CONTINUOUS TURBIDITY MONITORING SYSTEM

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Degree of Master of Science

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Dissertation submitted in partial fulfillment of the requirements for the degree
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DECLARATION

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ABSTRACT

It is very important to measure the turbidity of raw water because the turbidity of treated water should be less than 5 NTU. In water treatment plants, three water samples per day are taken for turbidity testing. The main objective of this research is to propose on alternative continuous turbidity monitoring system instead of manual test.

Several experiments were alone to fine out a relationshipbetween colour difference and turbidity. Colour difference was measured and calculated by MATLAB program. Turbidity was measured by “HACH” turbidity meter. Thereafter best fitted curve was development by using E - views software.

After few verification experiments the project was implemented at the laboratory of the treatment plant at Kandana. Final implementations was done at Ingiriya Water Supply Scheme and according to the results arrange error percentage is below 4.14%

Accuracy of the proposed System can be further improved by fitting a better models and by increasing the population of sample data set.

DEDICATION

I dedicate my dissertation work to both my parents. My Father late Mr.Lionel Kuruppu did not only raise and nurture me but also taxed himself dearly over the years for my education and intellectual development. Also motherly care and support of my mother Mrs.Nanda Kuruppu, have been shown in incredible ways recently.

ACKNOWLEDGEMENT

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Without the help and support given by Mr.Shehan Fernando, Lecturer, KDA, I would not have been to able to complete this research project in time and I am very thankful to him for his support.

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Love and affection to my mother Nanda Kuruppu, my wife Manjula Kurppu and my daughter Thisari & Senali for their patience and understanding.

Lastly, I should thank many individuals, friends and colleagues who have not been mentioned here personally in making this educational process a success. May be I could not have made it without your support.

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LIST OF ABBREVIATIONS

NTU - Nephelometric Turbidity Units.

TSS - Total Suspended Solids.

MSE - Mean Square Error

LED - Light Emitting Diode

MGD - Million Gallons per Day

SSC - Suspended – Sediment Concentration

HD - High Density

CRT - Cathode Ray Tube

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Water Treatment.

The water that is found in rivers and reservoirs are usually not suitable for drinking. The rivers and reservoirs are polluted by the activities of men and animals. The effluents of the industries situated along the water source, domestic wastes, storm water and sewage all enter the water source through a system of drains water ways.

The removal of contaminants from untreated water to produce drinking water is known as “Water Treatment” or “Purification”. World Health Organization(WHO) guidelines are generally followed throughout the treatment process. Water treatment costs fifteen to twenty five rupees per cubic meter. The water treatment process consists of five major sub processors. They are Aeration, Addition of Chemicals, Sedimentation, Filtration and Disinfection [3,4].

- Introducing oxygen into water is called aeration. Removal of dissolved iron and manganese, removal of gases can be done by aeration. Aeration is also an effective method of bacteria control.

- Process of addition of chemicals is also called a process of coagulation and flocculation. Lime and alum are the chemicals used in water treatment. When chemicals are added to water it reacts with soil and clay particles, microorganism and other substances. This is called coagulation. These particles associate with similar particles to form big flocks. The process is called flocculation. The flocks when it is heavy sink to the bottom. The result is clear water at the top [4].

- The third step sedimentation is a treatment process in which the velocity of the water is lowered, particles settle out of the water due to gravity. However, sedimentation may not be necessary in low turbidity water less than 10 NTU. In this case, coagulation and flocculation are used to produce very small flocks which are removed from the water in the filters.

- The next step is filtration and its purpose is to remove suspended particles from water by passing the water through sand. As the water passes through the filter, flocs and impurities get stuck in the sand and the clean water goes through. Filters must reduce turbidity to less than 0.5 NTU.

- Disinfection is the last step. This is also called as clorination as it uses chlorine gas to disinfect water. Chlorine is a strong oxidizing agent and it destroys pathogens –

that are diseases causing organisms like Bacteria remaining in the water. After disinfection water is supplied to the customers [4].

1.2 Turbidity of water.

Turbidity is the amount of cloudiness in the water caused by individual particles. This can vary from a river full of mud and silt where it would be impossible to see through the water (high turbidity), to a spring water which appears to be completely clear (low turbidity).Turbidity can be caused by:

- Silt, sand and mud.
- Bacteria and other germs.
- Chemical precipitates.

The measurement of turbidity is a key test of water quality. Turbidity of water is measured in nephelometric turbidity units (NTU).The instrument used for measuring is called nephelometer or turbidimeter. According to the "WHO" regulations turbidity of treated water should not be more than 5NTU, and should ideally be below 1 NTU, [1]. Water treatment plants remove turbidity with a combination of sand filtration, settling tanks and clarifiers.

It is very important to measure the turbidity of raw water, as this raw water supply undergoes some type of water treatment which can be affected by turbidity. Also Alum and Lime dosage will have to be changed, according to the turbidity level of raw water.

Absolute turbidity can be defined as the fractional decrease of incident "manometric" light intensity, due to scattering in travelling 1cm of fluid.

1.3 Measurement.

In water treatment plants turbidity of raw water is measured by digital turbidity meter. This instrument is commonly known as "HACH" meter.

Turbidity in lakes, reservoirs, channels and the ocean can be measured using a secchi disk. This black and white disk is lowered into the water until it can no longer be seen; the depth (secchidepth) is then recorded as a measure of the transparency of the water. This provides an estimation of the turbidity level in the lake.However this cannot be used in shallow wells where the disk can still be seen on the bottom.

Another device, which may help measuring turbidity in shallow waters, is the turbidity tube.The device cannot be used to measure very low turbidities (usual minimum is 5 NTU) and also the accuracy is very low [19, 22, 24].

1.4 Problem Background

All above turbidity measuring devices need water samples to give turbidity measurements. In the water treatment plants, normally three water samples per day are taken for turbidity testing (time interval is 8hrs).In the rainy season they take 5 water samples per day. (Time interval is 5hrs).

According to the turbidity measurements, Alum (Al_2 SO_4) and Lime {$Ca(OH)_3$} dosage is changed by the plant operator. Since the sampling period is nearly5-8 hrs, time between two adjacent chemical dosage adjustments is also 5-8hrs.Sometimes turbidity is changing suddenly due to following reasons

- Raining in the upstream area or catchment area.
- Human activities such as mining and commercial construction near the river
- Animal behaviors

But the shift officer in the treatment plant comes to know the turbidity change after several hours. (from the next turbidity test). Only after turbidity change is known he can change the chemical dosage.

1.5Research Objective.

The main objective of this research is to propose an alternative continuous turbidity monitoring system instead of manual test. It is real time monitoring system, which can display the turbidity measurement in 5minutes intervals on a monitor of a computer. Other objectives of the project are:

- To minimize chemical usage and hence minimize the cost.
- To prevent filter blocking due to high turbidity.
- To meet water quality targets
- Dated storage throughout the year.

1.6Organization of Dissertation

This report consists of six chapters. The first chapter discusses the background of the study, shape of the problem and goals which are going to achieve. The second chapter is a technical review. The third chapter describes about the research and methodology.

CHAPTER 2

LITERATURE REVIEW

This chapter presents literature a continuous turbidity monitoring systems in water treatment plants, rivers and water distribution systems. Several journal articles, thesis reports and implemented projects are found and some of them are described as follows.

2.1 Continuous turbidity monitoring in streams of North Western California.

Redwood science laboratory, a field office of the USDA Forest service, Pacific South West Research station, California has developed and refined methods, and instrumentation to monitor turbidity in streams of northern California since 1996. They operate 21 stations and they have provided assistance in the installation another 6 stations [6].

According to their report, these installations employ a method called Turbidity Threshold Sampling (TTS), an automated data collection and sampling system in which a data logger employs real – time turbidity. They have properly installed several turbidity sensors at different places with a reliable wiper.

They have fixed all sensors in a fabricated housing because sensor is not accessible at high flows. The velocity inside the housing was restricted by this design, especially when the screen was clogged. Articulating booms have been designed to keep the sensor out of the bed load zone but adequately submerged at all flows.

They have recorded the median of 60 values taken at 0.5 s intervals. Drawbacks of the system are described as follows:

- When high turbulence occurs sensor reading is very poor.
- Near the sensor, flow velocity should be restricted.
- According to the light intensity, the turbidity measurement is changing.

2.2Continuous Turbidity Monitoring and Regression Analysis to Estimate Total Suspended solids Fecol Coliform Bacteria Loads in Real Time.

In the research article by Victoria G. Christenson, Andrew C. Ziegler and XiaodongJian [7]; was discussed a methodology to obtain timely and continuous

water quality information for several Kansas streams. They have proposed on innovative, continuous, real time monitoring approach instead of manual sample collection system because manually collected samples do not provided continuous data, constituent loads during peak flows ware missed, this procedure took time and when human health is concern, immediate information is necessary. Continuous recorded data and data from periodic collection ofwater quality samples have been used to develop relations between turbidity and constituents of concern. Regression equations have been developed to estimate turbidity and fecal coliform bacteria.

They have focused to two gaging stations namely Halstead gaging station and Sedgwick gauging station. The range in turbidity valves used to develop the equation for the Halstead gaging station was 4.69 to 1150 NTU. The final liner regression equation for Halstead is

$$\log10(TSS) = 0.920\log10(Turb) + 0.243 \quad (2.1)$$

The mean square error (MSE) for the equation is 0.193, and the coefficient of determination (R^2) is 0.911

The equation for Sedgwick is

$$\log10(TSS) = 0.878\log10(Turb) + 0.300 \quad (2.2)$$

The MSE for the Sedgwick equation is 0.209 and R^2 is 0.889

A“MicroTol”[7]; continuous monitoring turbidity meter was used by them. Main features of the “MicroTol” turbidity meter include fast and easy calibration, verification in seconds, low maintenance and turbidity reading range: 0 – 1000 NTU, bubble rejection system and optional automatic continuous ultrasonic optical clearing system.

2.3 Turbidity Measurement: A simple effective indicator of water qualitychange.

In the research article by Mike Sador [10]; it was discussed about the common turbidity meter designing criteria. According to the article, common turbiditymeters involve a light source and one or more detectors with a specific orientation to one another. The vast number of turbidity monitoring technologies can be categorized by three design criteria – the type of incident light source that is used, the detection angle for the scattered light, and the number of scattered or attenuated light detectors used. There are three types of light sources used commonly in turbidity meters: incandescent, LED and laser.

- Incandescent light source are typically polychromic with tungsten filaments with a colour temperature of 2200 K to 3000 K and emit relatively short wavelengths. These shorter wave lengths will be more effectively scattered by smaller particles.

- LED light sources are lower energy emitting light sources when compared to tungsten filament lamps. The most common wavelengths used in turbidity measurements emit 830 – 890nm that is typically not absorbed by visible colour in the sample.

- Laser – based light sources. A small portion of turbidity measurement techniques will have laser – based incident light sources that emit energy at a discrete wavelength. Laser – based light sources are very sensitive to small changes in turbidity and are often used to monitor filtration performance for clean water.

  The detection angle is the angle formed between the center line of the incident light beam and the center line of the detector's received angle.

- A 90^{o} detection angle is often referred to as the nephelometric detection angle and is the most common detection angle because of its sensitivity to a broad range of particle sizes [10].

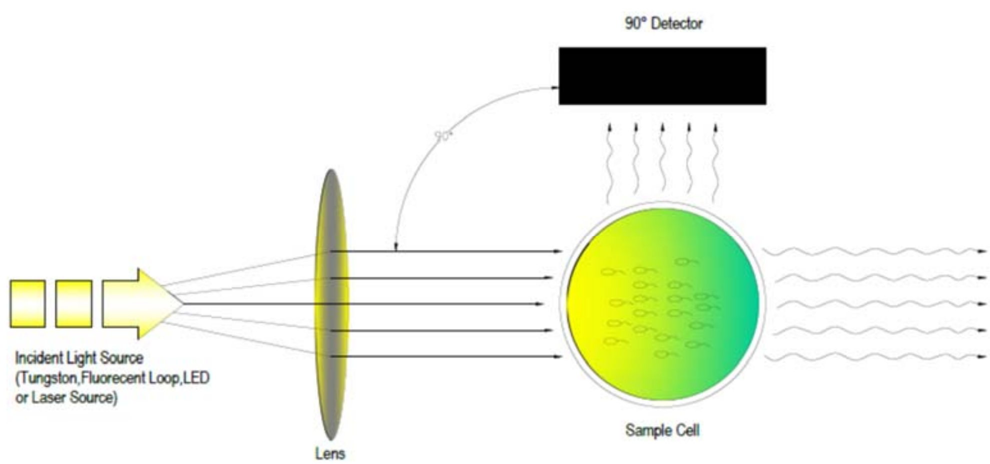

Figure 2.1: 90^{o} detection angle.

- The attenuated detection angle is geometrically oriented at an angle that is 180^{o} relative to the incident light beam. This detection angle measures the attenuation of the incident light beam.

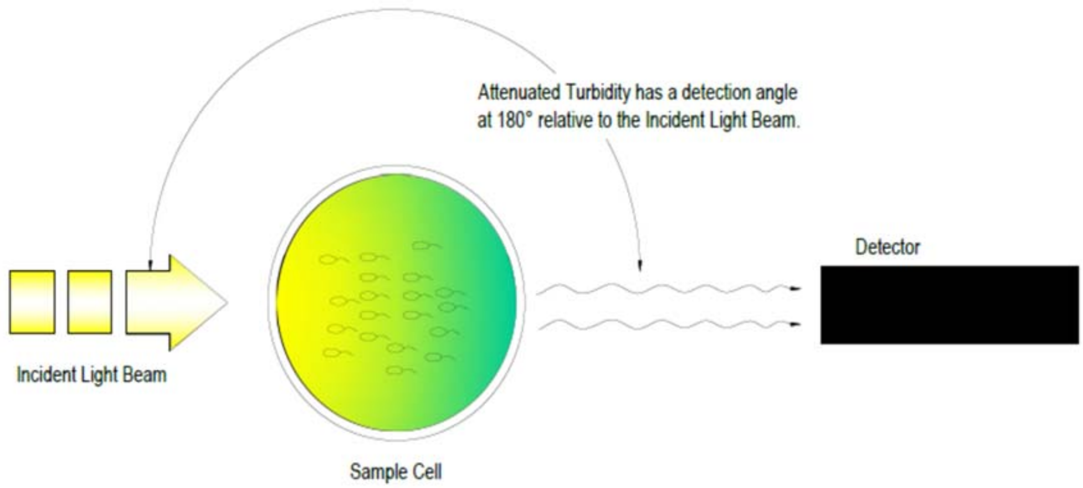

Figure 2.2: The attenuated detection angle.

- The backscatter detection angle has a detector that is geometrically centered at an angle of between 0 and 45 degrees relative to the directional centerline of the incident light source, which is characteristic with extremely high turbidity samples [10].

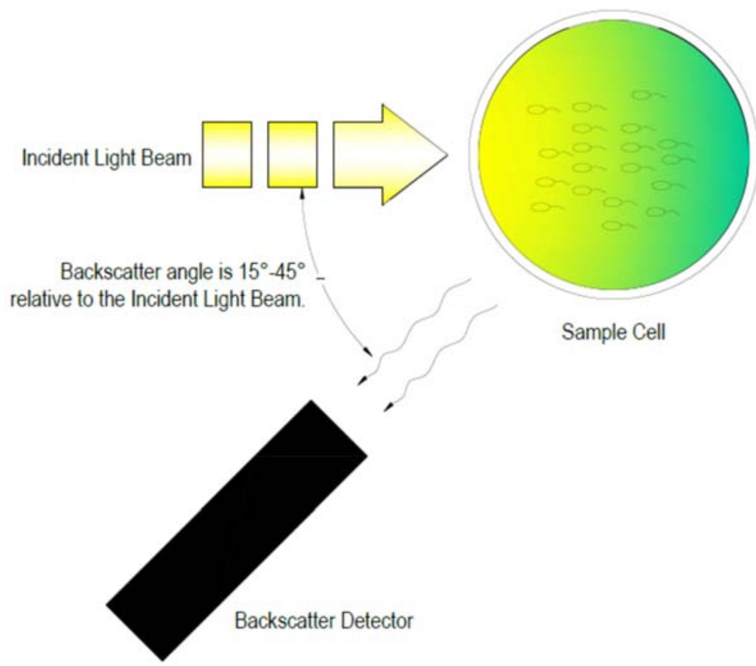

Figure 2.3: The back scatter detector.

Some turbidity measurement technology involves the use of signal ratios of two or more detectors to determine the turbidity value. One detector is at 90^0 from the incident source and the other detector(s) can be at any of several different angles.

2.4 Continuous monitoring of suspended sediment in rivers by use of optical sensors.

In the research article by Mr. David H.Schoellhamer, U.S.Geological Survey, Senaramento [9];, California it was discussed about to measure turbidity and suspended-sediment concentration(SSC) by using optical sensors,[23]. He pointed-out that how to provide automated continuous time series of suspended-sediment concentration of the discharge in rivers by using optical sensors.

He compared conventional water sampling method with optical sensors and stated that optical sensors have the primary advantage of ability to provide automated continuous time series of SSC.

Optical sensors transmit a pulse of infrared light through an optical window. The light is scattered or reflected, by particles in front of the window to a distance of about 4 to 8 inches at angles up to 165^0. Some of this scattered, or reflected, light is returned to the optical window. Where a receiver converts the backscattered light to a voltage output. The voltage output is proportional to SSC if the particle size and optical properties of the sediment remain fairly constant. Calibration of the sensor output voltage to SSC will vary according to the size and optical properties of the suspended sediment.

Two sensors were installed in two rivers and the following results were observered. Particle size effects on optical sensors were not seen in the sancramen River at Freeport, but were present in the Colorado River at Cisco. Optical sensor measurements of Freeport river were continuously collected in every 15 minutes. The collected measurements were analyzed for SSC. The linear equation for SSC as a function of sensor output was determined using the repeated median method. The sensor cleaned in every 1-2 months.

As a summary he stated that, optical sensor,[23]; calibration was satisfactory at Freeport but not at Cisco. Measurements of optical sensors depend on local conditions, and the particle size variations [9].

CHAPTER 3

RESERCH AND METHODOLOGY

3.1Selection of a Suitable Place

Kethena Water treatment plant is situated at 12km away from Kalutara. Intake pump house is situated at 1/2 km away from the treatment plant and takes water from the Kaluganga. Kaluganga is starting from mountain Samanala and flowing through Rathnapura area. Turbidity variation of Kaluganga is very high and turbidity changes within a short period, because of some human activities and recently raining in the upstream area.

Therefore Kalutara-Kethena Water treatment plant is selected for this research and following are the basic information of Kethena treatment plant.

- Regional Support Centre :Western – South
- Region :Kalutara
- Year of Commissioned :1980
- Water Source :Kalu Ganga
- Capacity of the plant :7.5MGD
- Location:12km away from the KalutaraTown, towards the upstream of the river.
- Filters :Slow sand Filters
- Serving area:Kalutara, Wadduwa, Payagala,Maggona,Beruwala&Dharga Town.

3.2 Water Treatment Operation.

The treatment plant gets its water supply from Kaluganga. Water treatment involves Physical, Chemical and biological processes that transform raw water into drinking water. Aeration, Addition of Chemicals, Sedimentation, filtration and disinfection are the major steps. In the aeration process air (oxygen) is introduced to water. By this means, the taste, colour and odour causing substances and gases are removed. Then chemicals (Alum – $Al_2 (SO_4)_3.14H_2O$, Lime-$Ca(OH)_2$) are added to the raw water. Then chemicals react soil and clay particles, microorganisms and other suspended solids. This is called coagulation. These particles associate with similar particles to form big flocs. This process is called flocculation. The flocs when it is heavy sink to the bottom. The result is clear water at the top. Then the sedimentation process is carried-out. The flocs as stated above are formed in large sedimentation tanks. Then water passes to the pre-treaters. Clear water is found at the surface of the tanks. Top layer water is then sent to the sand filters through open channels. Suspended solids and microorganisms are removed by the filtration process. After filtration, chlorination process is carried out. Chlorine is a strong oxidizing agent and it destroys pathogens. Finally water is collected in treated water tanks and pumped to desired overhead tanks by high lift pumps.

3.3Designof the measuring system.

Measuring apparatus is illustrated in the figure 3.2. Exiting pipe line from the raw water pumping main (from Kethena intake pump house to the treatment plant) was used to take raw water to the measurement apparatus. End of this pipe line is at the laboratory of the treatment plant. Pressure reducing valve is already installed to this pipe line because the pressure of the raw water pumping main is 3.5 bar. Through the pressure reducing valve pressure at the lab end was reduced to 1 bar. Size of the pipe line is ½ inch. This pipe line was used by the Lab Assistant to take water samples for checking turbidity and other parameters.

The sampling water line was fixed to a large container to prevent turbulence flow in the glass tank. Finally this large container was fixed to a glass tank. Glass tank was fabricated out of 1/4" glass sheet. Size of the glass tank is 8"x 6"x6".

3.3.1 Selecting a light source.

Colour rendering index is a rating of a light sources ability to reproduce a day light source. Rating is between 0 to 100.

Colour Temperature is a rating of a light sources colour output. It is based on the Kelvin scale in which 0^0 is at Absolute zero (-273^0C).The lower the colour temperature of the light source, the redder the source will be. Inversely, the higher the colour temperature of the source, the bluer it will be. There are three common types of daylight colour sources. Those are D75 (7500K), D65 (6500K) and D50 (5000K)[18].

- D75 (7500k) - A bluish coloured light source originally used for grading cotton and other evaluation applications. It has been replaced by D65 as the standard source for these applications. It is derived from the light coming in a north facing window at noon throughout the year. It is commonly called "North Sky Daylight"

- D65 (6500k) – A light bluish coloured light source used in colour matching applications of paints, plastics, textile and other manufactured products. It is the only day light source that was actually measured. The other daylight sources (D75 and D50) were mathematically derived from these measurements. Commonly used as a primary light source in colour measurement instrumentation. It is derived from the overage measurements, made of light coming in the north facing window.

- D50 (500K) - Anear white light source used in the evaluation of graphic art and imaging applications. It has similar amounts of red, green and blue energy. This light source is used when viewing press sheets and original images.

Out of the above three daylight sources, D65 light source was selected because D65 light source is more appropriate to use in colour matching applications. One number of 40W, fluorescent light was fixed to the top of the box, which was used to cover the glass tank.

3.3.2 Selecting a camera

A web cam with USB 2.0 interface was fixed at the middle of the 8” x 6” side of the glass tank.

3.3.3 Glass tank

The glass tank is fully covered to prevent entering external light.A paper with half black and half white was pasted on the outside surface of the glass wall which is in front of the camera (background of the image)

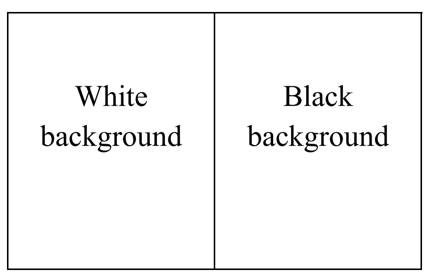

Figure 3.1: Background of the image

An overflow pipe was fixed to maintain the flow level of the glass tank.

3.4 Digital Turbidity Meter

Turbidity of water samples were measured by using a digital turbidity meter. It is a portable battery powered small meter. In water board laboratories "HACH",[19]; branded turbidity meters were used.

Figure 3.2: "HACH" brand digital Turbidity Meter

A digital turbidity meter contains few plastic bottles. To measure the turbidity it is necessary to fill one bottle with water and put it into the machine. Close the cover and press the read button. After few seconds the turbidity value will show in the LCD display. The bottle must be cleaned with distilled water before take another reading. It is recommended to check three samples and get the average value for better results.

3.5 Methodology of the proposed system

Several experiments were done and found a set of data of Turbidity (Measurements were taken by the Turbidity meter) and the colour differences. Colour difference was measured and calculated by a Matlab program[13,14].

Measured data were plotted in a graph and best fitted curve was selected by using the E-views program. Best fit model deciding factors were skewness, kurtosis and regression values ($R^{2)}$. Also residual plot of the fitness of each model was used to decide the best fitted curve.

Best fitted curve was checked by several water samples taken from the river. Turbidity of water samples were measured by the new system and simultaneously turbidity was measured by the digital turbidity meter. Then two measurements were compared by plotting them in the best fit model graph.

By using the best fit curve, an implementation was done at the Kandana water treatment plant. Final results were obtained.

CHAPTER 4

COLOUR SPACES AND IMAGE PROCESSING

4.1 Colour

Colour is a visual, perceptual property of human beings. Colour derives from the spectrum of light interacting in the eye with light sensitive cells. In our environment, materials are coloured depending on the wavelengths of light they reflect or transmit. The visible colour spectrum starts from red to blue wavelengths, approximately 360nm – 720nm. Three things are necessary to see colour,[15]:

- Alight source
- An object
- An observer / processor

4.2 MatchingColours

Each person verbally describes and defines an object's colour differently. Colour and colour comparisons of each person's perceptions and interpretations are highly subjective. Eye fatigue, age and other physiological factors can influence the colour perception. But even without such physical considerations, each observer interprets colour based on their personal perspective, feelings, beliefs and desires.

The solution to this problem is an instrument that identifies a colour by measuring it and comparing the colour to standards. That is, an instrument that differenciates a colour from all others and assigns it a numeric value.

Today, colorimeters, spectrophotometers and spectrophotometric colorimeters are the most commonly used instruments for measuring colour worldwide. These technologies measure the proportion of reflected or transmitted light at many points on the visual spectrum. The points can be plotted graphically to form a spectral curve. The spectral curve of each colour is unique. The curve is an excellent tool in identifying, specifying and matching colours,[11,18].

4.3 Colour Spaces

A colour space is a method by which we can specify create and visualize a colour. Humans are defining colours by its attributes of brightness, hue and colourfulness. A computer may describe a colour using the amount of red, green and blue. Aprinting press may produce a specific colour in terms of the reflectance and absorbance of cyan, majenta, yellow and black inks on the printing paper.

A colour is thus usually specified using three co-ordinates or parameters. These parameters describe the position of the colour within the colour space being used. Different colour spaces are used for different applications. Some colour spaces are perceptually linear. Many colour spaces, particularly in computer graphics are not linear. Some colour spaces are very easy to use. User can easily navigate within them and creating desired colours are relatively easy. Some colour spaces are confusing to user.

Some colour spaces are devise dependent and some are devise independent. A device dependent colour space is a colour space where the colour produced depends both parameters used and on the equipment used for display. For an example, brightness and contrast settings on the CRT. On the CRT display colours vary. A device independent colour space is one where a set of parameters will produce the same colour on whatever equipment theyare used,[15].

4.3.1 RGB Colour Spac

An RGB colour space is any additive colour space based on the RGB colour model. A particular RGB colour space is defined by the three chromatities of the red, green and blue additive primaries. sRGB is most commonly used RGB colour space.

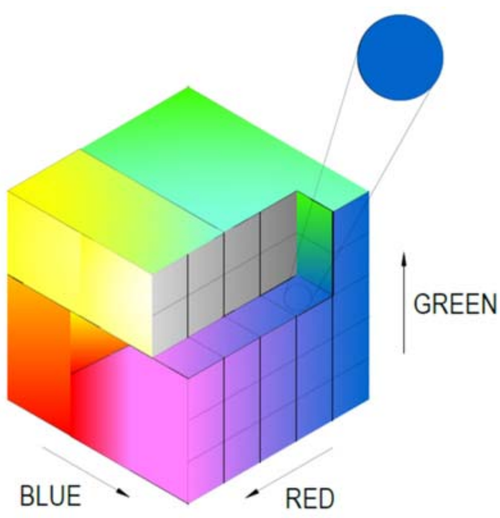

Figure 4.1 : RGB Colour Space

RGB is a convenient colour model for computer graphics because the human visual system works very similar to RGB colour space. RGB colour space is used particularly in consumer grade digital cameras, HD video cameras, and computer monitors. RGB colour space is used mostly in consumer applications. If all devices use the same convenient colour space, then the image does not need to be converted from one colour space to another colour space. But the actual situation is not so. Different devices are used different colour spaces.

Since RGB is the colour space produced on a CRT display when pixel values are applied to a graphics card. RGB space is visualized as a cube with three axes are red, green and blue. The bottom corner, when red=green=blue=0 is black, opposite top corner, where red=green=blue=255 is white, [15,18].

4.3.2 Commission Internationale de I'Eclairage(CIE) based colour spaces

In 1931, the commission Internationale de I'Eclairage (CIE) established standards for colour representation based on the physiological perception of light.They are built on a set of three colour matching functions related to the red, green and blue cones in the eye.

There are two CIE based colour spaces. Those are CIELur and CIELab colour space. They are nearly linear with visual perception, and they are very close to each other. Since they are based on the CIE system of colour measurements, which is itself based on human vision. CIELur and CIELab are device independent. To make them more user friendly, the CEI defined two analogues spaces – CIELhs and CIELhc where h stands for hue, s for saturation and c for chroma.CIELur useful in applications using CRTdisplays. CIELab colour space has no associated two dimentional chromaticity diagram and no correlate of saturation,[15].

4.3.3 Hue, saturation, Luminance (HSL) Type Colour Spaces

The two representations rearrange the geometry of RGB in an attempt to be more intuitive and perceptually relevant than the cartesian (cube) representation, by mapping the values into a cylinder loosely inspired by a traditional color wheel. The angle around the central vertical axis corresponds to "hue" and the distance from the axis corresponds to "saturation". These first two values give the two schemes the 'H' and 'S' in their names. The height corresponds to a third value, the system's representation of the perceived luminance in relation to the saturation,[15].

This is the most natural way of human describing colours. Human brain tends to organize colours by hue, saturation and brightness. This is the mind's representation.

- Hue : Hue is the attribute which tells us whether the colour is red, green, yellow, blue…..
- Saturation : Saturation is the level of non-whiteness. Saturated colours are very pure and vivid. An extremely saturated colour has only one spectral component while an unsaturated colour white is added. Sometimes this attribute is called chroma.
- Luminance / Brightness : Luminance / Brightness is a measure of the intensity of light. Sometimes this attribute is called as intensity.

Phenominal colour spaces are deformations of the RGB colour space. They are usually a linear transformations of the RGB space.

4.3.4 Commission Internationale de I'Eclairage(CIE) XYZ Colour Space

The CIE XYZ colour space was derived from a series of experiments done in the late 1920s by William David Wright and John Guild. Their experimental results were combine into the specification of the CIE RGB colour space, from which the CIE XYZ colour space was derived,[15,18].

4.3.5Commission Internationale de I'Eclairage or International Commission on Illumination (CIE) L*a*b Colour Space

Colour space defined by CIE based on one channel for Luminance (Lightness-L) and two colour channels (a and b). One problem with the XYZ colour system, is that colorimetric distances between the individual colours do not correspond to perceived colour distances. The CIE solved this problem in 1976 with the development of the three-dimentionalCIELab colour space.

In this model colour differences which perceive correspond to distance when measured cholorimetrically. The a-axis extends for green(-a) to red (+a) and the b-axis from blue (-b) to yellow (+b). The brightness (L) increases from the bottom to the top of the three dimensional model,[15].

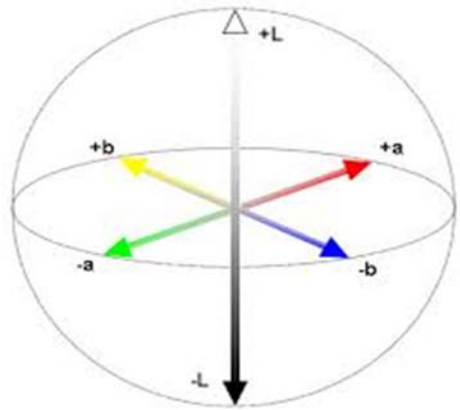

Figure 4.2: CIELab Colour Space

This colour space is more suitable for many digital image manipulations than the RGB space,which is typically used in image editing programs. The CIELab colour space is useful for sharpening images.

4.4 Transformations between colour spaces

Most common tasks in image processing are to alter colour of an image and to find colour distance from a reference image. There will be correlations between different colour spaces.

4.4.1 Transformation between XYZ plane and LMS plane

LMS is a colour space represented by the response of the three types of cones of the human eye, named after their responsivity (sensitivity) at long, medium and short wavelengths.

Conversion of device independent XYZ space to LMS space can be done by using followings conversions,[18].

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 0.3897 & 0.6890 & -0.0787 \\ -0.2298 & 1.1834 & 0.0464 \\ 0.0000 & 0.0000 & 1.0000 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

4.4.2 Transformation between RGB colour space to XYZ space

The process of transferring coordinate value in RGB colour space to corresponding values in XYZ colour space involves three linear Equations. In following equations, primaries of the RGB colour space are called R,G and B. Primaries of the XYZ colour space are X,Y and Z.

Transformation equations are :

$$X = m_{11}R + m_{12}G + m_{13}B \quad (4.1)$$

$$Y = m_{21}R + m_{22}G + m_{23}B \quad (4.2)$$

$$Z = m_{31}R + m_{32}G + m_{33}B \quad (4.3)$$

Above equations can be written in the matrix form where the nine coefficients (constants), m, define the transformation,[18].

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{b11} \begin{bmatrix} b11 & b12 & b13 \\ b21 & b22 & b23 \\ b31 & b23 & b33 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (4.4)$$

Actual coefficient values for transforming "RGB" to "XYZ" can be written in matrix form:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{0.17697} \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00 & 0.01 & 0.99 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (4.5)$$

4.4.3 Transformation between XYZ colour space to CIELab colour space

This is based direcly on CIE XYZ (1931). It is non-linear.and the conversions are still reversible. The non-linear relationships for L,a and b are the same as for CIELuv and are intended to mimic the logarithmic response of the eye.

$$L^* = 116 f\left({}^{Y}/_{Y_n}\right) - 16 \quad (4.6)$$

$$a^* = 500[\, f\left({}^{X}/_{X_n}\right) - f\left({}^{Y}/_{Y_n}\right)] \quad (4.7)$$

$$b^* = 200[\, f\left({}^{Y}/_{Y_n}\right) - f\left({}^{Z}/_{Z_n}\right)] \quad (4.8)$$

If $^{Y}/_{Y_n} \leq 0.008856$

L* Scales from 0 to 100

Xn, Yn and Zn refers to reference point values of D65,[18]

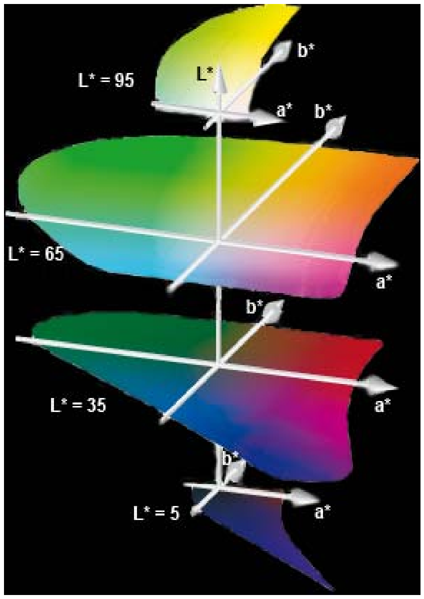

Figure 4.3: Colour Distance of CIELab Colour Space

When determining CIEL*a*b* or CIEL*u*v* values for CRT displayed colours it is usual to used the CRT's white point as the reference white.

4.5 Colour Difference

The difference between two measured colours can be expressed using the CIE colour difference formular. Colour differences can be calculated by using following set of equations for the two versions, CIEL*u*v* and CIEL*a*b*,[18].

ΔE^*uv for CIEL*u*v* colour space

$$\Delta E^*uv = [(\Delta L^*)^2 + (\Delta u^*)^2 + (\Delta v^*)^2]^{0.5} \tag{4.9}$$

If colour difference is d;

$$d_{uv} = [(L_1-L_2)^2 + (u_1-u_2)^2 + (v_1- v_2)^2]^{0.5} \tag{4.10}$$

Where ; ΔE^*uv = colour difference according to CIEL*u*v* colour space

ΔL^* = difference in lightness

Δu^* = colour difference in u-axis

Δv^* = colour difference in v-axis

Colour difference (ΔE^*ab) for CIEL*a*b* colour space

$$\Delta E^*ab = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{0.5} \quad (4.11)$$

If colour difference is d;

$$d_{ab} = [(L_1-L_2)^2 + (a_1-a_2)^2 + (b_1- b_2)^2]^{0.5} \quad (4.12)$$

Where; L* - Lightness

a* - Red Green axis

b* -Yellow-Blue axis

ΔE^*ab = colour difference according to CIEL*a*b* colour space

Δa^* = colour difference in Red-Green axis

Δb^* = colour difference in Yellow-Blue axi

CHAPTER 5

RESEARCH FINDINGS

5.1 Introduction

This chapter discussed about the research works, experiments that I did, to find the correlation between turbidity and colour distance. Also the chapter includes analysis of results, and at the end of the chapter, final results will be discussed.

5.2 First Experiment

First experiment was done at the Central Laboratory, Thelewala. Aim of this experiment is to observe the colour difference of different water samples (with different turbidity values). High turbidity water samples were prepared by adding some mud to the tap water.

- Apparatus used:
  - Fabricated glass tank
  - 6MP Digital camera
  - Turbidity meter ("HACH" meter)

Figure 5.1 : Glass tank and the cover box

- Preparation :
  A Glass tank was filled with tap water and was placed inside the large box. The box was fully covered except the front side. A background paper (half white and and half black) was pasted to the out-side surface of the back wall of the glass tank. A D65 light source was placed at the top part of the box and connected to the 230V power supply. The digital camera was placed in-front of the glass tank.

- Sample No. 1:
  An image was taken by the digital camera. Simultaneously a water sample was taken to the small bottle of the turbidimeter and was measured the value.

Figure 5.2: Image of the sample No. 1

Turbidity measured by the turbidimeter = 0.9 NTU

- Sample No.2 :
  Very small amount of mud was added to the glass tank and stirred well. An image was taken and turbidity was measured simultaneously.

Figure 5.3: Image of the sample No.2

Turbidity measured by the turbidimeter = 17.4 NTU

- Sample No.3:
  Some more mud was added to the glass tank and and again stirred well. An image was taken and turbidity was measured by the turbidimeter.

Figure 5.4: Image of the sample No.3

Turbidity measured: 42.8 NTU

- Observations and Results
  Three images were observed and noticed that there is a significant change in colour, when increasing turbidity.It is desided to go head with the project.

5.3 The second experiment

A set of readings was taken at the central laboratory of National Water Supply and Drainage Board, Thelawala. Aim of this experiment was to find a correlation between turbidity and the colour distance.

- Apparatus Used :
- 8” x 6” x 6” Glass tank
- A digital Camera
- Digital Turbidimeter
- D65, 40W florescent light source
- A large bucket
- Small water pump (Aquarium pump)
- Flexible tubes -02 Nos.

- Preparation for the experiment:

Same preparation was done, as for the previous experiment. In addition to that the aquarium pump was installed inside the glass tank and two flexible hoses were connected to the pump and the large bucket to circulate water. Siphon system was used to get the water from the bucket to the glass tank and the water pump was used for the return path. Tap water was filled to the bucket and circulation process was started.

Figure 5.5: Aparatus Arrangement

- Methodology of the experiment

Sample No.1:
After starting the circulation process image 1 was taken and simultaneously turbidity was measured by the turbidimeter. 1st image was taken as the reference image.

Figure 5.6: Reference image
Turbidity measured by the turbidimeter = 2.7NTU

Sample No.2:
Small amount of mud was added to the bucket. After few minutes the image was taken and simultaneously turbidity was measured

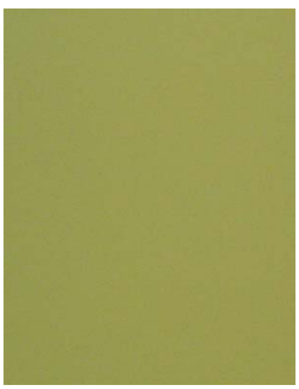

Figure 5.7: The 2nd image

Turbidity: 28.6 NTU

Likewise 15 images were taken and corresponding turbidity valuewas also recoded.Colour difference related to each image was obtained by a Matlab program. Results are as follows:

Table 5.1: Test Results of the 2nd Experiment

Sample	***Color Diff.***	***Hach Measure***
1	*0*	*2.1*
2	*33.3*	*28.6*
3	*46.41*	*67.7*
4	*59.21*	*116*
5	*59.16*	*148*
6	*68.98*	*201*
7	*71*	*287*
8	*74.53*	*314*
9	75.62	359
10	76.23	425
11	76.9	474
12	77.61	502
13	78.88	540
14	79.95	580
15	81.51	615

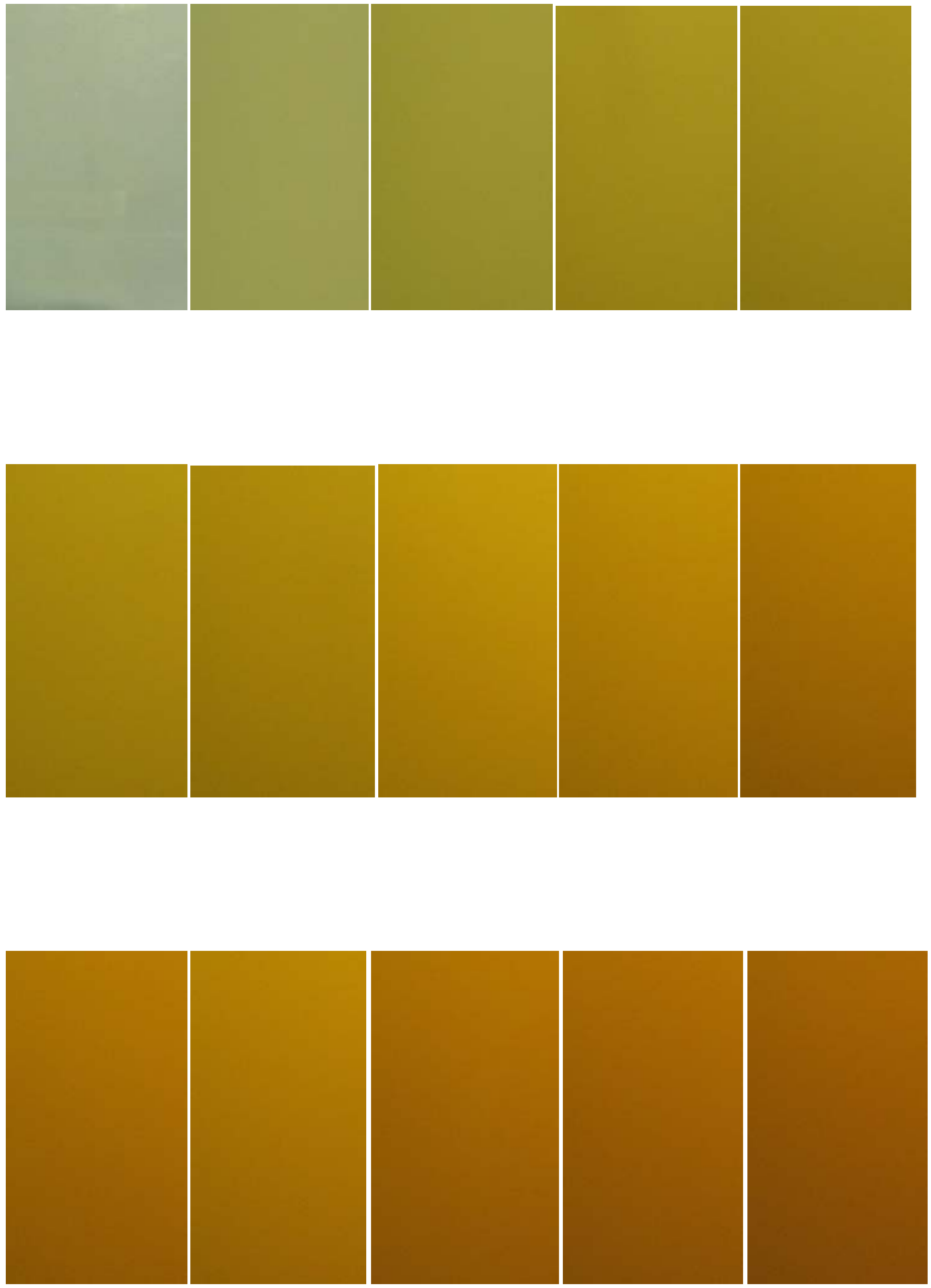

Figure 5.8: First fifteen images

By taking the colour difference to X -axis and turbidity measurement to Y-axis all points were plotted in a graph.

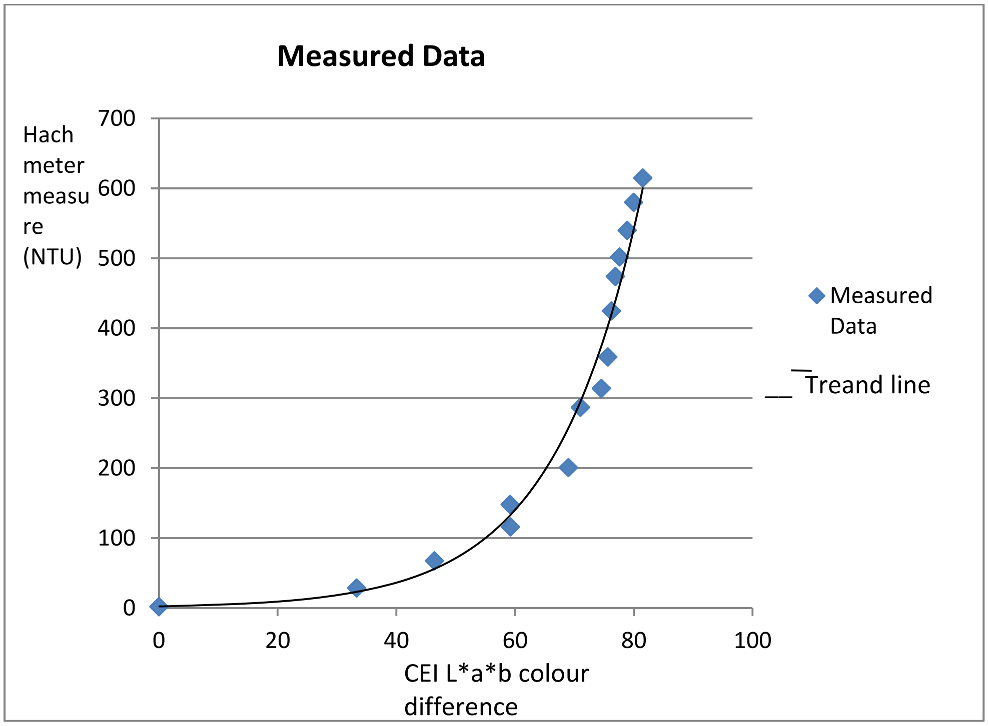

Figure 5.9: Observed data points

5.4 Analysis of Results

5.4.1 Polynomials.

A polynomial in a single indeterminate can be written in the form

$$a_n x^n + a_{n-1} x^{n-1} + \cdots + a_2 x^2 + a_1 x + a_0, \qquad (5.1)$$

where $a_0, \ldots, a_n$ are numbers,and x is a variable.

The degree of a polynomial is the highest degree of its terms, when the polynomial is expressed in canonical form.

The expression $ax^2 + bx + c$ in the definition of a quadratic function is a polynomial of degree 2, or a 2nd degree polynomial, because the highest exponent of x is 2. The graph of a quadratic function is a parabola whose axis of symmetry is parallel to the y-axis.

- If $a > 0$, (or is a positive number), the parabola opens upward.
- If $a < 0$, (or is a negative number), the parabola opens downward.

The coefficient a controls the speed of increase (or decrease) of the quadratic function from the vertex, bigger positive a makes the function increase faster and the graph appear more closed. The coefficients b and a together control the axis of symmetry of the parabola. The coefficient b alone is the declivity of the parabola as y-axis intercepts.

If the polynomial is $f(x) = x^2 + bx$; for different values of 'b' the graph will be different as shown below.

$$f(x) = x^2 + bx \ ; b = \{1,2,3,4..\} \qquad (5.2)$$

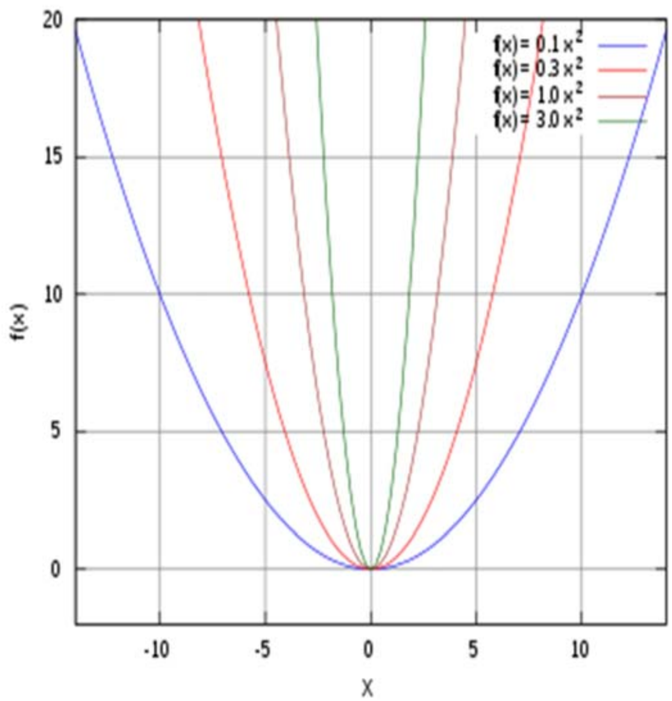

Figure5.10 Common 2nd degree polynomial graph

Graphs of Third Degree Polynomials

- $f(x) = ax^3 + bx^2 + cx + d$(5.3)

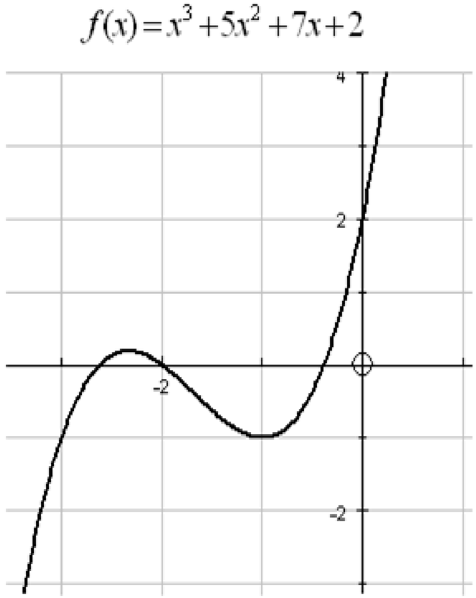

Figure 5.11common 3rd degree graph

5.4.2 Curve fitting

Curve fitting is the process of constructing a curve, or mathematical function, that has the best fit to a series of data points. Fitted curves can be used as an aid for data visualization,to infer values of a function where no data are available, and to summarize the relationships among two or more variables.

Many statistical packages such as R, E-views and numerical software such as the GNU Scientific Library,MatlabandSciPy include commands for doing curve fitting in a variety of scenarios. There are also programs specifically written to do curve fitting.

The best fit model of the above graph (Figure 5.4), can be taken as the correlation between turbidity and the colour distance. To find the best fit curve, E-views software was used.

5.5 Skewness

In probability theory and statistics, skewness is a measure of the asymmetry of the probability distribution of a real-valued random variable about its mean. The skewness value can be positive or negative. The negative skew indicates that the tail on the left side of the probability density function is longer than the right side. Positive skew indicates that the tail on the right side is longer than the left side. A zero value indicates that the tail on both sides of the mean balance out, that is symmetric distribution.

5.6 Kurtosis

In probabilzitytheory and statistics, kurtosis is a measure of the "Peakedness" of the probability distribution of a real valued random variable. Kurtosis is a measure of whether the data are peaked or flat relative to a normal distribution. That is, data sets with high kurtosis tend to have a distinct peak near the mean, decline rather rapidly, and have heavy tails. Data sets with low kurtosis tend to have a flat top near the mean rather than a sharp peak. A uniform distribution would be the extreme case.

5.7 R2 value

R^2 is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination. The definition of R^2 is the percentage of the response variable variation that is explained by a linear model. R^2 is always between 0 and 100%. In general, the higher the R^2, the better the model fits the set of data.

5.8 Experimented Models

When finding the best fit curve, a polynomial has to be written in trial and error method. E-views program will match the estimated polynomial and data points and show the fitness results. Several No.of polynomials were matched and three of them are shown below.

By analyzing the shape of the fig.5.9 (Measured data points), following characteristics were noted.

- It should be a 2nd order or 3rd order polynomial. (Trend curve may be a upper right side part of a upward parabola or upper right side part of a 3rd order polynomial with positive coefficient of the highest degree term.)

- Value of the coefficient of the highest degree term is very small (less than one).
- Coefficient of the highest degree is positive.

Model No. 1:

$$y = -3.25847 + 0.677965x - 0.0246478x^2 + 0.00030439x^3 \quad (5.4)$$

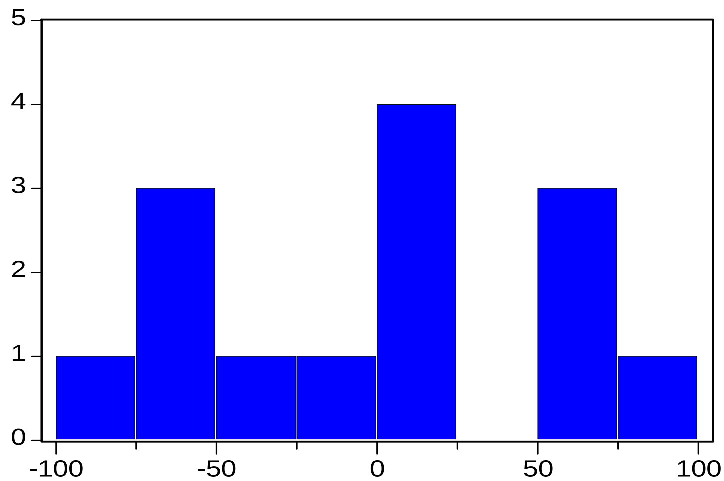

Figure 5.12: Residual plot of model 1

Skewness : -0.03
Kurtosis : 1.8

R^2 : 92%

Model No.2:

$$y = 1.745 - 6.827x + 0.5446x^2 - 0.126x^3 + 0.000101x^4 \quad (5.5)$$

Skewness: -0.1

Kurtosis: 1.6R^2 : 93%

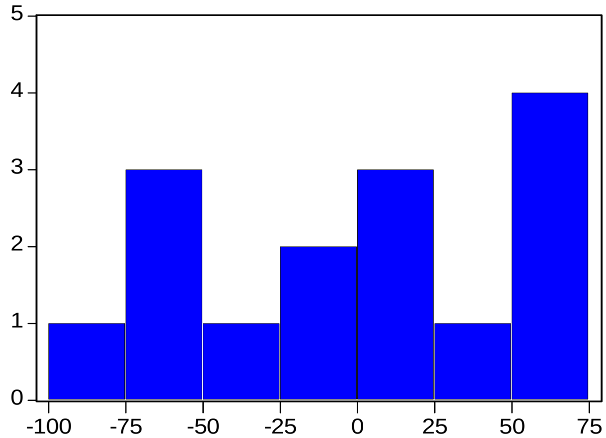

Figure 5.13: Residual plot of model 2

Model No.3:

$$y = (4.095838072 + 1.222939437 \times 10^{-11} x^5 e^{x/2} + 0.0001296715059 x^3 \ln(x)).^{1/1.0142} \quad (5.6)$$

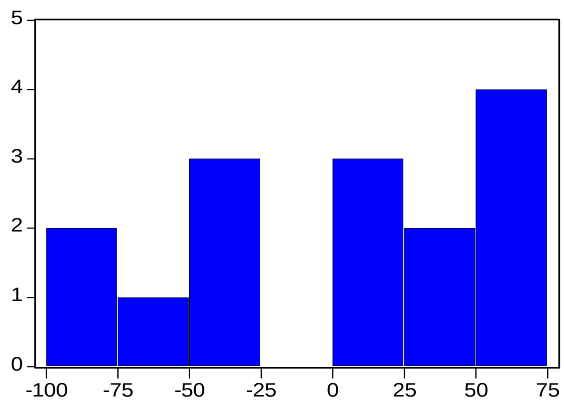

Figure 5.14: Residual plot of 3

model

Skewness: -0.3

Kurtosis: 1.7

R^2 : 90%

Comparing Different Models on Observed Data Points

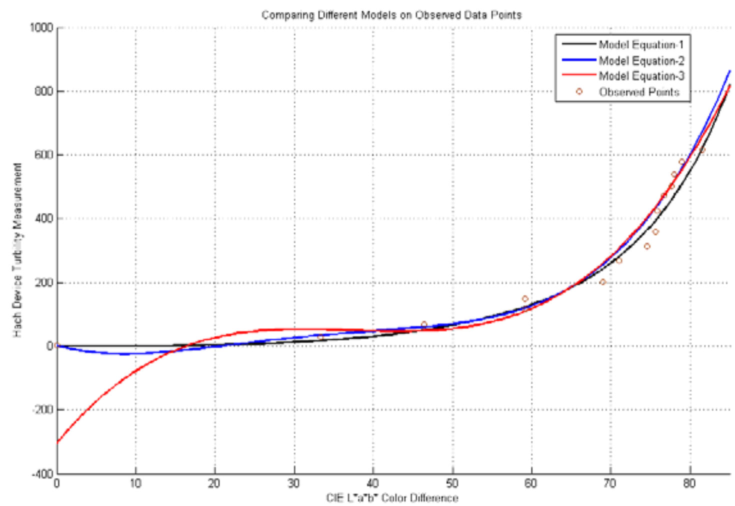

Figure5.15Graph: comparing different models on observed data points

5.9 Conclusion of analysis

For a better fitness of the polynomial, the R2 value must be closed to 100. Simultaneously the kurtosis values were considered. Higher kurtosis value was preferred.

The model-1 has the higher R2 value and higher kutosis value. Also

By considering three evaluatorsR^2, Skewness and kurtosis, the fitted model is selected as Model-1.

Best fitted Model is

$$y = -3.25847 + 0.677965x - 0.0246478x^2 + 0.00030439x^3$$

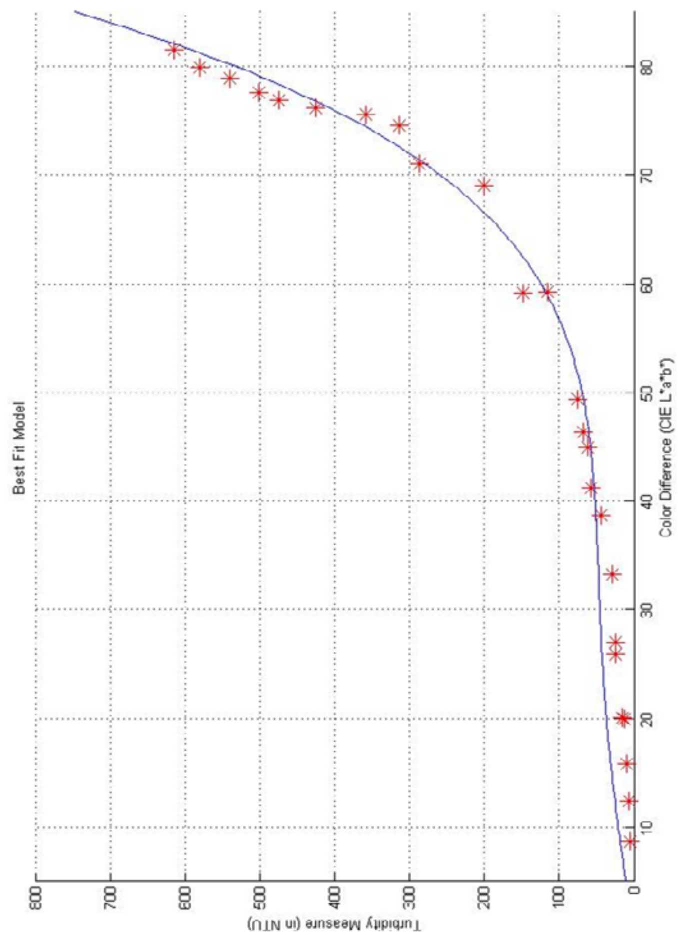

Figure 5.16:Best fitted Model

5.10 Measuring Turbidity of actual water samples

Five water samples, which were taken from the river, were tested by the same way.Turbidimeter reading and colour difference is shown in the table 5.2.

Those five points were plotted in the graph 5.15 (Best Fitted Model) is shown below.

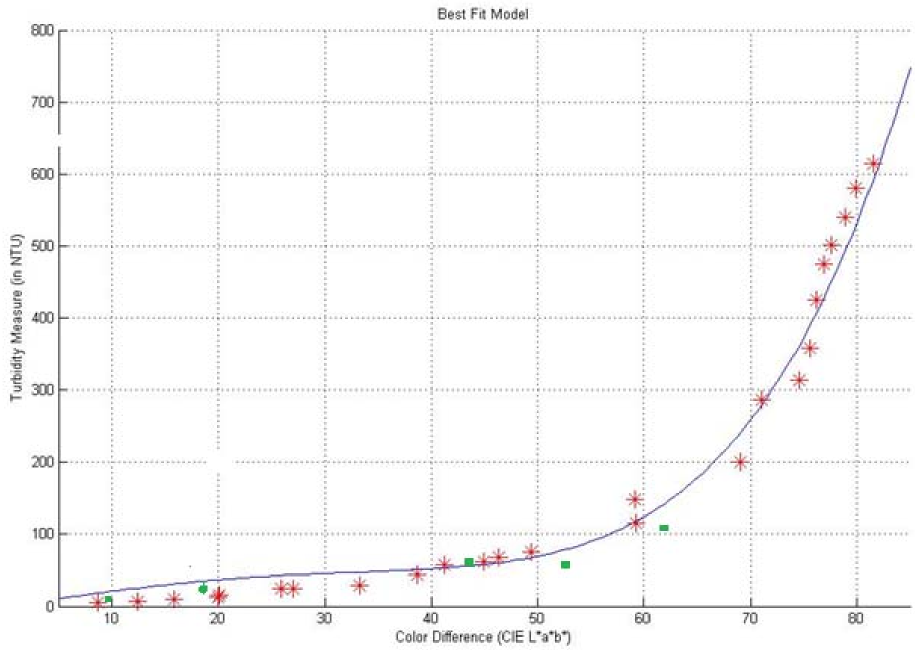

Figure 5.17: Best fit model with five new points

Five green points are the newly plotted points. Those points seems to be very close to the best fit model.

The result confirms the best fit model.

Table 5.2 : Measured data of water samples taken from the river

	Turbidity value measured by the "HACH" meter								Average Turbidity Measured by "HACH" meter	Colour Difference
Random Sample 1	12.8	12.8	12.6	12.5	12.9	12.4	12.9	13.0	12.7	8.8
Random Sample 2	22.5	22.0	22.1	22.1	22.1	19.5	22.2	19.6	21.5	18.75
Random Sample 3	48.0	47.2	48.2	48.0	48.0	47.5	47.6	41.5	47.0	53.4
Random Sample 4	58.0	59.1	58.2	28.2	59.2	58.7	58.7	58.0	54.8	43.7
Random Sample 5	106.5	107.3	107.1	107.0	106.0	106.0	106.0	105.8	106.5	63.26

CHAPTER 6

IMPLEMENTATION AND RESULTS

6.1 Introduction

This chapter discussed about the implementation of the project. Apparatus used, implementation procedure, obtained results will be discussed. At the end of the chapter results will be analyzed to match main objectives.

6.2Flushing System

A flushing system was introduced to prevent sedimenting of mud and other particles inside the tank.

A pressure pump was installed, and connected to the same water inlet line. A fresh water line was connected to the inlet of the high pressure pump.A drain pipe was also introduced to the glass tank.

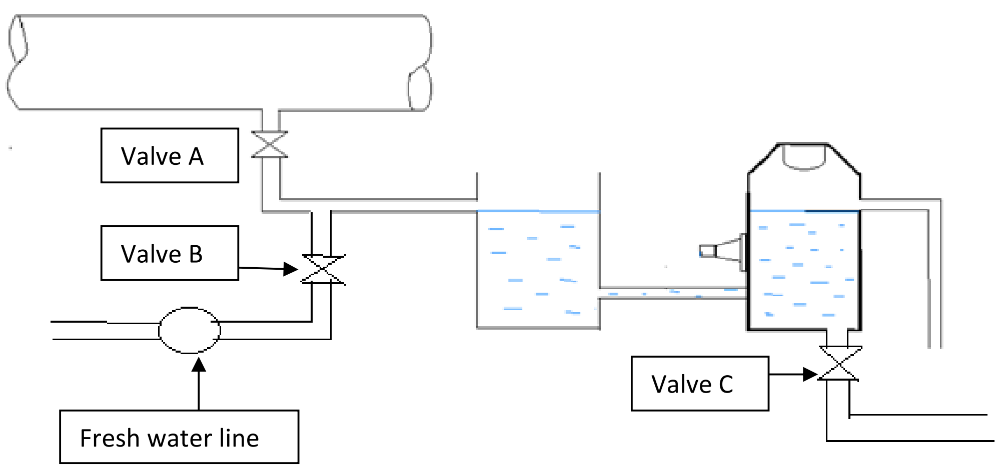

Figure 6.1: Turbidity measuring system with flushing

Once a day an operator has to close the valve A and open the valves B and C. After flushing five minutes, Valves B and C have to be closed and valve A has to be opened.

6.3 Implementation

The project was implemented at the laboratory of the water treatment plant, Kandana. Branch-off pipe of raw water pumping main was used to feed water to the new measuring system. New measuring system was arranged according to the figure 3.2 and five set of readings were obtained. Five different readings were fairly enough to check the accuracy of the system.

Figure 6.2: Measuring arrangement

Figure 6.3:Digital Turbidity meter

1st set of readings:

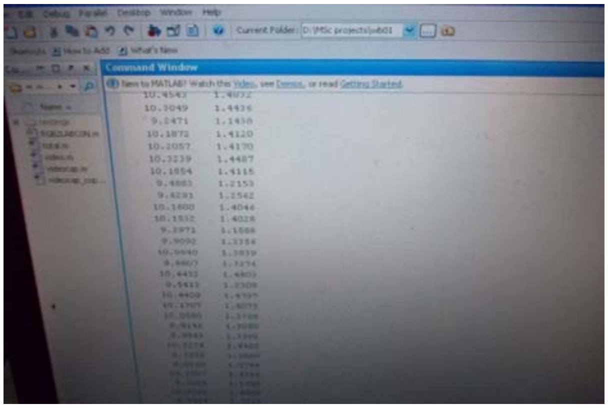

Figure 6.4:Results given by the computer

Turbidity reading given by the new system = 1.25NTU

Turbidity reading, taken from the turbidimeter = 0.6 NTU

2nd set of readings

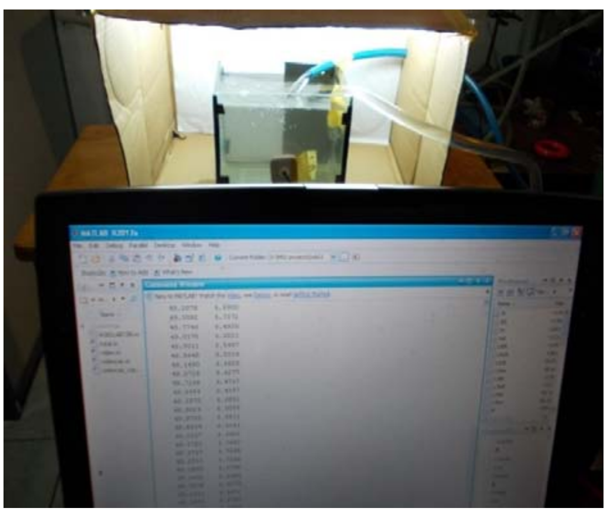

Figure 6.5:Results given by the computer

Turbidity reading given by the new system = 6.5NTU

Turbidity reading, taken from the turbidimeter = 5.6 NTU

Figure 6.6:Reading given by the Turbidity meter

6.4 Results

Table No.6.1: Results

Colour Distance	Turbidity measured by the new system	Turbidity value measured by the "HACH" meter
9.5	1.25	0.6
37.4	3.4	2.2
48.7	6.5	5.6
56.2	11.2	10.1
60.2	14.5	14.1

6.5 Analysis of results

Result shows a considerable error between the turbidity measured by the "HACH" meter and the turbidity measured by the new system. Major reason for this error is the mismatch in curve fitness. Lower part of the graph is not perfectly fit with data points. It is very difficult to fit a single polynomial for all data points. Therefore it is essential to develop a better model to minimize the error.

6.6 Better model

The whole data set was divided into two parts, the lower part is up to colour distance 40 and remaining part was separated as the upper part. By using the E-views software a second order polynomial was developed for the lower part, and for the upper part previously used polynomial was selected, because it was fitted successfully to the data points which were in the upper part of the graph.

Polynomials obtained by above method:

$$y = -0077x^2 + 1.1167x + 3.67 \quad (6.1)$$

- For the lower part of the graph

$$y = -3.25847 + 0.677965x - 0.024647x^2 + 0.00030439x^3 \quad (6.2)$$

- For the upper part of the graph

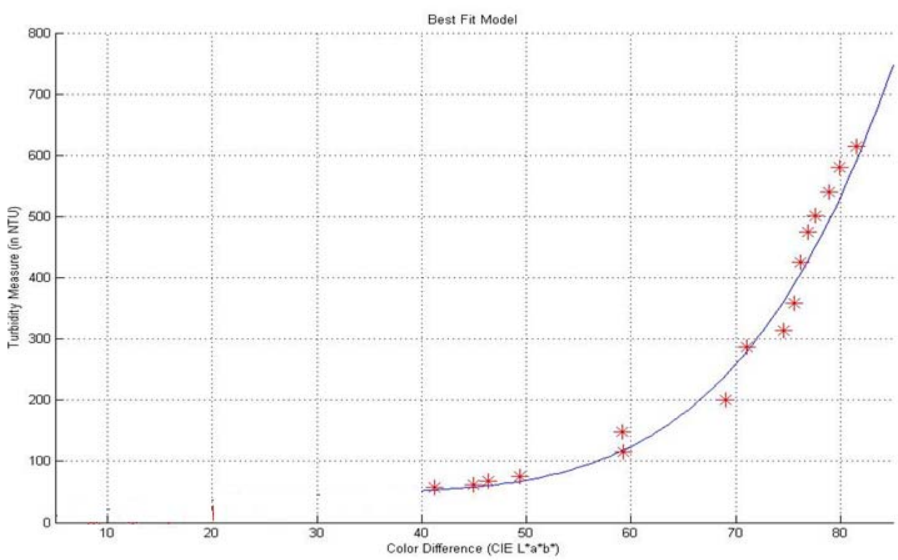

Figure.6.7: Best fit curve (upper part)

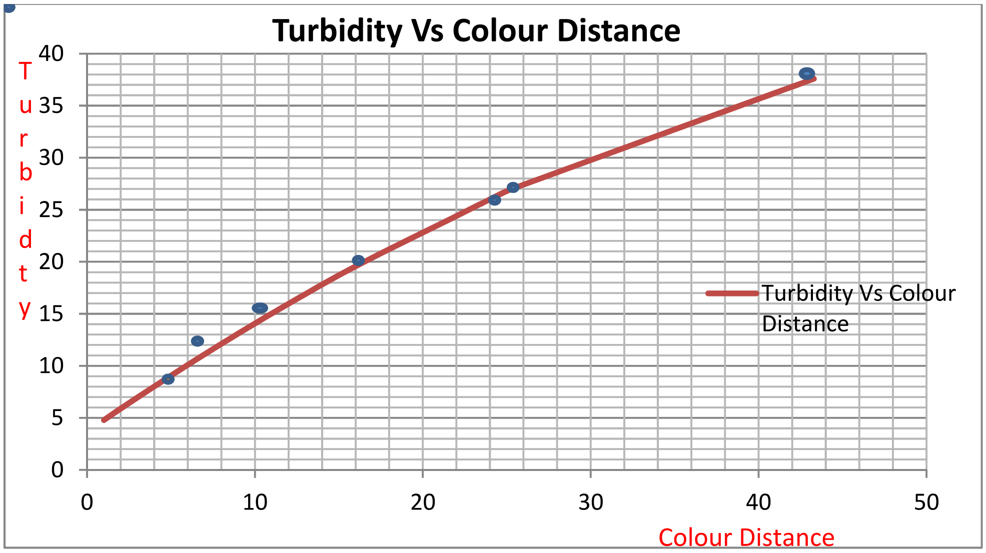

Figure 6.8: Best fit curve (lower part)

Lower part of the best fit curve was further clarified by testing 50nos. samples, because,turbidity of river water normally varies within this range.

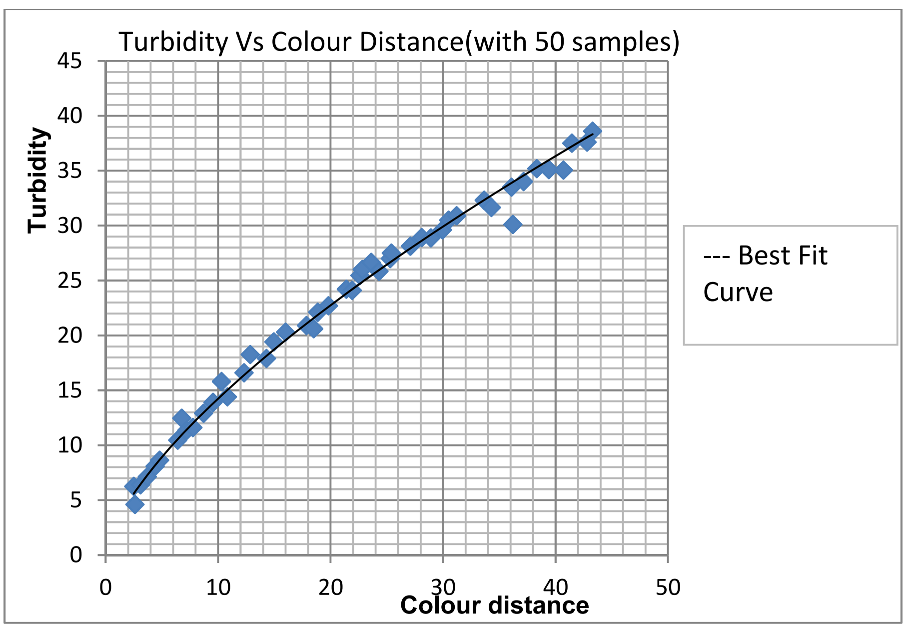

Figure 6.9:Best fit curve (with 50 samples)

According to the above curve, the polynomial (lower part) was changed as follows

$$y = -0.008x^2 + 1.12x + 3.675 \tag{6.3}$$

By using (6.2) and (6.3)polynomials, the practical test was done again and obtained following results.

Table No.6.2 : Results of the final practical test

Turbidity (Obtained by the HACH machine)	Turbidity (Obtained by prog.)
9.1	9.3
13.1	12.6
26.6	26.7

6.7 Implementation at Ingiriya water supply scheme

The new system was fixed at the Ingiriya intake pump house, and operated for three days continuously. Readings were taken at 08 hrs. intervals. Simultaneously a calibrated turbidity meter was used for data verification. Also higher resolution video camera was used for obtaining better results. Obtained results were stated as follows:

Table No.6.3: Results obtained from Ingiriya test

Date	Time	Turbidity Reading (NTU)		Error %
		New System	Turbidity Meter	
16th March 2015	8.00 am	12.4	12.1	2.5%
	4.00 pm	12.4	12.1	2.5%
	9.00 pm	12.6	12.2	3.27%
17th MarchMarch	8.00 am	12.6	12.1	4.14%
	4.00 pm	18.8	18.2	2.29%
	9.00 pm	18.8	18.3	2.73%
18th March 2015	8.00 am	18.2	17.7	2.82%
	4.00 pm	18.2	17.6	2.84%
	9.00 pm	18.3	17.6	3.8%

6.8 Analysisof finalresults

Result shows a small error in the new measuring system. In the water treatment process, chemical dosage will not be changed, due to small variations of turbidity. As such above results are in acceptable level. Furthermore the accuracy of the “HACH” turbidity meter is 5%.

However, the main reason for the deviation in results is the best fit curves are not perfectly matched with data. By using a perfectly matched curve errors can be minimized.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusion, Recommendation and Discussion

Toconclude, this research adhered to the initial objectives, which were stated at the begining. The major objective of this research was to propose an alternative automated turbidity monitoring system, instead of conventional sampling system. The above main objective is achieved and the proposed system shows the value of turbidity on a computer monitor throughout the day. As a result of achieving the main objective, the other objectives were also achieved. Therefore alum and lime dosage can be changed at any time, with respect to the turbidity of raw water.

Few researches related to continuous monitoring turbidity, had been done earlier. But in all research studies, scattering type turbidity sensors had been used for monitoring turbidity continuously. Main disadvantage of a turbidity sensor is when it blocks with mud& silt, the accuracy of readings comes down.

Accuracy of the proposed system can be improved by fitting a better model. To obtain a better model following improvements can be done.

- Population of the sample data set which was used to find the best fit curve, was 25. Highly populated sample data set (containing 100 or 150 points) could be used to find the best fit curve.
- R^2 is the major factor which helps to obtain the best fit curve. R^2 is a statistic that will give information about the goodness of fit of a model. R^2 value of the existing best fit curve of the proposed system was 92%. An $R^2$of 100 indicates that the regression line perfectly fits the data. A better model with R^2 value closer to 100can be obtained by using the E-views software.
- There are alternative methods to find the best fit model. One of the best alternative methods is MATLAB software. Therefore MATLAB software can be used to find the best fitted curve.

Suitable flushing system was introduced to prevent sedimenting mud and silt inside the tank and the tubes. But it is a manually operated system. For better performance and easy usage, an automated system can be introduced.

All experiments and implementation were done under a D65 light source. Correlation between turbidity and colour distance depends on the light source and the light intensity. Therefore future improvements should be carried out under a same light source.

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