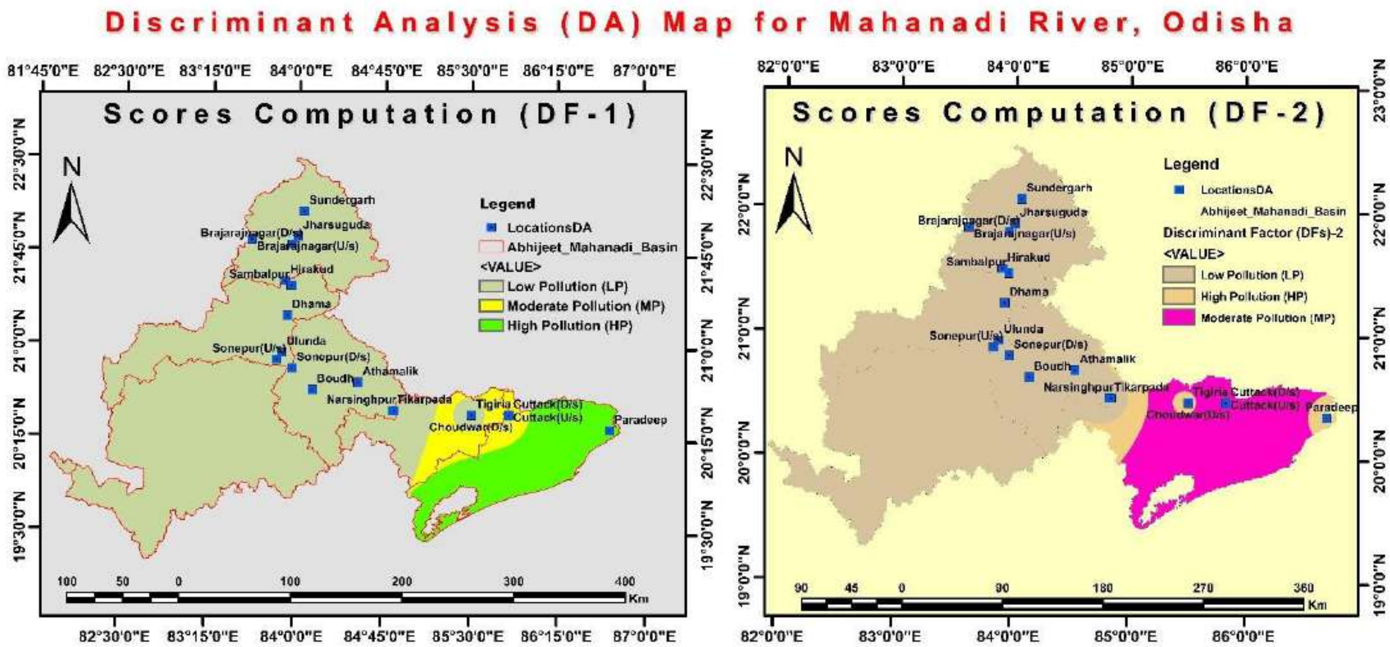
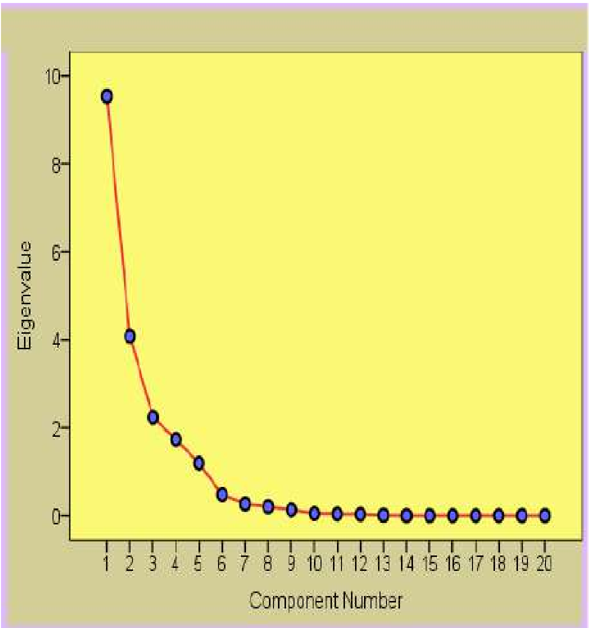


Fig. 7. Discriminant analysis of surface water sample points at the site area

PCA has been applied in the research region for the connection of chemical compositions, specified by a single or many variable loadings on the component that helps in determining the surface water quality. To Calculate the number of PCs required to fully uncover the internal data structure, a scree plot was utilized [58]. It is shown in Figure 8 and is used to define the point of inflection on the curve. After the fifth eigenvalue, which denotes the dominance of five components in the water chemistry, the slope drops off from the scree plot. Five principal components (PCs) were derived from the original data set based on the eigen value greater than 1, and these five PCs accounted for 93.91 %. PC1 consists of 47.68% variance in the dataset with high loadings of ‘TH, SO_4^{2-}, EC, TDS, Cl^-, SAR, B, TSS and TKN’. Reversible electron transfer and carbonate degradation produce EC. Cl^- is produced by the leaching of industrial effluents and longer surface water migration distances [59]. Site sanitation and nutrient contamination from an unsewered urban context explain TKN loading. There is a 20.40 % variation in PC2 that shows considerable COD, free NH_3, and NH_3-N loadings [60, 61]. It might be attributable to human activities like runoff from farmers' excessive fertilizer use or clothes washing along the basin's borders. These ions originate from human activity in the research area. PC3, which further clarifies 11.19% of the entire variance, includes positive loadings of F^- and DO while TC and BOD belongs to moderate loadings. Commercial trash, landfill dumping, and untreated sewage water are the prominent F^- sources [62]. DO indicate that the river was well oxygenated [63]. TC and BOD appear to be caused by the impacts of both human induced practices and scheme of partial ecological restoration [64]. This component is associated with sub-surface activities. Component 4 (PC4) accounts for 8.67% of the entire variance, which comprises of parameters like TA and NO_3^-. Leaching of fertilizer from fertilizer from agricultural land results in higher loading. It is well associated with external activities [65]. A 5.96% of variance with moderate loading of pH and negative loaded with NO_3^- in PC5, that originates from urban and agricultural activities [66]. In addition, pH change may be due to the characteristics of waste water and sea water. Seasonal variability affects the river water quality as the rise and fall in temperature (influenced by changes in season) affects the pH of water [67]. In Table 6, eigenvalues for various parameters, such as cumulative percentage variance and % changes/variances, are displayed. Positive PCA results (Figure 9) imply that the factor scores (FS), which are heavily loaded on a certain component, have an impact on the water sample, whereas negative PCA results imply that these parameters have little to no impact on water quality [68]. They are frequently acquired using the regression method [69]. This phase was performed in order to better understand the factor distribution scores in Figure 9 and Table 7. Consequently, the combined geogenic and anthropogenic activity that takes place throughout the region is represented by the score FS-1 [70]. FS-2 mostly depicts a natural process (salinity component). The outcomes of human actions are depicted in FS-3. According to [71]), FS-4 had an impact on the contamination caused by urban liquid waste discharges. Human-caused factors (agrochemicals and domestic sewage) according to the FS-5, affect the water quality [72, 73]. In conclusion, this approach assists in extracting data sets that contain information on the sources of ions and factors that affect the quality of surface water (Figure 10).



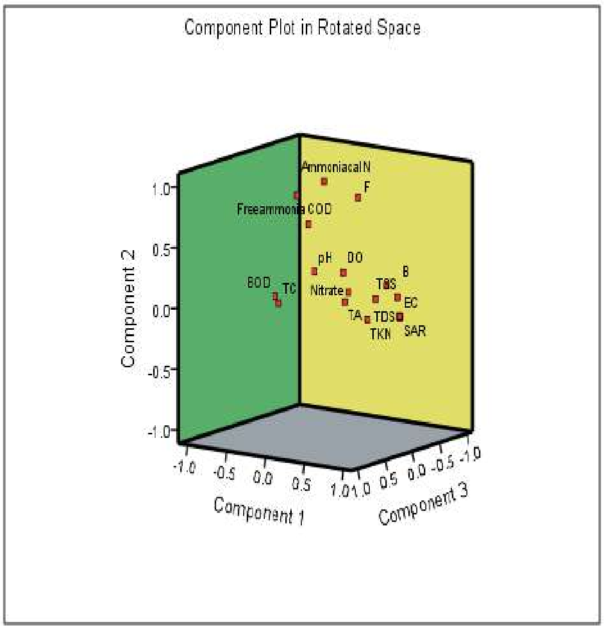


Fig. 8. Scree and loading plot of variance of PCs

Table 6. Results of loadings on significant PCs

Parameters	Principal Component (PC)				
	1	2	3	4	5
pH	0.10	0.63	0.02	0.30	0.65
DO	-0.52	-0.19	0.75	0.16	0.24
BOD	0.16	0.67	-0.62	0.15	0.03
TC	0.21	0.58	-0.71	-0.19	0.10
TSS	0.78	-0.10	-0.08	-0.56	-0.08
Alkalinity	0.48	0.28	-0.01	0.76	0.07
COD	0.37	0.91	-0.02	0.07	-0.06
NH_3-N	0.07	0.77	0.55	-0.22	-0.17
Free NH_3	-0.03	0.88	0.23	-0.32	-0.14
TKN	0.76	-0.15	-0.20	-0.14	-0.30
EC	0.98	-0.17	0.05	0.05	0.07
SAR	0.98	-0.18	0.04	0.04	0.07
B	0.98	-0.03	0.13	0.05	0.02
TDS	0.98	-0.17	0.05	0.05	0.07
TH	0.98	-0.15	0.05	0.06	0.07
Cl^-	0.98	-0.17	0.05	0.04	0.07
SO_4^{2-}	0.98	-0.16	0.05	0.05	0.08
F	0.47	0.62	0.58	-0.04	-0.16
NO_3^-	0.47	0.05	0.06	0.52	-0.61
Fe^{2+}	0.71	-0.01	0.17	-0.45	0.33
Eigen value	9.54	4.08	2.24	1.73	1.19
% Of variance	47.69	20.41	11.19	8.67	5.96
Cumulative%	47.69	68.10	79.28	87.95	93.92

Table 7. Factor Scores in each sample

Site No.	FS1	FS2	FS3	FS4	FS5
St-1	-1.28	-1.26	-0.03	0.15	-0.27
St-2	-0.47	-0.39	-0.63	0.51	-1.64
St-3	-1.56	-1.09	0.31	1.11	0.34
St-4	-0.58	1.10	0.04	1.61	0.52
St-5	-0.79	-0.71	0.39	-0.21	0.87
St-6	-0.74	-0.40	0.32	0.85	0.77
St-7	-1.31	0.47	1.02	-0.88	2.54
St-8	0.89	4.38	-4.69	-1.00	0.59
St-9	12.46	-1.37	0.29	0.20	0.33
St-10	-0.67	-1.77	0.33	-3.22	0.17
St-11	-1.59	-1.99	-0.01	-1.38	0.40
St-12	-0.82	-1.97	0.07	-0.38	-1.64
St-13	-0.31	-0.89	-1.23	-1.41	-1.58
St-14	-0.54	1.42	-0.49	2.13	-0.11
St-15	-1.38	-0.88	-0.07	1.58	-0.38
St-16	-0.37	-0.54	-0.22	0.72	-0.85
St-17	-0.64	-0.34	0.02	0.99	-0.07
St-18	-1.05	0.58	0.75	-0.33	1.26
St-19	0.75	5.67	3.82	-1.02	-1.26

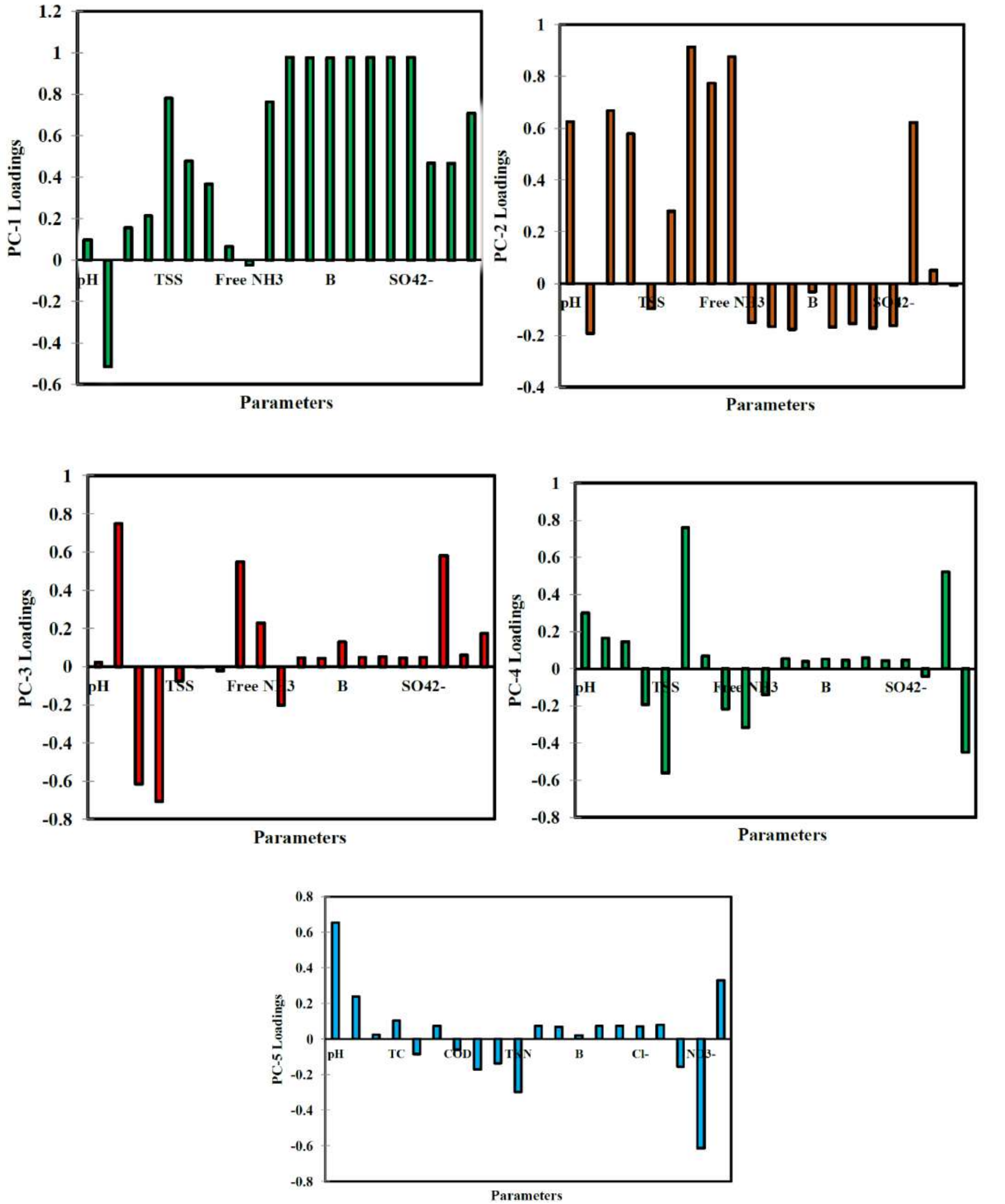


Fig. 9. Variation of 1st to 5th surface water factors extracted by PCA

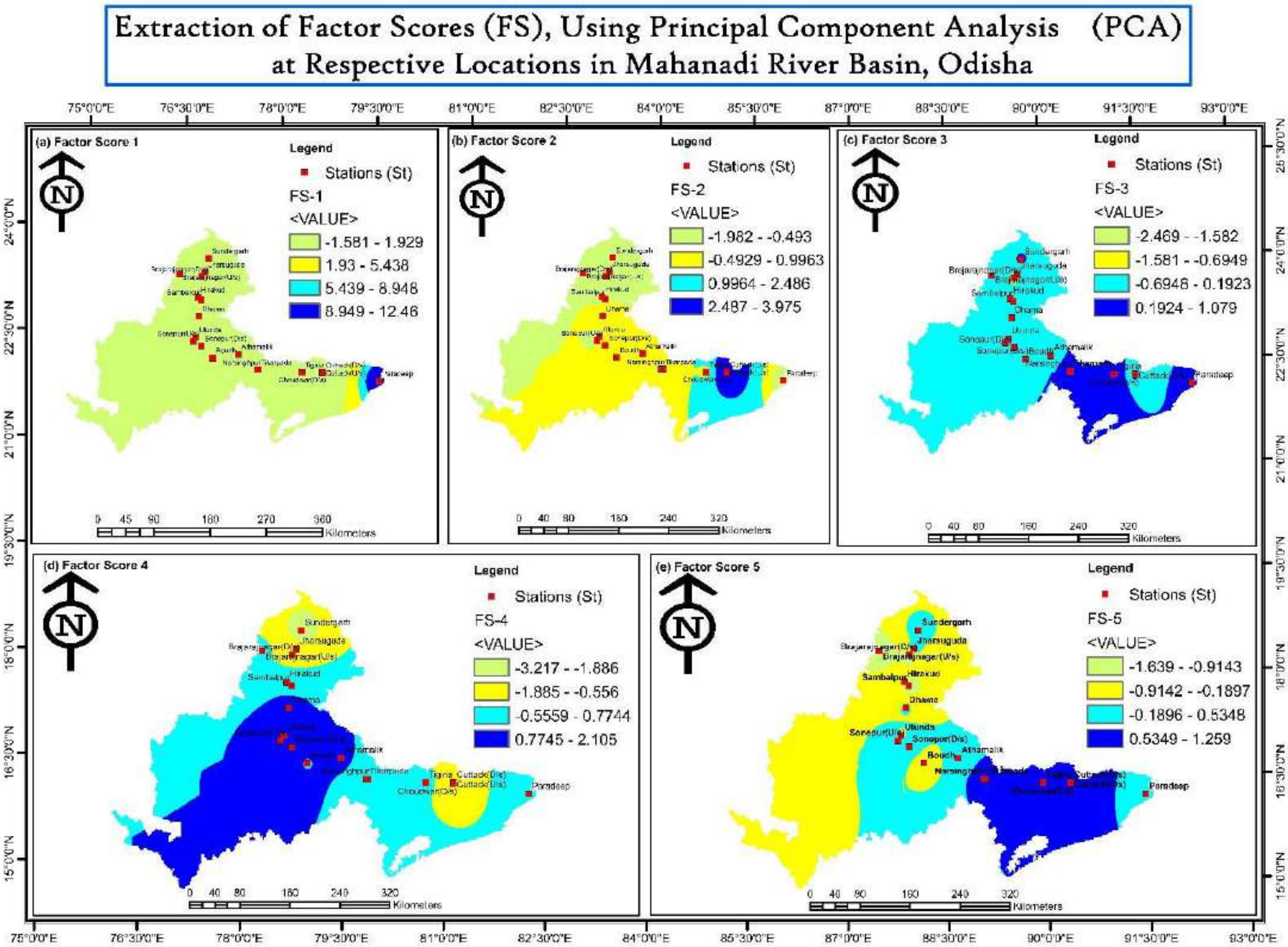


Fig. 10. Geo-spatial distribution of factor scores/loadings using GIS

6. Conclusion

The study has defined the surface water identification for human consumption and agriculture/farming uses, in the Mahanadi Basin, Odisha. In this study, applying multivariate statistical analysis techniques, the contributions of numerous likely sources to each water quality feature were allocated, such as CA, DA, and PCA, as well as MCDMs like ELECTRE and TOPSIS. A set of 20 water quality variables comprising 19 test sites over a 7-year period (2016-2023) was used for this. The study of EWQI reveals that the water quality is polluted at St-(8), (9) and (19) and not fit for drinking purpose, even though the local people are drinking. The high EWQI values at St. (9) were due to the high value of TC, TKN, EC, TDS, Cl^-, SO_4^{2-}, NO_3^- and Fe^{2+}. Seasonal fluctuations, agricultural practices, and other human-caused activities may be too responsible for this. On the basis of comparisons between the attributes of the river water quality, CA grouped the sampling places into 3 major classes. One of the explanations could be that industrial and domestic wastewater effluent emissions were often kept at a level that was relatively constant over the whole period. The best outcomes for spatial analysis come from DA. It used only 10 parameters (TC, TKN, EC, SAR, TDS, TH, Cl^-, SO_4^{2-} and Fe^{2+}) were shown to be the most accurate predictors (discriminant variables) of the heterogeneity of water quality in three clusters in stepwise method. It may be determined that the main causes of river water contamination are fluxes of point sources from human - caused climate change spurred on by the release of industrial, residential, and agricultural trash. According to the PCA analysis, five factors accounted for around 93.92 % of the variations in the dataset across the entire time period. The PCA results showed that the level of pollution increases as you move downstream. MCDMs were incorporated to examine the geospatial distribution of the relative water quality in relation to physicochemical characteristics. The developed TOPSIS and ELECTRE was applied on the dataset and ranked the St-9 as the most contaminated sampling point on the degree of performance score/closeness coefficients, followed by 2nd (St-8) and 3rd (St-19). Last but not least, the study has supported the viability and dependability of EWQI, MCDM, and multivariate statistical approaches for data analysis and justification from surface water quality analysis. More investigation would be needed to accurately evaluate the changes in other water quality parameters, which were not included in this current study, as well as the unidentified sources of contamination.

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