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DEVELOPMENT AND TESTING OF INFRARED WATER CURRENT METER

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ABSTRACT
Continuous monitoring of the river flow is essential for assessing water availability. River flow velocity is crucial to simulate discharge hydrographs of water in the hydrological system.This study developed a digital water current meter with infrared. The infrared current meter was tested using Ebonyi River at Obollo-Etiti and the test was performed at three different verticals (A, B, & C) across the watercourse of Ebonyi River. At each location, the velocity readings were taken at the 0.6 of the depth below the surface. The total depth of water at locations A, B, and C are 0.35m, 0.4m and 0.54m respectively. The digital water current meter with infrared display velocity readings obtained per second. To confirm the accuracy of the infrared current meter, it was tested alongside with a conventional water current meter. The measurements performed with the infrared current meter compared well with the measurement performed with conventional current meters. The linear regression equation for the measurements obtained using the two current meters was obtained.

Keywords: *Infrared, Current meter, Propeller, Velocity, Measurement*

1. INTRODUCTION
Flow in streams is of special interest because it is the only hydrologic cycle component that can be measured with any significant degree of accuracy. Continuous monitoring of the river flow is essential for assessing water availability [1]. Because the rate of discharge in a river channel depends upon the flow depth as well as on the flow velocity, it is necessary to know each of them to determine the flow rate [2]. There are four basic techniques used to measure flow in open channels namely: hydraulic structures, velocity-area methods, dilution techniques, and slope-hydraulic radius-area method. Hydraulic structures are a broad classification of devices constructed to control flow to allow for a highly accurate measurement of discharge. Flumes, weirs, dam outlets, and other structures are included in this category. Velocity-area methods include most of the stream-gauging methods employed in stream-gauging such as current meters, acoustic Doppler devices, floats, and other methods. All of these methods involve the measurement of flow velocity and area components of a measurement section in a stream. Current meters are the best example of this category, where mean velocity and depth are measured for a set of subsections that constitute a measurement section. The product of the individual subsection areas and subsection velocities constitute an incremental discharge, and the sum of the incremental discharge values is a total stream discharge. Dilution techniques commonly referred to as dye-tracing methods, determine the discharge in a stream by measuring the dilution and dispersion of a suitable dye tracer. Dilution techniques can be based on color, conductivity, fluorescence, or radioactivity of the tracer injected into the waterway. Slope-hydraulic radius-area method is the most commonly employed indirect discharge estimation technique. This technique involves the measurement of parameters for use with the Manning's equation:

$$v = n^{-1} . R^{2/3} . S^{1/2} \quad (1)$$

where v is the flow velocity [m/s], n is the river bed Roughness coefficient [−], R is the hydraulic radius [m] and S is the river slope.

1.1 Current Meters
Velocity of flow at a point is usually measured by counting revolutions of a current meter rotor during a short-time period measured with a stopwatch. Current meters are still the most widely used method of measuring velocity in a stream. According to [3], the most exact method of establishing the circulating flow rate through a canal that does not include any form of

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measuring element is by taking readings with a propeller type meter. The majority of current meters are of a mechanical design, where stream velocity is related to the angular velocity of the rotor. This relationship is determined by counting the number of revolutions of the rotor over a designated period of time. In spite of the development of new methods for velocity measurements, the well-established measuring method with rotating element current meters still has its very own fields of application.

According to [9], it has also been shown that at very low speeds, the performance of current meters may vary greatly, often with significant deviations [10].Flow velocity is measured in shallow streams with a miniature type current meter whereas for wide rivers, the river is gauged from a boat held in position along a fixed alignment across the section [4], [5]. Sometimes, permanent installations such as a cable car (gauger travels with car and operates current meter) or a cableway (gauger operates current meter from the bank with mechanical winches) are used to carry out velocity and water level measurements. According to [6], the current meter should be removed from the water at intervals for examination.

Types of current meters: There are two types of current meter namely: mechanical or electromagnetic. Mechanical current meters can be divided into two groups based on the orientation of the axis of the rotor: vertical-axis rotor meters also known as cup-type meters, and horizontal-axis rotor meters referred to as propeller-type current meters. According to [7], both types use a make-and-break contact to generate an electric pulse for indicating the revolutions of the rotor [8]. Optical, non-contact type counters are also in use with cup-type meters. Propeller-type current meters are used in a wide range of velocity from a few centimeters per second up to several meters per second. An ideal current meter, whether mechanical or electromagnetic, should respond instantly and consistently to any changes in water velocity, and should accurately register the desired velocity component. Additionally, the meter should be durable, easily maintained, and simple to use under a variety of environmental conditions. Mechanical current meters measure velocity by translating linear motion into angular motion. The two types of mechanical current meters, vertical-axis and horizontal-axis; differ in their maintenance requirements and performance because of the difference in their axial alignment. The cup-type current meters require little maintenance and the rotor can be changed without changing the rating of the meter. Advantages of horizontal-axis current meters include the fact that the propeller is less likely to become tangled in grass and debris. Mechanical meter performance depends on the inertia of the rotor, friction in the bearings, and the ease with which water turns the rotor. Electromagnetic current meters measure velocity using Faraday's Law, which states that a conductor (water) moving in a magnetic field (generated by the probe) produces a voltage that varies linearly with the flow velocity. Electrodes in the probe detect the voltages generated by the flowing water. Performance for electromagnetic current meters depends on the , location of the electrodes on the probe, and the construction of the meter electronics.

River flow velocity is crucial to simulate discharge hydrographs of water in the hydrological system [11]. And this flow velocity data is not available for many rivers in Nigeria. This could be as a result of lack of measuring equipment/instruments. Because of that this study develops a digital water current meter with infrared that can be used in measuring velocity of water. This study also compared the measurements obtained using the new current meter with the conventional current meter.

1.2 Determination of mean velocity

The mean velocity of the water in each vertical can be determined by one of the following methods [7]: (a) Velocity distribution method;(b) Reduced point methods;(c) Integration method.

1.2.1 Velocity distribution method

The measurement of the mean velocity by this method is obtained from velocity observations made at a number of points along each vertical between the surface of the water and the bed of the channel. The velocity distribution method may not be suitable for discharge measurements made during significant variations of stage because the apparent gain in precision may be more than offset by errors resulting from the longer period required to make the measurement. The velocity distribution method is valuable in determining coefficients for application to the results obtained by other methods, but it is not generally adapted to routine discharge measurements because of the extra time to compute the mean velocity [7].

1.2.2 Reduced point methods

(i) One-point method – Velocity observations should be made at each vertical by placing the current meter at 0.6 of the depth below the surface. The value observed should be taken as the mean velocity in the vertical [7];

(ii) Two-point method – Velocity observations should be made at each vertical by placing the current meter at 0.2 and 0.8 of the depth below the surface. The average of the two values should be taken as the mean velocity in the vertical;

(iii) Three-point method – Velocity observations are made by placing the current meter at each vertical at 0.2, 0.6 and 0.8 of the depth below the surface. The average of the three values may be taken as the mean velocity in the vertical. Alternatively, the 0.6 measurement maybe weighted and the mean velocity may be obtained from the equation:

$$\overline{V} = 0.25(V_{0.2} + 2V_{0.6} + V_{0.8}) \quad (2)$$

where $\overline{V}$ is the mean velocity; $V_{0.2}$ is the velocity at 0.2 of the depth below the surface; $V_{0.6}$ is the velocity at 0.6 of the depth below the surface and $V_{0.8}$ is the velocity at 0.8 of the depth below the surface

(iv) Five-point method - It consists of velocity measurement son each vertical at 0.2, 0.6 and 0.8 of the depth below the surface and as near as possible to the surface and the bottom. The mean velocity may be determined from a graphical plot of the velocity profile as with the velocity distribution method or from the equation:

$$\overline{V} = 0.1(V_{surface} + 3V_{0.2} + 3V_{0.6} + 2V_{0.8} + V_{bed}) \quad (3)$$

(v) Six-point method – Velocity observations are made by placing the current meter at 0.2, 0.4,
0.6 and 0.8 of the depth below the surface and as near as possible to the surface and the bottom. The velocity observations are plotted in graphical form and the mean velocity is determined as with the velocity distribution method or from the equation:

$$\overline{V} = 0.1(V_{surface} + 2V_{0.2} + 2V_{0.4} + 2V_{0.6} + 2V_{0.8} + V_{bed}) \quad (4)$$

(vi) Two-tenths method – In this method, the velocity is observed at 0.2 of the depth below the surface. A coefficient of about 0.88 is applied to the observed velocity to obtain the mean in the vertical;

(vii) Surface velocity method – In this method, velocity observations are made as near as possible to the surface. A surface coefficient of 0.85or 0.86 is used to compute the mean velocity in the vertical.

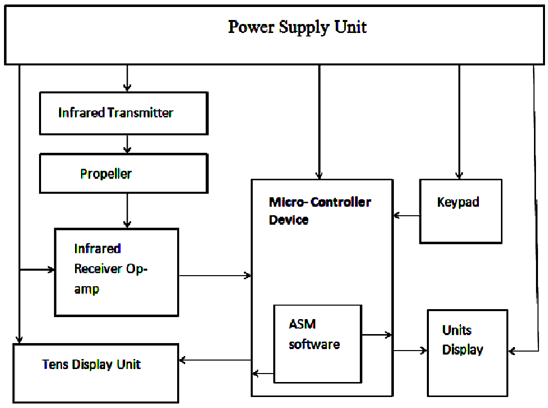

Figure 1: The System Block diagram

1.2.3 Integration method

In this method, the current meter is lowered and raised through the entire depth at each vertical at uniform rate. This method is rarely used in water having a depth of less than 3 m and velocities of less than 1 m s^{-1}. The integration method should not be used with a vertical axis current meter because the vertical movement of the meter affects the motion of the rotor [7].

2. MATERIALS AND METHODS

The materials used for the work are microcontroller, infrared, key pad, op-amp, 7-segment display, transistor, propeller and other electronic components which include resistors, diode, capacitor, crystal, voltage regulator, light emitting diode, connecting wire, 555-timer and variable resistors. The system block diagram and circuit diagram are shown in figure 1and 2 respectively.

The entire circuit is controlled from one power button which turns on an LED when pressed down to indicate that the device has been powered. Once the device is powered, the micro controller (MC) starts its operations based on the interval codes. It will display EE on the start of the device but after about five seconds, it will display 00 if the propeller does not rotate within this period. The microcontroller detects the slightest rotation of the propeller. This device uses only one 9VDC battery which needs to be replaced once in a while. Thus, the electronic circuit section is protected from getting in contact with water while only the propeller is immersed into the flowing river.

2.1 The Micro controller

This is an 8051 family microcontroller family I.C with 40pins. It has a total of four ports for binary data communication with the external sub-circuit like the infrared receiver op-amp, the keypad and the 7-

segment display. The input and output of the micro controller and its operations / preferences are controlled by the use of software code. However, the micro controller (MC) uses crystals for stabilizing its clock speed which depend on the programming code delay routine running inside the MC at any point in time.

An assembly language code was written and its equivalent hex file was generated and burnt or programmed into the micro controller. It is this hex file that enables the micro controller to intelligently source all the information it needs from time to time and as well process the information accurately and thus display any of the stored data we desire from it at any time.

2.2 The Op-amp

This is an 8-pin operational amplifier sub-circuit. Its major role is to compare the positive and negative voltages at its pins as the infrared receiver component is placed on one of the pins. It can as well amplify the signal input into its pins or amplify the difference between the two signal inputs to its pins. This I.C used is also called a voltage comparator since it compares the degree of positive and negative voltage at its two pins. The infrared receiver component is connected to this op-amp such that the op-amp will be bringing out an output of a low (negative) only when the infrared receiver stop receiving an infrared light from an infrared transmitter due to blockage by an intruder or by the rotation of the propeller longer blade.

The two lower switches represent the roles of the Op-amp section of IR receiver and its transistors and the IR transmitter section whose key sensory components are mounted inside the propeller.

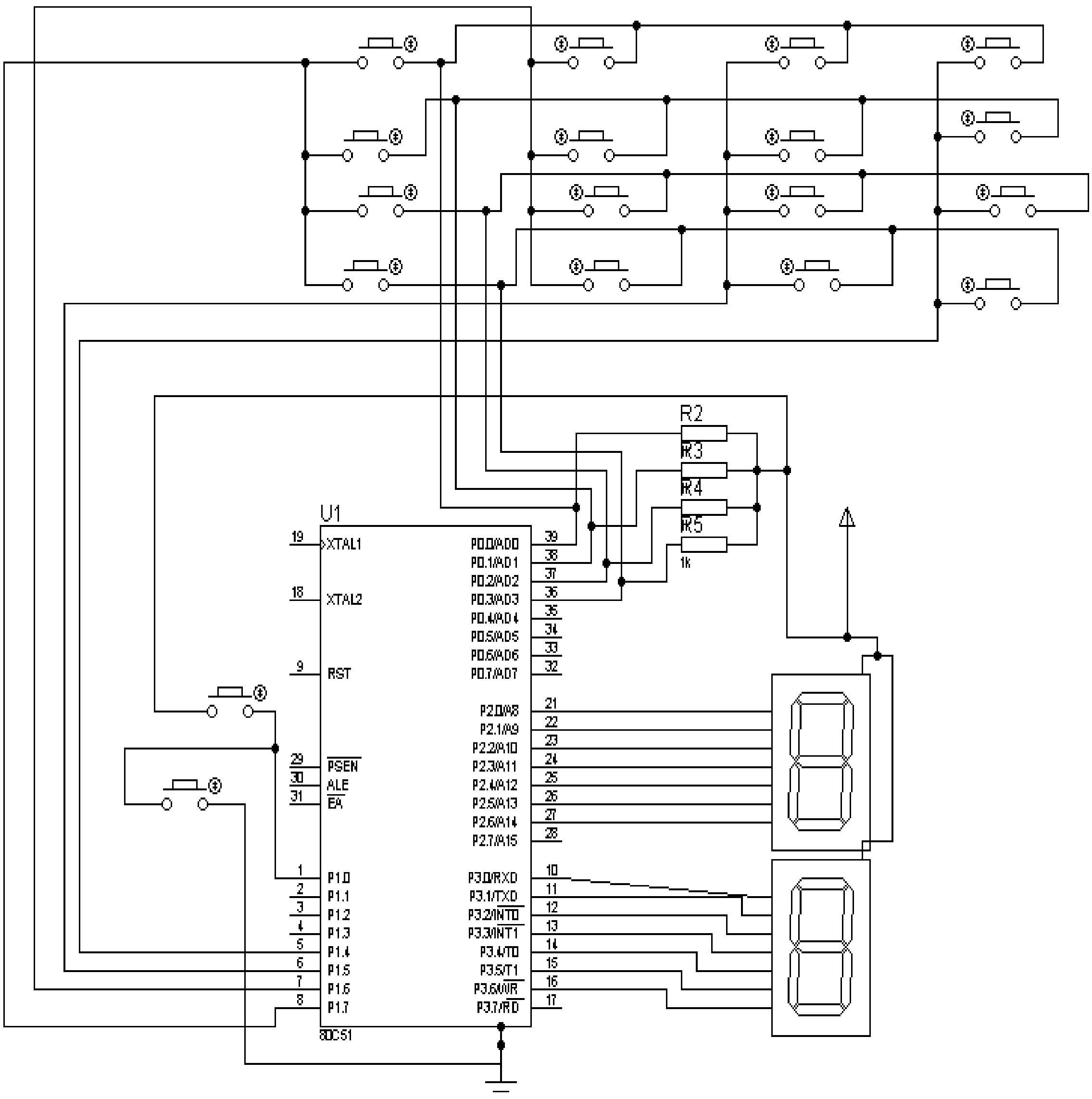

Figure 2: The Circuit diagram

2.3 The Transistors

These are Bipolar Junction Transistor (BJTs) transistors which are used for several switching processes. They help us to switch the output of the op-amp into the port 1of the 8OST micro controller. However, the major role of transistor is either as switches or as amplifiers.

2.4 The Infrared Design

This comprises both the infrared transmitter design and the infrared receiver design. The infrared transmitter is made from an oscillating current and infrared transmitter components which transmits infrared light when repeatedly being clocked by the oscillating circuit.

From an experiment, the generated infrared light can be reflected back by any opaque object depending on its angle of incidence. However, the infrared receiver comprises of the black infrared receiver component (which changes its resistance in the presence of white light, infrared light and other sources of light) and the operational amplifier sub-circuit. With the help of black infrared receiver component, the op-amp knows when the infrared light is being received (i.e. being reflected by the propeller blade into the black infrared receiver component) and when it is blocked or not reflected back towards the black infrared receiver component. Each time the reflected infrared light is received by the op-amp, the op-amp sends out a negative output to the micro controller section so that the micro controller receives the negative output as the number of revolution of propeller per second.

2.5 The Keypad

This is a mechanical arrangement of 16-contact points into a 4 x 4 matrix arrangement. Each of the metal contact points represent one of the numbers from 0 to 9 and from A (i.e. 10) to F (i.e. 15). The keypad is connected to port 0 of the micro controller I.C. Thus, it helps to retrieve the stored data recorded by the micro controller into the internal register of the micro controller itself. The system is also designed in such a way that one can change the time interval the MC will stay before storing any data.

2.6 The 7-Segment Display

This is an electronic component made from a segment of 7 light emitting diodes (LED) which are arranged to have common positive legs. It displays the decimal equivalent of the digital input it receives from the output pins of the 8OST micro controller being ports 2 and 3. It also displays the decimal forms of the water velocity readings based on the number of revolutions made by the propeller blade per second.

2.7 The Propeller

This is an electrochemical construction which has the infrared transmitter component and the infrared receiver component being mounted on it such that movement of the propeller will cause a reflection of the infrared light from the transmitter to the receiver. Thus, the infrared receiver component that is on the propeller supplies the op-amp which supplies the micro controller that finally counts the number of revolutions per second. The propeller blade is made very light, free and sensitive to the slightest water movement.

3. RESULTS

The infrared current meter was tested at Ebonyi River at Obollo-Etiti. The current meter was tested at three different locations (A, B, & C) along the water course of Ebonyi River. At each location, the velocity readings were taken at the 0.6 of the depth below the surface [2]. The total depth of water at locations A, B, and C are 0.35m, 0.4m and 0.54m respectively. The digital water current meter with infrared display velocity readings obtained per second instead of number of revolutions. To confirm the accuracy of the infrared current meter, it was tested alongside with a conventional water current meter. This conventional current meter does not display velocity reading but number of revolutions made per second. The number of revolutions per second readings obtained was converted to velocity using the manufacturer's calibration equations (equations 5 and 6) developed for that particular current meter. In all the locations, different sets of measurements were performed concurrently with both current meters. The readings are shown in Table1.

$$V = 0.0560n + 0.040; \qquad for\ n < 4.67 \qquad (5)$$

$$V = 0.0545n + 0.047; \qquad for\ n > 4.67 \qquad (6)$$

where V is the velocity (m/s) and n is the number of revolutions per second

4. ANALYSIS AND DISCUSSION OF RESULTS

The measurements performed with the infrared current meter compared well with the measurement performed with convectional current meters. On the average, the measurements performed using Infrared current meter is higher than that of convectional current meter in all the locations. Though this difference is more at location *A* with the lowest depth of 0.35m compare to other locations.

Table 1: Velocity (m/s) reading at 0.6 of the depth at locations A, B & C

	Infrared Current meter (m/s)			Convectional Current meter (m/s)		
S/N	*A*	*B*	*C*	*A*	*B*	*C*
1	0.25	0.23	0.35	0.25	0.25	0.3
2	0.3	0.25	0.36	0.28	0.28	0.34
3	0.25	0.21	0.33	0.26	0.25	0.33
4	0.3	0.27	0.33	0.20	0.25	0.29
5	0.3	0.30	0.3	0.25	0.25	0.33
6	0.27	0.27	0.4	0.23	0.25	0.32
7	0.21	0.28	0.3	0.23	0.26	0.32
8	0.33	0.3	0.3	0.25	0.25	0.33
9	0.25	0.27	0.36	0.25	0.25	0.34
10	0.3	0.21	0.36	0.25	0.25	0.33
Total	*2.76*	*2.59*	*3.4*	*2.45*	*2.54*	*3.23*
Average	*0.28*	*0.26*	*0.34*	*0.25*	*2.25*	*0.32*

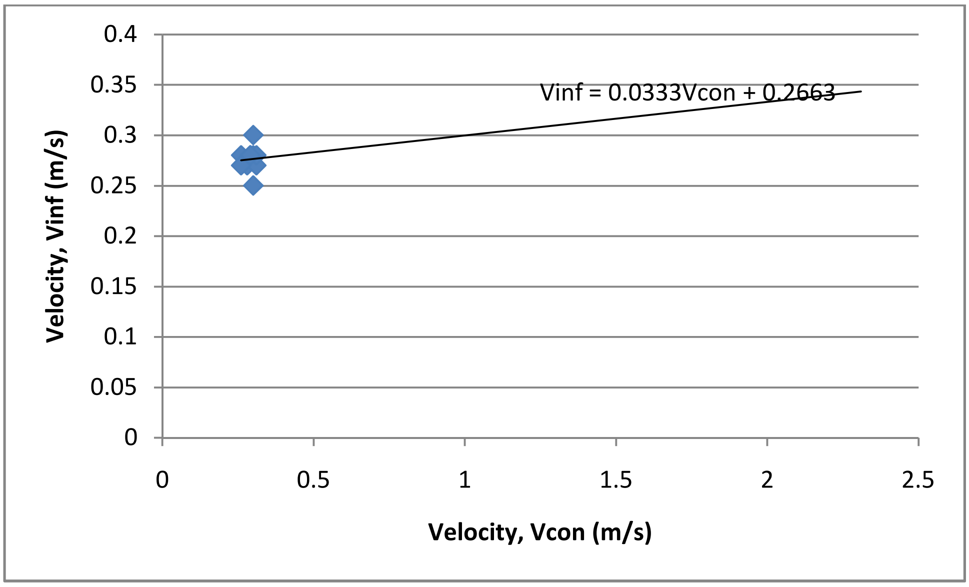

Figure 3: Comparison of velocity measurements obtained using the infrared and the convectional current meter.

The sources of these errors could be as a result of (1) human intervention (2) propeller positions while carrying out the measurement. These instruments were held by human hands especially, the propeller which is the most sensitive part of the system. There is tendency of movement of hands used in holding the propellers and this could introduce errors. Because these measurements were performed concurrently, the two propellers were not place at the same point but rather side by side. This is also source of error because velocity varies across the water channel.

Average readings obtained by the two current meters are plotted as shown in figure 3. The linear forecast trend line is obtained with the regression equation as:

$$V_{\inf} = 0.0333V_{con} + 0.2663 \quad (7)$$

where V_{inf} is the velocity obtained using infrared current meter and V_{con} is the velocity obtained using convectional current meter

5. CONCLUSION

Water current meter is used to measure the water velocity at various vertical locations within a transverse section of a watercourse. The 0.6 of the depth below the surface was chosen because of the value obtained represents the mean velocity in that vertical using the one point method [7]. This infrared component was chosen because of its high accuracy in keeping propeller counts.

Regular maintenance is needed to keep this digital water current meter working. The battery should be replaced whenever it runs down and the propeller component should be handled with care.

REFERENCES

1. Shaw Elizabeth M. *Hydrology in Practice*. Third edition, Taylor & Francis, UK.1994, P. 103

2. Chaudhry M. Hanif .*Open-Channel Flow*. Second Edition, Springer Science+Business Media, New York, 2008, P. 315
3. Monta˜n´esJos´eLiria. *Hydraulic Canals: Design, construction, regulation and maintenance*. Taylor & Francis, New York,2006, P. 268
4. Novak P., A.I.B. Moffat, C. Nalluri and R. Narayanan. *Hydraulic Structures*. Fourth Edition, Taylor & Francis, Abingdon, Oxon.2007, P. 333
5. Novak P., A.I.B. Moffat, C. Nalluri and R. Narayanan. *Hydraulic Structures*. Third Edition, Taylor & Francis, Abingdon, Oxon.2001, P. 305
6. WMO (World Meteorological Organization). *Guide to Hydrological practices*. Fifth edition,1994, P. 86
7. WMO (World Meteorological Organization). *Guide to Hydrological Practices*. Volume I: Hydrology – From Measurement to Hydrological Information, WMO-No. 168,2008, P. 1.5-4
8. International Organization for Standardization, ISO. *Liquid Flow Measurement in Open Channels: Rotating Element Current-meters.* Third edition, ISO 2537, Geneva.1988a
9. Tazioli A. Experimental methods for river discharge measurements: comparison among tracers and current meter.*Hydrological Sciences Journal*, Vol. 56:7,2011, Pp. 1314-1324
10. Whalley, N., Iredale, R.S. and Clare, A.F. Reliability and uncertainty in flow measurement techniques: some current thinking. *Physics and Chemistry of the Earth (C)*, 26, 2001, Pp. 743–749.
11. SchulzeK., M. Hunger, and P. Doll. Simulating river flow velocity on global scale. *Advances in Geosciences*, Vol. 5, 2005, Pp. 133–136