MATERIAL FLOW ANALYSIS (MFA) FOR WATER CONSERVATION: A CASE STUDY OF GANGA RIVER BASIN IN UTTAR PRADESH

Minor Project Thesis

Submitted by

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CERTIFICATE

I hereby certify that the project work entitled **"Material flow analysis (MFA) for water conservation: A case study of Ganga River basin in Uttar Pradesh"** carried out by Ms. Anshika Kandhway, M.Sc. (Environmental Studies and Resource Management), TERI University, New Delhi isan authentic record of work carried out by her during May 23, 2015 to July 20, 2015 undermy guidance.

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Abstract

Material Flow Analysis (MFA) is a multidisciplinary approach which adverts to systematic analysis of flows and stocks of materials within and across a system. Unlike other tools which focus on quantity of the materials being utilized in the system, MFA concept talks about the fate and impacts of various materials entering and leaving the system. In many conventional techniques for identifying theconstituent of water pollution, statistical or modeling methods are employed to identify the main pollutants for a particular region. MFA utilizes the available data and environmental statistics to establish a stationary model which can help to determine the origin and dynamics of pollution in the most presentable way. The MFA technique has been used in many countries for laying policy frameworks for water management practices.

In the present study, MFA was performed for a stretch of Ganga River flowing across Uttar Pradesh using the available data for the year 2011. The discharge of wastewater from different point sources is a major cause of deterioration of river water quality. In this study, the sub-basin of Ganga river in Uttar Pradesh is considered as a system, and the principal pollutants present in the discharged wastewater from the selected industrial sector (covering chemical, distillery, food, dairy & beverage, sugar, paper & pulp, textile, bleaching & dyeing,and tannery) were studied.
A qualitative assessment of identified sub-systems, namely, Industry, Sewage Treatment Plants and Sewage drains was conducted using Principal Component Analysis (PCA) and subsequently, the flows were quantified using graphical representation and line diagrams. The main contributors of pollution load were identified in the wastewater from the various sewage drains of Bijnor, Kanpur, Allahabad and Varanasi towns. The major parameters of pollution in sewage water turned out to be BOD, COD, Total Suspended Solids (TSS) and BOD load for Bijnor; BOD, COD and BOD load for Kanpur; BOD, COD, TSS, TDS and BOD load for Allahabad and COD, BOD and TSS for Varanasi. Their source activities and main polluting industries were identified.

The MFA results suggested that the water consumption and wastewater generation values for Sugar industry were 278.4 MLD and 85.7 MLD, whereas for Pulp & Paper industry, the values were 96.3 MLD and 68.1 MLD, respectively. In case of Kanpur, Allahabad and Varanasi, the assessment yielded that the sewage treatment plants are less efficient as compared to the overall wastewater generated. Using a similar analysis for the complete river basin, MFA can be successfully applied to enhance the knowledge for existing action plans, projects and activities. The MFA is a promising technique and need detailed exploration for use in the river conservation and rejuvenation efforts in India.

1. Introduction

River system and its drainage basin are complex and vast systems that are one of the most important environmental components. They regulate the working of anthroposhere andat the same time get influenced by the dynamic activitiessuch as agriculture, manufacturing, social and biophysical components of environment. They play a crucial role for the functioning of environmental and biological components and thus it is necessary to understand the sources of their degradationand develop an integrated model for solving them. From past few decades, the pace of industrialization and urbanization has increased in developing countries. India being one of them has not only prospered economically but has also degraded its natural resource quality in the meantime. The major culprits of resource debasement are fossil fuel combustion, industrial effluents, agricultural runoffs, vehicular exhaust, power plants, and municipal sewage.

The Integrated Water Resources Management (IWRM), aimed to propound water management strategies, whichcould mitigate impacts of anthroposhere on natural water systems and interrelated processes (Terekhanova,2009). However, this requires the knowledge of quantitative as well as qualitative aspect of water resources and their interactions with natural and anthropogenic environment. These descriptions can be amalgamated using the material flow analysis tool."MFA is used in a variety of environmental-engineering and management applications, including environmental-impact statements, remediation of hazardous-waste sites, design of air-pollution control strategies, nutrient management in watersheds, planning of soil-monitoring programs, and sewage-sludge management" (Brunner and Rechberger, 2005).

In case of river system, water is the carrier of substances and goods, which can be studied using water balance approach. In addition, water quality influenced by these flowing materials can be quantified using MFA tool (Terekhanova, 2009).Herein, the most ubiquitous water quality parameters which are used in of river studies are temperature, pH, dissolved oxygen (DO), Biological Oxygen demand (BOD), Chemical Oxygen demand (COD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS).These parameters are exploited to gain knowledge of the status of Ganga River and chief pollutants in sewage discharge from drains.

In the research, terms, procedures, and figures are explained to model and analyze the material flow analysis, and rendering to reach a comprehensive and transparent result depicting account of material's flows and stocks contained in the system.

1.1 Problem statement

Since 1970's, the water quality of the much revered stream Ganga began to deplete due to elevated volume untreated sewage and industrial effluent discharge (CSE, 2013). The Sub-basin of Ganga River in Uttar Pradesh has various point and non-point sources of pollution. Their causes and impacts are frequently studied separately which fails to produce a common solution to the existing problems. Many pollutant-discharging activities are also the most important economic activities such as agriculture, industries, commercial activities, construction, and sewage treatment plants. The water flows out from the river system to ponds, estuaries, agriculture, atmosphere, groundwater and ultimately to biological system. It should be kept in mind that the waste generating activities and their impacts are inter-correlated in the system.

In 1985, the government launched the Ganga Action Plan (GAP) to bring back the water quality to acceptable standards by installing sewage treatment plants, improving sanitation, and afforestation in 25 towns. But the effort remained ineffective due to numerous drawbacks such as land acquisitions difficulty, poor planning, lack of infrastructure and implementation strategies, and incapability and erroneous position of treatment pants. Since then the quantum of sewage generation has increased from 1340 million liters per day (MLD) to approximately 3000 MLD (CSE, 2013).

Complexities and problems persisting in Ganga basin include:

- Oxygen depletion. -Addition of organic and nitrogenous waste in enormous quantity as well as declining aquatic vegetation has altered the natural environment of river.

- Chemical imbalance and toxicity-Metals and minerals change the pH of the water and give rise to a number of side reactions ad products. The fish populations are found to be stressed due the alkaline water (Schaik, et al.)

- Exceedence of permissible concentration limit of pollutants in wastewater discharged in streams.

- Diminishing river flow as a result of sedimentation and riverbed degradation.
- Inadequate number of monitoring stations and observatories for reporting hydrological and physicochemical status of stream environment.
- Atmospheric and soil pollution- Nutrients, elements and compounds undergo reactive transformations and enter other systems such as atmosphere by volatilization and ground by flooding.

Above these, the major drawback in the system is insufficient numbers of sewage and wastewater treatment plants. Even regions with treatment plant have another set of problem that is, the incapability of removing all types pollutants collected from different source and example, a municipal wastewater treatment plant can effectively remove organic pollutants but it is beyond its capacity to remove heavy metals and chemically stable inorganic pollutants. One of the difficulties in developing countries like India is availability and acquisition of data regarding natural water resources.

1.2 Aim and Objectives

The aim of the study is to develop a material flow analysis model for water management in Ganga River system in the state of Uttar Pradesh. The focus of the study is to understand the water and wastewater flows in the system for selective processes.

The research holds the following objectives:

⇒ MFA setup: Establishment of a material flow analysis (MFA) model that tracks flows and fluxes of water and wastewater in the Ganga river basin confined in Uttar Pradesh. The model should explain the relevant flows, input and output goods and interconnection among the processes in the system.

⇒ Quantification of flows in the sub-systems namely, Industry and Sewage treatment plants (STPs). (Quantitative approach)

⇒ Identification of the principal parameters of water quality from drains discharge for four districts of Uttar Pradesh using Principal Component Analysis (PCA) and prepare a flow chart relating to their sources. (Qualitative approach)

2. Study area

Ganga River forms the largest river basin in India and it constitutes about 26.3 per cent of country's geographical area. Forty-three percent of country's population is dependent and inhabiting on this basin. (CSE, 2013 and CPCB, 2013). The climate of Gangetic plain in India varies from semiarid to sub-humid. The river is flowing through the five states of India namely, Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal. Among them, Uttar Pradesh and Uttarakhand are together sharing the 34 % area of the entire basin.

Uttar Pradesh is one of the largest states of India with the highest population. It also constitutes the largest drainage area of Ganga River basin. Some facts and figures are mentioned about the river Ganga and Uttar Pradesh in the following table:

Table 2.1: Physical features of Ganga River	
Physical features of Ganga River:	
Total length	2525 km
Average flow	16 m
Average Annual discharge	4,93,400 million cubic meter
Mean Annual Flow of Streams in Ganga Basin	84.98
Catchment Area Ganga Basin	8,61,404 sq. km (26.4%) of India
Uttar Pradesh specific information's:	
Length of Ganga	1000 km
Major Cities located on the bank	Bijnor, Narora, Kanauj, Kanpur, Allahabad, Varanasi, Mirzapur
Total population (2011)	199,581,447
Population Density (persons per km2)	828/km2
Urban population	4, 44, 70.455 (22.28 %)

Source: CPCB, 2013, CSE 2013, and NGRBA, 2011

The extreme temperature varies between zeros to 50 degrees. The state receives maximum rainfall from June to August from South-west Indian monsoon. The annual precipitation in the basin ranges from 650 mm in the southwest corner of the state to 1000 mm in the eastern and southeastern parts of the state.

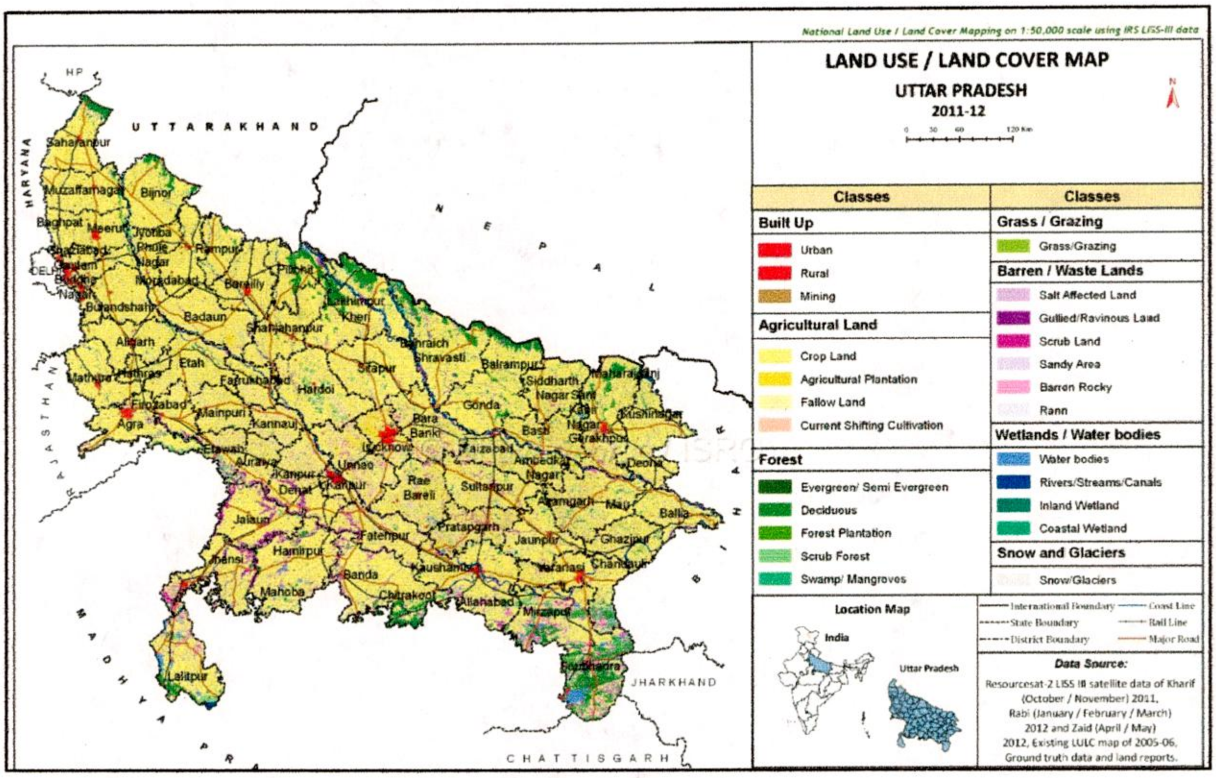


Figure 1: Land Use / Land Cover map of Uttar Pradesh (2011-2012) Source: NRSC, 2012

Table 2.2: Land Use / Land Cover in Uttar Pradesh (2011-2012)

Category	State: Uttar Pradesh
Agriculture	190894.83
Unculturable/ Wastelands	14369.43
Builtup	11398.04
Forest	12589.17
Grass / Grazing	310.48
Water bodies	11366.07

Source: Adapted after modification from NRSC, 2011-12

Uttar Pradesh forms a large part of fertile Indo-Gangetic plain. For most of the region water scarcity is not an issue due to a large network of rivers, canals and irrigation measures. The state produces a large amount of food grains, pulses, potatoes, oil seeds, fruits etc. Sugarcane is the main cash crop in the state. There is a large population of livestock in state which further adds to the livelihood of people. As it can be seen from the Land Use / Land Cover table agriculture is the prime economic activity

Industrialization has grown rapidly after liberalization of economic policies in the country. The main industries in the state are of textile, sugar, tannery, lead, chemical, electronics, electrical parts, automobile and steel. In recent years, it has emerged as the hub of Information technology and semiconductor industries. A good part of economy is dependent on industrial sector. Apart from this, historical monuments, culture and religious beliefs keep up the tourism industry alive.

Improved economy is the boon of above activities but the damage done to nature is beyond irreparable. It has been estimated that around 500 MLD of industrial effluents are discharged in to river Ganga and 90 percent of those industries are in Uttar Pradesh (CSE, 2013). Though government has tried to improve upon the health of river but the problems of insufficient infrastructure, lack of monitoring, awareness and technologies are bigger than the efforts made. Agricultural practices have become dependent on more technology and chemicals and their adverse effects are not unknown to us.

3. Literature review

Commonly used techniques to assess the river health are water quality models and statistical tools. Recently, sustainable development and ecological cycles have been recognized to be equally significant as environmental protection. El-Baz, et al. (2004) suggests that “environmental biocomplexity” can provide a framework to incorporate the inprotection act. Environmental biocomplexity can be analyzed using material flow analysis tool. The article emphasizes that material flow analysis characterize the cause of pollution in an ecosystem when all relevant process acting as source, sink and pollutant pathways are accounted. The unique characteristic of MFA enables to build a technique, which can readily be engaged in decision-support tool for managing the resources, environment and waste products (Brunner and Rechberger, 2005). To assess the sustainable management opportunities for water supply, wastewater treatment system andhydrologicalcycle flows at regional levelcan be done to identify the potential to reuse wastewater and harvest the rainwater (Marteleira et al., 2014)

Material flow analysis (MFA) is a multidisciplinary approach, which adverts to systematic analysis of flows and stocks of materials within and across a system observed for a particular time and space (Brunner andRechberger, 2005).It set up a connection between source, pathway of flows and sinks of a material. It follows the law of conservation of mass, hence the “results of MFA can be controlled by a simple material balance” (Brunner and Rechberger, 2005). Through input and output balance, we can detect the path of flow, loading in environment and stocks for waste matter.The system and set up of its boundary can be chosen based on the problem formulation and objective investigation.

Conventional models investigating the river water quality requires intensive data assessment while MFA take advantage of existing knowledge and data. It uses simple data on natural state, time, space, pollution data, environmental statistics, and land use related to river stream to develop a MFA model. This saves us from gathering large amount of data. Still, one of the difficulties that researchers face while performing the analysis is data availability. (Terekhanova, 2009).In a research by Espinosa and Otterpohl (2014), it was demonstrated that incomplete data sets could be used to determine the flow of nitrogen and water to integrally evaluate the urban water and wastewater management system (WWMS) in developing countries using MFA. In India, Venkatesh (2012) studied the important material flows into the households associated with water usage and simultaneously relating them the environmental impacts.

To a large extent, water quality of rivers is dependent on the bed composition that is, the type of soil and rocks present in channel. Then, the MFA set up established on water balance concept is applicable for the "quantitative assessment of water quality formation process on a watershed" (Terekhanova, 2009). Water quality problems assessment and mitigation measures can be proposed using MFA framework for a river system is explained by studying the case of the That Chin River Basin, Thailand (Schaffner, 2005).There are few researchers who are involved in studying nutrient emissions; heavy metal discharges; wastewater and effluents discharge in rivers using material flow analysis.

Every nation'seconomy is measured through capital productivity and energy efficiency.But they renege to provide a holistic view of how the fate of natural resources and energy changes from its generation to processing and to disposal or recycling. In that matter, material flow analysis proves to be a powerful tool to fill the knowledge gaps and decide an appropriate policy intervention for sustainable resources use (OECD, 2008).Geo Information Systems (GIS)and their concepts are applied to enhance the knowledge outcome of material's spatial property and region specific values. A thesis submitted by Terekhanova, (2009), a brilliant combination of water quality model MONERIS (to estimate nutrient load) and MFA was presented and results were produces using GIS tools for Western Bug basin, Ukraine. In a similar study, spatial land use analysis along with material flow analysis yielded the nutrient flow in such a way that their sources and processes could be geographically located(Kupkanchanakul et al., 2015).The visual results is attractive to make local stakeholders of the critical situation (Nga Do-Thu, 2010; OECD, 2008; Kupkanchanakul et al., 2015)

4. Methodology

4.1 Methods

4.1.1 MFA

Since 1960ths, the material flow analysis has been successfully employed in works of chemical engineering, agricultural lands investigation, industrial enterprises, private economies, and craft, as well for the whole nation or watersheds (Baccini 1996 cited in Terekhanova, 2009, p. 13).

The foremost objective of this MFA is to improve the assessment method of waste generation and transport along with local treating capacity of these wastes. The system analysis is the first step in the material flux analysis, which answers the following questions:

- Which materials and processes are to be considered in the study?
- What is the confining boundary (system boundary)?
- Which time span is considered?

The term "goods" defines the valued material or a group of materials in material flow analysis. Material includes chemical elements and their compounds present in the flowing material. The goods are transported, transformed, and stored which are denoted by the term "process." Various processes are liked with each other by means of goods. During transportation and storage, the goods retain their chemical composition whereas in cases of transformation, goods arechanged into new products with distinct chemical properties. However, all these activities require energy and other materials, which facilitate to link other processes. Each good has an origin and a destination process. The goods, which are entering into the system process, are said to be "import goods" and the flows are called "import flows" (denoted by I). Similarly, the ones leaving the system process are called "export goods," while the process is 'export flows" (denoted by E).

A systematic material flow analysis comprises of following steps: (Schaffner, 2005, Terekhanova et al., 2012, OECD, 2008)

i. Define the objective of MFA

ii. A system analysis constituting materials and processes

iii. Determination of flow processes of the considered parameters/elements- a qualitative approach

iv. Determination of concentration of considered parameters

v. Calculation of fluxes of selected elements and draw up balances

vi. Interpretation and graphical representation of results and drawing conclusions

Table 4.1.1.: Common terms used in Material Flow Analysis

Terminology	**Description**
Material	An umbrella term for both substances and goods. It includes raw materials as well as all physically or chemically modified substances.
Substance	Any single (chemical) element or compound matter consisting of uniform units. They are unique and homogenous.
Goods	Goods are substances or mixtures of substances that have economic values assigned by markets referred to as to material goods (positive or negative values).
Process	It is defined as a transport, transformation, or storage of materials. It can be natural or man-made.
Stock	A material reservoir (mass) stored within the analyzed system, and It has the physical unit of kilograms
Flow	Mass flow rate or flow is mass per time that flows through a conductor. The physical unit used is kg/sec or t/yr.
Flux	Flux is defined as mass per time and cross-section of materials.
System	A system comprises a set of material flows, stocks, and processes within a defined boundary
System boundary	It is defined in space and time. Space can consist of geographical borders (region) or virtual limits.
Imports or exports	Flows/fluxes across systems boundaries inside or outside are called imports or exports respectively.
Activity	It is useful when evaluating and designing new anthropogenic process and system.
Sankey diagram	It is a directional flow chart where the width of the streams is proportional to the quantity of flow. It is typically used to visualize energy or material transfers between processes.

Illustration of material flow analysis can be done using following types of charts: (UNIDO, *Cleaner Production Toolkit*, Anonymous, N/D)

- Flowcharts representing material flows and process steps;

- ➢ Pie charts and histograms illustrating ratios and compositions;
- ➢ Time-travel diagrams showing time relations;
- ➢ Sankey diagrams visualizing material flows true to scale.

4.1.2 STAN Software

Over a past couple of decades, Material Flow analysis has become more reliable to identify and delineate the flow of material and its stock within the various systems. In year 2005, in order to apply MFA concept in Waste Management, the Austrian Standard ÖNORM S 2096 standardized the terminology and methodology of MFA. These standards form the basis of the STAN software. STAN, the word was derived from "**substance flow Analysis**," and it was developed by the Vienna University of Technology (Institute for Water Quality, Resources and Waste Management). It is a freeware for MFA which was able to overcome earlier inadequacies of developing MFA concept for the system.

i. Prior to this software, the MFA model was designed using paper and pen, data was managed and calculated with Excel spreadsheet and finally results were presented using graphical software. This proved to be tedious and erroneous job.

ii. Other than this, handling uncertainty and inconsistency on data is a major drawback in many MFA studies. Henceforth, "uncertainties their consequences" are not concluded in results of these studies. Therefore, an important portion of information is lost.

Above mentioned difficulties are overcome by STAN. The software enables us to use Graphical User Interface (GUI), model a system, enter numeric data, calculate the flow and stock and display results. Graphical User Interface (GUI) comprise of several windows with handy tools. The Drawing Area provides the ground to produce a schematic flow in the system, that is, a Model of the system

4.1.3 Principal component analysis

Principal component analysis identifies the most important variables from the parameter dataset. It gives a completely new set of data with reduced dimensionality through linear combination of original variables without losing much of information from the original data.

This statistical technique is employed to obtain relationship between water quality parameters and sampling sites, to suggest the factors and sources influencing quality of water (Usman et al., 2014). It attempts to provide an explanation for variance in large set of inter-correlated variables. By converting them into compact set of independent variables through linear combination toyield *principal components or factors.* (Gorver, 2007) The linear combination of variable can be expressed as follows (Nasir et al., 2011):

$$y_{mn} = z_{m1}x_{1n} + z_{m2}x_{2n} + \dots\dots + z_{mi}x_{in}$$

Where, y= component score,

z = component loading,

x= measured value,

m= component number,

n= sample number

Scores are new variables that are the computed value of the linear combination of the original variables. The scores are normalized so that their sum of squares equals the variance of the principal component.

Varimax rotation is an orthogonal rotation, explained by Kaiser in 1960 that effectively minimized the number of variables with high loading on each component. Varifactors coefficient associated with a correlation value more than 0.75 represents "high proportion of its variance explained by the factor" that means it has a strong factor loading (Usman et al., 2014). Whereas correlation between 0.50 and 0.75 means moderate significant factor loading whereas, between 0.30 and 0.50 means weak significant factor loading or less important variable.

4.2 System analysis

A schematic flow diagram was prepared for the overall Ganga river system to understand the major inputs and outputs related to anthropogenic processes. To achieve this, system analysis was done which includes defining mass balance and balance period, identifying the process steps, and drawing the flowcharts. The system is comprised of 10 processes, internal flows, as well as import and export flows within the system boundary. The geographical boundary of Uttar Pradesh was selected as the system boundary. The processes were shown as black rectangular boxes. The Ganga River is selected as a process in which export materials, that is, waste from other processes is collected. Other environmental compartments such as atmosphere, soil, and groundwater are not investigated here. In figure 4.1, the qualitative assessment of flows and processes were done through personal understanding and discussions. The system illustrated the import of raw materials and water from outside the system and generation of various categories of waste from each process namely, agriculture, household, industry, construction activities, livestock, drainage, landfills, sewage treatment plants and groundwater.

To model the system of MFA, modeling software called STAN (version- 2.5.1202) was used. The detailed description of the software was mentioned in the earlier section. The predefined elements in the software such as system boundaries, processes, flows, and text fields were used to plan the MFA models in a graphical way. The arrow showing internal flows facilitates connection between two processes while export and import flows demonstrate the connection of a process with external areas that are outside the system boundary. A system boundary comprehensively hems in the processes and flows except import and export flows.

A similar system analysis diagrams were prepared for the sub-systems, Industries, Sewage Treatment Plant sand Drains in the state. An exhaustive and purposeful analysis was carried out for water consumption, wastewater and sewage generation, and their treatment. The material influxes and waste flows were quantified using the existing statistics. In case of Industries and STPs, a quantitative analysis was achieved using volume flows of parameters chosen. While for Drains, a qualitative assessment was carried out using the water quality parameters.

The numeric values and designating names were entered manually for each flow and process. Calculation of unknown quantities is possible in STAN using the reconciled values after recognizing the errors in data using statistical tests.

The flow values and calculated values are shown in the result in form of a Sankey diagram. The width of an arrow is in accordance with the value of flow quantity (flow volume in this case).

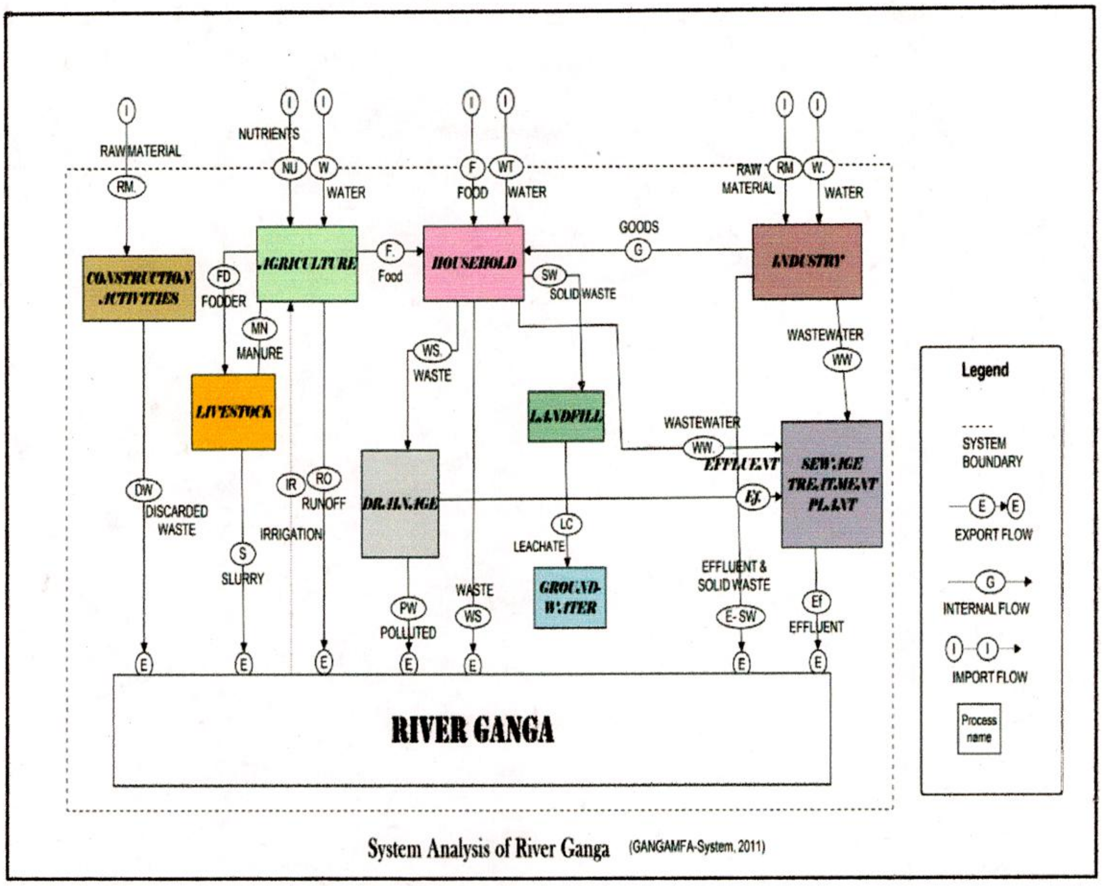


Figure 4.1: System analysis of river Ganga showing major processes, input and output flows in the Ganga basin of Uttar Pradesh

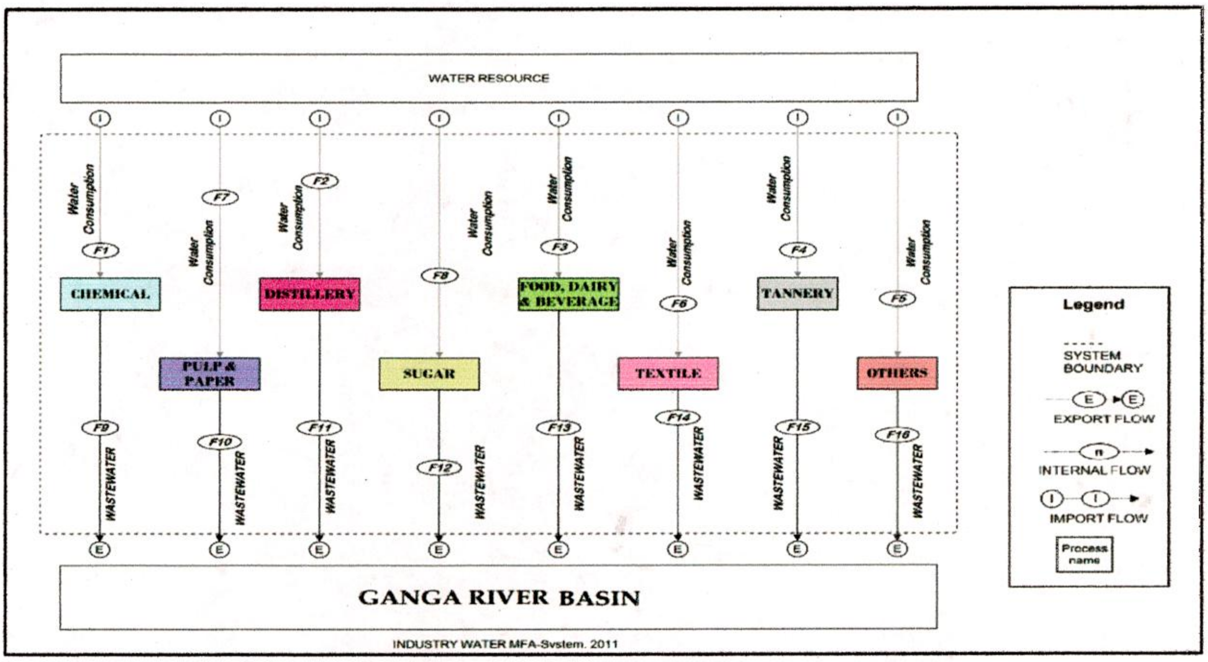


Figure 4.2: System analysis of industrial system showing main polluting industries in the Ganga basin of Uttar Pradesh.

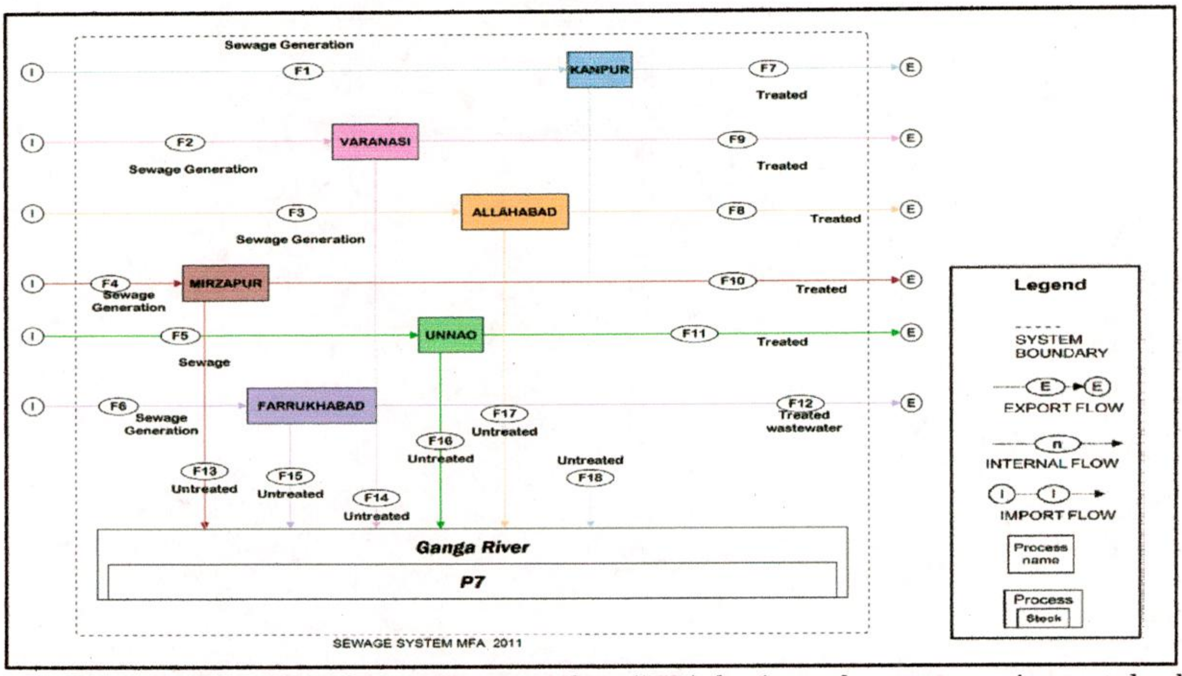


Figure 4.3: System analysis of Sewage Treatment Plants (STPs) showing total sewage generation, treated and untreated sewage discharged in Ganga basin of Uttar Pradesh. **Boxes represent the STPs in that area.**

For the system analysis of drains discharge, the flowing materials were river water and wastewater. Flow of river water is from Ganga River to each catchment area and flow of wastewater is from catchment areas to respective drains (Figure 4.4). Then, wastewater quality was analyzed to give main pollution parameters and their probable sources with special consideration to the major operating industries. The main pollution parameters were identified using Principal component analysis. Then, their causes were determined by relating them to the Land Use/ Land Cover data and type of major industries in those areas.

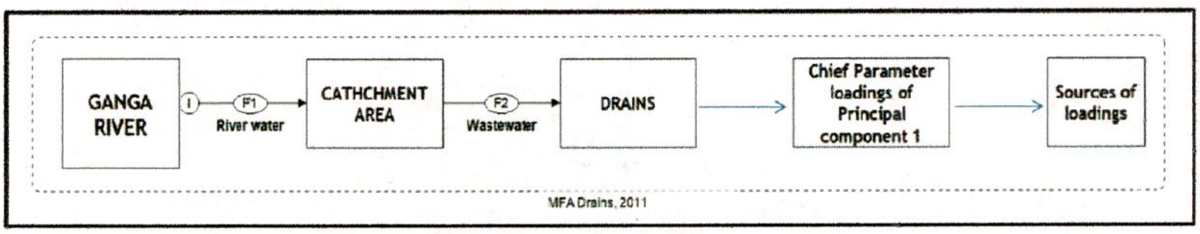


Figure 4.4: System analysis cum flowchart showing Drains discharging wastewater, main pollutant parameters and sources of pollution in selected areas of Ganga basin of Uttar Pradesh.

4.3Data Acquisition

The water flow analysis was of the system was done using the data from *Pollution Assessment: River Ganga* (2013), an annual report, published by the Central Pollution Control Board, Delhi. The report gives the insight Ganga River and established a monitoring network to quantify water quality of the Ganga and suggests measures for improving the water quality of Uttarakhand, Uttar Pradesh, Bihar, and West Bengal. Due to availability of comprehensive data for year 2011, it was chosen as base year for analysis.

- **Industry**- The water consumption and wastewater generation by various industries in Uttar Pradesh for the year 2011 is shown in tabular. In record, there were 687 industries from different fields were investigated for their water consumption and wastewater generation capacity for the year 2011.

Table 4.1: Status of sector specific industrial Water consumption and wastewater generation by Industries in Uttar Pradesh, 2011

Category of Industry	Water Consumption (KLD)	Wastewater Generation (KLD)	Number of Industry
Chemical	113	29.6	20
Distillery	69.2	33	27
Food, Dairy & Beverage	6.3	3.8	15
Pulp & Paper	96.3	68.1	33
Sugar	278.4	85.7	56
Textile, Bleaching & Dyeing	11.4	9	59
Tannery	27.4	21.6	442
Others	90.7	18.1	35
Total	693	269	687

Source: CPCB,2013

- **Sewage Treatment Plants (STPs)** - The data for the sewage generation, capacity of Sewage treatment plant and discharge of untreated sewage in the Ganga basin by six districts were tabulate (table). The import good is generated sewage while the export good are treated sewage and Untreated Sewage.

Table 4.2:Sewage Generation Capacity of Sewage Treatment Plants in of Class - I Cities in Uttar Pradesh, 2011

District	Sewage Generation (MLD)	Treatment Capacity (MLD)	Untreated Sewage (MLD)
Kanpur	339.3	171.1	168.2
Varanasi	187.1	141	46.1
Allahabad	208	89	119
Farrukhabad	30.5	8.3	22.2
Mirzapur-Vindhyachal	27.5	14	13.5

Unnao	23.9	19.4	4.5
Total	816.3	442.8	373.5

Source: Adapted with modification from CPCB, 2013

- **Wastewater Drains**

Discharge from drains is one of the chief sources of point pollution in rivers. Following are the analytical results of discharge for Ganga region in Uttar Pradesh for Bijnor, Kanpur, Allahabad and Varanasi areas. The quality parameters considered here are Flow (MLD), pH, COD, BOD, TSS, TDS, BOD load. Principal component analysis is performed on the following dataset to determine the main polluting parameter and the source of pollution.

Table 4.3: Drains discharging their wastewater to river Ganga

Catchment area	Point Source	Flow (MLD)	pH	COD (mg/L)	BOD (mg/L)	TSS (mg/L)	TDS (mg/L)	BOD Load (kg/day)
Bijnor	Bijnor Sewage Drain	7.6	7.32	221	58	167	796	440.8
	Malan River	16.5	9.16	22	5	99	358	82.5
	Chhoiya Drain	124	8.07	407	130	126	1132	16120
Kanpur								
	Dabka Nalla-1	94	7.16	543	168	86	1540	15792
	Dabka Nalla-2	25	8.71	484	139	230	648	3475
	Dabka Nalla-3	0.26	8.81	43	39	789	1132	10
	Shetla Bazar	29	9.64	1,793		257	5076	12296
	WazidpurNalla	54	9.3	2,491	843	923	-	45522
	SattiChaura	1.1	7.54	189	88	608	797	97
	GolaghatNala	0.83	7.48	236	137	315	1,111	114
	BhagwatdasNala	11	7.42	209	104	218	850	1144
	SisamauNala	197	7.81	7,478	2,930	327	644	544980
	PermiyaNala	186	7.44	93.5	58.3	156.5	523	11485
	Rasulabad-1	29.8	7.99	1362	680	1,858	5,132	20,264
	Rasulabad-2	20.2	7.96	587	280	550	707	5,656
	Rasulabad-3	14.2	8.03	192	93	108	587	1,320
	Rasulabad-4	48.5	8.12	88.5	49	176	571	2,376
	Nehru Drain	7	8.1	17.3	8.65	21	637	61

Allahabad	Kodar Drain	20	7.63	148	52.4	219	734	1,040
	Pongaghat Drain	8	7.8	96.9	20.1	67	678	161
	Solari Drain	34.8	8	105.8	31.6	121	770	1,087
	Maviya Drain	65	7.31	104	52	182	523	3,380
	Mugalaha Drain	46	7.68	33.9	13.2	15	284	598
Varanasi	Rajghat drain	16.19	7.28	100	49.9	81.8	454	808
	Nagwa drain	66	7.46	156	61.1	106.42	608.4	4,060
	Ramnagar drain	23.65	6.65	144	40.7	110.86	703.6	963
	Varuna drain	304.5	7.31	46.2	12.4	433.8	552.4	3,776

Source: CPCB, 2013

- **Land Use Land Cover data-** The provisional LULC statistics corresponding to Land Use Land Cover Map of Uttar Pradesh, 2011-12 (Figure 1.1) for Bijnor, Kanpur, Allahabad and Varanasi. Classification is done in the following manner:
  a. Agriculture consists of crop land, current shifting cultivation, fallow and plantation.
  b. Unculturable/ Wastelandscomprise of salt affected area, rocky terrain, gullied land, rann and scrub land.
  c. Builtup means rural, urban and mining areas.
  d. Forest consists of deciduous, evergreen, forest plantation, scrub forest and mangroves forest.
  e. Water bodies consist of wetland, river/stream/canals, and others

Table 4.4: Land Use / Land Cover data in Uttar Pradesh (2011-2012)

Category	**District**			
	Allahabad	Bijnor	Varanasi	Kanpur
Agriculture	3970.951	3827.76	1132.62	1451.72
Unculturable/ Wastelands	524.28	19.79	58.88	270.32
Builtup	145.97	172.86	138.19	341.09
Forest	193.95	5.96		
Grass / Grazing		17.72		
Water bodies	316.86	157.91	51.3	63.84

Source: Adapted with modification from NRSC, 2011-12

4.4 Line diagram

Line diagram is a pictorial way of representing a system with the help of lines and symbols showing major components contributing to the stream flow of the river. It has proved to be advantageous to illustrate the flow from a specific process or location to the stream. In this study, the diagram has been used to display the resulting inflow of waste matter in the Ganga river system across Uttar Pradesh. The line diagrams are made for following cases:

i. A diagram to represent wastewater flows from various sectors of Industries. The positions of the industries were not related with the actual location on ground.

ii. The diagram representing the quantum of untreated sewage that is discharged in the river from respective class I cities.

4.5 Principal component analysis- PCA

PCA is utilized in this study to extract the principal component and for this; there is a prior requirement of evaluating the variation in each wastewater quality parameter explained by the factors. Here, four districts of Uttar Pradesh, viz. Bijnor, Kanpur, Allahabad and Varanasi were selected for study. For each region, wastewater quality dataset of several drains was acquired. Then, PCA was run through the data sets for further analysis. This statistical method was performed on the Analyse-it, an add-in software for Microsoft excel.

Table 4.5: List of parameters used with their units

Parameter	Abbreviation	Unit
Flow		Million liter per day (MLD)
pH	pH	-
Chemical Oxygen Demand	COD	Milligram per liter (mg/L)
Biological Oxygen Demand	BOD	Milligram per liter (mg/L)
Total Suspended Solids	TSS	Milligram per liter (mg/L)
Total Dissolved Solids	TDS	Milligram per liter (mg/L)
BOD load	BOD Load	Kilogram per day (kg/day)

The first step of analysis was to explain the basic statistical calculations and get the value of mean, median and standard deviations of the dataset. Then, through Principal component analysis tool, principal components were extracted which explained the variance contributed by the new subsets (individual principal components) to the original dataset. It also helped in determining the proportion and cumulative variances or eigenvalues accounted by individual principal component. It is considered that the principal components with eigenvalue greater than 1 explains more variance in original dataset and those with eigenvalue less than 1 explain less variation than individual variable. So, for clear interpretation of data, principal components with eigenvalue greater than 1 is retained and was then subjected to varimax rotation for factor analysis in the Analyse-it software on Microsoft excel.

For further reduction in dimensionality of dataset and to establish interpreting criteria for principal components, factor analysis was performed. It aided to cut down the contribution made by less important components obtained earlier from PCA and gave a fresh set of variables. These new variables were called Varifactors (VFs), obtained by orthogonally rotating the axis defined by PCA (Nasir et al., 2011). Varifactors coefficient associated with a correlation value greater than 0.75 for first principal component (that is for VF1) were taken into consideration. So that it was possible to determine the primary constituents of pollution that affect the stream's water quality.

Later on, the land use characteristics of each area was tallied with the parameter loadings to determine the stipulated activities for the existing pollutants. The analysis was narrowed down to relate and mention the major polluting category of industries in each area.

Finally, a consolidated result was shown as the qualitative material flow analysis corresponding to the system analysis cum flowchart of Drains discharge.

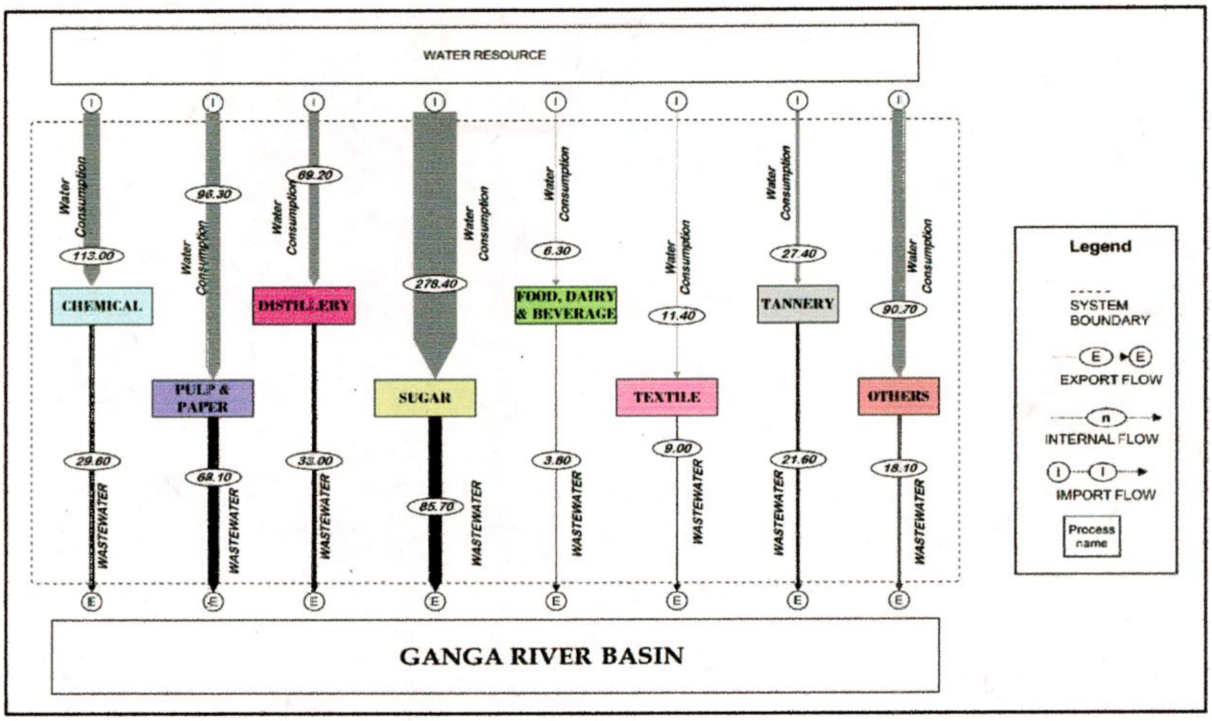


Figure 5.1: Results of MFA of Industries depicting water consumption and wastewater generation. Flows are in KLD.

The percentage contribution by individual category of industry can be shown with the help of pie charts also. It is an alternate way of representing the results of material flow analysis (Figure 5.2).

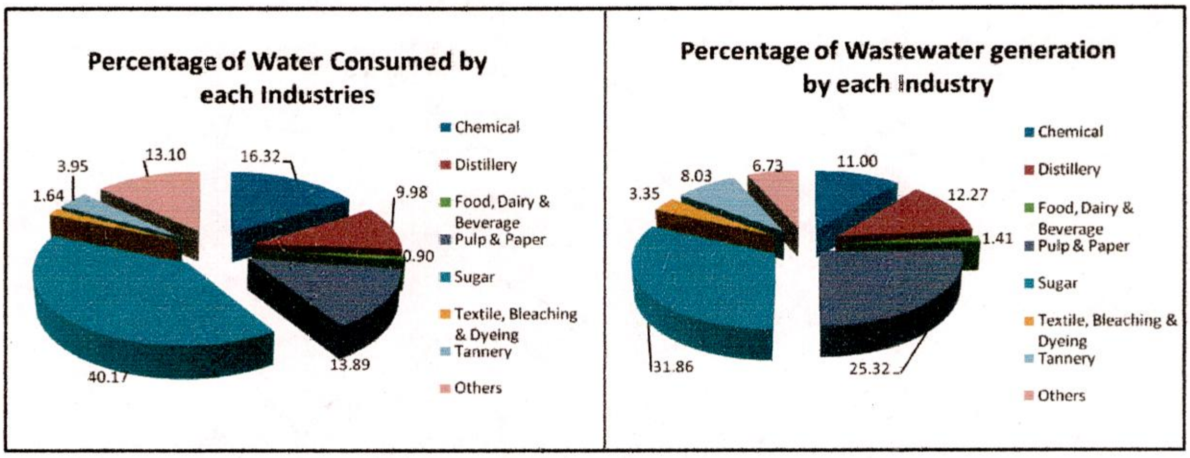


Figure 5.2: Percentage water consumption and wastewater generation.

The proportion of wastewater produced to water consumed can be comprehended using the bar graph in the figure 5.3. Textile, Tannery, and Pulp & Paper industry are disposing more than 80, 75 and 70 percent respectively, of the total consumed water as wastewater. Whereas, for Chemical, Distillery and Sugar sectors, the proportional wastewater production is less than 50 percent.

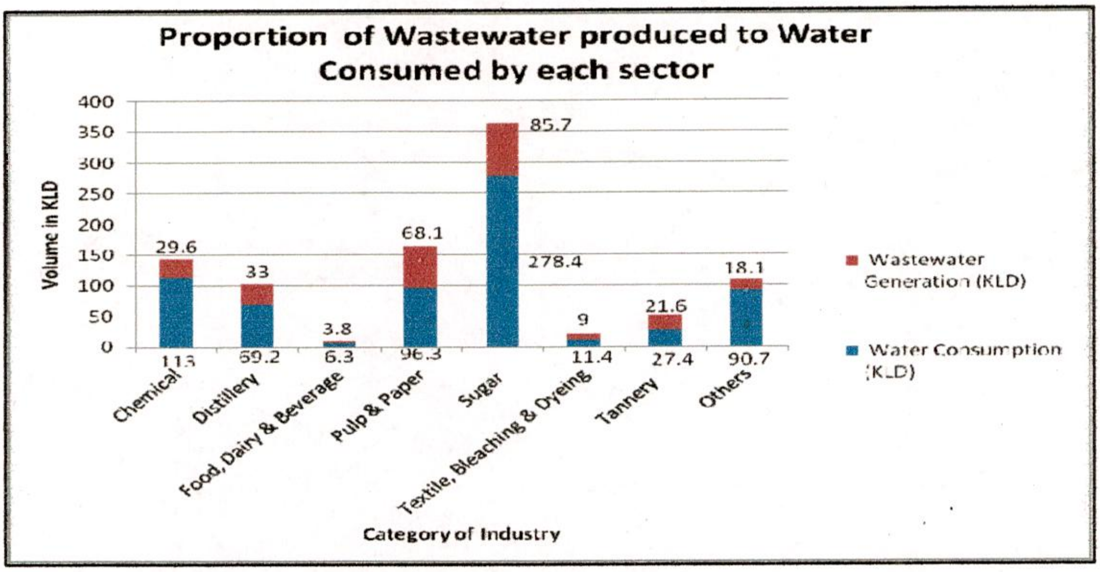


Figure 5.3: Bar graph depicts proportion of wastewater discharged as compared to water consumed by each category of industry in Uttar Pradesh

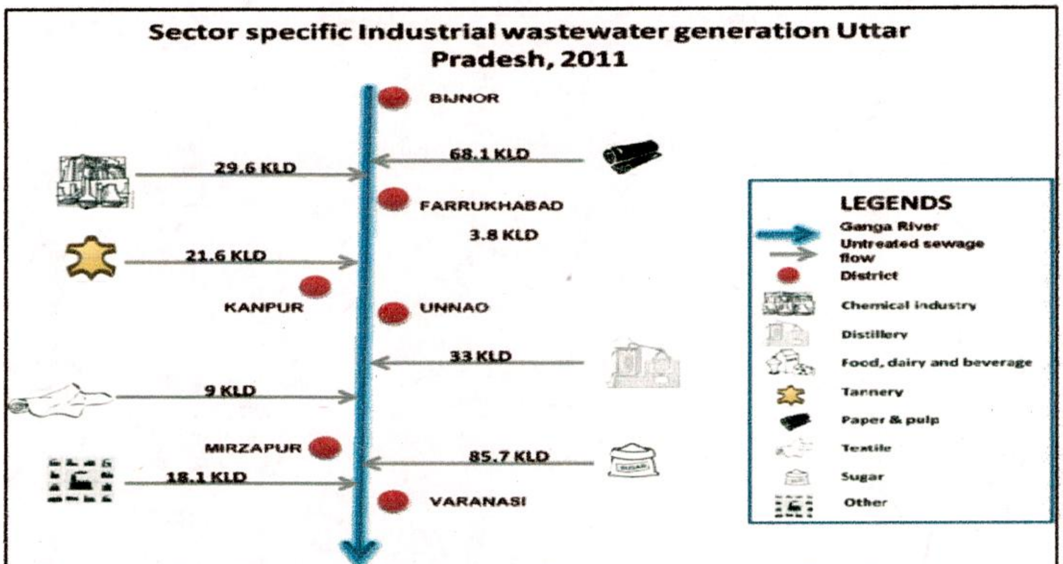


Figure 5.4: Line diagram showing sector specific flow of wastewater in Uttar Pradesh

The line diagram gives an easy outlook of the wastewater flow contributed by each category of industry to Ganga River in the Uttar Pradesh (Figure 5.5). As mentioned earlier, in the above figure, positions of industries are not related with the actual location of districts on ground.

5.2 Sewage Treatment Plants

The result of simulated flow of total sewage generated in the region whereas quantity of treated and untreated sewage discharged in river is shown the diagram shown in figure 5.5. Through mass balance approach, untreated flows of sewage were calculated for treatment plants of six cities-I in Uttar Pradesh for year 2011.

Sankey arrows (in Figure 5.5) show the sewage flows entering and leaving regional treatment plant (horizontal arrows) and the flow, which is left untreated (vertical downward arrow). The unit of flow is Million Liter per day (MLD) and thickness of arrows is proportional to its value. The boxes represent the Sewage treatment plants in the respective districts. The colour of flows and processes are distinct from each other to differentiate them easily.

From the figure, it can be seen that Kanpur, Allahabad and Varanasi are dominating in the case of sewage generation. Generation from Farrukhabad, Mirzapur and Unnao is not significant. The rate of sewage generation form Kanpur is 339.3 MLD and only 50.5% (that is 171.1 MLD) of it is treated before getting disposed off in river. Varanasi on other hand has a sewage generation of 187 MLD and about 75% of it is treated by the existing STPs (Figure 5.5). In other cities also, the STPs are incapable and insufficient to treat the sewage up to acceptable limits. The overall untreated sewage reaching Ganga River from six cities is 373.5 MLD.

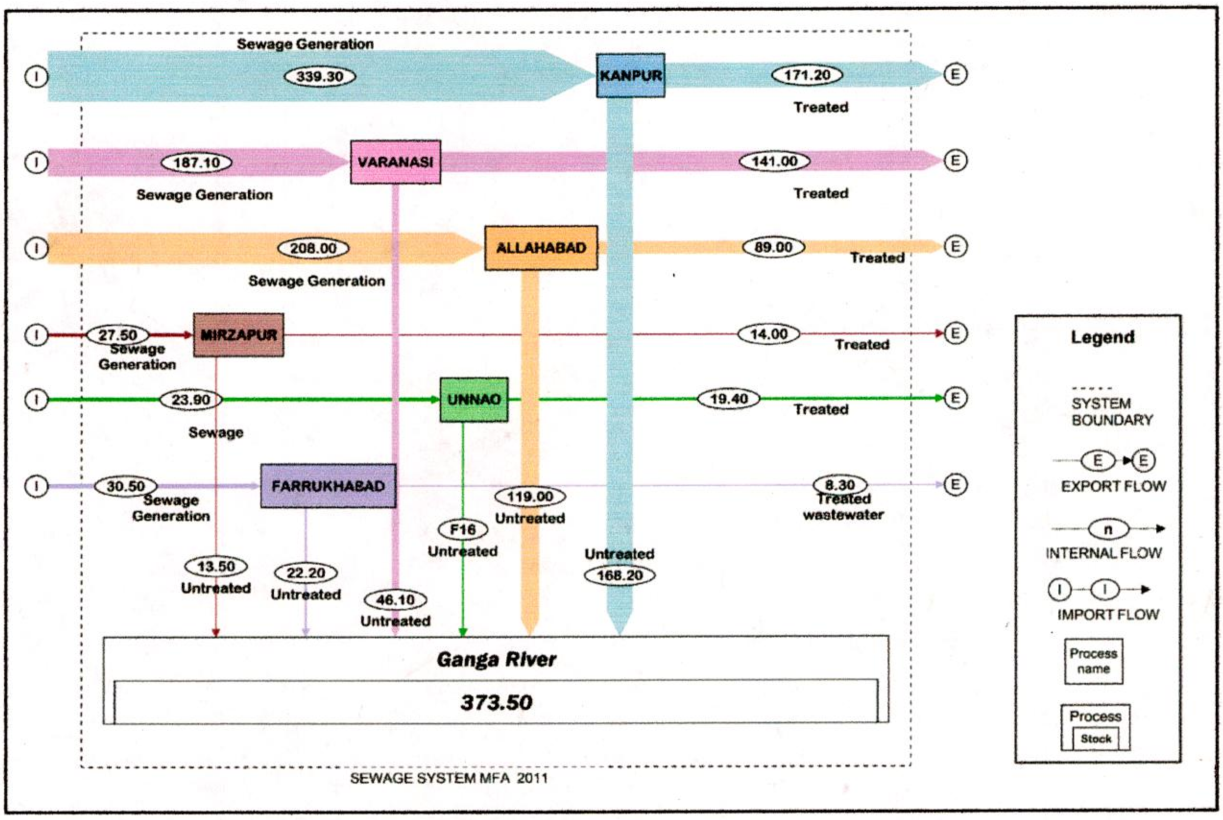


Figure 5.5: Results of MFA of Sewage Treatment Plants showing flow of generated, treated and untreated volume of sewage bv six districts in Uttar Pradesh. Flows are in MLD.

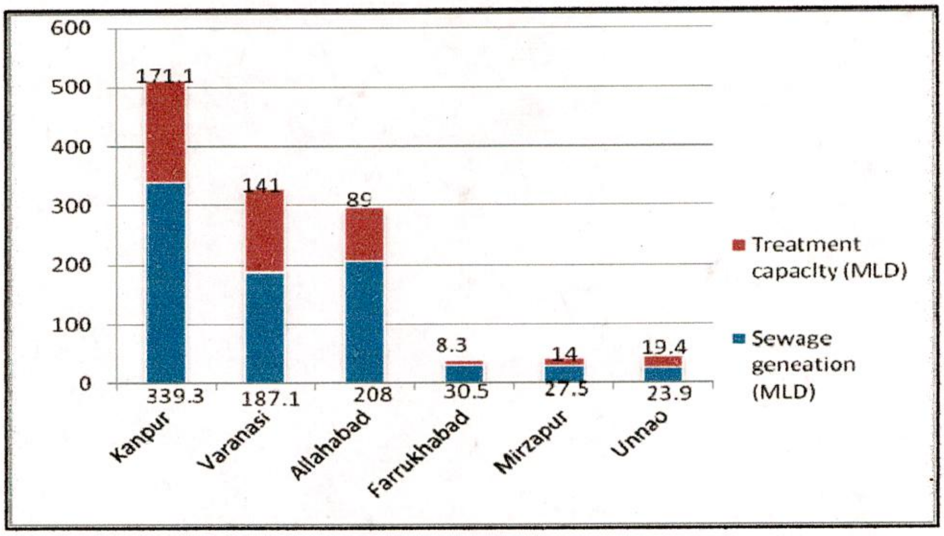


Figure 5.6: Graph showing relative sewage generation and treatment capacity of each city.

Figure 5.6 graphically explains the treatment capacity of functional STPs in the Class I cities installed during the Ganga Action Plan-I project. It illustrates the extent of sewage treatment capacity to total sewage production by each region. Only Varanasi and Unnao treatment plants are capable of treating more than 75% of total sewage generated.

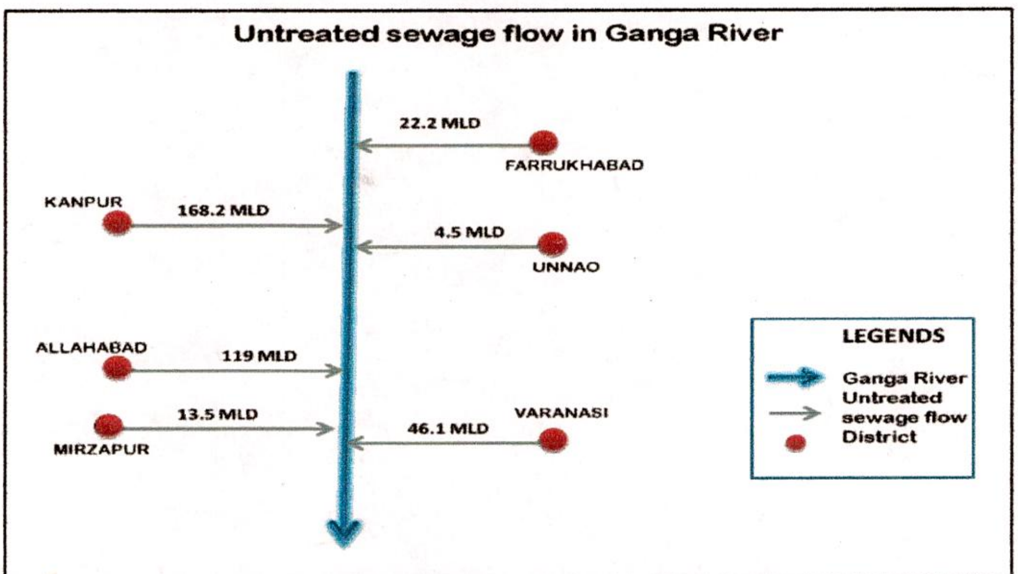


Figure 5.7: Line diagram showing volume of untreated sewage discharged in River Ganga.

The result in line diagram (Figure 5.7) displays the measure of untreated sewage load passing into the river stream from specific cities. With this, the given cities can be compared with each other in terms of sewage contribution to main river stream.

5.3 Drain

5.3.1 PCA results

The foremost need of using PCA was to lay a ground for comparing the compositional structure of wastewater selected from four riparian regions of the Ganga stream namely, Bijnor, Kanpur, Allahabad and Varanasi drains. Then, to understand which major factors are influencing the wastewater quality of those areas. PCA is performed on the raw dataset with 7 water quality parameters. The axis produced by PCA was rotated to generate a new set of factors consisting of subset of original water quality parameters called Principal components. Under the '**Descriptive**' heading, the table shows the calculation of mean, standard deviation, minimum, maximum and median values for each parameter of sewage water quality of Bijnor, Kanpur, Allahabad and Varanasi for the year 2011. Basic statistical values imparted to gain initial information about the wastewater quality data.

'Variances' table shows the extracted principal components and their initial variances or eigenvalues, proportion of variance they contribute and cumulative proportion. The '**Scree plot**' of variances for each principal component gives a better knowledge of major contributors. (Mishra and Tripathi, 2009) Major ones combined to give cumulative proportion greater than 0.75.To identify the significant principal components, which can give an adequate description of data set, an ad-hoc rule is followed. The rule says that the principal component with eigenvalue greater than **1.0** is significant. It is considered to carry more information than individual original variables.

In the **'PCA coefficient'**tablegave loadings that measures thedegree of closeness between variables and components. The highest value, either positive or negative shows highest contribution to that Principal component. The positive coefficient means "that the contribution of the variable increases with the increasing loading in a dimension; negative loading indicates a decrease" (Jayakumar and Siraz, 1997 cited in Mishra and Tripathi, 2009)

In the coefficient table of principal components, the absolute values near zero suggest that concerned parameter or variable contribute less to that principal component. The principal components with eigenvalue greater than **1.0**inVariances table, was subjected to varimax rotation to find out the Varimax Factors (VFs).The rotation function further reduced dimensionality of data to discover the most important new variables. Projecting the original variables on the subspace of PCs (that is the sum of square of coefficients for a component) produces alternate coefficient between PCs and variable, which is called '**factor loadings**'. These factor loading or coefficients are interpreted as correlation between original variables and principal component.

KANPUR-

The basic statistics information of data is presented in the descriptive data table given below (Table 5.3.1).

Table 5.3.1 : Descriptive Statistics

Variable	Mean	SD	Minimum	Median	Maximum
Flow	64.399	84.356	0.26	18.000	197.00
pH	7.796	0.621	7.16	7.510	8.81
BOD	457.91	999.80	39.0	120.50	2930.0
COD	1159.44	2559.04	43.0	222.50	7478.0
TSS	341.19	238.86	86.0	272.50	789.0
BOD Load	72137.1	191149.8	10	2309.5	544980
TDS	905.6	336.4	523	823.5	1540

To the available data set, (Table 4.3) PCA function was allowed to run for Kanpur area. Five principal components were yielded. A Scree plot was produced to give a visual feel of contribution by each component to total variance.

Out of five PCs extracted, first two PCs have eigenvalue greater than 1.0. These two eigenvalues explain for 76.8% of total cumulative variance in the water quality data set (table 5.3.1).

Table 5.3.2.: Variances

Component	Variance	Proportion	Cumulative proportion
1	3.671	0.524	0.524
2	1.707	0.244	0.768
3	0.934	0.133	0.902
4	0.414	0.059	0.961
5	0.273	0.039	1.000

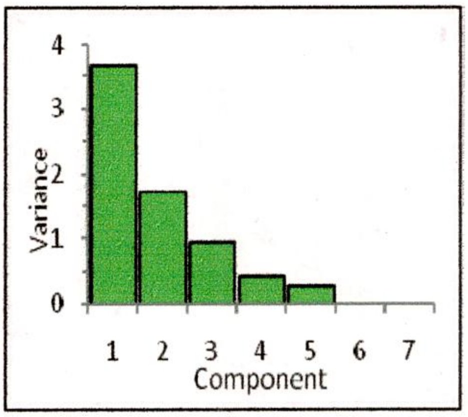


Figure 5.3.1: Scree plot

The principal component analysis resulted in two main principal components with eigenvalues up to 76.8% of total variances. The individual components, PC1 and PC2 explain 52.4% and 24.4% of total variances original observations.

Principal components 1 and 2 (PC1 and PC2) with eigenvalue greater than 1 were subjected to varimax rotation to give Varifactors (VF1 and VF2) (Nasir et al., 2011). VF1 (eigenvalue 3.67) accounts for 52.4% of total variability in data has strong loadings on BOD,COD and BOD load whereas moderate positive loading on Flow parameter.

The factor may be related to high concentration of organic matter in wastewater from municipal and industrial waste. The high flow of wastewater is coming from Sisamau Nala and Permiya Nala. Kanpur has more of urban settlement and has many tannery, lead, and textile industries. (Murphy, 2007).

Table 5.3.3 : PCA Coefficients

	Components						
	1	2	3	4	5	6	7
Flow	-0.417	0.269	-0.207	0.175	-0.823	0.035	-0.039
pH	0.054	-0.657	-0.187	0.727	-0.041	-0.018	-0.005
BOD	-0.503	-0.122	0.200	-0.023	0.186	-0.242	-0.774
COD	-0.503	-0.118	0.200	0.014	0.193	0.786	0.197
TSS	0.115	-0.648	0.236	-0.558	-0.446	0.039	-0.015
BOD Load	-0.506	-0.122	0.186	-0.029	0.111	-0.566	0.601
TDS	0.220	0.180	0.867	0.359	-0.195	-0.010	-0.002

Table 5.3.4 : Factor loadings - Orthogonal rotation (Varimax)

	Factors	
	1	2
Flow	0.504	0.330
pH	0.032	-0.528
BOD	0.985	0.012
COD	0.985	0.026
TSS	-0.013	-0.984
BOD Load	0.978	-0.001
TDS	-0.250	0.026

BIJNOR

The descriptive table (below) gives the mean and standard deviation value for the water quality of Bijnor drains.

Table 5.3.5 : Descriptive Statistics

Variable	Mean	SD	Minimum	Median	Maximum
pH	8.183	0.925	7.32	8.070	9.16
Flow	49.37	64.79	7.6	16.50	124.0
BOD	216.7	192.5	22	221.0	407
COD	64.3	62.7	5	58.0	130
TSS	130.7	34.2	99	126.0	167
BOD Load	762.0	388.1	358	796.0	1132
TDS	5547.77	9157.58	82.5	440.80	16120.0

Table 5.3.6: Variances			
Component	**Variance**	**Proportion**	**Cumulative proportion**
1	4.944	0.706	0.706
2	2.056	0.294	1.000
3	0.000	0.000	1.000

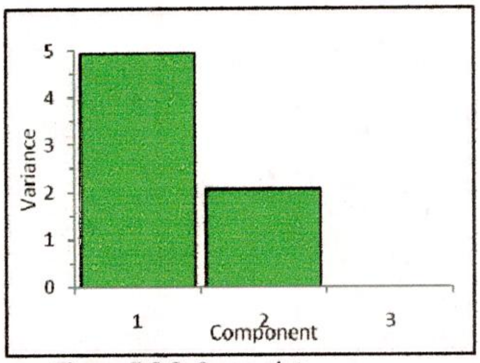


Figure 5.3.2: Scree plot

The PCA tool gave <u>two</u> significant principal components (Table 5.3.6). The Scree plot shows the contribution by each component to the total variance (Figure 5.3.2).

PC1 explained 70.6% of variation in original dataset while PC2 explained remaining 29.4% Factor analysis to find the main variables contributing to variance of principal component 1 and 2 carried out to get varifactors, VF1 and VF2. VF1 show strong factor loading from BOD, COD, FLOW, BOD Load, and TDS.

Due to high agricultural activity and sugar, pesticides and paper industries BOD and COD are higher. High volume flow is coming from Chhoiya Drain (124 MLD). Since flow and BOD are higher and BOD load is product of those two, the BOD load is also high. In addition, use of fertilizers and organic matter from industries and livestock increase the TDS loading.

Table 5.3.7 : PCA Coefficients			
	Component		
	1	**2**	**3**
Flow	0.377	-0.381	0.468
pH	-0.260	-0.569	-0.138
COD	0.449	0.023	-0.259
BOD	0.449	-0.051	-0.060
TSS	0.172	0.645	0.405
TDS	0.448	0.062	-0.629
BOD Load	0.397	-0.328	0.362

Table 5.3.8 : Factor loadings - Orthogonal rotation (Varimax)		
	Factor	
	1	2
Flow	0.984	0.173
pH	-0.210	0.977
COD	0.905	-0.424
BOD	0.945	-0.324
TSS	-0.013	-0.999
TDS	0.880	-0.474
BOD Load	0.996	0.086

ALLAHABAD

The descriptive statistics in the given table give the initial information about water quality data for 10 drains in Allahabad.

Table 5.3.9: Descriptive Statistics

Variable	Mean	SD	Minimum	Median	Maximum
Flow	29.35	19.15	7.0	25.00	65.0
pH	7.864	0.258	7.31	7.975	8.12
COD	273.54	415.11	17.3	104.90	1362.0
BOD	127.995	209.530	8.65	50.500	680.00
TSS	331.7	557.6	15	148.5	1858
TDS	1062.3	1436.6	284	657.5	5132
BOD Load	3594.3	6100.0	61	1203.5	20264

For the given dataset, 7 principal components were extracted. Out of them, first two components were significant with eigenvalues greater than one. The eigenvalue of PC1 is 4.928 and that of PC2 is 1.486 (Table 5.3.10). The Scree plot demonstrates the variance contribution by each component (Figure 5.3.3).

Table 5.3.10.: Variances

Component	Variance	Proportion	Cumulative proportion
1	4.928	0.704	0.704
2	1.486	0.212	0.916
3	0.489	0.070	0.986
4	0.091	0.013	0.999
5	0.003	0.000	1.000
6	0.003	0.000	1.000
7	0.000	0.000	1.000

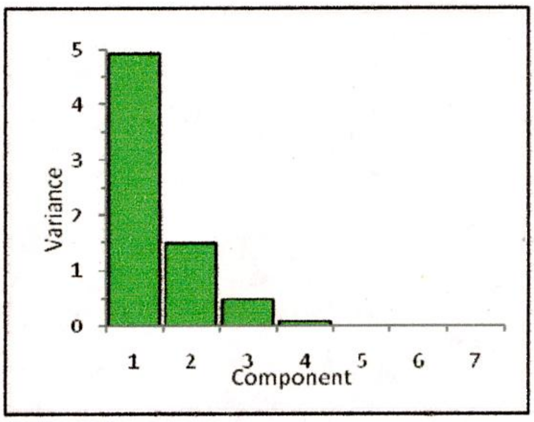


Figure 5.3.3: Scree plot

Factor loading were calculated for PC1 and PC2. PC1 accounts for 70.4% and PC2 for 21.2% of total variance. The factor loading for VF1 has strong influence due to COD, BOD, TSS, TDS, and BOD Load. The organic loadings from domestic, agriculture and livestock waste may be the sources of BOD, COD, and TSS levels. A considerable part of Allahabad is affected by salt deposition and use of fertilizers may be the reason of high TDS levels.

Table 5.3.11 : PCA Coefficients							
	Component						
	1	2	3	4	5	6	7
Flow	-0.018	-0.721	0.679	-0.020	0.071	0.109	0.028
pH	0.106	0.680	0.725	-0.007	0.018	-0.007	-0.013
COD	0.446	0.002	-0.083	-0.415	0.269	0.496	-0.551
BOD	0.447	-0.008	-0.040	-0.410	-0.287	0.197	0.714
TSS	0.449	-0.057	-0.031	0.023	0.662	-0.575	0.156
TDS	0.436	-0.012	-0.039	0.811	-0.017	0.378	0.079
BOD Load	0.445	-0.116	0.048	0.009	-0.633	-0.479	-0.394

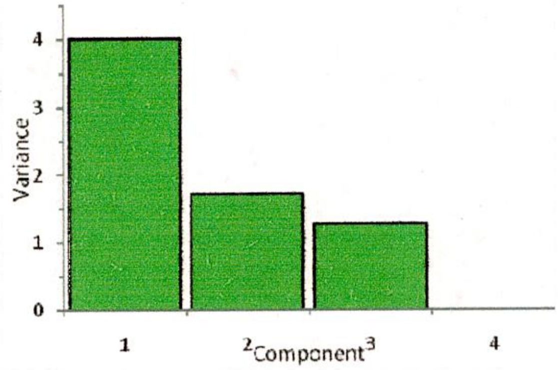
Table 5.3.12 : Factor loadings - Orthogonal rotation (Varimax)			
	Factor		
	1	2	3
Flow	-0.011	0.997	0.000
pH	-0.175	-0.501	0.016
COD	-0.990	-0.081	-0.101
BOD	-0.992	-0.055	-0.099
TSS	-0.998	-0.001	0.028
TDS	-0.962	-0.052	0.259
BOD Load	-0.994	0.088	0.025

VARANASI

The descriptive statistics table for four drains in Varanasi is given below for initial information.

Table 5.3.13: Descriptive Statistics					
Variable	Mean	SD	Minimum	Median	Maximum
Flow	102.698	136.345	16.19	45.050	304.50
pH	7.175	0.359	6.65	7.295	7.46
COD	111.55	49.78	46.2	122.00	156.0
BOD	41.03	20.83	12.4	45.30	61.1
TSS	183.220	167.542	81.80	108.640	433.80
TDS	579.60	104.44	454.0	580.40	703.6
BOD Load	2401.8	1755.8	808	2369.5	4060

Table 5.3.14.: Variances			
Component	**Variance**	**Proportion**	**Cumulative proportion**
1	4.018	0.574	0.574
2	1.723	0.246	0.820
3	1.259	0.180	1.000
4	0.000	0.000	1.000



In the above table, there are three significant principal components, which have variance greater than 1. The Scree plot shows their individual contribution to total variance. The eigenvalue of three components PC1, PC2, and PC3 are 4.018, 1.723 and 1.259 respectively.

PC1 and PC2 altogether accounts for 82% of total variance. Varimax rotation of these two components provided major contribution by each variable as shown in table 5.3.14. Varimax factor 1 (VF1) accounts for 57.4% of total variance has strong loading of BOD, COD, TSSand FLOW. VF2 (24.6) has strong factor loading of TDS and medium loading of pH.

Table 5.3 15 : PCA Coefficients				
	Component			
	1	2	3	4
Flow	0.978	-0.106	0.178	0.000
pH	0.418	0.899	0.130	0.000
COD	-0.896	0.053	0.441	0.000
BOD	-0.842	0.515	0.159	0.000
TSS	0.970	-0.222	0.097	0.000
TDS	-0.324	-0.675	0.663	0.000
BOD Load	0.573	0.361	0.736	0.000

The sources of high loading of BOD, COD may be urban domestic waster and effluents from wool, sugar, oil, and soft drink producing factories. Level TSS may be high because of salt affected lands, use of fertilizers and organic waste. High flow is due to Varun drain (304 MLD).

5.3.2 MFA results

Principal component analysis results, simulated flows and their relationship with land use pattern are consolidated to produce a simplified MFA model for the drains discharge system in Bijnor, Kanpur, Allahabad and Varanasi. The results were concluded on the basis of existing literature, statistics, personal understanding and discussions.

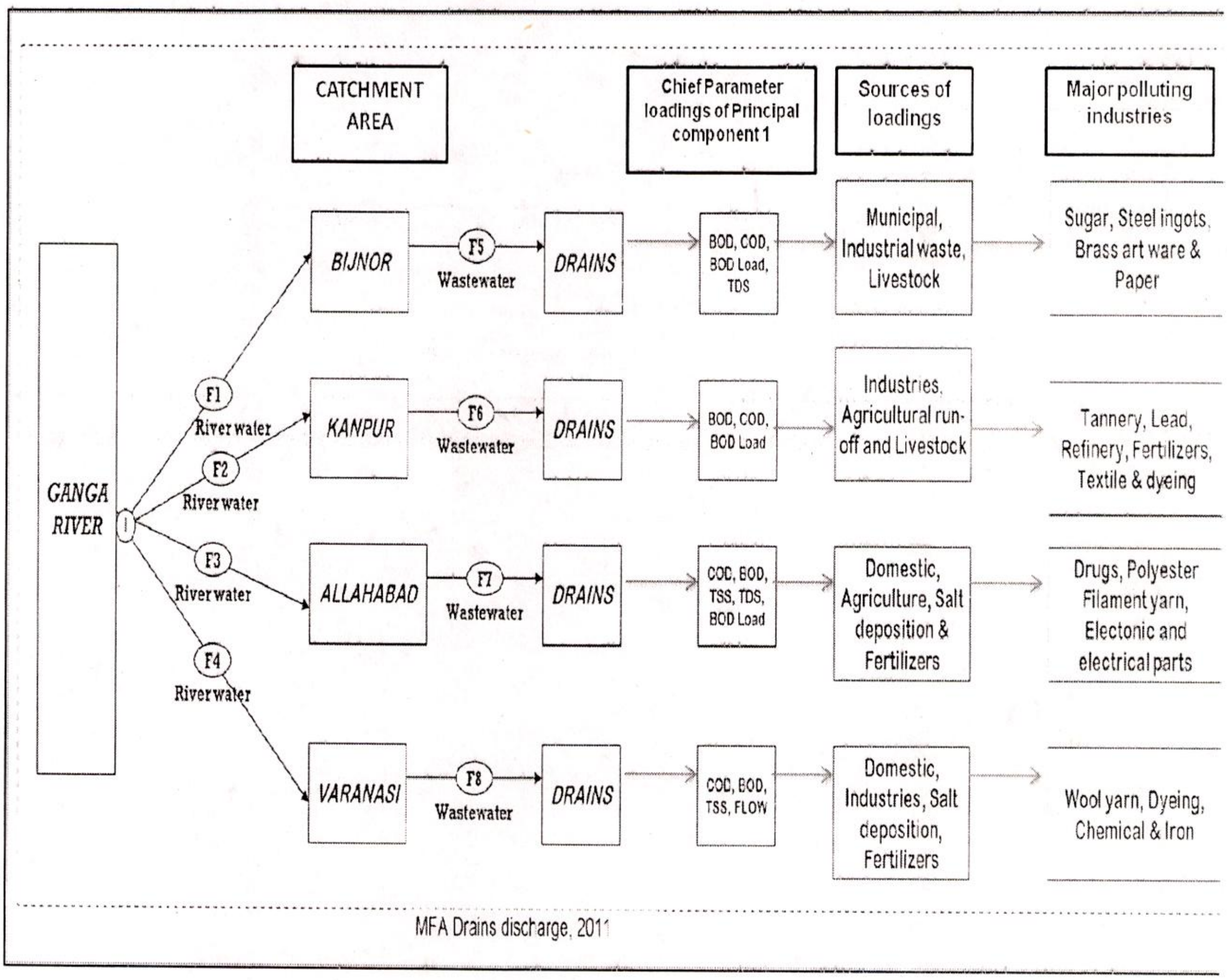


Figure 5.3.5 : MFA cum flowchart showing quality and causes of pollutants in wastewater discharge.

Bijnor has wastewater coming industrial and municipal waste due to presence of numerous sugar and brass art ware industries. Kanpur is one of the most industrialized and urbanized region and possess most hazardous industries in the state. Tannery and lead industries are the most frequent industries. Allahabad is more of an agricultural region and has few industries. So, maximum pollution load comes from domestic and agricultural activities. Varanasi is famous for wool yarn and it dyeing and has many industries. Also, the region has more urban settlement than rural, which results in huge amount of urban domestic wastes.

6. Conclusion

The uniqueness and significance of MFA method lies in its simplicity, integrated approach, cost effective technically limited approach, ability to involve many processes, and easy involvement and understand ability for stakeholders and government to acknowledge main sources of pollution. Even though it gives a stationary model but it can present the dynamic flows easily. STAN is easily exploited software to exhibit the flow of materials either simply or extensively using Sankey arrows. The best part of this diagram is that the largest flows of material can be pointed out quickly.

The study has introduced a systematic procedure to establish a material flow analysis model of Ganga basin in Uttar Pradesh. Initially, a conceptual MFA model was developed for the sub-basin including major processes and their interaction with the system. Later, the MFA system was quantified for Industry and sewage treatment plants and was illustrated using a line diagram. Finally, major sources of pollution were identified for the wastewater of drainage systems of four districts by running PCA though the basic water quality parameters. This helped to understand the quality of wastewater flowing into the Ganga River in Uttar Pradesh stretch from Bijnor to near Varanasi.

In year 2011, the status of wastewater production for Uttar Pradesh showed very high contribution by Sugar and Paper & Pulp industries viz. 31.86 and 25.32 percent of total waste water produced. This calls for urgent need of putting strict regulations on the amount of wastewater discharge by industries. Few of the industries are discharging very toxic substances in the river which has resulted in abolishment of river ecology.

The study of Sewage treatment plant systems of 6 Class-I cities concluded with full certainty that the amount of sewage generated and amount of it treated are very disproportionate. The volume of sewage discharged to river Ganga is much larger than the actual capacity of STPs to treat in the six cities. Thus, a planned project should be employed with least knowledge gaps about the actual scenario of sewage generation so that there will be less chances of failure.

Wastewater quality of several point sources in four districts of Uttar Pradesh helped to identify the main sources of polluting activities in these regions. In addition, category of industries were also mentioned which can easily enable the policy makers to detect which industries require immediate attention.

Hence, MFA can give a fair estimation of effects of each pollutant present in the river system, if a more detailed study is carried out with other water quality studies. It is beneficial to study both point and non-point sources of pollution and metabolism in any water resource and enhance the decision-making ability about which component of system needs attention and nourishment for a sustainable development in a region.

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