the research and lists of recommendations for improving the quality of water of Umkhrah river. The publications referred in the thesis are listed in the References.

CHAPTER II – REVIEW OF LITERATURE

Rivers play an important role in human development by providing drinking water, making the land fertile and serving as a conduit for transportation. For centuries, humans have been enjoying the ecosystem services provided by rivers without understanding how the river ecosystem functions and maintains its vitality (Naiman, 1992). Man has changed the nature of many of the world’s rivers by controlling their floods, by constructing large impoundments, by
overexploiting their living and non-living resources and by using rivers for disposal of wastes. Such taming of rivers and exploitation of riverine resources have often led to serious decline in river water quality impairing their use for agricultural, drinking, recreational and other purposes and causing serious implications on human health and the environment (Carpenter et al., 1998; Peterson et al., 1971). United Nations Environment Programme (1991) has reported that 75% of the population in developing countries lack adequate sanitary facilities and dump most of their waste into the nearest water bodies such as streams, rivers, lakes and estuaries, lagoons and the sea, thereby polluting such water bodies. In recent times, pollution of rivers has increased steadily and polluted rivers have become a norm rather than exception. This situation has arisen as a result of rapid growth of population, increased urbanization, expansion of industrial activities, dumping of domestic and raw sewage into nearby water courses, increased use of fertilizer and agrochemicals, lack of environmental regulations and their tardy implementation (Aina and Asedipe, 1996).

Surface water resources have played an important role in the development of human civilization. About one third of the drinking water requirement of the world is obtained from surface water sources like rivers, canals and lakes. These aquatic ecosystems also serve as the best sinks for the discharge of domestic as well as industrial wastes. This unscientific disposal of waste has caused immense problems not only to human well beings but also to the health of aquatic environment worldwide. In India, this problem started long back but intensified during the last few decades and now the situation has become alarming. Studies on the river ecosystems indicate that the major Indian rivers are grossly polluted, especially beside the cities (Upadhyaya et al., 1982; Srivastava, 1992).
Magayarkarsi (1996) studied the seasonal variation in physico-chemical characteristics of Cauvery river water and reported an increased content of nitrate and ammonia during post monsoon season and attributed this to agricultural run-off.

Identification and quantification of natural or anthropogenic inputs and understanding the contaminant source is crucial to planning, mitigation and cleanup process of rivers (William, 1998). A good number of studies on the impacts of land use change and anthropogenic activities on water quality have been carried out in the last three decades focusing on heavily polluted rivers in industrialized countries and major rivers in less developed countries (Bellos et al., 2004; Haratty and Stefan 1998; Meissner et al., 1999, Massoud et al., 2006). In contrast, studies concerning small rivers in developing countries are rather limited (Dassenakis et al., 1998). Walling and Webb (1975) studied the water quality of river Exe and reported that water quality was affected by lithology and land use. They found that specific conductance of water is a sensitive indicator of interrelationship between the river and its catchment. Webb and Nobilis (1994) studied the water-air temperature relationship in river Danube and Linz and reported a significant (0.8°C) rise in temperature during twentieth century but cautioned that care should be exercised in using such relationship to predict future river water temperature.

Makinaw river in Central Illinois was reported to be contaminated with faecal coliform. Animal waste (cattle, pig, goats) and untreated wastes from townships were found to be the principal source of such pollution (Kelly et al., 1998).

Offiong and Edet (1998) assessed the quality of Akpsbuyo Cross river (Nigeria) and reported that the water was acidic, soft, fresh and characterized by low Na absorption ratio. The acidity was attributed to the humic acid produced during decomposition of vegetation buried in the river. A study on water quality of river Buriganga receiving discharge of tannery effluents
revealed that the river was totally devoid of oxygen and up to 500m downstream no fish or other aquatic animals were recorded during dry season of the year (Huq, 1998).

Lampman et al. (1999) observed that in river Hudson all N components showed summer time low concentration while phosphate increased during the same period. The seasonal variation in nutrient concentration was particularly low which the authors described as a characteristic of the river. Razumov and Tyutyunova (1999) studied the physico-chemical characteristics of Moskva river, the main waterway of Moscow megapolis, and reported that the self purification capacity was severely damaged by inflow of heavily polluted wastewater. Wang (2001) studied the relationship between land use and river water quality measured using physico-chemical and biological indicators in Little Maimi River, Ohio, USA and reported that wastewater treatment plant has significantly enhanced the water quality of the river. Olajire et al. (2001) assessed the water quality of river Osun and reported higher concentration of phosphate, nitrate and ammonium ions. This was attributed to leaching of fertilizer residues used on agricultural farms into the river system.

Jain et al. (2003) investigated the hydrochemical characteristics of the Hindon river receiving municipal and industrial wastes as well as agricultural run-off. Samples were collected from thirteen locations on a monthly basis for a period of two years. The study revealed that water quality changes along the course of river. Joining of tributaries pouring in industrial wastes degrades the water and an open stretch of long distances without any waste input helps improve the water quality through aeration and decomposition of organic wastes.

Das and Acharya (2003) reported the possible impact of domestic sewage on the lotic water quality in and around Cuttack city, India. A majority of water samples exceeded the maximum permissible limit set by WHO (1997) for NH$_4^+$ and NO$_3^-$ contents. The analysis of
nutrient characteristics exhibited drastic temporal variation indicating higher concentration during the summer season compared to winter and rainy seasons.

They also reported that DO deficit persists all along the water courses of the river Kathajodi and Taladanda canal. It was found that reduced flow of water during summer enhanced the BOD values and domestic sewage was the main source of pollutants.

Status and trends of Ontario’s Sydemham river ecosystem in relation to aquatic species revealed that source of chloride in rivers of tropical countries is domestic sewage while in western countries it also comes from use of road salts (Bowlby et al., 1987; Baruah et al., 1993).

Studies in river Padma revealed that higher chloride content were invariably associated with sewage contamination and periods of higher temperature coincided with low oxygen content attributed to high community respiration (Ahmed, 2004).

Charkhabi and Sakizadeh (2006) studied the spatial variation in water quality parameters in most polluted stretch of the Anzali river (Iran) and reported that fertilizers applied in paddy fields were the major causes for higher phosphorus and total nitrogen contents of the river water. The study also reported that BOD and COD values were higher during summer which coincided with lower discharge of the river.

Ouyang et al. (2006) studied the river water quality in rural and urban areas and reported that type of river pollution varied markedly between two areas. While higher concentration of ammonium, total phosphorus, COD and TOC was associated with urban waters, higher DO, nitrite, turbidity and pH values were noted in rural areas.

Mallin et al. (2006) investigated physical, chemical and biological variables contributing to BOD in the 17 North Carolina lotic and lentic water bodies affected by mild to severe hypoxia. They reported that in the Piemont-derived Cape Fear River, BOD was primarily driven
by the decomposition of phytoplankton biomass. The river received both point and non-point nutrient loading, and algal blooms form behind dams under lentic-like conditions. Downstream of the river serves as an important labile contributor to the BOD load and chronic hypoxia characterizing the lower river and upper estuary.

The monitoring of water quality and assessment of organic pollution load in the Nilufer stream, Turkey was done by Karaer and Kucukballi (2006). Their results indicated sub-standard water quality in most parts of the stream. Untreated domestic wastewaters, industrial discharges and agricultural activities contributed to the total annual organic loading. The study revealed the importance of construction operation, maintenance and legislation of wastewater collection and treatment programmes, as well as the need for strict control of point and non-point nutrient loads for the preservation of the Nulifer stream’s water quality. The study reported higher DO during rainy months which dropped during summer and autumn with an increase in temperature. The higher BOD value during winter also coincided with low flow.

Kannel et al. (2007) studied the water quality of river Baghmati and its tributaries in Kathmandu. A comparative study of the river water quality in rural and urban areas showed that in rural areas water was contaminated with chemical fertilizers and industrial wastes while in urban areas major pollutant was untreated municipal waste. They demonstrated that higher COD, BOD ratio was an indicator of industrial activity.

Ecological characteristics of Vrishbhavathy river in Bangalore, India were investigated by Ahipathy and Puttaiah (2006). They observed that the river in upper stretches was highly polluted while the same declined downstream showing self purifying capacity of the river. Seasonal variation in pollution indicator parameters showed lowest values during rainy months
due to dilution while a maximum was recorded during summer owing to evaporation and reduced input of runoff water.

Pippo et al. (2006) in their study in the river Sarno (Southern Italy) found that the pollution level of the river varies drastically with season. They reported that during dry months the river water had turned almost like sewage, when most of the flow was generated by discharges of industrial effluents and wastewaters of domestic origin.

A study on impact of paper mill effluents on the pollution load of river Gola (India) revealed that the BOD, COD, TDS, TSS, chloride and nitrate contents of river water increased by 20-30 times after confluence of the paper mill waste with the river (Chandra et al., 2006).

A study on physico-chemical characteristics of Mouri River of Khulna, Bangladesh has shown that the river has capacity to buffer and thereby maintain the pH within a narrow range (Kamal et al., 2007). Roy (1955) had also reported similar results in case of Hoogly river.

Impact of urban waste water discharge on water quality of Gomti river in Lucknow has been extensively studied by Tripathi et al. (2006). They have reported that as soon as the river enters the city the water quality deteriorates. The main sources of effluents are the tributaries that pour domestic sewage and industrial wastewater into the river making the river water unfit for human use all along its course till it flows out of the city.

Studies on impact of paper mill and cement factory effluents on the quality of water of river Surma (Bangladesh) have revealed that season had a great effect on the water quality parameters. During rainy season the waste assimilation capacity of the river increases bringing down the BOD and coliform count much below the dry season maxima (Alam et al., 2007).
Nandan (2007) studied the water quality of Periyar river and reported that downstream locations were more contaminated with heavy metals and nutrients like $\text{PO}_4$, $\text{NO}_3$ and $\text{SO}_4$ due to joining of tributaries bringing in the industrial wastes.

Ogun river of southwest Nigeria has been studied extensively for water quality parameters. It has been found that deterioration in river water quality could be attributed to urban run-off, discharge of untreated sewage, industrial effluents and run-off from agricultural fields. The most important factor determining water quality of Ogun river was found to be rainfall which was reflected in high variation in water quality parameters during rainy season and dry periods of the year (Jaji et al., 2007).

A study on water quality assessment of three rivers of Central India viz., Kanhan, Pench and Nag has revealed that water quality of Nag river passing through the city of Nagpur is impaired more significantly than the other two. In general, the water quality in upper reaches of these rivers was better than those in lower reaches (Khadse et al., 2007).

Girija et al. (2007) in her study on the water quality assessment of an untreated effluent impacted urban stream - the Bharalu tributary of the Brahmaputra river, India found that BOD, DO and total phosphorus were the sensitive parameters for monitoring the water quality of the river. Relationship among different parameters revealed that the causes of water quality degradation in the river were urban waste discharge, sub-surface flow, and inflow of untreated sewage. It was found that flooding during rainy seasons improves the water quality to some extent.

Prasad and Patil (2008) studied the physico-chemical characteristics of river Krishna and reported that most parameters studied were within the standard permissible limits of Indian Council of Medical Research (1975) and World Health Organisation (1997).
Hassan et al. (2008) while studying the phytoplankton community of river Shatt Al-Hilla reported that Baccilariophyceae was the most dominant group followed by Chlorophyceae and Cyanophyceae. Most phytoplankton species were isolated from the benthos and maximum diversity was recorded during spring.

Prabu et al. (2008) studied the quality of water of Huluka river of Ambo, Ethiopia and reported that the water quality deteriorated along the length of river from upstream to downstream characterized by high BOD, COD, high conductivity and low DO. The deterioration in quality of water was mainly due to direct discharge of domestic and municipal sewage water.

Adeyemo et al. (2008) studied water quality of river Ibadan receiving urban waste and sewage from Ibadan city, Nigeria and reported that discharge of domestic, agricultural and industrial wastes adversely affected and impaired the water quality of the river. In general, the quality of downstream water was worse than the upstream sampling stations.

Raja et al. (2008) studied the physico-chemical characteristics of river Cauvery near Trichirapalli and reported that domestic sewage and run-off from agricultural fields were main sources of pollution which was reflected in large depletion of dissolved oxygen, higher COD, higher nitrate and phosphate contents and occurrence of Microcystis bloom. Umaheshwari (2009) in their study on river Cauvery reported that maximum BOD was recorded during pre-monsoon dry seasons which were mainly attributed to reduced volume of water in the river.

A study on impact of sand mining from rivers of Vembanad lake (India) by Padmalal et al. (2008) revealed that the population of aquatic insects viz., mayfly, dragonfly, caddisfly and other insects of the order Diptera had dropped significantly in areas affected by sand mining.

Moskovchenko et al. (2009) studied the water quality of Vatinsky Egan river in West Siberia and reported that water quality of this river is largely governed by the presence of bogs,
lithological and hydrological settings and land use of the area. Impact of urban waste discharge was minimal and noted by the presence of nitrate content in the water at certain locations.

A study on spatio-temporal variations in water quality of Nullah Aik-tributary of the river Chenab, Pakistan by Qadir *et al.* (2008) revealed that the upstream sites show better water quality in comparison to sites located downstream. The water quality declined in the middle of the stream as the stream passes through the Sialkot city due to waste input from municipal sewage and industrial units.

In Haridwar the water of River Ganga was found to be of excellent quality in winter season which starts declining in summer and touches the lowest level during rainy season (Gangwar *et al*., 2007).

Studies on water quality of river Buriganga (Dhaka) revealed that the water was contaminated with organic, chemical as well as bacterial pollutants which are reflected in higher BOD and COD values and higher population of enteric bacteria (Hasan *et al*., 2006).

A study conducted by Mishra *et al.* (2009) on physico-chemical and bacteriological characteristics of Ganga river water in Varanasi (Mishra *et al*., 2009) has revealed that the river water was not safe for human use and values of most water quality indicator parameters were much beyond the permissible limit of WHO (1997).

Bilgrami and Kumar (1998) studied the water quality of river Ganga in Bhagalpur and reported that the coliform maxima were recorded during rainy season which was much beyond the permissible limits of WHO (1997). The deterioration in quality of Ganga river in Bhagalpur was attributed to discharge of untreated municipal and industrial effluents.

Hyderabad city releases large quantity of wastewater into Musi river impairing the quality of water. A survey conducted on purification capacity of the river found that the water
quality improved dramatically with distance from the city and water was safe for use in irrigation at about 40km downstream of the city (Ensink, et al., 2010).

Recently, Venkateshwaraju et al. (2010) studied the water quality of Cauvery river and suggested that the water quality parameters could be grouped into two categories-conservative which included TDS, TH, conductivity, Ca, Na, K and sulphate and non conservative included DO, BOD,COD, nitrates and phosphate. He found that most conservative parameters peaked during post monsoon period while non conservative parameters peaked during pre-monsoon season.

Results of the study conducted by Joseph and Jacob (2010) on physical, chemical, bacterial and fungal characteristics of Pennar river indicated that the water of the river is highly contaminated and not safe for human use. Most contaminants of the river water come from nearby paddy fields, coconut and oil palm plantations and human habitations. The water quality parameters showed definite seasonal and spatial variations. The study revealed that run-off water from coconut and palm oil plantations were more detrimental to water quality than other land uses as river stretches near such plantations were more seriously impaired.

Solaraj et al. (2010) reported that large scale utilization of Cauvery river water for irrigation and drinking purposes and lack of appropriate water management has deteriorated the water quality of the river. The monsoonal rain increases the river flow rate and affects water characteristics viz., dissolved solids, phosphate and dissolved oxygen. Agricultural run-off from the watershed, sewage and industrial effluents were the most probable causes of Cauvery river water pollution.

A comparative study on seasonal variation in physico-chemical characteristics of Cauvery, Bhavani and Noyyal rivers of Tamil Nadu showed that Noyyal river water was more
polluted followed by Bhavani and Cauvery. Lower BOD, COD, TSS, turbidity and electrical conductivity values in Cauvery river was attributed to higher discharge rate and volume of water of this river as compared to the other two which are the tributaries of Cauvery (Varunprasath and Daniel, 2010).

Jindal and Sharma (2010) studied water quality of Sutlej river near Ludhiana and reported that the water quality was better in upstream sampling stations and significantly deteriorated downstream due to inflow of agricultural runoff and industrial effluents. This study also brought to fore the impact of water current on the plankton population and productivity.

Studies on phytoplankton and zooplankton in river waters have not received as much attention as the physico-chemical and bacteriological analysis. A few important studies with special emphasis on Indian river systems are reviewed here under:-

Decamps et al. (1984) studied the phytoplankton population in Lot river of Europe and reported that of Microcystis granulate, Fragillaria crotonesis and Cyclotella sp., Chlamydomonas sp. and Anabaena sp. were the dominant phytoplanktons in the river.

In river Khandagad, a tributary of Alaknanda, the planktonic community consists of the member of Bacillariophyceae, Chlorophyceae Cyanophyceae and Cladocerans whose density was low during monsoon than other periods of the year. Among these groups Bacillariophyceae was the most dominant group (Nautiyal, 1985).

Srivastava et al. (1990) reported that zooplankton population in river Ganga was maximum during summers and minimum during rainy season.

In Periyar river (Kerala) phytoplankton community is comprised of Chlorophyceae, especially desmids and members of Bacillariophyceae (Nandan, 2007). Studies on impact of
industrial pollution on phytoplankton community of river waters has revealed that in industrially polluted waters members of Cyanophyceae and Chlorococcales dominate (Joy, 1992).

Poornima et al. (2007) studied the impact of effluent discharge from power plant on the biomass and productivity of phytoplankton and reported that low temperature rise (upto 40°C) did not cause any significant change in phytoplankton biomass and productivity and diatom growth was not much influenced by low temperature shock.

**Literature on River Umkhrah**

The Umkhrah may not be a very big river, however, it has a place of importance as it flows through the city of Shillong and it is one of the main perennial rivers feeding the Umiam reservoir. The widespread discharge of municipal waste that happen along the course of this river has attracted attention of researchers and a few studies have been conducted and reports written on the deterioration in quality of the river water. Literature on the water quality of river Umkhrah is reviewed here under:-

In the year 1996 the North-Eastern Hill University, Shillong, compiled the data on water quality of 15 rivers and 5 lakes in Meghalaya, the Umkhrah river was one of the rivers described in the report (NEHU, 1996). It was reported that this river had the highest BOD and COD, high load of solids and very large number of coliform bacteria. The river water also contained high values of nitrate-nitrogen which indicated that complete decomposition of biodegradable materials was still going on in the river. The source of data was from the records of Meghalaya State Pollution Control Board, Shillong.

Rout (1991) studied the algae of two tributaries of Umkhrah viz., Wah Dienglieng and Wah Risa and reported that diatoms were dominant in the epilithon of the streams. Among diatoms, species *Caneis silicula, Eonotia pectinalis, Gomphonema gracilis, G. lanceolatum,*
Navicula cari, N. complanatula, N. gracilis, Pinnularia gibba, P. interrupta, Synedra acus and S. ulna were abundantly found. A few blue green algae were also recorded by her from the two streams.

A study was conducted by Nongbri (2002) with the main objective of assessing the environmental status of the Umiam Lake and pollution levels in the Umkhrah and Umshyrpi rivers. She reported that silt carried by Umkhrah and Umshyrpi rivers have led to the siltation of the Umiam lake. She further concluded that the quality of the lake water has deteriorated to the point of being classified as not fit for human consumption.

The Meghalaya State Pollution Control Board and North-Eastern Hill University conducted a joint study to assess the water quality of the Umkhrah river (MSPCB-NEHU, 2004). It was reported that low DO levels and high values of BOD, COD, total bacteria and oil and grease have made the river water unsuitable for human use.

The North East Educational and Development Society (NEEDS), a non-governmental organization (NGO), undertook a short term project entitled “Save and Clean Wah Umkhrah” funded by the Blacksmith Institute, United States of America in the year 2004-2005. NEEDS found that the condition of sanitation and drainage was in a bad state with no proper drains and toilets facilities in localities adjoining the river.

The review of literature revealed that except the joint publication of Meghalaya State Pollution Control Board and North-Eastern Hill University (MSPCB-NEHU, 2004), no temporal and spatial sampling based research has been conducted on the river Umkhrah. Therefore, there is an urgent need for a study on water quality of Umkhrah river which can be used for developing management strategies and for improving the water quality of the river.