Water Treatment Process Options for Gravity-Feed System of Rural Water Supply Scheme in Western Sarawak

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DECLARATION

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

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ABSTRACT

Water resource is abundant in Malaysia. The renewable water resource from both surface water and groundwater is about 630 billion cubic meters. About 97 percent of the rivers in Malaysia are abstracted for public water supplies. This contributes to the establishment of 487 water treatment plant intake points in Peninsular Malaysia and 91 in Sarawak. The number does not include the number of water treatment plants established in the State of Sabah.

Nevertheless, the nation aspiration of overarching vision 2020 to achieve the fully developed nation status has caused impacts to the national water resources because of the rapid pace of socio-economic development. The stakeholders have started expressing their concern on the issues of freshwater scarcity because of apparent degradation in water quality standard. Furthermore, the land-use developments have extended into the rural areas to exploit the natural resources for economic purposes. Consequently, the pollutions generated from unregulated development activities have caused environmental impacts and scarcity of freshwater sources from designated water supply catchment areas.

Since the urban populations are getting their water sources from major river basins, which are larger, the populations living in remote rural areas are experiencing the opposite. In the State of Sarawak, 60 percent of the population are living in the remote rural areas. They get their water supply from freshwater sources that come from smaller water catchments provided by the State Health Department, known as the gravity-feed water catchment.

In this regard, only designated first-priority water catchments with sources that comply with the requirement of the drinking water quality standards as well as passing the catchment sanitary survey are chosen for development as gravity-feed systems. Because of the high raw water quality, the villages are supplied with these sources as their drinking water, through piped-gravity water without the provision of any basic treatment. The communities are only advised to boil their water for safety reasons. The

State Health Department carries out routine drinking water quality surveillance programmes to monitor the water quality from the gravity-feed systems. In 2002, there are 2,730 gravity-feed system established in Sarawak.These gravity-feed systems are developed by the State Health Department.

The purpose of this study is to determine the conditions of raw water quality from various State Health Department gravity-feed systems as of whether these raw waters are still safe as drinking water for the rural populations. Due to some constraints and limitations, only water quality data from selected water catchments in three districts of Western Sarawak, namely, Lundu, Serian and Betong are used for the study. In addition, the study is trying to determine the best available solution to overcome the water quality problems by finding a feasible and economical water treatment process options to enhance existing practice adopted by the State Health Department for the rural water supply.

TABLE OF CONTENTS

CHAPTER FOUR: WATER AUTHORITIES FOR COMPARATIVE STUDY

CHAPTER FIVE: RESULTS AND ANALYSIS

CHAPTER SIX: DISCUSSION

CHAPTER SEVEN: CONCLUSION AND RECOMMENDATION

APPENDICES

DATA ON MUARA TEBAS WATER AUTHORITY

DATA ON LUNDU WATER AUTHORITY

DATA ON TRIBOH WATER AUTHORITY

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOS

LIST OF MAPS

ABBREVIATIONS

PWD:	Public Works Department
SHD:	State Health Department
MOH:	Ministry of Health
NCR:	Native Customary Rights
LAKU:	Lembaga Air Kawasan Utara Sdn.Bhd (A water company owned by the State Government)
WHO:	World Health Organization
NDWQSP:	National Drinking Water Quality Survillance Programme
NDWQS:	National Water Drinking Water Quality Standard (Rev.2000)

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CHAPTER ONE: STUDY BACKGROUND

1.1. Introduction

The study is trying to determine the best available solution to overcome the water quality problems at sources by finding attainable alternatives or feasible economical water treatment process options, other than the current best practice adopted by the State Health Department, on treating the raw water from the gravity-feed system for the rural water supply. The study effort is to minimize any potential harmful health impact to the rural communities living in the remote interior of Sarawak that consume directly the piped-gravity water for their daily household needs. The water sources might be contaminated due to interference by human activities within the designated small gravity-feed catchments. Furthermore, these gravity-feed catchments function as a critical source of fresh drinking water for the rural settlements that are without accessibility to potable piped-water from any of the water supply authorities.

Before going in-depth with the research study details, sufficient background information related to water matters on water resources in Sarawak, water supply schemes and catchments protection will be provided. To support the recommendation of the study, the research study from the literature review shall enhance the understanding of pertinent issues related to the importance of water quality to human health as well as providing better insight on dealing with the raw water quality problems for the rural water supply. The literature review also provides views from the perspective of different experts who are exposed with the water resources and catchment issues in Sarawak.

In addition, the issue on the significance of catchment protection and management to ascertain sufficient long-term availability of freshwater for the rural population is elaborated in the literature review. Although this particular topic on catchment protection is not extensively covered in the study, its importance cannot be ignored totally. This is because effective catchment protection will ensure the pollution generated by human activities could be reduced and the freshwater quality could be maintained at a high standard.

To carry out this study, the water quality data from a total of 329 identified gravity-feed water catchments scattered across the Western Sarawak (Unit BAKAS Negeri,2001), which is about 30 percent of the established gravity-feed systems in this region, shall be investigated and selected for the study. The compiled water quality data are gathered from the respective district health offices responsible with the water quality monitoring programme and water quality analysis. The water quality data originated from various gravity-feed systems in Western Sarawak, namely those situated in the administrative districts of Lundu District in Kuching Division, Serian District in Samarahan Division and Betong District in Betong Division.

The detailed breakdown on the numbers of gravity-feed systems in the study area and general information on numbers of houses and population directly tapping the piped-gravity water are tabulated in Table 1.

No.	District	Division	Number of Gravity-Feed Systems for the study	Number of Houses	Total Population
1	Lundu	Kuching	78	3,505	19,832
2	Serian	Samarahan	112	7,606	46,600
3	Betong	Betong	139	2,658	14,136
		TOTAL	**329**	**13,769**	**80,568**

Table 1 – Distribution of gravity-feed systems in the study area

Source: (Unit BAKAS Negeri,2001)

Besides studying the water quality data from the gravity-feed systems situated in Western Sarawak, use of any previous research on gravity-feed systems from Eastern Sarawak is taken into consideration. The reason is to ensure knowledge on common water quality problems from gravity-feed catchments in the eastern region of Sarawak could be acquired. However, because of the land coverage, carrying out the full extensive study of gravity-feed systems for the entire Sarawak is not possible to be achieved due to the travelling distances, accessibility, remote localities of gravity-feed catchments and restricted financial budget.

In addition, a comparative study between the selected water supply authorities operated by the Public Works Department that use various types of water treatment system and process methods to treat raw water sources originating from different gravity-feed catchments, which inherit similar characteristic like State Health Department gravity-feed catchments, are incorporated in this thesis study to analyze the quality of treated water being produced as drinking-water from these different water treatment systems. The results of this comparative study are used to determine the simplicity of treatment system that can be considered to enhance the existing State Health Department gravity-feed system in the recommendation of the study.

The involvement of public participation shall be taken into consideration on the choices of the final treatment process options. The economic of scale of the treatment system and treatment process to be adopted is significant for implementation of the rural water supply. Sufficient information on the economic aspect on the cost of various treatment options will be provided as guideline.

Although it is envisaged in the future planning of water supply that rural communities shall be served with fully-treated potable water, after the pipeline networks are extended from any of the nearby Water Supply Authority and road accessibility are made available by the government (Government of Sarawak,2003), the important function of the gravity-feed catchment is still significant to these rural folks. Notwithstanding, the significant of scenic and serene rural environments with natural water flowing from the highland that form part of the local heritage, these sources of free freshwater system can still be utilized by the inhabitants for irrigation purposes as well as a supplementary supply for drinking-water provided the sources are free from contamination.

1.2. Study Focus

In order to provide a comprehensive coverage of this study, the study focus will draw attention on the following emphasis:

(i) To provide sufficient overview on issues of land use development, water resources and water supply development in Malaysia, with particular focus on Sarawak. Adequately cover the subjects related to water matters at both national and state level, jurisdiction over water supply schemes, protection of water catchment areas and the development strategy of water supply schemes for rural communities.

(ii) To gather sufficient amount of data from the respective authorities so that the status of raw water quality parameters from the groups of selected gravity-feed systems in Western Sarawak can be determined. This is to find out the types of pollutions being faced by these gravity-feed catchments. The basic question that needs to be answered is on the safety factor of consuming the raw water without affecting the health of the rural population.

(iii) To explore the possibility of existing available technologies or best available practices that are practical and economical to deal on certain water quality problems, hence could be accepted as an option to improve the raw water quality for the gravity-feed systems. The literature review will be used as a platform to explore the possible solutions to deal with the water quality issues.

(iv) The catchment protection will be considered as the immediate option, if this is the best solution to improve the raw water quality problems for the gravity-feed water catchments.

(v) The contribution from this study should benefit the government as well as the rural communities in Sarawak.

(vi) Generally, with the assumption that most of these small gravity-feed systems will eventually face similar environmental problems once affected by the land use developments, the recommendation of this study could be considered as generic guidelines to improve the design concept to overcome the raw water quality problems for the gravity-feed system in Sarawak.

1.3. Research Question

The human activities that are not regulated could cause environmental impacts to the raw water sources originating from the gravity-feed catchments. With most of the water from the gravity-feed system in Sarawak are not provided with any kind of basic or primary treatment, thus this study is initiated to examine whether problems of pollution have taken place and affecting the raw water quality of designated first-priority gravity-feed catchment areas, which is the preferred option by the State Health Department in Sarawak (MOH, 1984).

If there are indicators after analyzing the raw water quality data that pollutions do exist and could cause health impacts to the inhabitants, recommendation to improve the design concept of existing gravity-feed system will be elaborated to ensure the raw water could be maintained to an acceptable limit of drinking water quality standard for safe consumption.

Consideration on use of available new technology on water treatment process that is deemed practical for implementation in the rural environment of Sarawak will be included in the study, provided that it is feasible for implementation. Otherwise, the choice for the most economic and feasibility application to enhance the existing gravity-feed system shall be pursued.

The comparative study is to reveal whether the raw water sources using simple treatment process and conventional treatment process could provide some kind of solutions to improve the drinking water quality problems for the rural gravity-feeds being provided by the State Health Department. It is to determine the best treatment process options by analysing the water quality results and findings in the literature review on the most economical and feasible water treatment choices for rural environment.

In this regard, three water supply authorities that draw raw water using similar gravity-feed system will be studied on the effectiveness of using different conventional treatment methods to treat their raw waters, namely, (a) Triboh Water Supply Authority, (b) Muara Tebas Water Supply Authority and (c) Lundu Water Supply Authority.

1.4. Hypothesis

The hypothesis of the study is that the existing design practice for gravity-feed systems is insufficient to sustain safe drinking water supply to rural communities in the long-term because of human activities are affecting the raw water catchments hence making the water unsafe for consumption. If the hypothesis is correct, then water treatment process options or measures to improve the affected raw water sources are compulsory for implementation.

1.5. The Purpose and Limitation of Study

The purpose of this study is to research the condition of raw water quality from various gravity-feed water catchments in Western Sarawak and to determine whether these raw waters are still safe for direct consumption by the rural populations that are directly dependent on these sources for their livelihood.

If the compiled records of raw water quality data from these selected gravity-feed catchments indicated presence of poor water quality standard and significantly threats the water users, then alternatives in the forms of best available practices for water treatment process that are acceptable to rural conditions as well as economical to implement will be looked into. In addition, available technology that is practical for water treatment process options to treat raw water from the gravity-feed systems will also be considered.

The limitations that are acknowledged in implementing this study include the followings:

(i) The gravity-feed systems in Western Sarawak and under the jurisdiction of State Health Department that demonstrated extensive amount of recorded water quality data over the past years are only used for the study.

(ii) Due to time constraint, limitation of resources and budget, the study of the gravity-feed system for the whole state is not attainable. Since all the gravity-feed catchments are quite similar in sizes and characteristic as well as the potential environmental problems being encountered are quite similar, the findings in this study are relevant for use in other gravity-feed systems in Sarawak.

(iii) Since the purpose of the study is to examine the condition of raw water quality and to determine the best available solution to solve the water quality problem for the gravity-feed system, this study is not carried out to examine the characteristic of a specific gravity-feed catchment or specific demographic profiles for a particular catchment, but rather focusing on the accumulative effects of water pollution faces by the selected groups of gravity-feed systems in Western Sarawak.

(iv) In general, the recorded raw water quality data compiled from Medical Department contains data gaps and missing records of certain water quality parameters. The major problems being experienced during the course of carrying out this study is to convert the compilation of water quality data from hardcopy to softcopy from both the State Health Department and the Public Works Department. The efforts of doing the conversion have taken major portions of the study period to accumulate sufficient amount of data for the purpose of data analysis.

(v) The problems of water shortage faced by the inhabitants due to reoccurrence of prolonged drought period, problem of low water pressure in the pipeline system due to the design failure, increase of water demand by consumers due to population growth and reduction of safe yield from the catchment are not considered as key factors in this study.

CHAPTER TWO: LITERATURE REVIEW

The literature review on works of others that are relevant to the current research is encompassed in this document for purpose of consolidating available knowledge on the discussed topics. The collective minds and different point of views on the particular subject will broaden the understanding on the subject matters; besides acknowledging the extent of available literatures used to support the research study. Importantly, the substantial benefit of this literature review is enabling the research questions to be responded accordingly, in-depth analysis of key issues on the water quality problems could be explored through different perspectives as well as positioning the research focus in providing purposeful answers to support the prediction in the hypothesis.

2.1. Water Resources in Malaysia

The remark by the President of the World Water Council described that “water is life, in all forms and shapes” (Cosgrove,et.al.,2000), but apparently water scarcity is afflicting more nations to have access to clean drinking-water and sanitation, as the world population increased, urbanization and industrialization keep expanding (Cosgrove,*et.al*.,2000). Similarly, the report by the World Water Vision also highlighted that the world is facing an adverse water crisis because of high water demand from various major sectors that are substantial water users, namely the agriculture, industry and municipalities (Cosgrove,*et.al*.,2000). Because of the anthropogenic activities from these substantial water users, the generation of waste effluents or pollutions originating from discharges of point-sources or non-point sources hence contributed to the magnitude of water quality deterioration that causes detrimental impacts to the environment.

From the perspective of Malaysia, the availability of water resources has been the basis of socio-economic development over the past decades. Lately, the water supply situation for the country has changed from a relative abundance to one of scarcity. The water quality has starting to become a paramount concern. The population growth, urbanization, industrialization and expansion of irrigated agriculture areas are pressing for increased demand on water resources. It is becoming the national concern that developing beyond the carrying capacity of the river basins could result to unsustainable future for the country and could cause irreversible impacts to the environment.

Furthermore, development must be pursued within an acceptable limit of the environmental carrying capacity, while encouraging the efforts of protecting and restoring the environment. This could reduce the potential water pollution problems (Malaysian Water Partnership,2002).

Aware on the significance of water resources for the growth and socio-economic development of the nation, the Malaysian Government initiated in 1999 the formation of the National Consultation Meeting to formulate the *Malaysian Vision for Water in the 21st.Century*. The consensus reached in the meeting by the participating stakeholders endorsed the desired goals of water use that should be both sustainable and achievable in the long-term. This is in-line with the World Water Vision and the overarching national vision to achieve the industrial status and fully developed nation status by the year 2020 (Abdullah,1999).

Based from the experience in Malaysia, the drastic changes of rivers morphological characteristics are very much contributed to land clearing activities. These land-clearing activities accelerated the increased level of suspended solids in the water (Johari,1999). On the other hand, the impact of urbanization and industrialization reduced significantly the prescribed water quality classification for beneficial uses in several rivers to about 68 percent in Malaysia (Johari,1995). The direct impacts from these development activities are the environmental pollution and degradation of water quality in the country.

As highlighted in the Table 2, the trends of water quality of selected rivers in Malaysia between the periods of 1992 until 1998 indicated about 75 percent of the rivers within that particular period are exceeding more than 50 percent in the *slightly polluted* category. Similarly, the trends of *very polluted* rivers are on the increase from 1992 until 1997, that recorded only 8.1 percent in 1992 and rising to 21.4 percent in 1997. The percentage only starts to show a declining trend to 13 percent in 1998. This 1998 data is supported by the chart in Figure 1. The gradual increases on numbers of clean water category that are recorded during the periods of 1998 to 2000 supported the reduction of rivers categorized as being *very polluted*.

Category	1992		1993		1994		1995		1996		1997		1998	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Very polluted	7	8.1	11	9.5	14	12.1	14	12.2	13	11.2	25	21.4	16	13
Slightly polluted	55	63.2	73	62.9	64	55.2	53	46.1	61	52.6	68	58.1	71	59
Clean	25	28.7	32	27.6	38	32.7	48	41.7	42	36.2	24	20.5	33	28
Total	**87**	**100**	**116**	**100**	**116**	**100**	**115**	**100**	**116**	**100**	**117**	**100**	**120**	**100**

Table 2 – Trend on quality of river water from 1992-1998

Source: (Abdullah. S, 1999)

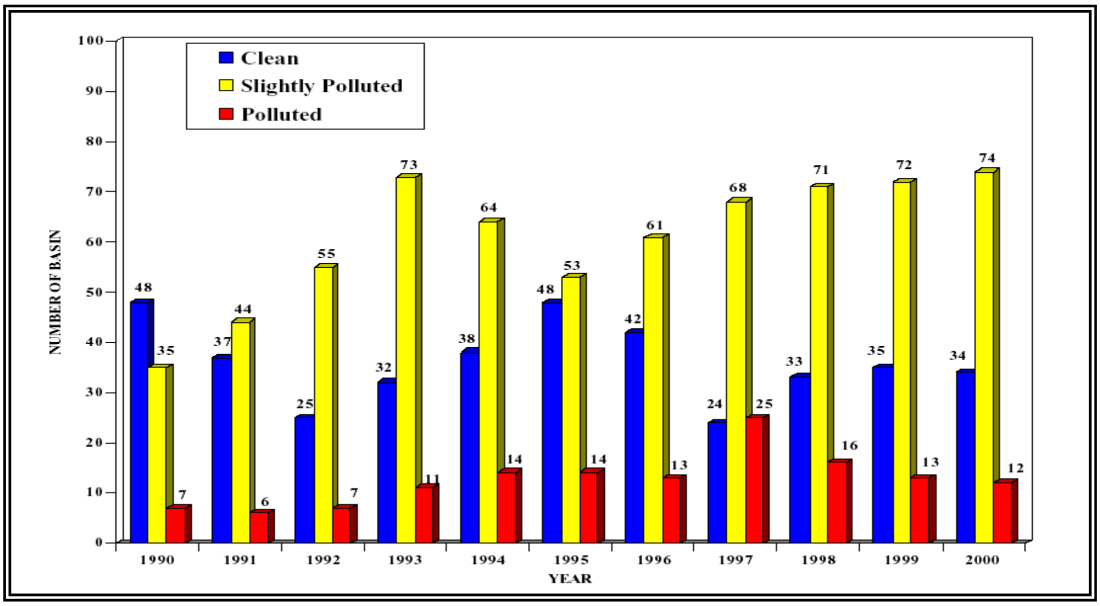


Figure 1: River basin water quality trend in Malaysia (1990- 2000)

Source: (Abdul Rahman.Z,2002)

According to Zakaria (2000), only 2.5 percent of the surface runoff is currently used in Malaysia. Still, shortages of river water are being experienced during prolonged drought periods. On distribution of rainfall, the state of Sarawak received the most, with an average annual rainfall of 3,830 mm as compared to Peninsular Malaysia that received 2,420 mm and the state of Sabah receiving at an average of 2,630 mm annually. In terms of volume, out of 566 billion cubic meters of surface runoff in Malaysia, 306 billion cubic meters are in Sarawak, 147 billion cubic meters in Peninsular Malaysia and 113 billion cubic meters in Sabah.

The summary on the distribution of water resources in Malaysia is tabulated in Table 3.The renewable water resource, which is the summation of surface runoff and groundwater recharge, totalled to 630 billion cubic meters. This translates into an annual average water availability of about 28,400 cubic meters per capita. Based on this fact, Malaysia is a country with abundant water resources (Malaysian Water Partnership,2002).

Annual rainfall	990 billion m^3
Surface runoff	*566 billion* m^3
Evapo-transpiration	*360 billion* m^3
Groundwater recharge	*64 billion* m^3
Surface artificial storage (dams)	25 billion m^3
Groundwater storage (aquifers)	5 000 billion m^3

Table 3 – Distribution of water resources in Malaysia

Source: (Malaysian Water Partnership,2002)

About 97 percent of the rivers in Malaysia are abstracted for public water supply purposes (Zakaria,2000). In the urban areas, water sources for drinking purpose are mainly taken from rivers and treated by the authorities before distributed to individual houses. Streams and rivers with and without impounding reservoirs contribute 98 percent of the total water used in Malaysia; the remainder is contributed by groundwater. River flow regimes are irregular and to secure safe yield from surface water sources, storage facilities were constructed. Currently, there are 47 single-purpose and 16 multipurpose dams with a total storage capacity of 25 billion cubic meters. The main reason for lacking in utilizing the groundwater in the country is due to availability and abundance of surface water resources; there are over 150 river systems in Malaysia (Abdullah,K. and Mohamed, A., 1998).

In Malaysia, the water demand from 1980 to 2000 has been increasing from 9.9 billion cubic meters to 15.5 billion cubic meters respectively. Due to the rapid population increase and the rapid growth of industries, the annual water demand for the domestic and industrial sector has been expanding at the rate of about 12 percent. By the year 2020, the domestic and industrial sector is projected to be the main water users in the country (Economic Planning Unit, 2001). It is estimated that the water demand is projected to increase to 20 billion cubic meters by 2020 (Zakaria,2000).

On the extent of water supply coverage for the national level, the years between 1990 to 2000, have indicated an increase from 96 percent to 99 percent for urban areas. While the rural coverage only increased from 67 percent to 83 percent in the same periods (Economic Planning Unit, 2001). Initially, the developments of the rural water supplies were confined to areas within the vicinity of “urban water supply systems and the newly formed land settlement schemes developed by the Government” (JKR Homepage,1998). The government’s interest on rural water supply becomes a priority only during the Third Malaysia Plan (1976-1980).This was a result of the rapid increase in rural populations that prompted the following Malaysia development plans to emphasize more commitments in providing water supply to those growing rural population. Towards this end, more water supply projects were extended to the rural areas with several being implemented in large schemes (JKR Homepage,1998).

2.2. Water Resources Management System Status

As a whole, to ensure sustainability of the water resource, the protection of water catchment is essential because it also complements the protection of the water sources, particularly the selected gravity-feed systems in the rural areas. However, the experiences gathered by the World Health Organization (1993) indicated that the protection of open surface water is a problematic endeavour. Lots of factor needs to be taken into consideration to protect the rivers such as existing and historical values or uses of these rivers by the locals.

The United Nations (1998) in a publication on sources and nature of water quality problems in Asia and the Pacific calls for "…strategies leading to the reduction of pressure on water resources, while also ensuring adequate supplies of freshwater for present and future generations". The urgency for an immediate attention for strategic water resources development is raised due to concern of startling situation on water shortages and water quality deterioration being faced by nations in part of the developing regions. To overcome the potential water crisis, the United Nations (1998) advocated the adoption of an integrated water resources planning and management concept as well as advising the nations to protect all known or potential water resources to prevent the freshwater calamity to sustain their own future development interest. In this regard, it further stressed that effort should be made to integrate the social and economic development, the protection of natural systems, land use and water system throughout the water catchment areas to overcome the persisting water problems (United Nations,1998).

In the case of Malaysia, Lee (1997) described that the future success of water resources management in Malaysia could be achievable provided the development of a socio-political institutional mechanisms at both state and federal level are working effectively with full-cooperation. Similarly, the public and private sectors could contribute to the changing needs and protection of the environment as well as the society in the long-terms. The author asserted that besides the legal and operational framework are essential for the regulatory roles to be carried out by the respective authorities, emphasis of promoting greater pubic awareness, human resources development and supportive research, and information dissemination to the public must be comprehensively implemented by the relevant authorities.

Furthermore, Lee (1997) stated that the support of political-will indefinitely reduce the resistance and criticism amongst affected departments that fear the loss of control over their jurisdictional empowerment. With clear provision of regulatory powers entrusted to the respective authorities, this shall warrant the successful implementation of the integrated water resources and environmental management (Lee,1997).

The experience from the State of Sabah, which borders Sarawak in the north-eastern region of Borneo Island, on water resource management to support their sustainable development is very much encouraging (Government of Malaysia,1997). In a water resources master plan study commissioned by Sabah Government, (Sabah Government,1994), an inclusion on the significance of the pipe-gravity feed systems is being advocated for consideration by the state. The gazette of the gravity-feed catchments was put forward as a recommendation to protect the water supply for the rural settlements.

It is clearly stated in the master plan document that the aim is to ensure sustenance of water quality and quantity for the rural inhabitants as well as in-line with the role of the master plan to provide framework for the development of detailed plan of any specific purposes related to water resources utilization that will offer advantages in the field of water resources planning, investigation and management to sustain the economic, social and environmental uses (Sabah Government,1994). Significantly, the master plan also addressed the need of an integrated approach in managing the water resources that encompassing the water quality and quantity, the aquatic environment and land use (Sabah Government,1994).

While in the state of Sarawak, the issues and problems on water resources has gradually raised public attention and demanding effective and efficient water management. In this regard, the challenges of water resources management in Sarawak are well addressed by Memon and Mohamad (1999) in their book on *Water Resource Management in Sarawak, Malaysia*. The authors mentioned that the state is the biggest land owner and developer in Sarawak. With the state aspiration to develop the rural agro-based and timber industries, and pursuing the development objective of developing the "estate and plantation agriculture, based on the development of NCR land" (Memon and Mohamad,1999), thus these have "become the engine of growth for the agriculture sector and for the rural society" (Memon and Mohamad,1999).

Memon and Mohamad (1999) further described that the pursued development programme of amalgamating the plantation of crops such as oil palm, forestry, aquaculture and agro-tourism, has resulted a consequential impact of "..major implications from an environmental perspective, particularly with regard to water" in the rural environment. Even earlier study on rural development had indicated that several small hill catchments had already been subjected to small scale logging activities by the local residents for their personal use (Government of Sarawak,1990).

Initiating five identified key economic areas to be further pursued by the state of Sarawak, namely, on manufacturing, commercial agriculture and land development, tourism, construction and the service sector targeted for implementation until the year 2020, Memon and Mohamad (1999) assessed that further downstream environmental impacts will be expected to the environment and water resource, if effective management strategies are not formulated by the state government to overcome the future detrimental impacts caused by the development activities (Memon and Mohamad,1999).

According to Boehmer, Memon and Mitchell (2001), they reported that the extent of in-depth coverage of the existing strategies on water resources management in Sarawak is not cohesive enough as compared to the development of water resource master plan study being formulated by the neighbouring State of Sabah. Therefore, the state government of Sarawak should focus to initiate its own water resources master planning by adopting the integrated and holistic approach that are customized to the local environmental needs, to ensure sustenance of these water resources which is essential to support the future vision of the state socio-economic development planning.

2.3. Water Catchment Protection in Sarawak

Classified into three major categories by Johari (1999), the water catchments in Malaysia are namely defined as follows: (a) urban water catchment - contain developed areas such as town, industrial zones and other economic activities. (b) rural water catchment – predominantly covered by forest, wetlands and reserves and (c) impounded water catchment – impounded water stored within reservoirs. On the abstraction of surface water from the water catchments, some 487 water treatment plants are drawing raw water from the designated catchment areas that approximately covered almost half of Peninsular Malaysia. The raw water is treated in the water treatment plants to serve the 20 million Malaysian people for domestic use and industrial water demand in the urban and industrial areas (Johari,1999).

In the case of Sarawak, some 91 water treatment plants are abstracting raw water from rivers situated in water catchments that cover about 70 percent of the state land mass (Shakeran,2001). These demarcated water catchment areas are scattered throughout the 23 Sarawak river basins; the Department of Drainage and Irrigation of Sarawak has demarcated these river basins (Hiung et.al.,1997). The raw waters are abstracted by the water treatment plants, which are treated and supply as potable water to urban users and major rural settlements through reticulated pipe systems. The operation and maintenance of the water treatment plants are carried out by the Water Supply Authorities (JKR,1996).

The provisions enacted in the water ordinance (1994) have allowed Sarawak to gazette 18 water catchment areas for the purpose of public water supply in 2002. The total land coverage of these 18 gazetted water catchments is about 3,920,461hectares, which covers about 32 percent of the state land mass. At the same time, the Sarawak Water Resources Council has endorsed additional 17 water supply catchments that are classified as priority one for gazette. Once these catchments are approved by the State Legislative Assembly for gazette, an additional 1,043,409 hectares of land areas will be declared as gazetted water catchment areas (Shakeran,2002). The various water catchments that already being declared as gazetted water catchments are highlighted in Table 4.

No	Gazette (no./year)	Gazetted Water Catchment	Administrative Division	Approximate Area (Hec.)
1	807/1993	Ulu Mukah	Sibu	107,350
2	808/1993	Ng.Sekuan/Ng.Stapang	Sibu	89,992
3	404/1994	Saratok	Sri Aman	4,988
4	80/1996	Bintulu	Bintulu	18,100
5	37/1999	Lambir	Miri	7,776
6	45/2000	Asajaya	Samarahan	6,184
7	46/2000	Betong/Spaoh/Debak	Betong & Sri Aman	33,898
8	47/2000	Bintangor	Sarikei	11,447
9	48/2000	Lubok Antu LDS	Sri Aman	46,191
10	49/2000	Sebuyau	Samarahan	39,941
11	50/2000	Tatau	Bintulu	827
12	7/2002	Stumbin Bijat	Sri Aman	2,310
13	8/2002	Pusa	Sri Aman	5,802
14	9/2002	Lingga	Sri Aman	483
15	10/2002	Lawas	Limbang	4,749
16	11/2002	Sungai Sarawak Kiri	Kuching	63,569
17	12/2002	Sarikei	Sarikei	10,036
18	13/2002	Kapit	Kapit	3,466,818
Total Area of Gazetted Water Catchments				3,920,461

Table 4 – Gazetted water catchment areas in Sarawak

Source:(Shakeran,2002)

A directive has been made by the state government pertaining to water catchment areas that are situated in the totally protected areas, such as the National Parks or Wildlife Sanctuaries. This category of catchment areas shall not be gazetted under the Water Ordinance, 1994. The respective forest legislation will be applicable for the protection of the water catchment areas residing in either the National Parks or the Wildlife Sanctuaries (Shakeran,1999).

The Sarawak Water Resources Council has classified the water catchment areas in Sarawak into three main categories for management purposes by adopting the following definitions (Shakeran,1999):

(i) Specific Independent Catchment
A water catchment area that is independent by itself and does not have any sub-catchment and neither does it form part of a main catchment.

(ii) Main Catchment
A principle water catchment area, which is an aggregate of smaller catchments to form a larger water catchment.

(iii) Sub-Catchment
A smaller individual water catchment area situated within a main catchment area.

For smaller water catchment areas designated as the gravity-feed water catchments, the policy that being adopted by the Sarawak Water Resources Council is not to re-gazette those gravity-feed catchment that are situated within any of the gazetted water catchments. Only water catchments categorized as Specific Independent Catchment and Main Catchments are to be gazetted. The declaration of gazette for the gravity-feed catchment is dependence on the condition of the gazette status of the major catchment where it resides (Shakeran,1999).

The general procedures adopted by the Sarawak Water Resources Council to gazette the water catchment areas are enumerated in the following steps (Shakeran,1999):

(i) The identified water catchment area shall be reviewed to determine under which category it will be classified.

(ii) Only the identified water catchment areas, which are classified as Specific Independent Catchment or Main Catchment, shall be gazetted.

(iii) The identified water catchment areas, which are classified as Sub-Catchment, shall not be gazetted; but the abstraction points will be identified in the gazette notification and marked in the catchment maps.

(iv) The Planning and Management Committee shall prioritize the identified water catchment areas to be gazetted based on the proposed regional water supplies by the Public Works Department.

2.4. Water Supply in Sarawak

2.4.1. State Water Legislation

Since 1959 until 1994, the State of Sarawak was still adopting the old Water Supply Ordinance (1972) that was enacted using the pre-Malaysia day law to regulate the water supply authorities and any related activities associated with water use of the State (Dewan Undangan Negeri,1994,p.16). Less was emphasized on the importance of its water sources since amount of water was then still abundance. Because of the fast development pace of the State and rapid expansion of townships and settlements along the coastal region where most of the water catchments are situated, competition arises on the water demand for other development usage (Dewan Undangan Negeri,1994).

In order to secure this water sources and its catchments for human consumption as well as regulating the development activities that could affect the sources, the old Water Supply Ordinance was repealed in 1994 and replaced by a new ordinance, the Water Ordinance, 1994, that includes both subjects related to water resources and water supplies (Water Ordinance,1994).

The Water Supply Regulations (1995) is made under section 51 of the Water Ordinance (1994) for the purpose to regulate the associated water supply activities of established water supply authorities in the state. It is the duty of these water supply authorities to supply potable and treated water to the consumers that reside within the gazetted limits of areas of supply as allowed in the provisions of the ordinance and water supply regulation.

2.4.2. Rural Community Water Supply

Sarawak has a vast landscape with area coverage of about 12,444,900 hectares (Government of Malaysia,1997). About 60 percent of the population in Sarawak is rural (Memon et.al.,1999). They are scattered over the entire state living in villages and in small groups. In 1996, some 4,500 villages were established in the state with inhabitants averaging about 200 people per village. Due to the diversity of population sizes, remoteness and isolated villages, it impeded the effort of the state government to provide potable and treated water supply to these rural settlements because of difficult accessibility and uneconomical to implement the water supply scheme (JKR,1996).

Considering the remoteness and distances of the rural settlements from major development areas, the alternative approaches initiated by the government to increase the provision of water supply coverage for rural communities living far away from any of the water supply authorities are by providing free and untreated water supply that are safe for consumption. This is implemented through the development of the gravity-feed system, rainwater harvesting scheme, household tank, groundwater abstraction scheme, rainwater harvesting pond and sanitary well system (Meng, 2002).

On the development of the gravity-feed system, the emphasis by the government on the community participation has been an on-going programme during the project implementation since the commissioning of the rural water supply scheme in Malaysia. The supervision of the project will be carried out by the relevant government agencies. This is able to “reduce capital investment, stimulates feeling of pride and commitment, develops local capabilities and promotes the proper use and care of the water supplies” (JKR, 1988).

At the same time, the effort to eradicate poverty among the rural poor has initiated the implementation of rural development strategies initiated under the National Rural Development Plan starting from the second Malaysia Development Plan (1961-1965). It is aimed to reorganize as well as mobilize the institutions towards modernization of the rural sector in Malaysia (Abdul Rahman,2000). The implementation is carried out through the Hard-core Poverty Development Programme promoted by the Ministry of Rural Development (Government of Malaysia,1997). Subsequently, the rural industrialization strategy spurs the setting up of "zones for rural industries, agricultural and timber processing complexes and light industrial zones" in some rural areas in Malaysia (Abdul Rahman,2000).

Similarly, the State of Sarawak has embodied the same policy to develop the rural land areas with land development programmes that are defined by the government. The selected sites for the rural areas must be strategic and having the potential for growth. The development plan includes the provision of public amenities to promote sustainability of the projects and serving the needs for the local population (Sarawak Government,2002). Nevertheless, the government still provide fund for the basic amenity such as provision of electricity and water supply under the rural development funding for those rural communities that are too remote and having smaller population size of less than 3,000 people. These people still carry on with their routine daily livelihood with minimal economic incomes. (Sarawak Government ,2002).

In pursue for rural development, the high demands to utilize the arable land for agriculture development and exploitation of timber resources to improve the rural economic growth have raised conflict of interests on the same land resource. This happens when the same landmarks form part of the water catchments that serve as the freshwater source for the nearby settlements. On this matter, Jusoff and Nik Mustafa (2003) asserted in their report that "logging activity since 1982 has greatly accelerated erosion in the catchment area. Poor road design and maintenance and lack of post-logging attention to forest roads and skid trails are a major cause of the increased sediment loads now experienced in the Malaysian rivers and their tributaries". Similar views was addressed by Ibuh (1997,p.4) which expressed his concern on the safety of the rural water supply with "the increasing of agricultural and timber extraction activities".

2.4.3. Water Supply Authorities

Stipulated in the Federal Constitution of Malaysia, water supply matters are the responsibility of the States, hence the state governments are empowered the responsibility with the development, operation and maintenance of their water supplies. It is the state's prerogative to execute its responsibility to supply treated water to the public by adopting the various preferred options of either through the State Public Works Department (JKR), State Water Supply Department, State Water Supply Board or State Water Supply Corporation/Company (Malaysia,1999).

In Sarawak, the State Financial Secretary was appointed as the State Water Authority in 1995 (JKR,1996). The provision cited under section 16(1)a of the water ordinance (1994) allows the appointment of an officer from the Public Service to become the State Water Authority. Generally control and supervise the water supply authorities as well as the water catchment areas in Sarawak, the State Water Authority was conferred the powers and functions to carry out the task to regulate the activities of various water supply authorities in the state (Water Ordinance,1994 and JKR,1996).

The field operation and management of water supply systems in Sarawak are under the jurisdiction of the Public Works Department and three water boards namely, Kuching Water Board (KWB), Sibu Water Board (SWB) and LAKU Management Sdn.Bhd.. These water supply authorities are responsible with the supply of potable treated water to the population living within the limits of supply of urban, sub-urban and major rural settlement areas (JKR,1996).

The generic design set-up of water treatment plant system that is widely adopted by the water supply authorities and the water boards, which supply potable and treated water to the consumers, is depicted in Figure 2. The system encompasses the following components (JKR,1996):

(i) River Intake
(ii) Raw Water Pump House
(iii) Treatment Plant
(iv) Filter System
(v) Clarifier
(vi) Clear Water Well
(vii) Treated Water Pumping Main
(viii) High Level Tank
(ix) Delivery Main
(x) Water Consumers

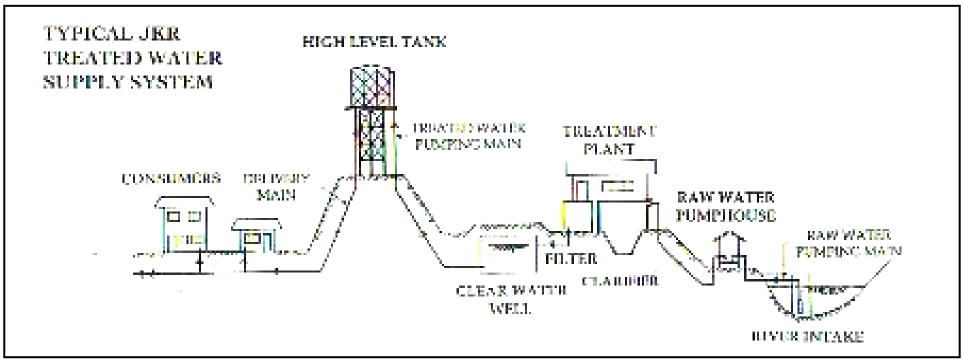


Figure 2: Typical layout of the Public Works Department treated water supply system Source: (JKR,1996)

In order to provide the services and funding to implement the various water supply schemes, the State Water Authority has empowered several government agencies to carry out the project implementation programmes. These government bodies are primarily the Water Supply Branch of Public Works Department, the State Health Department and the Minerals and Geoscience Department Malaysia, Sarawak (Government of Sarawak,2003). Specifically, in the case of developing the gravity feed system, the State Health Department is given the prerogative and responsibility by the government to provide the rural communities in Sarawak with free and untreated water supply (Water Supply Branch,2000).

The Figure 3 illustrates the linkage between several government agencies with the State Water Authority in implementing the various types of water supply projects in Sarawak. The State Health Department and the Department of Minerals and Geoscience Department Malaysia of Sarawak are under the jurisdiction of federal government. While the others are directly under the local state government (State Health Department,1998 and Mineral and Geoscience Department Malaysia, Sarawak,2001).

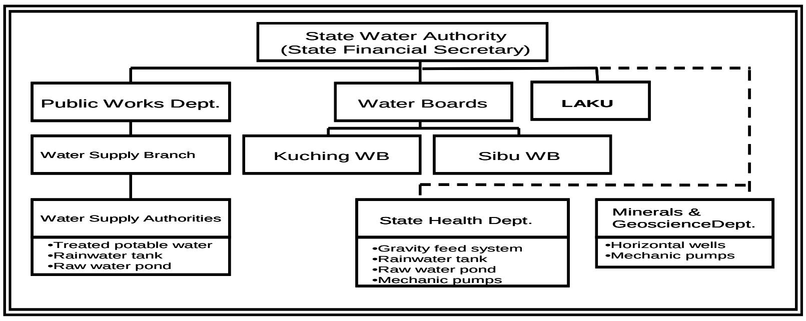


Figure 3 – Jurisdiction on water supply in Sarawak

Source: (Water Supply Branch,2000)

The State Development Plan for water supply development in Sarawak targeted about 98 percent of the rural population shall have access to safe drinking water by the year 2005. Out of this, 75 percent of the State's populations will be provided with fully treated piped water (Government of Sarawak,2003). On the contrary, those populations in the remote rural areas that are not being served with treated water supply system will still depend on mountain streams. These freshwater sources will be developed into the gravity-feed systems by the State Health Department. It was reported by State Health Department that about 2,730 gravity-feed systems had already being established in Sarawak to serve the rural communities living in the remote part of Sarawak (Shakeran 2000;Unit BAKAS Negeri, 2001).

The rapid pace of development being experienced by Sarawak endeavours great challenges to the authority and communities in safeguarding the water catchments for the gravity-feed system because some development activities have started encroaching into these catchments (Shakeran,2000). It is the ambition of the state government through formulation of the following strategies in the Malaysia Development Plan to anticipate the increase coverage to the unserved population by constructing new water supplies, further upgrading, modernization and expansion of existing water supply systems to increase the capacities and treatment efficiency as well as improving the quality and reliability of supply, meeting the needs of industry, commercial, agricultural land development and new growth centres, and to manage and develop the water resources (Government of Sarawak,2003). These strategies shall provide a well balance socio-economic development programmes in Sarawak.

2.5. State Health Department Gravity- Feed System

The most economical and preferred option for the development of rural water supply is by tapping the freshwater originating from the mountain stream sources and directly delivers the water using pipes as conduit for household use. This has brought the concept of adopting the gravity-feed system to supply raw water to the rural communities because it is the best solution to overcome the problem of water shortage to the local community. Furthermore, the water sources are of abundant and the gravity-feed system is simple to build and involves low-cost maintenance (MOH,1984).

In Sarawak, the implementation of gravity-feed water supply systems has started under the programme known as Rural Environmental Sanitation programme (RESP) since 1963. In 1965, this programme was renamed as the Rural Health Improvement Scheme (RHIS) and implemented under the supervision of State Health Department from the Ministry of Health, Malaysia. It is a sign of commitment from the government to improve the sanitary conditions of the rural communities in Sarawak (State Health Department Sarawak, 1998).

The gravity-feed water supply systems are extensively used to provide water to various sizes of communities in the rural areas. The population being served ranges from less than 50 people to more than 3,000 people in a settlement. The distance from the water sources to the community varies from less than one mile to five mile into the hill catchment (Division of Engineering Services et.al.,1982).

The community willingness to participate in the development of the gravity-feed systems, such as involved in constructing the gravity-feeds, has contributed to the success of the programme that they feel relevant to their social and health needs (State Health Department Sarawak,1998).

2.5.1. Typical Design of Gravity-Feed System

In this study, the definition of a gravity-feed system follows the interpretation by the Ministry of Health, Malaysia (1984), which defines the system as the piping down of water from a river or spring under the force of gravity to homes in the villages.

The typical design of the gravity-feed system in rural areas of Sarawak adopts the basis of piped-gravity flow of untreated water that is channelled to individual house without basic or primary treatment being introduced to the water (MOH,1984). Figure 4 shows the typical setup of a gravity-feed system with small-enclosed impoundment with concrete weir being constructed at a higher elevation, to develop sufficient head and hydraulic gradient, to gravitate the water down to the dwellers situated on the lower ground.

Commonly, plastic pipes are used for purpose of distributing the water to individual houses (MOH,1984;SKAT,1980;US AID,1982d). On the other hand, Gabriel (2000) mentioned that many modern gravity-piped systems are provided with temporary storage tanks before the water reaches the houses. The author remarked that before the introduction of plastic pipes, matured bamboo was commonly used as conduit to transport the water to individual homes as piped-gravity water. However, High Density Polyethylene (HDPE) pipes are now commonly used in some districts.

Figure 4 – Typical gravity-feed impoundment

Source: Photograph by M.Sabari Shakeran

The standard procedures adopted by the State Health Department to develop the gravity-feed system for rural project are as followings (MOH,1984):

(i) The preferred raw water source for rural water supply is without treatment and meets the drinking water quality requirements. This is the first-priority source for consideration of selection.

(ii) A concrete weir for intake structure is constructed and should be able to retain a pool of water with sufficient depth for the gravity-feed system.

(iii) The sources should have sufficient water, water pressure and free from any source of contaminants, such as agrochemicals use in agricultural activities.

(iv) The planning development for the gravity-feed system includes the following scope of works:

a	Preliminary survey	village survey, measuring the flow rate and catchment sanitary survey
b.	Routes selection for the pipelines	survey data to include longitudinal section, elevations and layout of pipeline routes
c.	Pipeline survey	
d.	Design of the gravity-feed system	
e.	Cost estimates	to get adequate fund for the project from the government

2.5.2 Maintenance of Gravity-Feed System

The project implementation for the gravity-feed system is carried out by the State Health Department assisted by government funding (State Health Department Sarawak,1998). It is the standing government policy, upon the completion of the project, the system is handed over to the respective community for the routine maintenance of the system. Only when emergency repairs are required, the government will take the responsibility to render the necessary assistance (JKR Homepage,1998).

2.5.3. Drinking Water Quality Surveillance Programme

In Sarawak, the starting of the drinking water quality surveillance programme has established since the 1987. Initially, the focus of the surveillance programme is only for monitoring the activities. This includes the regular sampling schedules carried out by the water supply authority in the water treatment plant and the measurement of residual chlorine on site. Currently, the Department of Chemistry is assisting in carrying out the sampling analysis for the bacteriological and chemical parameters, which includes heavy metals. The bacteriological quality, total plate count, total coliform and faecal coliform are tested as indicators for polluted raw water sources. Before 1986, the presence of heavy metals or pesticides in water quality are not considered for sampling (Ministry of Health, et.al.,1986). Effectively in 2004, all State Health Departments are directed to carry out sampling for pesticides for the water quality.

After the state starts experiencing scarcity of good quality raw water sources, the former surveillance programme was deemed inadequate to serve as an early warning system. Hence, the new drinking water quality surveillance programme has been enhanced with the following key elements of surveillance components that encompass more comprehensive activities that include: (a) monitoring, (b) sanitary surveys (c) data processing and evaluation (d) remedial actions and (e) institutional examination (Ministry of Health, et.al.,1986).

2.5.4. Drinking Water Quality Standard

The Drinking Water Quality Surveillance Unit of Engineering Services Division, Ministry of Health with the guidance from the World Health Organization, has developed the National Guidelines for Drinking Water Quality standard (1983a). The WHO Drinking Water Quality Guidelines published in 1982 was used as the main reference by the panel experts. In developing the national drinking water quality standard, the local practices and experiences in Malaysia are incorporated into the document.

The government agencies involved with the drinking water surveillance programmes in Sarawak are the Public Works Department, the Chemistry Department and the Department of Environment. It is a standard practice in Malaysia that the State Health Departments and the Water Supply Authorities to comply with the raw water quality criteria and the drinking water quality standards (Ministry of Health,1983a).

The most recent edition for the National Standard for Drinking Water Quality that is adopted by Ministry of Health was revised in December 2000. The main improvement on the contents of the standard, compared with the previous editions, is on the aspects related to the water quality parameters. Particularly on the recommended acceptable value and the frequency of monitoring schedule for sources of water from surface, ground and direct impounding under the raw water quality criteria and drinking-water quality standard (Ministry of Health,1983b). Since 1983, this National Drinking Water Quality standard has been revised three times in 1989, 1990 and 2000; these improved editions are to keep pace with the progressive technological developments, available best practices and scientific knowledge (Ministry of Health, 1983b).

In the case of the raw water from the gravity-feed system, the quality criteria and standards prescribed in the National Guidelines for Drinking Water Quality mentioned that the raw water source must confirm with the recommended standards set in the drinking water quality standard (Appendix A), then it can be supplied with minimal treatment that involves disinfection only. If the raw water quality does not confirm with the recommended raw water quality criteria (Appendix B), then appropriate action shall be taken to identify and overcome the problem (Ministry of Health,1983b).

The guidelines adopted by the Engineering Services Division, Ministry of Health, to carry out the drinking water quality control for the rural water supply system to enhance the rural public health follows the monitoring programme illustrated in Table 5 on the frequency of sampling (Cawangan Kejuruteraan Alam Sekitar.nd.):

Water Supply System	Number of Samples	Frequency of Samplings		
		Physical	Bacteriological	Chemical
Gravity-feed System	Depends on system. (Minimum 2 stations)	Once every three months (YEAR/4)	Once every three months (YEAR/4)	Twice a year (YEAR/2)

Table 5 – Frequency of samplings for gravity-feed system

Source: (Cawangan Kejuruteraan Alam Sekitar.nd.)

According to the Guidelines for Drinking Water Quality Control for Rural Water Supply System (Cawangan Kejuruteraan Alam Sekitar,nd.), the various water quality sampling for the physical, bacteriological and chemical properties to be undertaken by the staff members of State Health Department are enumerated as follows :

A	**Physical Testing** (i) Turbidity (ii) Colour (iii) pH (iv) Residual Chlorine (v) Dissolved Oxygen (only for gravity-feed sources) (vi) Temperature (vii) Conductivity
B	**Bacteriological Testing** (i) Faecal Coliform
C	**Chemical Testing** (i) Total Dissolved Solid (TDS) (ii) Ammonia (NH3) (iii) Nitrate (NO3) (iv) Iron (Fe) (v) Fluoride (F) (vi) Aluminium (Al) (vii) Manganese (Mn)

Note:

(1) Aluminium and Fluoride are only required to be carried out for purpose of screening only. If the initial water sampling does not indicate the presence of these parameters, future sampling exercises of the same parameters are not required.

2.5.5. Instruments for Water Sampling

The Guidelines for Drinking Water Quality Control for Rural Water Supply System highlighted that the health inspectors who are appointed to carry out the sampling works in the field are required to take the water samples for the physical properties on-site, while the samples for bacteriological and chemical are sent to the Chemistry Department. To assist the field work on water sampling, the following instruments and accessories are provided to the district health offices to execute the works (Cawangan Kejuruteraan Alam Sekitar,nd.):

(i) Millipore Field Test Kid with Dual Chamber Incubator
(ii) Turbidimeter
(iii) Lovi Bond Accessories (measuring colour)
(iv) Portable pH/Temperature Meter or pH Comparator
(v) Dissolved Oxygen Meter
(vi) TDS/Conductivity Meter
(vii) HACH DREL 2000 Spectrophotometer
(viii) Sampling Boxes
(ix) Sampling Bottles
(x) Thio Bag

2.6. Rural Water Supply

2.6.1. Significance of Water Quality Standard

During the earlier years on the development of public water supply, Wagner,et al.(1958) stated that water had been found to cause health impact to the population because of neglecting the water quality safety standard; the importance of water supply is valued from the standpoint of availability and adequate supply only. Hence, before developing a treatment system for a small water supply, the first critical factor that should be considered is to insure the water sources of the highest quality are selected as drinking-water for the public (Hubbs,1985). The World Health Organization (1993) also voiced similar statement on the requirement of good quality water sources for the purpose of public consumption. The State Health Department practices to select only water sources that demonstrated good water quality parameters characteristic. The department will reject the sources that are unfit for human consumption for rural water supply. The most preferred water sources for development of the gravity-feed system in rural areas of Sarawak are the sources that show reliability and not needing any primary treatment (Unit BAKAS,1995).

Highlighting on the importance of water quality, the World Health Organization (1984a) asserted that the "..microbiological quality of drinking-water is of the greatest importance, …and must never be compromised in order to provide aesthetically pleasing and acceptable water" for purpose of public health protection. This being significant because microbial risk is unachievable to be eliminated entirely, since waterborne disease may transmit easily through various hosts and cause vital and widespread effects to the public health (World Health Organization,1993;Cairncross,1987). The different types of diseases and water-related illness that can cause harmful effects to public health as described by the American Water Works Association, based on epidemiological consideration, can be divided into four major groups as follows (Pontius,1990):

a.	Waterborne diseases	transmitted though ingestion of contaminated water.
b.	Water-washed diseases	diseases that are related with poor hygienic habits and sanitation.
c.	Water-based diseases	the pathogens spend its completion of lifecycle dependence on aquatic organisms. The example of water-based diseases such as schistosomiasis and dracontiasis.
d.	Water-vectored diseases	transmitted by insects that breed in water through bites such as malaria.

Awin (1999) stated that despite the present day advancement, water still remain a real threat in the spread of large scale epidemics. In formulating the prevention and control strategies, the most important strategy to improve the public health is to ensure safe water is made available to the public. The World Health Organization (1993) emphasized that it is of paramount importance to protect the water sources from contamination by human and animal waste, "..,which could contain a variety of bacterial, viral and protozoan pathogens, and helminth parasites.." and potentially causes the "..risk of outbreaks of intestinal and other infectious diseases" in the community. In terms of health-risk, it is strongly emphasized that, ".. pathogenic micro-organisms remain the most important danger in drinking-water in both developed and developing countries" (World Health Organization,1993). Svandlenka (2001) indicated that the surface water such as streams, rivers, ponds, lakes, marshes and other wetland environment are the most obvious sources of surface water in the rural areas and often contaminated with numerous waterborne pathogens; in fact, 80 percent of all illness in developing country is directly attributed by waterborne pathogens.

To safeguard the public health, it is essential that the water quality monitoring programme to be carried out. The indicator bacteria of highest priority, namely, the coliform and faecal coliform organisms must be detected before infectious disease could be transmitted through the drinking-water. Likewise, the priority of monitoring the chemical constituents in the surface water is still important and may in accord with the knowledge of human activities within the catchment. The sanitary survey of the catchment could assist as an early warning to determine the potential chemical pollutants in the catchment; hence, the detection of possible chemical substances being discharged into the environment can be predicted from the types of activities being identified during the field works. This practice is acceptable for small community water supply (World Health Organization,1984a).

Recommended by the World Health Organization (1993) on microbial detection, the indicator of first choice for drinking-water is *Escherichia coli* (E. coli), which are found in greatest number in both human and animal faeces. These bacteria can be found in sewage, treated effluents and natural waters or soils that subjected to faecal contamination from sources such as humans, agriculture, animals and birds. The alternative testing to detect the present of E.coli is the thermotolerant coliform bacteria. As cited in the WHO guidelines, this form of bacteria "..may also originate from organically enriched water such as industrial effluents or from decaying plant materials and soils" (World Health Organization,1993). Therefore, it is recommended that thermotolerant coliform be used as indicator to detect the efficiency of water treatment plant to remove faecal bacteria as well as assess the acceptable limit of treatment needed to remove bacteria for water of different quality (World Health Organization,1993)

The total coliform bacteria could be found in faeces and the environment that contain nutrient-rich waters, in soil and plant material that is decaying. In addition, the presence of total coliform bacteria has been detected in drinking-water with relatively high concentrations of nutrients. When use as indicator, the presence of coliform bacteria detected in treated water will reveal poor or inadequate treatment, contamination of post-treatment and excessive nutrients in the system (World Health Organization,1993).

Comparing between the impacts of microbial risk and the health risk due to toxic chemicals in drinking water, the World Health Organization (1993) pointed out that chemical contaminants are placed "…in a lower priority category than microbial contaminants..". This is because chemical risk is "…not normally associated with acute effects"; hence, deduces the chemical contaminants in drinking-water as secondary when compared with severe bacterial contamination. The major concern on chemical contamination is on the long-term health effects due to prolonged exposure to the chemical constituents in drinking water that having "cumulative toxic properties, such as heavy metals, and substances that are carcinogenic" (World Health Organization, 1993).

Nevertheless, the significance of other water quality components such as health-related organic and inorganic constituents, aesthetic constituents and radioactive materials should not be ignored of its importance for safe drinking-water because if these specific water constitutes exceeded the acceptable limits of the prescribed standard, it could susceptibly endanger the life of human beings that ingested the waters (World Health Organization,1984b).

As explained by Awin (1999), it is arduous to detect chemical contamination in a person. Even though the chemical seems harmless, non-specific and with low level of exposure, the exposure over a long period of times not only make it chronic but also difficult to detect because chemicals effects are not easily distinguish from those caused by other factors such as air quality, stress and nutritional factors. Generally, the chemical pollution problems that cause toxic effects is a growing phenomena and more likely to occur in countries undergoing rapid pace of socio-economic development (Awin,1999).

In compliance with the requirements of good quality water for the population in rural areas, the Ministry of Health, Malaysia, has published the guidelines on low-cost technology for rural water supply that underlines water quality as one of the factors that must be considered before selecting any raw water source for the gravity-feed system. Particular aspects on water quality parameters that must be taken into consideration are those related with the "variety of substances either dissolved or in suspension…substances have direct harm on man's health, while others affect the senses of man that is taste, odour and appearance." (MOH,1984).

In Sarawak, most of the rural population are still dependent on untreated water from the gravity-feed system (JKR,1996). According to the State Health Department, the protection of water sources that normally situated in the highlands from potential pollution is quite well safeguarded to secure the public health. This is because the State Health Department has carried out the catchment sanitary survey before selecting the gravity-feed sources (Unit BAKAS,1995). Nonetheless, as reported to the Sarawak Water Resources Council, some of these sources are not fully-free from pollutions or contaminants due to human activities (Shakeran,2000). For example, it was highlighted in the report disseminated by the State Health Department in 1995, despite the chemical constituents were not detected in all the water gravity-feed systems established in 27 districts in the Sarawak, violation occurrences caused by microbiological organisms of total coliforms recorded a total of 299 numbers and by faecal coliform a total of 215 numbers (Unit BAKAS,1995). Since no water treatment is used for current piped-gravity water, the rural communities are strictly advised to boil their untreated water before drinking as minimum form of protection to their health (Ministry of Health, 1982).

The World Health Organization has started the initiative to develop a universally acceptable drinking-water quality standard in 1958. The endeavour has brought forward nations of the world to develop their own drinking-water quality standards. The initiative has encouraged every nation to establish their independent drinking-water quality standards that keep on improving throughout the years and subsequently comply with the "trend toward the internationalization of such activities" (Taras,1981).

In addition, the World Health Organization (1984a) produces guidelines for drinking-water quality and recommendations for the effective compliance and surveillance of various water quality parameters for the public protection. On carrying out the surveillance works on behalf of the public, the guidelines recommended the task to be preferably conducted by the agency involves with public health protection, rather than the others. This is to avoid conflicting priorities or interest when the same agency is looking after both the operation and surveillance function. In the case of Sarawak, the task on protection of public health is under the jurisdiction of the State Health Department (Unit BAKAS Negeri,2001).

In Sarawak, the background on the development of the National Drinking water Quality Surveillance Programme (NDWQSP) was initiated in compliance with the requirements of the National Guidelines for Drinking Water Quality (Ministry of Health et.al.,1986). The principal objective is to raise the health standard of the people by ensuring safety and acceptability of public drinking-water (Ministry of Health,1983a). As aforementioned, the guidelines are in compliance with the World Health Organization to improve the conditions of water quality for public health protection (Ministry of Health,1983a).

Recently, a study for the purpose to investigate the safety of rural water supply in one of the districts in Eastern Sarawak was conducted by Ibuh (1997). The primary emphasis was to find out the actual problem of health risks associated with piped-gravity water, to formulate the Health Risk Assessment Format applicable for the system, and trying to determine the effectiveness of the supply of untreated water without the provision of basic or primary treatment (Ministry of Health,1984). The scheduled study period was eight months, involving a total of 11 gravity-feed systems with 2,835 people living in 11 designated villages consuming piped-gravity water from the gravity-feed systems (Ibuh,1997).

The research methodology adopted includes the gathering of field information through interviews with the villages, studying the project records and observation, confine study area within the selected gravity-feed water catchments, study focus limited to the detection of the coliforms and Escherichia Coli in the water, and conducting simple health risk assessment of the water sources and catchment areas (Ibuh,1997).

Based on the study results by Ibuh (1997), he found out that all the sources from the 11 villages indicated 100 percent detection of coliforms, 54.5 percent showed the presence of both the *E. coli* and *coliforms,* and 45.5 percent the presence of coliforms only but without E.Coli being detected. Ibuh (1997) concluded in his study, the detection of these types of indicator organisms substantiate the risk of contamination to the population using existing piped gravity-feed systems; even after the water sources have already being carefully selected from existence of human activities (MOH,1984). Furthermore, Ibuh (1997) expressed his concern that a secondary contamination may occur in the distribution system due to pipes leakages that cause further degradation of water quality and making the water not safe for consumption by the villagers.

2.6.2. Effective Water Treatment

In the developing countries, the aspects of design, construction and operational of small-scale water treatment systems for individual homes and small communities cause significant challenge in providing safe drinking water to the public due to the water sources possess wide variety of water quality conditions; besides the limitation of expertise, adequate human resources and availability of materials (Hubbs,1985). The survey being carried out by the World Health Organization on water and excreta disposal gives the impression that "…the conditions in rural areas are much worse than in urban ones; yet most people live in these rural areas" (Wijk-Sijbesma,1981).

In planning a water treatment system for rural area, stresses should be given onto bacteriological treatment, the removal of pathogens through filtration and chemical disinfection (US AID,1982c). Hubbs (1985) also stated that basically the water treatment for any freshwater system involves the removal of solids, pathogens (disease-causing bacteria, viruses, other microbial organisms), and substances that impart bad tastes or odours. In isolated cases, even toxic compounds detected in the source must be removed before the water can be ingested; but the removal of such agents can be technically difficult and economically burdensome. Thus, it is more desirable to locate a water source that is free from toxic agents for water supply to individual homes and villages in rural areas (Hubbs,1985). In comparison, the presence of solid constituents in water may not be of health concern except for the "various types of particulate matters in water that could shield microorganisms from the effects of disinfectants", this could result in water quality problems despite being treated accordingly (Hubbs,1985;World Health Organization,1984b).

An ideal small-scale water treatment system must be affordable, simple to design, construct, operate and capable of changing unacceptable water to the types of water that is free of taste, odour, turbidity and disease agents in a single process (Hubbs,1985). Hubbs (1985) further emphasized that one of the goals in treatment of water is the removal of suspended solids, which is considered the most difficult. Applying the chemical or physical treatment methods is necessary for the removal; thus, either one of the methods involves more sophisticated equipment and a higher level of maintenance. Describing about solids in water, Hubbs (1985) categorized solid constituents into three groups, namely, the solids that float, those that sink, and the suspended solids that neither float nor sink within reasonable periods of time. Regarding the problem of floating solids, it can be avoided by abstracting water from below the surface water. Whereas solids that settle without the need of chemical treatment can be removed by allowing the water to remain for one or more days in specialized design storage facility that allows quiescent conditions (Hubbs, 1985).

Since the choice and availability of sources can be a critical issue in providing safe water to rural communities, the use of local knowledge will give full-advantages on the appraisal and selection of a new water source (Wijk-Sijbesma,1981). Unless it is otherwise, efforts must be made to select water sources flowing under gravity from the open-stream waters situated higher than the villages or the spring water by gravity as the most preferred option (SKAT,1980). Nonetheless, the best preference is still good quality water that requires no treatment (Pilley,1997).

Although the minimal water treatment suggested by the World Health Organization (1984a) is sufficient through the protection of water source as a possible form of treatment for rural water supply serving small communities, but still the guidelines for drinking-water quality pointed out that even for surface sources of high-quality and unpolluted for public consumption, "disinfection should be regarded as obligatory for all piped supplies using surface water,.. there should always be more than one barrier against the transmission of infection in a water supply". Only when the decision of abstracting water sources of poor microbiological quality are unavoidable, then all available resources of water treatment options to produce safe drinking-water are compulsory for a water treatment plant (World Health Organization, 1984a).

In developing an effective water treatment suitable for rural area, SKAT (1980) recommended in a published manual for rural water supply stated that "..the policy of a responsible engineer to restrict the use of water treatment under rural conditions to only those cases where such treatment is absolutely essential and where correct plant operation and maintenance can be secured and supervised". Even though in reality there is no perfect system, the designer should always strive to achieve adequate quantity in the least technically complicated way in developing the system (Hubbs,1985). If it is unavoidable, the water treatment system for small communities must strive to achieve the basic goals of water purification through simple design, operation and maintenance of the system. (Hubbs,1985).

Svandlenka (2001) mentioned that the configuration of water supply system can vary widely according to several factors such as the environmental factors, community resources, and local needs. Appropriate technologies on water supply are important consideration in designing a new water supply system. The adopted technologies must be suitable for the water sources to deliver adequate quality of water to meet community needs for agriculture, drinking and sanitary; besides being affordable, maintainable, culturally sensitive, with methods and techniques that are sustainable. Use of modern treatment processes such as chlorination, ozonation or ultraviolet systems are readily available for small communities, to purchase and maintain these types of system are too expensive for the purpose of rural water supply. Steel and Mc Ghee (1979) highlighted that there are several treatment methods that have been developed to produce water to an acceptable degree of standards, the more advanced techniques involved the application of the ion exchange, reverse osmosis, electrodialysis, and distillation. The various choices of sophisticated techniques are very much determine by the conditions of the raw water source and the demand for final water quality products.

The quantity of raw water is also essential to ensure the continuous supply of water to the public. The compilation of data related to water quantity will enable the demand which the source could provide for long-terms water use could be calculated for estimation (AWWA,1984). Firstly, in designing a water supply system, Cairncross et.al.(1980) indicated the essential need is to produce the set of design standards that can be used in deciding the design flows for the water supply system. The design standards should have sufficient data such as the average water use, peak factors, rate of growth of the rural population, consumption per head and lifetime of the typical supply to develop the system. The design lifetime for rural water supply might be in the order of fifteen years and the extent is very much dependence on the changes of water use, collection, supply and socio-economic development of the local community

(Cairncross,1980). On the same matter, the experience-data compiled by SKAT (1980) on similar subject suggested that the rural water supply that are well maintained and having the origin from spring and stream catchment could be expected to have a service life within the range of 30 to 50 years.

The roles and contribution of the locals in successfully implementing the rural community water supply are very essential. The major task as described by Wijk-Sijbesma (1981) is to involve the community participation through integration of various programmes related to environmental protection encompassing water supply, waste disposal and education. Svandlenka (2001) mentioned that by pooling local resources with varying degrees of external assistance, a new water supply in a rural community can be accomplished and maintained. The most important of the local resources is labour, which is typically of abundance.

The sources of other assistance from outside can usually be in the form of education, equipment, community planning and facilitation. Cairncross et.al. (1980) insisted that there must be consideration to derive policy and possible models to incorporate local level organization and the agency that provides the water supply assistance, to ensure successfully maintenance procedures in administrating the rural water supply system. The community participation during the construction and maintenance of the water supply scheme could reduce the operating cost as well as provides benefit in the sense of commitment to the scheme once the system is handed over to the community (Cairncross et.al.,1980).

2.6.3. Water Treatment Process Options

According to Steel and Mc Ghee (1979), the choice of water treatment process to be applied for particular surface water is very much influenced by the water quality conditions and nature of the sources. Similar remarks on surface water by Kiely (1998) also mentioned the water quality can vary according to seasonal variations and during flooding. Furthermore, the need to treat the raw water is very much dependence on several numbers of reasons, such as "..the removal of pathogenic organisms, unpleasant tastes or odours, excessive colour or turbidity, certain dissolved minerals, and a variety of unpleasant or potentially harmful chemical species" (Steel and Mc Ghee,1979).

To determine whether the treatment process is suitable for the selected water source, the Malaysian Water Association (1994) highlighted that adequate water samples are collected to study the fluctuation and characteristic of water quality for the purpose of physical and chemical analysis. Kiely (1998) described that " the selection of the set of treatment process is preceded by detailed raw water quality analysis". It is recommended for analysis to be carried out over a longer period of time or a minimum of one year, where possible; samples of raw water should cover the periods of low, medium and high flows for surface water sources (Kiely,1998). The selection of effective treatment process will be carried out using jar tests to establish the appropriate chemical coagulants used and setting effective dosing rates to achieve satisfactory water quality outputs from the coagulation, flocculation and sedimentation process (MWA,1994;AWWA,1982). The following recommended processes to remove specific impurities are outlined in Table 6:

Parameter	Treatment Process
Floating matter	Coarse screens, fine screens
Suspended matter	Microscreens
Algae	Microscreens, pre-chlorination, carbon adsorption, rapid filtration
Turbidity	Coagulation, sedimentation, post-chlorination
Colour	Flocculation, coagulation, filtration
Taste and odour	Activated carbon
Hardness	Coagulation, filtration, lime softening
Iron and manganese ➢ >1 mg/L ➢ <1 mg/L	 Pre-chlorination Aeration, filtration, lime softening
Pathogens,MPN/100ml ➢ <20 ➢ 20-100 ➢ >100	 Pre-chlorination Coagulation/filtration/post-chlorination Pre-chlorination Coagulation/filtration/post-chlorination
Free ammonia	Post-chlorination Adsorption

Table 6 – Recommended treatment for specific impurities

Source: (Kiely,1998)

Adopting the term derived from the Ministry of Health (1983b), the conventional treatment is to include the following water treatment processes, namely, screening, straining, aeration, coagulation and flocculation, sedimentation, filtration and disinfection. Using suitable technology on water treatment process that is economically available in the market can also be considered based on a special case basis to render assistance to the communities that really required the system to improve their drinking-water quality, provided the particular system is economically feasible and affordable for long-term use.

From the literature review research on the most common technical application to overcome the rural water supply problems, the following conceptions of the water treatment process options allow an understanding on the mechanics and advantages of the conventional treatment system which are simple and widely use by the rural communities for their rural water supply scheme to overcome and solve the specific types of raw water quality problem:

<u>(i) Sedimentation</u>

The sedimentation as generally defined by SKAT (1980), is a removal process of suspended particles that are heavier than water through the gravitational settling. The removal of suspended particles in the water help to prevent the frequent blockage of the gravity-pipe, reduced storage capacity of tanks for household use and reduce the deterioration of water quality.

Steel and Mc Ghee (1979) also asserted that the simple treatment process methods using only the storage and plain sedimentation could produce water to an acceptable limit for consumption. On top of that, the MWA (1994) referred to an earlier study indicating that even bacteria and viruses could be removed effectively from 90 percent to 99 percent, when coagulation and sedimentation system are operated efficiently. Incorporated as part of the system, Wagner and Lanoix (1959) also supported the claim that to a certain extend, this choice of simple treatment using the sedimentation system helps to reduce bacteria. Both the US AID (1982b) and Hubbs (1985) provided similar explanation on the effect of storing water over an extended period of time can act as a beneficial pre-treatment approach and could result to "destruction of bacteria as well as turbidity removal… and can remove up to 90 percent of disease-causing organisms", provided there is no problem with algae growth in the water and the storage container must be cleaned regularly to prevent organisms growth in the settled sludge; thus, covering the sedimentation basin is recommended if filtration system is not built into the system. For safety purpose, the stored water should be boiled or chemically disinfected to make it completely safe for ingestion. The Figure 5 illustrates the typical design for a sedimentation basin.

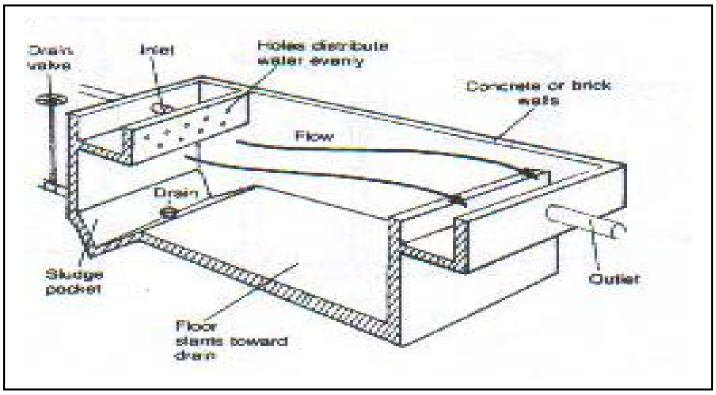


Figure 5 – Layout of sedimentation basin

Source: (US AID,1982b)

On the principle design of a sedimentation basin, Hubbs (1985) remarked that the critical aspect to consider is on the surface area of the basin and not the overall volume of water to be treated. Importantly, sufficient depth must be designed to ensure good hydraulic flow patterns in the basin with inlet and outlet structure operating efficiently without causing short-circuiting to the system. On the maintenance works, removal of accumulated solids in the basin could interrupt the provision of continuous water supply. This being the case, additional units might be built to provide necessary access of water supply during the maintenance works. The thick sludge layer must be removed to prevent decomposition from occurring that could affect the tastes and causing odours (US AID,1982a).

The best illustration for sedimentation process is derived from the *Manual for Rural Water Supply* prepared by SKAT (1980) on the applied plain sedimentation that has been successfully implemented in Cameroon. Because the system is suitable for use in warm climates and water that contains numerous suspended matters, the applied principle of higher temperatures in the region shall lower the water viscosity which then generates the effectiveness of sedimentation process where "..impurities are separated from the suspending fluid by gravitation and natural aggregation of the particles" will take place in a special designed tank. The purpose of this tank is to reduce the velocity of the water flow and collect the settled substances as well as requiring less and simpler maintenance works (SKAT,1980). For easier removal of settled sludge at the bottom, the floor design for the sedimentation basin is often being sloped to collect the accumulated sludge (US AID,1982b).

The other two types of sedimentation methods that can be applied into the system, where deemed appropriate, are the coagulation and chemical precipitation. The coagulation occurs when input of chemical substances are introduced into the water hence induces the aggregation of suspended matters that allow settlement to occur. The chemical precipitation is performed when chemicals are mixed into the water to precipitate dissolved impurities that promote changes into insoluble substances that could be removed (SKAT,1980; MWA,1994).

(ii) Filtration

According to Hubbs (1985), the slow sand filters have been used to remove solids and bacteria for over two centuries. The sand filters normally produce high-quality water as well as improve the quality of surface water significantly, provided the concentration of turbidities is not too high. Effective filtration will require the filter surface must always be submerged and algae growth should be prevented. The biological growth in the submerged surface water known as "schmutzdecke", an active microorganism, should be allowed to grow and assist in breaking down the organic matter and the other suspended matters being retained in the graded filter media. If the filter system is used to treat contaminated water, some forms of disinfection are still required before the water can be consumed safely. Likewise, care must be stressed when the filter starts to indicate some signs of blockage and contamination that reduce the filtering efficiency and flow rate; actions must be taken to replace the filter media or clean the filter media frequently (US AID,1982b). Figure 6 shows the layout of a slow sand filter and storage tank.

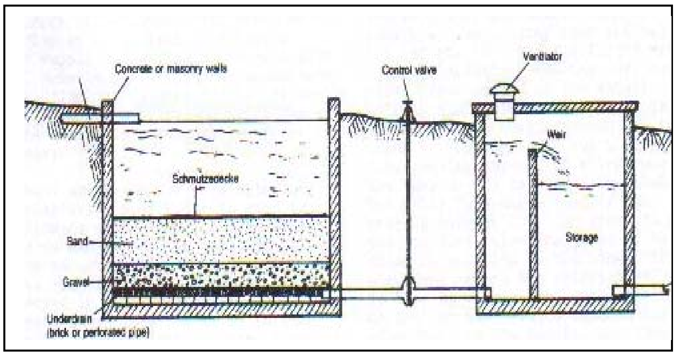


Figure 6 – The slow sand filter and storage tank

Source: (US AID,1982b)

According to Hendricks (1991), the main purpose of filtration is to remove many kinds of particles of various categories from the ambient raw waters. These include those categorized under mineral, biological and other form of particulates such as organic colloids. Similarly, the American Water Works Association (1984) stated in the guideline on design and construction of small water systems that the filtration and disinfection processes could be applied as a form of minimum treatment requirement for surface water. Nevertheless, the full-range coverage of water treatment will still depend on the treated water quality standards imposed by the respective state authority. The US AID (1982c) provided the following advantages of using the slow sand filter system:

(i) Removes 90-95 percent of bacteria responsible for water-related diseases.
(ii) Removes suspended matter and reduces colour.
(iii) Can generally be built with local materials using local skills and labour.
(iv) Needs no complex mechanical or electrical machinery.
(v) Requires simple operation and maintenance.

Hendricks (1991) further emphasized that the principles of particles removal using slow sand filtration or rapid sand filtration are adopting similar mechanisms. The filtration removal encompasses two key steps namely, the transportation and attachment of particles. The transportation mechanism comprises of interception, sedimentation and diffusion of particles that being carried with the flow. While the attachment mechanism is considered complete when "..the biofilm on the sand grains making up the sand bed may metabolize organic contaminants, resulting in permanent removal of the contaminant particles" (Hendricks,1991).

The following tabular listed in Table 7 illustrates the types of particles that are found in ambient waters and have been successfully removed using filtration process:-

No.	Category	Group/Name	Size (micrometers)
1.	Mineral	Clays (colloidal)	0.001-1
		Silicates	no data
		Nonsilicates	no data
2.	Biological	Viruses	0.01-1
		Bacteria	0.3-10
		Giardia lamblia cysts	10

		Algae, unicellular Parasite eggs Nematode eggs *Cryptosporidium* oocysts Biological concentrate from 5-um cartridge filter	30-50 10-50 10 4-5 mixture
3.	Other particles	Amorphous debris, small Amorphous debris, large Organic colloids	1-5 5-500 no data

Table 7 – Particles found in ambient waters

Source: (Hendricks,1991)

(iii) Aeration

The AWWA (1984) described the aeration process is by bringing air into contact with water that will cause oxidation process to occur. The US AID (1982b) refers the aeration as a conditioning process where substances and minerals that cause water to inherit bad colour, tastes or odour are eliminated. The waters that contain some quantity of dissolved iron or manganese will change into insoluble forms upon contact with air. Depending on the aeration systems that want to be developed, the various applicable methods could either through spraying of water into the air, falling water over a spillway or discharging droplets of water through series of perforated trays. To collect the precipitated insoluble iron or manganese that settle, an enclosed storage is required for the purpose. In addition, this aeration process provide the advantage of increasing the oxygen contents in the water that experiencing deficient in dissolved oxygen as well as helping to remove odours in the water (US AID,1982b).

(iv) Disinfection/Chlorination

One of the most commonly acceptable methods to kill bacteria is by boiling the water; even life form in turbid water could be destroyed through boiling (Hubbs,1985). Substantially, pathogenic organisms are destroyed upon reaching the state of rolling boil in few minutes (US AID,1982b). Other forms of disinfection can be fulfilled by means of using mechanical, chemical and thermal techniques (Hubbs,1985). The AWWA (1973) described the water disinfection processes are essential to eliminate the disease-producing organisms such as pathogen that are of intestinal origin. These types of organisms could survive for weeks up to months depending on the temperature variations. Other factors that could control the survival rates of the organisms in water "..depends on environmental, physiological and morphological, such as pH, oxygen and nutrient supply, dilution, competition with other organisms, resistance to toxic influences, and ability to form spores" (AWWA,1973). Nevertheless, it depends on each individual vulnerability and susceptibility to these organisms that could cause harmful effects to the health upon ingestion.

On the use of chlorine, the AWWA Manual indicated that the most effective disinfection period occurs when the hypochlorous acid, a highly efficient bacteriocide and one of chlorination regimens, becomes predominant in the water; this normally happens after chlorine is added to pure water and the reaction forms a mixed product of hypochlorous (HOCl) and hydrochloric (HCl) acids (AWWA,1973;Hubbs,1985). The advantages of chlorine as mentioned by AWWA (1973), besides destroying the "..."inactivate" microorganisms of sanitary significance", chlorine could be used for purpose of oxidation "..to purposely modify the chemical character of the water to which it is applied" or used for both disinfection and oxidation purposes.

2.6.4 General Costing for Rural Water Treatment Methods

In terms of economic costing and acceptable as general guideline based on international experiences for use in this study, the works by US AID (1982b) illustrated in Table 8 show the commonly implemented types of treatment process methods that are acceptable for rural water supply. They use simple technology and capable of producing safe drinking-water:

Method	Type of Treatment	Construction Cost	O & M Cost	Reliability	Construction Skill Required	O & M Skill Required
Storage	Clarification of mild turbidity	Low	Low	Small Volume of water only: used with filter and/or disinfection	Low	Low
Household filter	Clarification of turbid water; removes some pathogens	Low	Low	Up to 2700 litres/day; used with disinfection	Low	Low
Boiling	Complete Disinfection	Low	High	Small Volumes	Low	Low

Chemical disinfection by hand	Disinfection of clear water; kills most pathogens	Low	High	Difficult to determine; taste test only	Low	Medium
Plain sedimentation basin	Clarification of very turbid water	Medium	Low	Use with filtration and disinfection	Low	High
Slow sand filter	Clarification and infection	High	Low	Kills most pathogens with proper maintenance	High	Medium
Simple disinfection unit	Disinfection of clear water	Low	High	Frequent chlorine checks are necessary	Medium	High

Table 8 – Methods of water treatment for rural water supply

Source: (US AID,1982b)

CHAPTER THREE: METHODOLOGY

3.1. Research Methods

The research methods to conduct this study involve several tasks including literature review, field investigation and site visits, gathering and compilation of water quality data, doing a comparative study, carry out the data analysis and present the recommendations of the study. The specific breakdown details for each task are enumerated as follows:

3.1.1. Literature Review

The literature review is positioned as an integral part of the study, which will be applied through out the document. The purpose is to support the background information and to enhance the in-depth understanding on the subject matters.

In particular, the chapter on literature review will attempt to emphasize the significance of the research for a specific topic and establish the methodological focus that could be used to derive the deliverables in the recommendation. In this regard, the following are the anticipated details in the literature review:

- ❖ To address the significance of raw water sources and problems of water quality for drinking water and elaborating the status quo of water issues, particularly to Sarawak perspective. Critical aspects on matters related to the priority of water quality parameters that are important to safeguard the human health, by taking into consideration the typical problems of water sources from the gravity-feed systems and the rural water catchment conditions in areas of Western Sarawak, will be focused. The authority responsible with the development of standards and guidelines for drinking-water quality will be referred.

- ❖ To identify the best available options from both local and international practices on water treatment process methods to treat polluted water commonly faced in the rural water supply schemes. Concurrently, the possibility to integrate existing conventional water treatment system into the existing practice of developing the gravity-feed system by the State Health Department, to solve prevailing water quality problems will be studied. The pertinent issues on the use of simple technology, advantages and economic of scale will be considered significantly.

- Although catchment protection is not the main subject in this study, the general importance of catchment protection and conservation is deemed essential to be addressed, to comprehend the extent of efforts being placed on this subject by the government to sustain the integrity of good water quality for the rural communities.

3.1.2. Field Investigation and Site Visits

- To carrying out an unstructured interviews and discussion with key personal members from the State Health Department at both headquarters and district levels who are involved with the planning, design and field operations. Besides, this will provide understanding on relevant issues and challenges associated with the public consuming the water and the gravity-feed systems.

Some of the basic information on the gravity-feed systems that are significant to understand the problems related to the study of the raw water quality that shall be covered encompasses the following aspects:

(a) encroachment of development activities into the catchment.
(b) exploitation of timber resources within the catchment.
(c) maintenance of the gravity-feed system by the local inhabitants.
(d) issue of land property located inside the catchment.
(e) hunting activity within the water catchment.
(f) the conditions of raw water quality between dry and wet seasons due to impact of development, if any.
(g) the availability of raw water quantity due to population growth and weather variations.
(h) to discuss on the types of methods or instrument used to collect water samples for the raw water quality analysis.

- Field visit to the gravity-feed sites of both the State Health Department and the Public Works Water Supply Authorities for the purpose of direct observation will be organized. Besides capturing the photos of water treatment plants, the particular interest to capture photographs on the design and layout of the gravity-feed systems will also be carried out. At the same time, to record any innovative work being implemented by the State Health Department onto the existing basic system as an enhancement to improve the system as well as the rural public health.

  Specifically, these captured images from the site visits will be used to illustrate the followings:

  (a) the typical design of concrete weir and pipe strainer for the intake.
  (b) the delivery pipe system.
  (c) the surrounding environment and typical landscape features of water catchments.
  (d) to capture the images of innovative system already installed online with the conventional gravity-feed system.

3.1.3. Data Collection

- The information on typical gravity-feed systems developed by the State Health Department in Sarawak will be compiled accordingly. The specific study will emphasize on compilation of the raw water quality data in various districts of Western Sarawak, namely, Lundu in Kuching Division, Serian in Samarahan Division and Betong in Betong Division. Based from these collected data, the reviews on the trends of water quality from the specific group of gravity-feed systems shall assist to illustrate the extent of degradation of water quality in the rural areas. Importantly, the water quality parameters that are significantly above the acceptable limits of drinking-water standard shall be the emphasis of the study.

  On the adopted protocol of water sampling techniques, the staff members of State Health Department responsible on carrying out the field works comply with the guidelines and instructions prescribed in the manual for Drinking Water Quality Monitoring on Sampling and Preservation of Water Samples issued by the Ministry of Health. This document is prepared in association with the Water Section of the Department of Chemistry (Kementerian Kesihatan & Jabatan Kimia Malaysia,2002). This manual stated that the protocols of water sampling programme encompass the compliance on method of preserving the water sample, adopting the specification of sampling bottles use for chemical and bacteriological analysis, application of preservatives (multiple-sampling protocol), adopting the guideline for getting water samples, sending of samples to the lab and apply the delivery forms for submission to the lab.

3.1.4. Data Analysis

- ❖ In the study, the anticipated amount of evaluated data for analysis shall be compiled from 329 numbers of State Health Department gravity-feed water catchments systems, which are scattered in the districts of three divisions in Western Sarawak.

- ❖ The data will be evaluated and analyzed based on the recorded values of selected water quality parameters being tested for sampling. The water quality standards that shall be used as reference are the National Standard for Drinking Water Quality (Ministry of Health,1983b) and the guidelines for drinking-water quality from the World Health Organization (World Health Organization, 1984a,1984b,1993). Other water quality standards that are relevant shall be referred, if applicable.

- ❖ The tool for data analysis that will be used to perform the statistical analysis shall be the Microsoft Excel software.

- ❖ For presentation of data in this report, tabulated format and graphical display will be used for illustration and for purpose of discussion.

3.2. Comparative Study Methodology

The entities for the comparative study involve three different schemes of the Public Works Department’s water treatment system and water treatment process for water sources that originated from water catchment areas that are quite similar in characteristic with the gravity-feed water catchment system under the State Health Department. The extent of catchment sizes for each water supply authority is denoted by its small acreage as compared with the magnitude of major urban water supply catchment. Detailed information for each of the water supply authority will be discussed under a new topic in the following Chapter Four. All three of the water supply systems are under the operation and maintenance, and jurisdiction of the Water Supply Branch of Public Works Department. The basic information for each of the water supply authorities is illustrated in Table 9.

No	**Water Supply Authority**	**Systems of Treatment Process**	**Catchment Size (Ha.)**	**Catchment Category**
1	Muara Tebas Water Supply Authority	Retention pond, filtration and disinfection	41	Specific independent
2.	Lundu Water Supply Authority	Coagulation & flocculation, sedimentation, filtration and disinfection	577	Specific independent
3.	Triboh Water Supply Authority	Filtration and disinfection	38	Sub-catchment

Table 9 – Details of water supply authorities

Source: (JKR 1996;Shakeran 2003)

The scope of works involves in the comparative study will entail several activities as illustrated in Figure 7, which involves compilation of water quality data from the respective water supply authorities and carry out the data analysis. The anticipated result outputs will provide better understanding on the operation of the conventional treatment, which later could be considered for use by the gravity-feed system, if the situation requires the need to adopt the simplicity of a conventional system. The consideration of integrating the conventional systems into the current design practice by the State Health Department shall be discussed in the recommendation section of chapter seven.

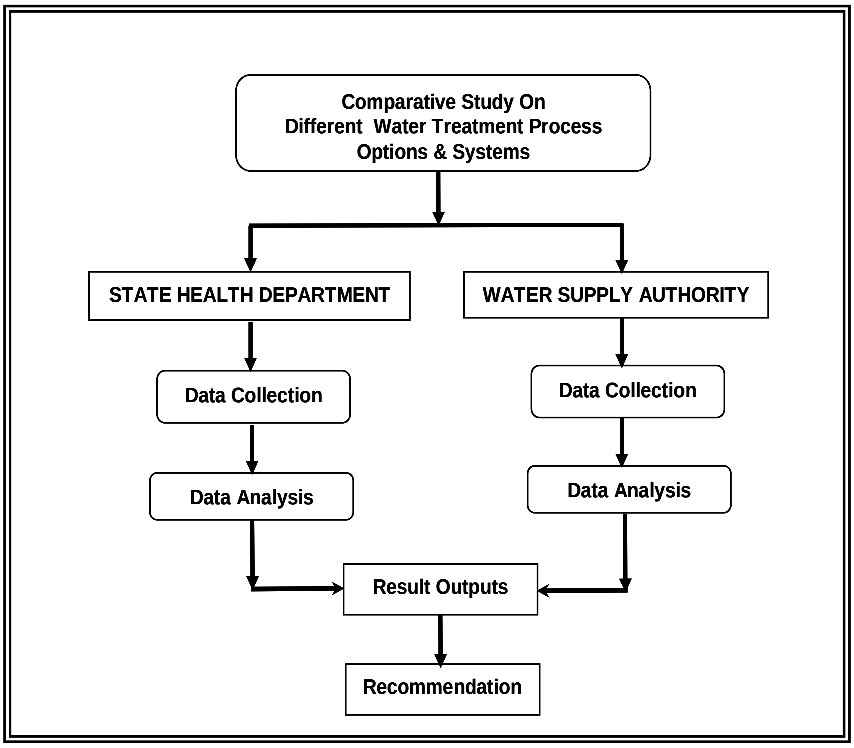


Figure 7 – Activities flowchart on comparative study

3.2.1. Purpose of Comparative Study

The significant reasons to carry out this comparative study are as follows:

- ❖ The water sources for the selected water supply authorities are from the small catchment areas that exhibit similar characteristic with typical gravity-feed water catchment of the State Health Department gravity-feed system that serve isolated rural population.

- ❖ Each of the selected water supply authorities are having different systems of treatment process; therefore, the comparison on effectiveness of treating the raw water using the simplest system could be derived for use by the State Health Department gravity-feed systems under studied. Hence, the result outputs from the comparative study could deduce benefits to solve problem to the existing State Health Department gravity-feed system, where applicable.

3.2.2. Data Collection and Compilation

All the water quality data for the three water supply authorities, namely, Muara Tebas, Lundu and Triboh, which are used for the comparative study are provided by the Operation and Maintenance Unit of Water Supply Branch, Public Works Department, Sarawak (Sui,Y.L. Personal Communication.13 Feb.2003;Seng,A.M.Personal Communication.Water Supply Branch HQ.13 Feb.2003).

The field visits to the respective water treatment plants will be carried out to gather site information from the ground staffs dealing with the actual operation and maintenance of the respective water treatment plants. The details are useful for understanding the site operation of the water treatment plant. During these visits, digital images of the water supply system covering the catchment, intake and treatment plant will be captured using a digital camera for illustration purpose in this study.

The protocol on procedures to collect water samples for the bacteriological analysis and chemical analysis from streams or rivers by the nominated staff members of the respective water treatment plant will follow the instruction prescribed in Standing Order No.2, which is published by the Public Works Department (1981). The details on Standing Order No.2 are elaborated in Chapter Four.

3.2.3. Data Analysis

- ❖ For the purpose of comparative study, the water quality data from the respective water supply authority used for analysis purposes are to derive for solutions in the recommendation for the study.

- ❖ The tool for data analysis that will be used to perform any of the statistical data analysis shall be the Microsoft Excel software.

- ❖ For presentation of data in this report, tabulated format and graphical display will be used for illustration for purpose of discussion.

- The water quality data from the Water Supply Branch are results of water samples analysis gathered from the sampling programme undertaken by the Department Of Chemistry, Sarawak. This is to comply with the requirements of the water quality standards to ensure safe water supply for the consumers as prescribes by the State Health Department (Public Works Department,1981).

For information, the following Table 10 provides the standard testing being carried out by the Department of Chemistry, Sarawak for the various ranges of water properties to be measured and the specific type of test methods to analyze both the raw water and treated water (Joon,L.S.Personal Interview.16 Sept. 2003):

Material/Product Tests	**Type of Test/Properties Measured/Range of measurement**	**Standard Test Method/Equipment/ Techniques**
Raw Water/ Treated Water	Ammonia	**APHA 4500 – NH3F** Phenate method
	Anions:Chloride, Fluoride, Nitrate and Sulphate	**APHA 4110 B** Ion chromatography with chemical suppression of eluent conductivity.
	Biochemical Oxygen Demand (BOD)	**APHA 5210 B**
	Chemical Oxygen Demand (COD)	**APHA 5220 C** Closed reflux (Hach Reactor) method
	Chloride	**APHA 4500 – Cl¯ B** Argentometric method
	MBAS	**APHA 5540 C**
	Organochlorine (OC)	**JKW W 0502** Gas chromatography with electron capture detector
	THM	**EPA 502.2** Purge and trap capillary column gas chromatography with electron captured detector
	Total Coliform & facial coliform (a) Treated Water (b) Raw Water	Methods for the examination of waters and associated materials, 3rd.Impression 1984, Multiple Tubes Method **JKM-M 2032** Membrane filter test method for detection and identification of coliform bacteria and *Escherichla Coli* in Water
	Total Dissolved Solids (TDS)	**AIR 007** Determination of TDS in raw and treated water by TDS/Conductivity meter

	Total Organic Carbon (TOC)	**APHA 5310 B** Total organic carbon by combustion infrared method
	Colour	**APHA 2120 B** Visual comparison method
	Turbidity	**APHA 2130 B** Nephelometric method

Table 10 – Standard test methods for raw water and treated water

Source:(Department of Chemistry,Sarawak,2003)

CHAPTER FOUR: WATER AUTHORITIES FOR COMPARATIVE STUDY

4.1 BACKGROUND

The details on purpose of the comparative study for the selected water supply authorities have generally being discussed in Chapter Three. Therefore, it is the aim of this chapter to deliberate details for each of the selected water supply system to clarify the technical background of the respective water supply authorities. Despite having similar characteristic of having the water sources using the gravity-feed system that originated from smaller water catchments, the distinct differences in system set-up and technical application between the Public Works Department and the State Health Department is on the use of the conventional water treatment method to treat the raw water. Generally, the Public Works Department operated a fully treated water treatment system, whereas the State Health Department piped-gravity system do not provide any basic treatment for the supply of drinking water in the rural areas.

Since this chapter will generally explain in the context of catchment area, system set-up and compliance of directives in the operation of the treatment plants, the detailed discussion of data analysis will be elaborated in Chapter Five. Meanwhile, the followings are the background information for the Muara Tebas Water Supply Authority and Lundu Water Supply Authority situated in Kuching Division and Triboh Water Supply Authority in Samarahan Division, which are under the jurisdiction of the Public Works Department (PWD). Exclusively for the purpose of illustration, the photographs of the water treatment plant systems indicated in the write-up below as well as the maps of the individual water catchment for Muara Tebas (W-5718), Lundu (W-5153) and Triboh (W-5145) are all itemized in-group and depicted in Section 4.1.1.

4.1.1. Muara Tebas Water Supply Authority, Kuching Division

The Muara Tebas Water Supply Authority was gazetted for operation on 1 Jun 1984. Situated in Kuching Division, it is about 29 kilometres to the north of the capital city of Kuching. Having a water treatment plant with a design capacity of 0.327 million litres per day, the raw water source is abstracted from a mountain stream originating from a small hill catchment. The local describes the name of this stream as Sungai Selabat (Selabat River). Already identified and demarcated by the Water Supply Section of Public Works Department as the *Muara Tebas Water Catchment*, the size of this catchment inclusive of the buffer zone is approximately 41 hectares (Shakeran,2001). Based on the importance of *Muara Tebas Water Catchment,* the Sarawak Water Resources council has categorized this catchment as a *Specific Independent Catchment Area* because of its isolation and the only available freshwater source in this particular region (Shakeran,1999;Shakeran,2001;Shakeran,2003). The typical catchment outlook and mountain stream are illustrated in Figure 2 on page 65.

Likewise, the *Muara Tebas Water Catchment* has also been classified by the Sarawak Water Resources Council as a *priority three catchment*. This is because under the Public Works Department future planning, the source from the *Muara Tebas Catchment* will not be used anymore and the water treatment plant will be decommissioned from operation. This plant decommissioning will be implemented once the Kuching Water Board, which having a more reliable raw water source from another bigger inland catchment of 63,563 hectares, will be supplying the treated potable water to this region (Shakeran,2001). With the recent assessment by the Waterworks Section of Kuching Division, Sungai Selabat is considered unreliable for long-term utilization by public water supply because it frequently dries up during prolonged drought period (Tahir,M.Personal interview.PWD Waterworks Section,Kuching.13 Feb.2003). Currently, the pipeline system from Kuching Water Board that supplied the urban areas of Kuching City has already being interconnected with the Muara Tebas pipeline network and still awaiting endorsement by the State Water Authority for full takeover of the Muara Tebas water supply system by the Kuching Water Board (Tahir,M.Personal interview.PWD Waterworks Section,Kuching.13 Feb.2003).

To elaborate further on the priority list of the water catchment, the following guidelines by the Sarawak Water Resources Council entails the classification and general criteria of a priority three water catchment for *Muara Tebas Water Catchment* area (Shakeran,2001):

1. The local community being directly supplied with treated water by other water sources classified under Priority One and Priority Two.
2. The raw water source has been identified and recorded as unreliable during severe drought occurrences.
3. The raw water source that experienced periodic cycles of saline intrusion.

4. Recorded inadequate availability of raw water to cope with the increasing water demand.
5. The raw water source is contaminated and water quality deteriorated, and after treatment is still unsafe for consumption.
6. Maintain the status of Priority Three and shall be subjected for review by the State Water Supply Authority over the long-term planning.

On the characteristics of catchment yield, the discussion during the study field site visit with the two plant attendants who have been working since 1984 (Personal Interview.28 March.2003), indicated that the flow volume from the mountain stream varies according to the intensity of rainfall being recharged into the catchment. They both agreed that during the dry period, there is not much surface water flowing down from the mountain, except for the groundwater discharged as spring water that are collected into the ground storage retention pond. During the extreme dry period, shortage of water will cause water crisis. The plant attendant described that due to the rugged terrains and rocky outcrops in the catchment, the only activity being observed are the cutting and felling of trees by the local inhabitants who used this forest resource as timbers for their household needs. Not much agricultural activity is known in the catchment area.

Nonetheless, the plant attendants reported in recent year, severe erosion of the cliff face situated in the headwater has gradually increased the level of turbidity in the raw water quality, especially during heavy torrential downpour. The highly turbid water affects the treatment process of the slow sand filtration; to an extend, several feet of the top sand media in the filter bed must to be shovel-off to avoid clogging effect by the mud residual that reduce the flow rate of water to be filtered. The attendants also indicated that from years of working experiences in the same treatment plant, the volumetric quantity of raw water from the mountain source has decreased remarkably. This is because the plant sometimes operated only from 3 to 4 hours daily base on pumping hours due to shortage of available raw water in the pump sump.

On the overall layout of the water treatment system, the technician in-charge of the operation and maintenance of Muara Tebas Water Treatment Plant, Mortadza Tahir mentioned that a concrete weir with a rose strainer was initially constructed at the intake source situated further upstream of Sungai Selabat (name of river). Later, because of the high accumulation of sediments due to the erosion, the small concrete weir becomes dysfunctional; hence, it was removed to allow water to flow directly into the storage retention pond (Personal interview.13 Feb.2003).

On the operation of the system, before the raw water is transferred to the slow sand filter beds, the water is initially channelled to the storage retention pond. There are two storage ponds available on site. The first unit is used as a storage retention pond to collect the incoming water from the mountain stream and the second unit is designed as a pump sump for the two high-lift pump units to deliver the raw water to the slow sand filter tank located on top of a hill. The elevation of the slow sand filters tank is sited about 40 meters from the original ground level because of the limited flat area, undulating and hilly landscape. There are three slow sand filter bed partitions in the tank. After the completion of filtration process, chlorine solution is injected into the filtered water as it flows into a storage tank reservoir with storage capacity of 178,000 litres. Figure 3(a) to 3(f) on page 66 to 68 shows the storage pond, the high-lift pumps, pump sump, the slow sand filter beds, chlorinator and the storage reservoir.

The following Table 11 on water supply statistics 2002 provided by the Water Supply Branch illustrated some details on the capacity of operation for Muara Tebas Water Supply Authority (Seng,A.M..Personal Communication.Water Supply Branch HQ.13 Feb.2003):

Daily Production (Litres/day)	Average daily consumption (Litres/day)	Estimated population served	Nos. of meter connection
318,352	308,828	1,524	293

Table 11 – Muara Tebas Water Supply statistics

(31 December 2002)

Source: (Water Supply Branch, 2002)

4.1.2. Lundu Water Supply Authority, Kuching Division

Lundu Water Supply Authority was gazetted for operation on 1 May 1959. Located on the extremely west of Sarawak, it is approximately 90 kilometres from Kuching City (Government of Malaysia,nd.). The main source of raw water used by Lundu water treatment plant originated from the Sungai Lundu (name of river) that flows down from a rugged mountain catchment identified as *Lundu Water Catchment* by the Water

Supply Branch. The size of the demarcated water catchment inclusive of its buffer zone is approximately 577 hectares (Shakeran,2001). Since it is the only available source of freshwater in the region for public water supply, the water catchment has been categorized by the Sarawak Water Resources Council as a *Specific Independent Catchment,* which is similar like *Muara Tebas Catchment*. Likewise, the *Lundu Water Catchment* is classified as a *priority two catchment* because the plan in the future on provision of potable water supply will be connected from the Kuching Water Board system and the existing source will eventually be a backup system as supplementary source (Government of Sarawak,2003). The following guidelines by the Sarawak Water Resources Council enumerate the classification and general criteria of a *priority two catchment* :

1. The future raw water source shall come from the identified regional raw water sources as in Priority One.
2. Shows substantiated reliability and continuous low flow yield of raw water source during severe drought.
3. Could serve as supplementary water source to complement isolated community and Rural Growth Centre.
4. Represent the groundwater aquifer reserved areas.
5. The source raw water is treatable using normal treatment processes to produce safe drinking water.
6. Maintain the status of Priority Two and shall be subjected for review by the State Water Supply Authority over the long-term planning.

A special attribute of *Lundu Water Catchment* is that it being part of the gazetted Gunung Gading National Park, declared by the state government in 1983. The size for the Gunung Gading National Park covers a much wider boundary area of approximately 4,104 hectares, as compared to the smaller size of *Lundu Water Catchment*. The National Park is opened for daily visit by the public. A mini recreation area and chalets are provided for visitors' home stay. The main attraction in this park is the world's largest flower known as the *Rafflesia tuan-mudae* (Ahmad & Abg.Morshidi,1993;Forest Department Sarawak,2003). To safeguard the raw water intake, the administrative centre, facilities and accommodation set-up for visitors are constructed outside the water supply catchment (Sui,L.Y.Personal Interview. Operation and Maintenance

Engineer,JKR HQ.12 Feb.2003). With the presence of forest officers stationed in the National Park, the human activities within the water catchment are well protected because of the routine enforcement works being carried out by the forest rangers (Ajisen,J.Personal Communication.20 March 2003). Figure 4(b) on page 68 shows the facilities of the Gunung Gading National Park.

Besides the National Park, another special feature of *Lundu Water Catchment* is the establishment of a mini-hydro dam situated about 2 kilometres upstream of Sungai Lundu from the existing water supply raw water intake. This mini-hydro dam has been constructed to cater for sufficient volume of water to run the generator in a turbine house, which was constructed downstream and near to the location of the Lundu treatment plant. This turbine house is illustrated in Figure 5 on page 69.The generated electricity is used as supplementary supply to support the Lundu Township and surrounding areas, which is operated by the Sarawak Electricity Supply Corporation (SESCO) (Ajisen,J.Personal Communication.20 March 2003).

According to Ajisen, the technician in-charge of waterworks section in Lundu (Personal Communication.20 March 2003), a mutual agreement have been sealed previously between the PWD and SESCO on any potential raw water supply issue. It is a common practice during emergency cases, when shortage of water being faced by the water supply authority, SESCO will consider releasing ample amount of raw water from the mini-hydro dam to a diversion pipe that is built as "tee-off" from the SESCO's delivery main to the turbine house, to support the required water demand. At the "tee-off" section, a gate valve has been fixed on-line to regulate this incoming water. Figure 6 on page 69 shows the concrete chamber for the "tee-off". Once the gate valve is opened, the considerable amount of available water from SESCO will flow to the raw water chamber that houses the intake pipe for water supply, constructed next to the concrete weir as illustrated in Figure 7 on page 69. From this raw water chamber, the raw water is gravitated through the delivery pipe to the Lundu treatment plant. The shortage of raw water from *Lundu Water Catchment* is normally being experienced during prolonged drought period.

Currently, there are two raw water intakes for the water supply purposes. The first is the concrete weir located on the main Sungai Lundu, where the water is gravitated using a delivery pipe to the treatment plant and the second water intake is a weir constructed downstream of the turbine house to collect the mini-hydro tailrace that being discharged. A pump sump is constructed next to this second weir to house the submersible pumps for boosting the raw water to the treatment plant for treatment process (Government of Malaysia,nd.). Figure 8(a) and 8(b) on page 70, depicted the overview of the typical catchment and the collection point of the mini-hydro tailrace.

The Lundu Treatment Works has a design capacity of 2.4 million litres per day (MLD). The set-up comprises of an aerator that initially treat the incoming flow of raw water from either one of the water supply raw water intakes. After going through the aeration process, several calibrated chemicals dosage is injected into the mixing channel. These chemicals are namely chlorine, which is injected into the raw water for disinfection purpose, dosage of Alum as chemical coagulant is injected into the untreated raw water using the mechanical dosing pumps and a pre-treatment for pH correction is being carried out at this point (Government of Malaysia,nd.;MWA,1994). Figure 9(a) on page 70 illustrates the aerator, the mixing channel for chemicals dosing.

The next stage is the flow of water passing through the baffled flocculation tank to agitate the water to form flocs before discharging into the lovo-type clarifiers or rectangular horizontal flow tanks. In the clarifiers, the flocs will settle as sludge formation at the bottom of the tank. The final stage of water treatment process will be the filtering of water through the rapid gravity filters to separate the suspended impurities and residual flocs which are carried over from the sedimentation process in the clarifiers. The filtered water will again be dosed with chlorine for purpose of post-treatment as well as for pH correction. Finally, the treated water is stored in the contact-balancing tank and pumped to fill-in the elevated storage reservoir with the capacity of 1,600,000 litres, which is situated on top of a hill before being distributed to the water consumers (Government of Malaysia,nd.;MWA,1994). Figure 10(a) to 10(d) on page 71 to 72 show the baffled flocculation tank, the lovo type clarifiers, the rapid gravity filters, the contact-balancing tank and elevated storage tank.

The following Table 12 on water supply statistics 2002 provided by the Water Supply Branch illustrated relevant details on Lundu Water Supply Authority (Seng,A.M.Personal Communication.Water Supply Branch HQ.13 Feb.2003):

Daily Production (Litres/day)	Average Daily Consumption (Litres/day)	Estimated Population Served	Nos. of Meter Connection
1,705,476	1,146,485	6,994	1,345

Table 12 – Lundu Water Supply statistics (31 December 2002)

Source: (Water Supply Branch, 2002)

4.1.3. Triboh Water Supply Authority, Samarahan Division

The Triboh Water Supply Authority was gazetted for operation on 1 November 1970. Although this water supply authority is in Samarahan Division, the road distance from the treatment plant to the Kuching City is about 70 kilometres. With a water treatment plant design capacity of 0.273 million litres per day, the raw water comes from a surface source known as Sungai Sinyaru (name of river) that originated from a small hill catchment of approximately 38 hectares, inclusive of the catchment buffer zone. The typical catchment outlook is shown in Figure 11 on page 72. Identified as *Triboh Water Catchment* by the Water Supply Branch, the Sungai Sinyaru is a tributary of the major Batang Krang (name of major river) that covers a catchment area of approximately 79,763 hectares and identified as *Gedong Water Catchment* (Shakeran,2001). The Water Supply Branch has categorized *Triboh Water Catchment* as a *Sub-Catchment* and given a *priority two* status by the Sarawak Water Resources Council because of the future supply will be coming from a more reliable water supply system; the detail description on classification and general criteria for priority two are similar with the aforementioned *Lundu Water Catchment* (Government of Sarawak,2002;Shakeran,2001).

Currently, the existing Triboh water supply system is an independent water supply network and nearby to the Serian regional water supply system that abstracts raw water from another major Batang Kayan (main river), which having a much bigger water catchment area of approximately 97,724 hectares (Shakeran,2001). With the series of development phases planned for Serian water treatment plant that includes expansion to increase the plant production capacity and pipeline system will enable to supply sufficient water demand to cater for Triboh Villagers, having a small population of about 551 people (Sui,L.Y.Pesonal Interview.Operation and Maintenance Engineer,JKR HQ.12Feb.2003). Upon completion of the Serian regional water supply system, the Triboh Water Supply Authority and the *Triboh Water Catchment* will be decommissioned and the existing pipeline networks will be connected to Serian water supply system (Government of Sarawak,2002).

According to Maling (Personal Interview.15 Feb.2003), the technician in-charge of Serian Waterworks Section in Samarahan Division, the layout of Triboh water treatment system comprised of a concrete weir constructed across Sungai Sinyaru to create an on-river storage impoundment. A rose strainer functions as intake pipe is placed almost to the bottom of the weir and connected to a delivery pipe to release the raw water directly to the slow sand filter tank. Due to the undulating topographical feature of the catchment, this weir has been constructed further upstream about 20 meters away from the slow sand filter treatment plant, and on a much higher ground. This makes it possible for the water to flow under gravity to the treatment plant. The height difference between the invert level of the intake pipe and the base of filter tank on the lower ground is about 3 meters, while the difference between the bases of the filter tank with the storage reservoir that is sited on a much lower ground, is about 4 meters. This shows that the flow of water in the entire systems from the weir to the slow sand filter tank and to the storage reservoir are operating using the force of gravity. Figure 12(a) to 12(d) on page 72 to 73 show the typical stream outlook at the intake, the concrete weir, the slow sand filters, chlorinator and storage reservoir.

Maling (Personal Interview.15 Feb.2003) further emphasized that the Triboh treatment plant is a straight forward gravity system without the use of any mechanical pump. In order to control the water flow between the various sections in the system, the plant attendants only need to open and close the sluice valves to regulate the flows within the plant. The water treatment plant system consisted of one number of filter tank with two partitions of slow sand filter beds. When the raw water is fill-in and reaches sufficient head on top of the filter beds, the water is released to flow through the slow sand filter media for the water treatment process to take effect for the physical-biological treatment. After passing through the filter media, the filtered water is collected by a system of under-drain pipes underneath the filter tank. While flowing to the storage tank, a chlorine dosing tank that is housed next to the filter tanks will inject chlorine solution into the filtered water for disinfection purpose. The treated water is stored in the 43,000 litres storage reservoir before being distributed to the water consumers.

According to Maling (Personal Interview.15 Feb.2003), the issue on shortage of water supply is only experienced during prolonged drought period. At the same time, the increase rate of population growth also contributed to shortage of public water supply especially during water demand at peak hours (Personal Communication.15 Feb.2003).

The following Table 13 on water supply statistics 2002 provided by the Water Supply Branch illustrated some relevant details on the operation of Triboh Water Supply Authority (Seng,A.M.Personal Communication.Water Supply Branch HQ.13 Feb.2003):

Daily Production (Litres/day)	Average daily consumption (Litres/day)	Estimated population served	Nos. of meter connection
213,714	109,161	551	106

Table 13 – Triboh Water Supply statistics (31 December 2002)

Source: (Water Supply Branch, 2002)

4.2. PHOTOGRAPHS OF THE WATER SUPPLY SYSTEMS

The following photographs illustrated in the figures below, for the water supply systems of Muara Tebas, Lundu and Triboh are captured using a digital camera by Mohamad Sabari Shakeran during a study visit to the sites. The water supply catchment maps used for illustration are provided by the Water Resources Unit of Water Supply Branch, Public Works Department Headquarters.

4.2.1. Muara Tebas Water Supply System

Figure 2(a)- Typical outlooks of Muara Tebas upper catchment

Figure 2(b)- The mountain stream flowing to the retention pond

Figure 3(a)- The storage retention pond collecting raw water from mountain stream

Figure 3(b) - The high-lift pumps delivering water to the slow sand filter treatment plant located on top of the hill

Figure 3 (c) – The water storage in the pump sump

Figure 3 (d) – The slow sand filter treatment plant

Figure 3 (e) – The chlorination system

Figure 3 (f) – The high level storage reservoir next to the slow sand filter

4.2.2. Lundu Water Supply System

Figure 4 (a) – The National Park signboard

Figure 4 (b) – The facilities for National Park

Figure 5 – SESCO turbine house

Figure 6 – The “tee-off” concrete chamber

Figure 7 – Collecting chamber for inflow from SESCO to supplement shortage of raw water at the intake

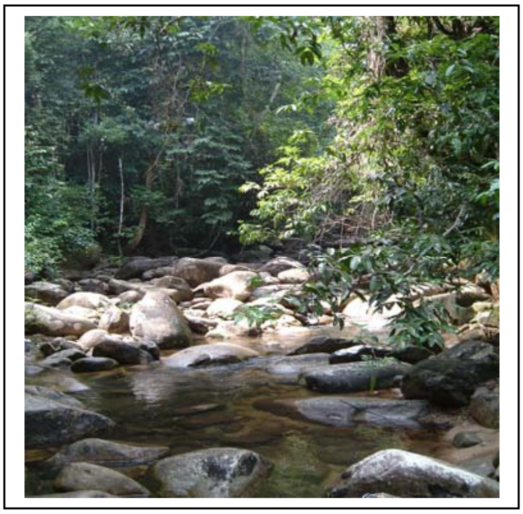


Figure 8(a) – Typical outlooks on the upstream of Lundu Water Catchment

Figure 8(b) – Discharge point of tailrace from the turbine house

Figure 9(a) – The aerator and mixing channel for chemicals dosing and baffled flocculation tank

Figure 10(a) – The lovo-type clarifiers

Figure 10(b) – The rapid sand filter tanks

Figure 10(c) – The contact-balancing tank

Figure 10(d) – The elevated high level storage reservoir

4.2.3. Triboh Water Supply System

Figure 11 – Overview of Triboh water catchment

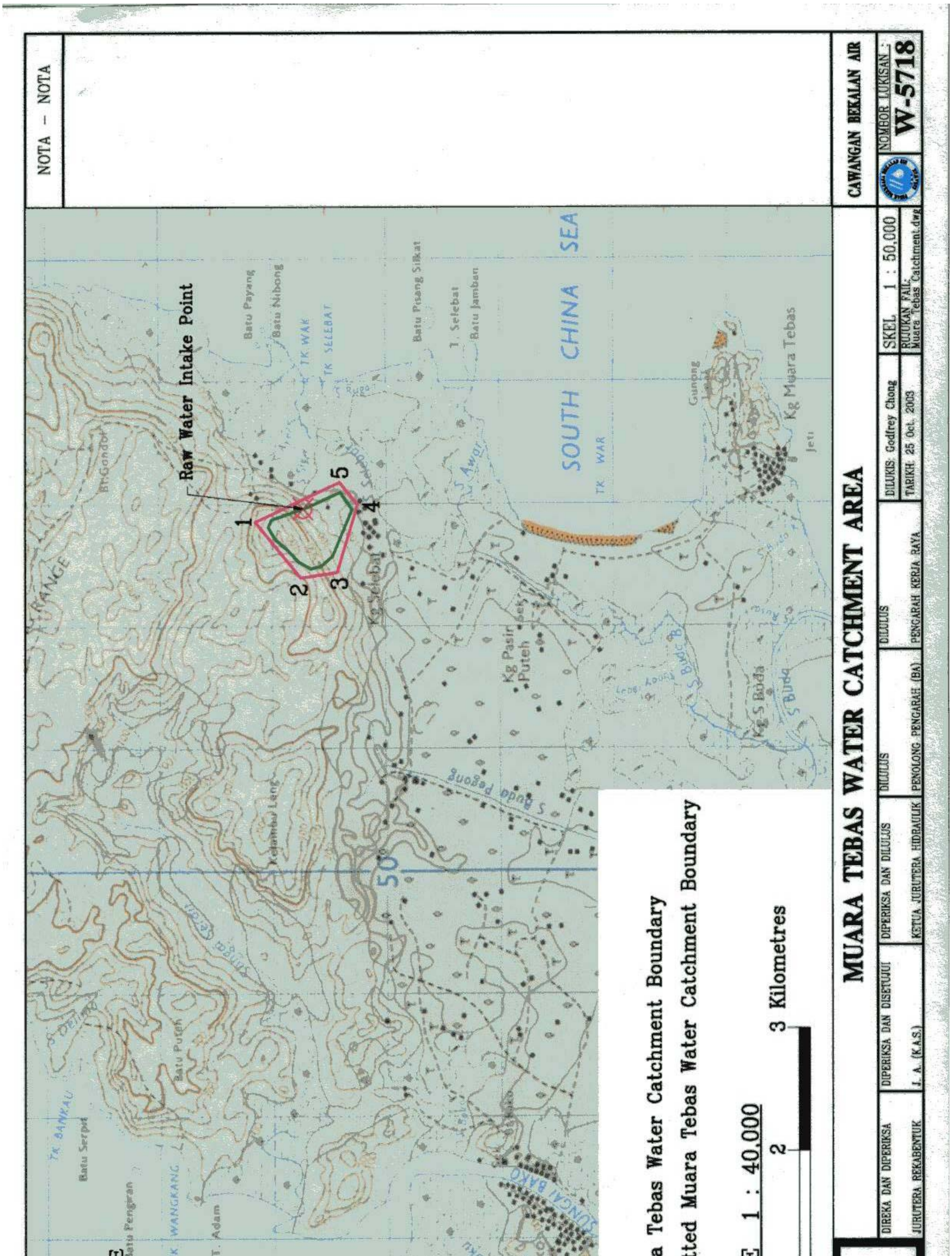
Figure 12(a) – The concrete weir and water intake

Figure 12(b) – The slow sand filter water treatment plant and chlorinator housing

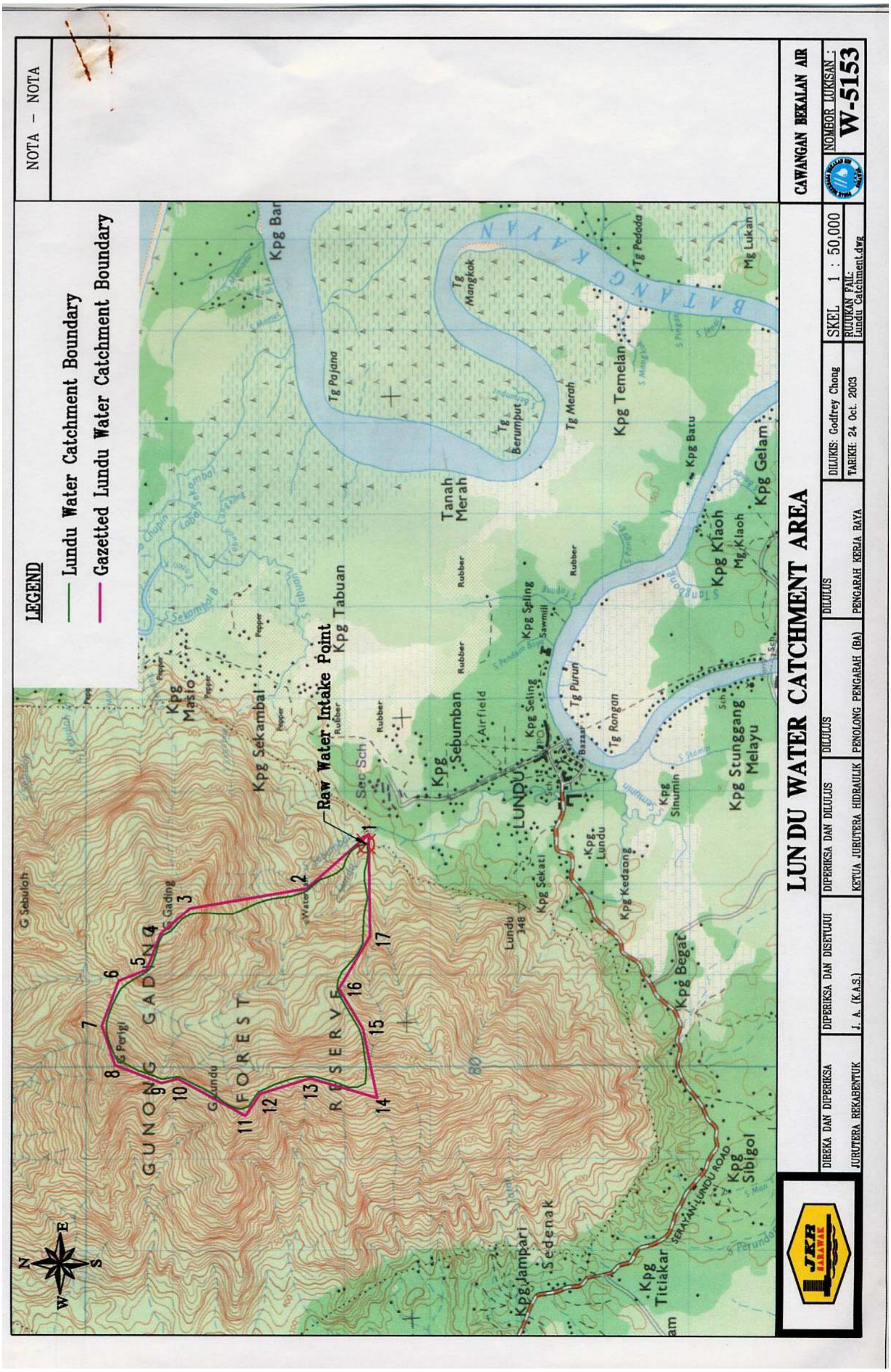
Figure 12(c) – The conventional chlorine dosing tank used by Water Supply Authority

Figure 12(d) – The storage reservoir

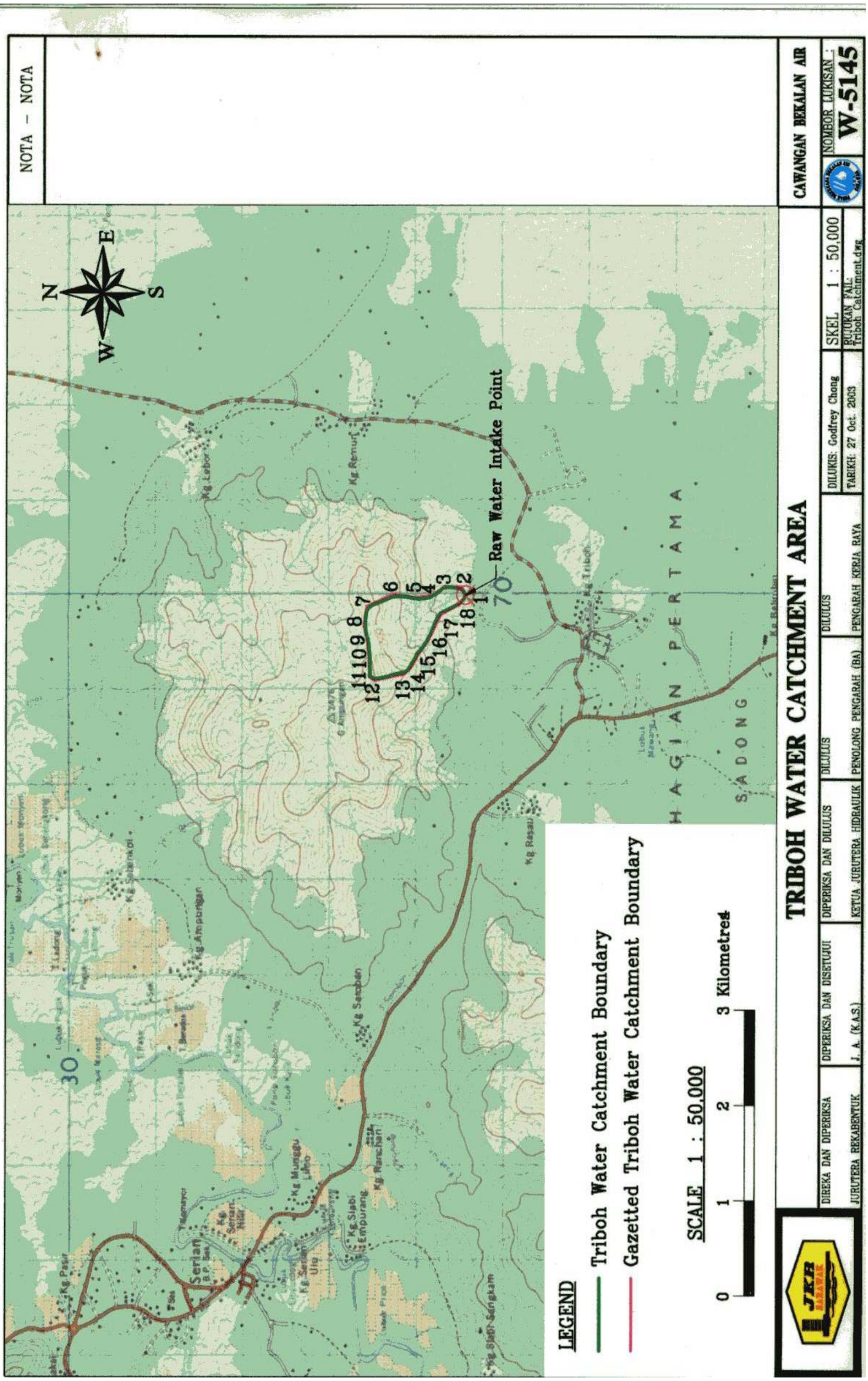
4.2.4 Muara Tebas Catchment Area (W-5718)



4.2.5 Lundu Water Catchment Area (W-5153)



4.2.6 Triboh Water Catchment Area (W-5145)



4.3. WATER SUPPLY AUTHORITY STANDING ORDERS

The directives that are issued by the Water Supply Branch as Standing Orders govern the smooth operation of the water supply treatment plants in Sarawak (Public Works Department,1981). As illustrated in Table 14, twelve Standing Orders are made available for strict compliance by the respective water supply authorities in the state to ensure high standards of achievement in the operation and maintenance of these water supplies. The Standing Orders consisted of the following keys subjects:

No.	Standing Orders
1.	Treatment Plant Operation and Maintenance for Atenden Loji and Atendan Pam
2.	Bacteriological and Chemical Water Quality Surveillance
3.	Fluoridation of Water Supplies
4.	Water Supply Hygiene
5.	Chemical Dosing
6.	Consumer Complaints and Pipe Burst
7.	Preventive Maintenance
8.	Sand Filter Operation and Maintenance
9.	Water Quality Analysis for Treatment Plant Control
10.	Pump Installation and Trouble Shooting
11.	Pointers on Public Relations for Water Supply Staff
12.	Contingency Plan in Time for Emergency

Table 14 – Lists of standing orders for water supply authority

Source: (Public Works Department, 1981)

Significance to the current study, the Standing Orders No.2 is of importance pertaining to the monitoring and analysis of raw water quality and treated water quality for the potable water supply that are consumed by the public. The aim of this specific Standing Order No.2 is to provide directive to the water supply authorities for ensuring the drinking water supply is well protected from any contamination and the public health is safeguarded by meeting the requirement of water quality standards imposed by the State Health Department. There are two types of sampling being carried out for the water quality analysis on a routine basis, namely, (Public Works Department,1981):

(a) samples analysis by Department of Chemistry, Sarawak

(b) samples analysis by waterworks staff at the treatment plant.

The frequency of samplings to be carried out by the Public Works Department (PWD) must comply with the schedule prepared by the Department of Chemistry, Sarawak. The

Department of Chemistry will base the interpretation of the water quality results using the National Guidelines for Drinking Water Quality Standard, depending on the latest revision being issued by the Ministry of Health Malaysia (Ministry of Health,1983b). For the purpose of illustration and guideline, the following Table 15 describes the frequency of analysis, water quality parameters tested and types of sample being scheduled for implementation by the PWD stipulated in the Departmental Standing Order that was revised in Jun 1999 (Ministry of Health,1983a;Public Works Department,1981):

No.	Frequency of Analysis	Parameters Tested	Remark	Types of Sample
1	**In-Plant Chemical Analysis** (Headworks samples) - Analysis may be done hourly or once per shift as required.	• pH • Hazen • Residual Chlorine • Turbidity • Residual Aluminium • Fluoride (where applicable) • Chloride (where applicable)		
2	**Weekly Bacteriological Analysis** (Reticulation samples)	• pH • Residual Chlorine	Analyzed at the treatment plant for the same bacteriological sample	
		• Coliform • E.Coli	Analyzed at Department of Chemistry	
3	**Monthly Chemical Analysis** (Reticulation samples)	**<u>Group I</u>** • Residual Chlorine (in-situ) • pH (in-situ) • Turbidity • Colour	**Group I** parameters are analyzed at the treatment plant	
		<u>Group II</u>	**Group II** parameters include in quarterly chemical analysis schedule	
		• Total Dissolved Solids		• RW & TW
		• Chemical Oxygen Demand		• RW
		• Biological Oxygen Demand		• RW
		• Ammonia Nitrogen		
		• Nitrate Nitrogen		• RW & TW
		• Total Carbon Organic (not required)		• RW & TW
		• Total Nitrogen (not required)		
		• Detergent		• RW & TW
		• Total Alkalinity (not required)		
		• Total Hardness		

		• Fluoride • Chlorine • Manganese • Iron • Aluminium		• RW & TW • RW & TW • RW & TW • RW & TW • RW & TW • RW & TW
4	**Quarterly Chemical Analysis** (reticulation samples)	**<u>Group III</u>**		
		• Arsenic		• RW & TW
		• Mercury		• RW & TW
		• Cadmium		• RW & TW
		• Lead		• RW & TW
		• Chromium		• RW & TW
		• Silver (not available)		• RW & TW
		• Copper		• RW & TW
		• Zinc		• RW & TW
		• Magnesium		• RW & TW
		• Sodium		• RW & TW
		• Selenium		• RW & TW
		• Total Organic Carbon		• RW
		• Sulphate		• RW & TW
		• Phosphate		
		• Mineral Oil (not required)		
		• Cyanide (not required)		
		• Phenol (not required)		
		• Chloroform		• TW
		• Trihalomethane		• TW
5	**Yearly Chemical Analysis**	**<u>Group IV</u>**		
		• Pesticides		• RW
		• Biocides		• RW

(**Note**: RW – raw water; TW – treated water)

Table 15 – Frequency of sampling programme for water quality analysis

Source: (Public Works Department, 1981)

According to the Standing Order No.9 on water quality analysis for treatment plant control illustrated in Table 16, the indicated list of frequency is provided as guidelines for compliance by the in-house treatment plant staffs who are responsible for the smooth running of the plant. The frequency to carrying out the water quality analysis depends largely on the hours of plant operations, size of treatment plant capacity, variability of incoming raw water flow rate to the plant and characteristics of raw water quality, and the accuracy of the chemical dosing (Public Works Department,1981):

No.	Water Quality Analysis	Frequency
1	• pH for raw water • Colour	Twice per shift
2	Jar Test	Once per shift
3	• pH • Colour of clarified water	Twice per shift
4	• pH • Colour of filtered water	Twice per shift
5	Fluoride concentration of treated water	Every 3 hours
6	• pH • Colour • Residual chlorine of treated water	Every 2 hours
7	Alkalinity	As required
8	Chlorides	As required
9	Residual Aluminium	Once per shift
10	Reticulation samples	Refer Standing Order No.2.

Table 16 – Frequency of testing for treatment plant control

Source: (Public Works Department, 1981)

CHAPTER FIVE: RESULTS AND ANALYSIS

5.1. Introduction

In this chapter, the interpretations of the water quality results for the gravity-feed systems under the jurisdiction of State Health Department and the Water Supply Authorities are discussed separately in two sections. Lastly, the outcomes of the comparative study on the water quality data are concluded in a matrix format to determine the best water treatment process options practically adopted as basic treatment for the rural gravity-feed system.

Basically, the first section focuses on the water quality from the State Health Department to determine the total violations of recorded water quality parameters by calculating the percentage of water samples violation exceeded the drinking water quality standards from the numerous piped-gravity waters. The second section focuses on the effectiveness of three different water treatment methods from the selected water supply authorities under the Public Works Department to remove the contaminants in the raw water and to determine the end-results of treated water quality.

As a study reference for drinking water standard, the National Standard for Drinking Water Quality (Revised December 2000) is adopted to determine the allowable limits of safe drinking water quality acceptable to Malaysian water quality conditions (Ministry of Health,1983b). The main reason that this standard is adopted because the Ministry of Health has several times improved and revised the contents of the National Standard for Drinking Water Quality for both the raw and treated water quality by integrating other international standards such as the Drinking Water Standards for New Zealand 1995, EEC Standard Council Directive (80/778/EEC), Australian Drinking Water Quality Guidelines 1996 and the World Health Organization recommendations (Ministry of Health,1983b).

5.1.1. State Health Department Water Quality Data

A total of five-year records, from 1998 until 2002, of water quality data from water samples taken from various gravity-feed systems in Lundu, Serian and Betong Districts situated in Western Sarawak, are used for the data analysis. The quantities of data gathered for the data analysis study are very much dependence on the availability of water quality reports provided by the State Health Department headquarters and the respective district offices. The numbers of water quality data are available in both hardcopy and softcopy formats depending on the years of record.

Initially, when the water quality data from these various sources were gathered from the State Health Department, the most tedious task was the conversion exercise of majority of the water quality data from hardcopies into a manageable digital database system. To overcome this issue, the Microsoft Excel 2002 software was chosen to simplify the task of carrying out the editing, graphics and charts presentation, generates statistical analysis and storage purposes.

In order to have a standard format to present the water quality data from the State Health Department and Water Supply Authorities, the *Guidelines for Drinking Water Quality Control for Rural Water Supply System,* is adopted as a standard for this purpose (Cawangan Kejuruteraan Alam Sekitar, nd.). The details are shown in Table 17.

In presenting the results, the quantities of water quality data are organized according to three major groups of water characteristics, namely, the physical, microbiological and chemical properties. Table 17 shows the organization of various water quality parameters and the prescribed reference that will be used for the water quality standards based on the National Standard of Drinking Water Quality.

Group	Water Quality Parameters	NDWQS (Rev. 2000) (Max.Acceptable Value)
A	**Physical Property**	
	(i) Turbidity	(i) 5 NTU
	(ii) Colour	(ii) 15 TCU
	(iii) pH	(iii) 6.5 – 9.0
	(iv) Residual Chlorine	(iv) Not less than 0.2 ppm
	(v) Dissolved Oxygen (only for gravity-feed sources)	(v) –
	(vi) Temperature	(vi) -
	(vii) Conductivity	(vii) 100 ms/cm
B	**Microbiological Property**	
	(i) Faecal Coliform	(i) 0 MPN/100 ml.

C	**Chemical Property**	
	(i) Total Dissolved Solid (TDS) (ii) Ammonia (NH3) (iii) Nitrate (NO3) (iv) Iron (Fe) (v) Fluoride (F) (vi) Aluminium (Al) (vii) Manganese (Mn)	(i) 1,000 mg/l (ii) 1.5 (*0.5) mg/l (iii) 10 mg/l (iv) 0.3 mg/l (v) 0.5-0.7 (*0.9) mg/l (vi) 0.2 mg/l (vii) 0.1 mg/l

Table 17 - Standard report format for water quality data

Note:

(a) NDWQS denotes National Drinking Water Quality Standard (Rev.2000)

(b) (*n) - Denote the value of water quality standard based on the last edition of the National Standard of Drinking Water Quality Standard, before the revision in 2000.

5.1.2. State Health Department Water Quality Data Results & Analysis

The water quality reports from the numerous water samples taken from the piped-gravity waters of gravity-feed system in Lundu, Serian and Betong Districts are presented in the *Summary Rural Water Sample Analysis* reports and the *Results of Data Analysis on Water Quality for Gravity-feed System* reports. These reports are annexed in the series of appendixes according to their groups. The summary and results are compiled using the following systems, namely, Lundu water quality data are grouped from Appendix C-1A to Appendix C-5B, Serian water quality data from Appendix D-1A to Appendix D-5B and Betong water quality data from Appendix E-1A to E-5B.

Using the data from the *Summary Rural Water Sample Analysis* reports, the study on the percentages of water quality violations for each year from water samples taken at numerous sampling points could be derived. The results are presented in Table 18, Table 19 and Table 20 for Lundu, Serian and Betong gravity-feed systems respectively. The information from the water quality violation studies highlight the extent of raw water quality degradation from the gravity-feed systems in the localities being studied.

The following are the results and interpretations of the gravity-feed systems from the various administrative districts:

(a) Gravity-feed Systems in Lundu District

Year	Total PG sample locations	**Physical** (Turbidity) % samples exceeded max.allowable value of NDWQS	**Microbiological** (Faecal Coli.) % samples exceeded max.allowable value of NDWQS	**Chemical** % samples exceeded max.allowable value of NDWQS			
				(Ammonia)	(Iron)	(Fluoride)	(Manganese)
1998	39	15.38	100	2.56	7.69	0	2.56
1999	40	17.50	100	0	0	0	20
2000	51	11.76	100	0	1.96	0	15.69
2001	56	7.14	100	0	1.79	5.36	39.29
2002	61	3.27	100	1.64	8.19	0	45.90

Note: (1) NDWQS denotes National Drinking Water Quality Standard (Rev.2000) (Ministry of Health,1983b).
(2) GFS denotes gravity-feed system; (3) PG denotes piped-gravity water

Table 18 – Lundu PG: Percentage samples exceeded NDWQS

Table 18 gives an overview of the results of Lundu piped-gravity water on the extent of contaminants in the raw water and percentage of water quality violations that exceeded the maximum allowable value of the drinking water quality standards (Appendix A). The calculated percentage of water samples exceeded the maximum allowable values of the National Drinking Water Quality Standard (Appendix A, Table 17) is based on the results of the summary rural water sample analysis data in the appendixes (Appendix C-1A, Appendix C-2A, Appendix C-3A, Appendix C-4A, Appendix C-5A).

To interpret the data, the use of minimum and maximum values of specific water quality parameters generated by statistical analysis, from 1998 to 2002, can be referred from the results of data analysis on water quality for gravity-feed system in Lundu annexed in the appendixes (Appendix C-1B, Appendix C-2B, Appendix C-3B, Appendix C-4B, Appendix C-5B). In addition, these results are used to produce the following graphs in Figure 8, Figure 9, Figure 10 and Figure 11.

The study of the Lundu piped-gravity water highlighted the water quality parameters in the raw water being detected to violate the drinking water quality standards are caused by the presence of turbidity, faecal coliform, ammonia, iron, fluoride and manganese.

(i) Physical Property: Turbidity Measurement

Table 18 shows that the turbidity levels before 1999 indicated an increase from 15.38% to 17.50%. After 1999, the turbidity levels fluctuated up to levels as high as 3.27% in 2002.

Figure 8 indicates that the ranges of turbidity maximum values are above the allowable standard of 5 NTU (Table 17). The lowest maximum value was 6.81 NTU in 1998, while the highest maximum value was 29.9 NTU in 2000. Throughout the five-year records, the average turbidity levels are measured below the allowable drinking water quality standard. In addition, the five-year records of maximum values for the turbidity levels shown in Figure 8 are much lower than the recommended raw water quality criteria of 1000 NTU (Appendix B).

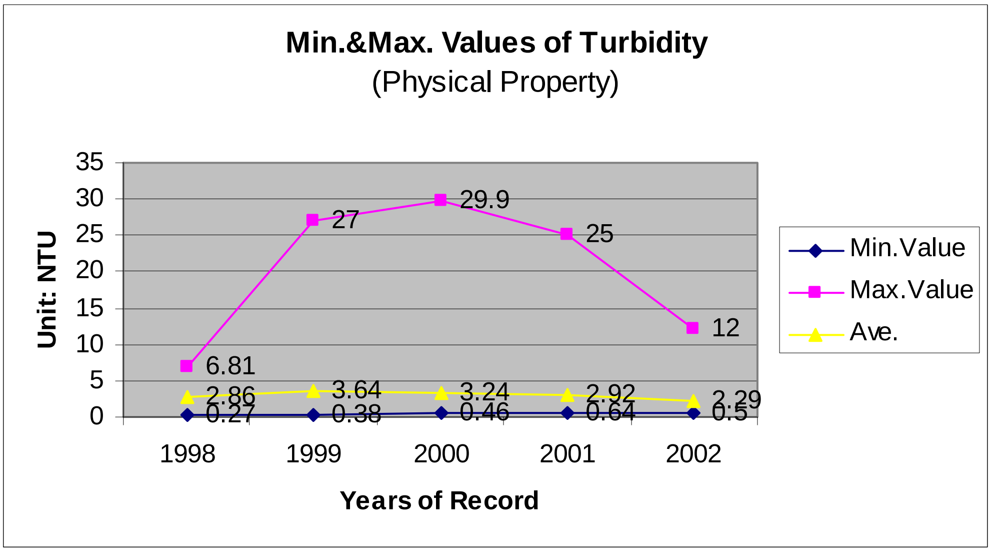


Figure 8 – Turbidity: minimum, maximum & average values

(ii) Microbiological Property: Faecal Coliform

Table 18 indicates the water samples from 1998 to 2002 contain 100% presence of faecal coliform. Specified in the drinking water quality standard (Appendix A; Table 17), the faecal coliform should not be detected in a water sample of 100 millilitre based on MPN Method.

Figure 9 shows the trend of the maximum values is on the increased between 1998 to 1999 and 2001 to 2002. The highest maximum value of 1,800 MPN/100mL was recorded in 2002. While the most minimum value was recorded as low as 2 MPN/100mL in 1998 and 2002. The distribution of average values for faecal coliform over the five-year records ranges between 65.44 MPN/100 mL to 182.31 MPN/100 mL.

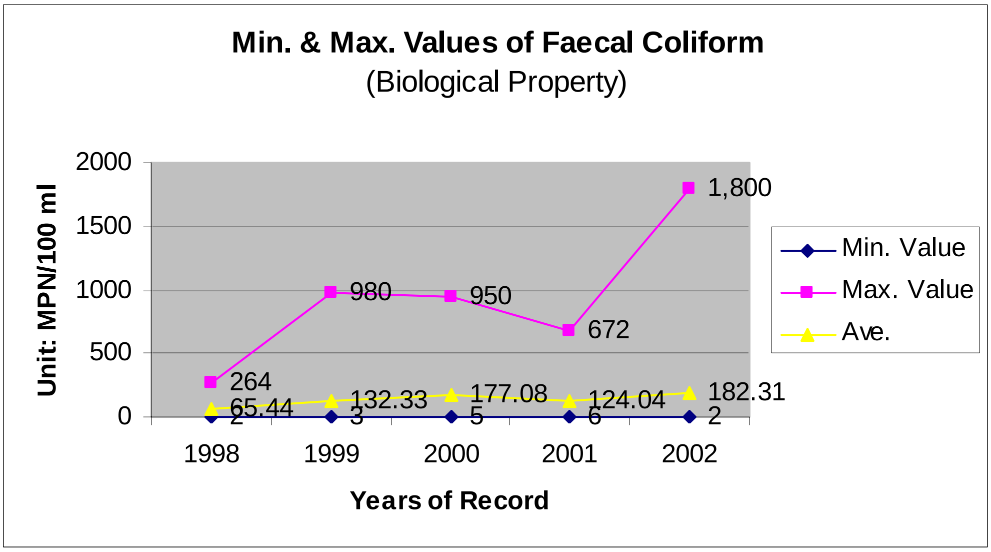


Figure 9 – Faecal Coliform: minimum, maximum & average values

(iii) Chemical Property: Ammonia/Iron/Fluoride/Manganese

Table 18 shows the presence of ammonia exceeded the drinking water quality standard (Table 17) in 1998 and 2002, with 2.56% and 1.64% respectively; while the violation of fluoride in 2001 was 5.32%.

Based on the total number of samples taken, the violation of ammonia is only one sample out of the 39 samples in 1998 and out of 61 samples in 2002. Similarly, the violation of fluoride is only three samples out of 61 samples in 2002. Therefore, the violation results for ammonia and fluoride are not that significant throughout the five-year records.

Likewise, Table 18 shows that the presence of manganese in the drinking water is most significant. The trend of manganese in the raw water was on the increase, from 2.56% in 1998 to a maximum of 45.90% in 2002. This indicates a maximum of 28 samples violation out of 61 water samples taken in 2002. Only one sample violation out of 39 water samples was recorded in 1998.

Figure 10 also shows the increasing trend of manganese constituents in the drinking water. The maximum values ranging between 0.2 mg/L in 1998 to 0.8mg/L in 2001. The maximum allowable value for manganese in the drinking water quality standards is 0.1 mg/L (Table 17; Appendix A). The average values in 2001 and 2002 exceeded the drinking water quality standards with the detection of 0.28 mg/L and 0.20 mg/L respectively.

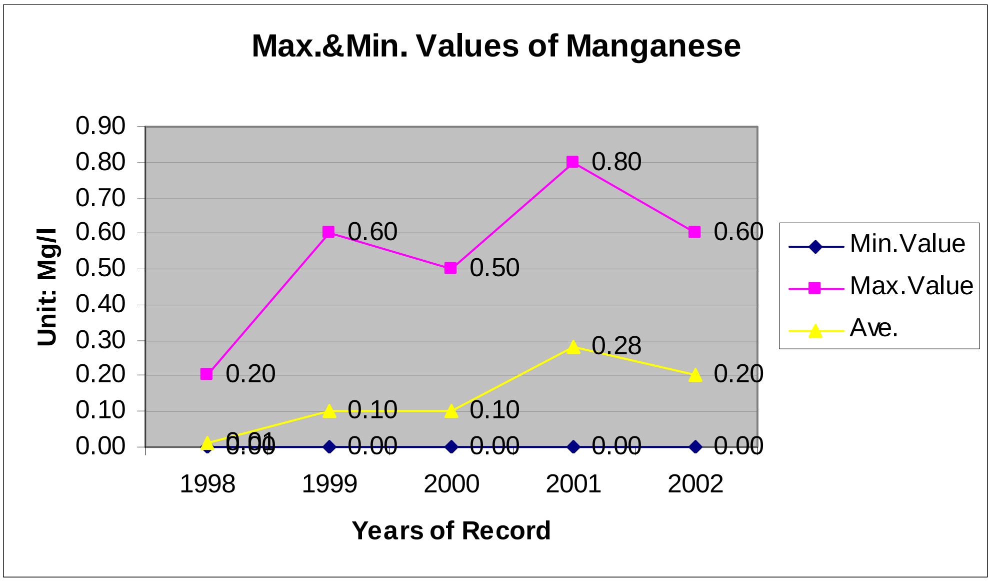


Figure 10 – Manganese: minimum, maximum & average values

Table 18 shows the violation of iron detected in the water was high with 7.69% in 1998 and 8.19% in 2002. These percentages translate to three samples violations out of 39 samples taken in 1998 and 5 samples violation out of 61 samples taken in 2002. There was no violation of iron in 1999.

Figure 11 indicates the iron levels before 1999 was on the decrease from the maximum value of 0.40 mg/L to 0.17 mg/L. After 1999, the iron levels were on the increasing trend to levels as high as 1 mg/L in 2002. The average values in Figure 11 shows throughout the five-year records, the iron levels are far below the maximum allowable value of the drinking water quality standard of 0.3 mg/L.

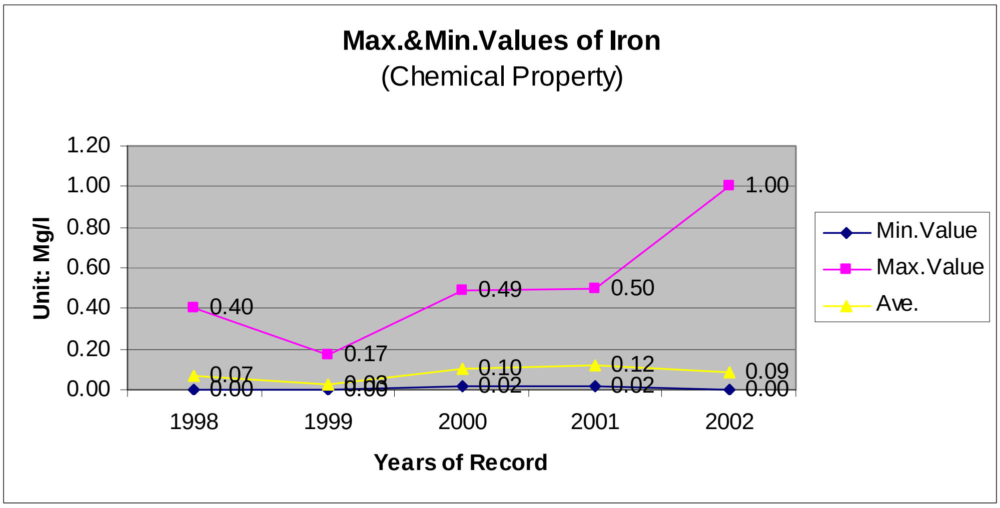


Figure 11 – Iron: minimum, maximum & average values

(b) Gravity-feed Systems in Serian District

Year	Total PG sample locations	Physical (Turbidity) % samples exceeded max.allowable value of NDWQS	Microbiological (Faecal Coli.) % samples exceeded max.allowable value of NDWQS	Chemical % samples exceeded max.allowable value of NDWQS			
				(Ammonia)	(Iron)	(Fluoride)	(Manganese)
1998	37	13.51	35.13	0	5.41	0	54.05
1999	36	19.44	30.56	0	13.89	0	94.44
2000	45	37.78	24.44	0	4.44	0	51.11
2001	49	4.08	44.90	0	0	0	16.33
2002	75	0	33.33	0	1.33	0	18.67

Note: (1) NDWQS denotes National Drinking Water Quality Standard (Rev.2000)
(2) GFS denotes gravity-feed system
(3) PG denotes piped-gravity water

Table 19 – Serian PG: Percentage samples exceeded NDWQS

Similar with the case of Lundu water quality results, the interpretation of data using the minimum and maximum values from 1998 to 2002 are based on the results in the appendixes (Appendix D-1B, Appendix D-2B, Appendix D-3B, Appendix D-4B, Appendix D-5B). These results are used to produce the graphs in Figure 12, Figure 13, Figure 14 and Figure 15.

Table 19 is derived base on the results of summary rural water sample analysis in the appendixes (Appendix D-1A, Appendix D-2A, Appendix D-3A, Appendix D-4A, Appendix D-5A) to calculate the percentage of samples exceeded the maximum allowable values of the National Drinking Water Quality Standard (Appendix A, Table 17).

In Serian piped-gravity water, four major violations of water quality standard are observed in Table 19. The violations are caused by turbidity, faecal coliform, iron and manganese constituents. Amongst these contaminants, the presence of faecal coliform and manganese are most significant because of violations being detected throughout the five-year records.

(i) Physical Property: Turbidity Measurement

Table 19 shows that the increased percentage of violation of turbidity levels before 2000, from 13.51% to 37.78%. After 2000, a significant drop was observed from 4.08% in 2001 to 0% in 2002.

Similarly, Figure 12 shows the turbidity levels are on the increase before 2000 to the highest maximum value of 29.9 NTU. After 2000, the turbidity levels show a sharp decline to 20.80 NTU in 2001 and 5 NTU in 2002. The zero value recorded in 2002 (Table 19) is because of no occurrence of violation being detected. The average value supports the highest record of 5.22 NTU in 2000, as compared with the others. The acceptable maximum limit in the drinking water quality standard is 5 NTU (Table 17, Appendix A).

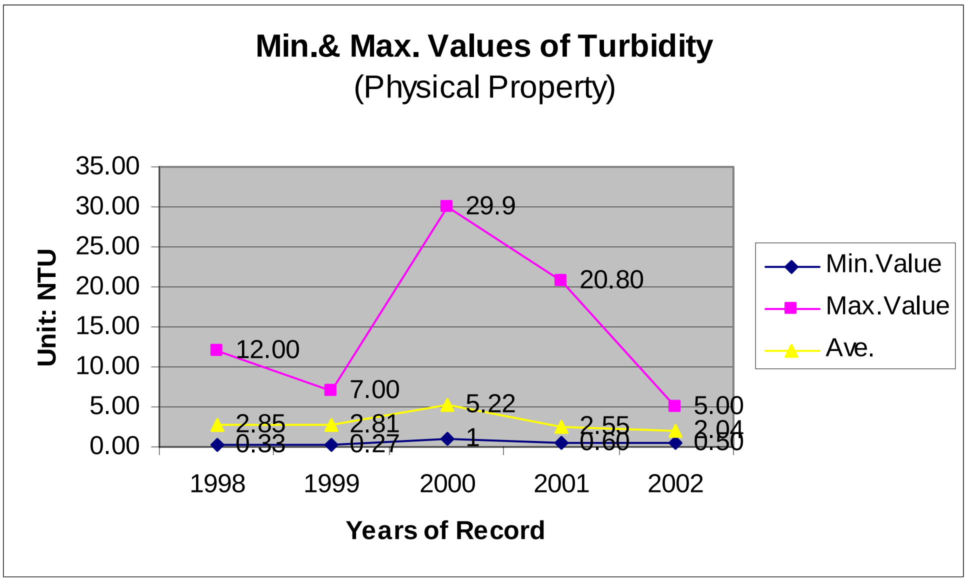


Figure 12 – Turbidity: minimum, maximum & average values

(ii) Microbiological Property: Faecal Coliform

Table 19 shows the detection of faecal coliform presence in the sampled waters from 1998 to 2002. The ranges of violations out of the total samples taken are between the minimum of 24.44% to a maximum of 44.90%. This means the contamination by faecal coliform presence in the raw water depends on certain months of the year.

Figure 13 indicates that the maximum value of faecal coliform detected in the water sample was 400 MPN/100mL in 1999, 2000 and 2002. The minimum value recorded for faecal coliform was 185 MPN/100 mL in 2001. The average values over the five-year records ranging from the lowest of 23.43 MPN/100mL to the maximum of 44.44 MPN/100 mL. The drinking water quality standards indicated the faecal coliform should not be present in the drinking water (Appendix A).

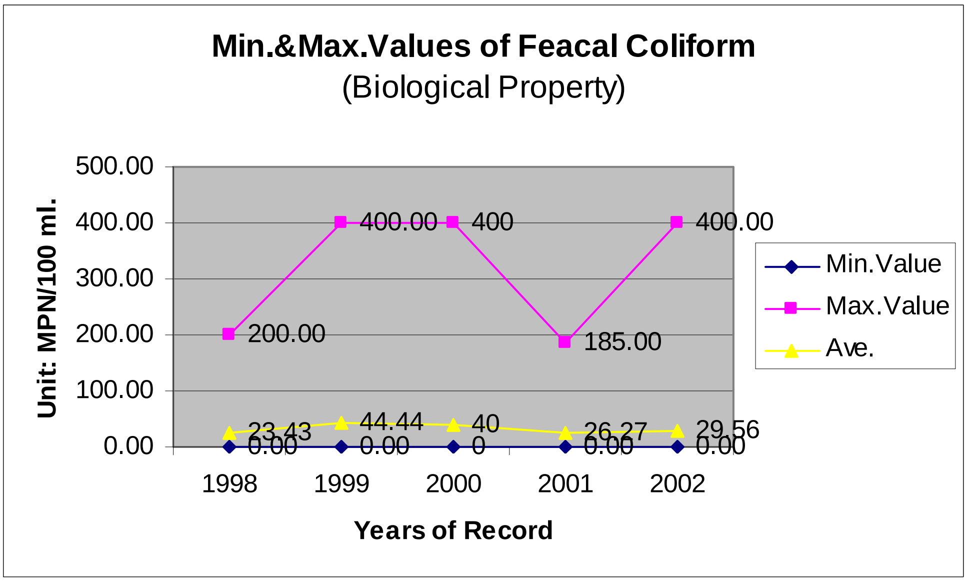


Figure 13 – Faecal Coliform: minimum, maximum & average values

(iii) Chemical Property: Iron/Manganese

Table 19 shows four records of iron violation in 1998, 1999, 2000 and 2002. The maximum value recorded was 13.89% in 1999 and the minimum with zero violation in 2001. Nevertheless, the violations were not significant in 1998, 2000 and 2002, with only 5.41%, 4.44% and 1.33% respectively. In terms of water sample violations, based on the total water samples, the samples exceeded the drinking water quality were 2 samples in 1998, 5 samples in 1999, 2 samples in 2000 and 1 sample in 2002.

Figure 14 shows that in 1998 and 1999, both had the same maximum value of 1.09 mg/L. The reason of no violation of excessive iron detected in 2001 because iron being detected was only 0.2 mg/L, which was below the drinking water quality standard of 0.3 mg/L in (Table 17, Appendix A).

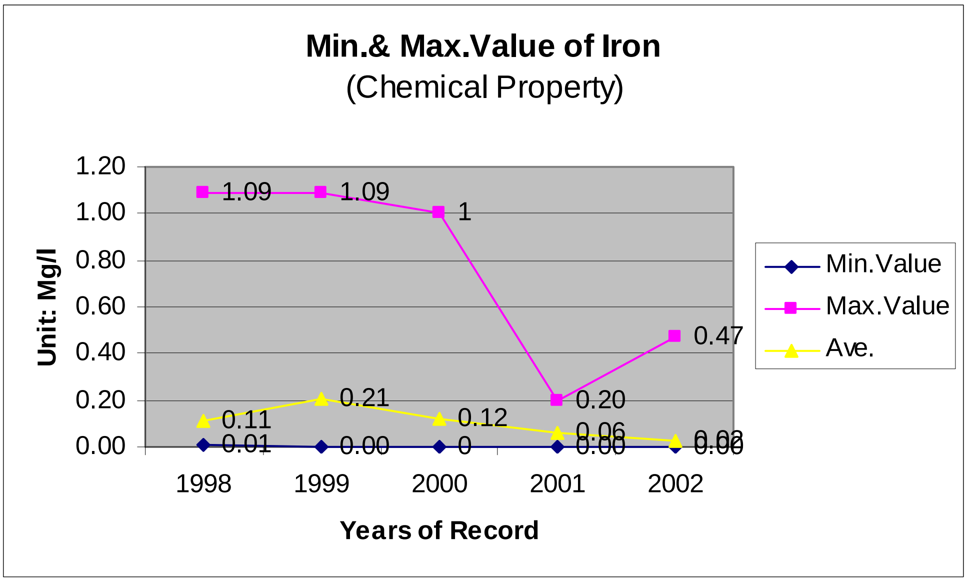


Figure 14 – Iron: minimum, maximum & average values

Highlighted in Table 19, the violations caused by the presence of manganese was quite significant from 1998 to 2000. The observation indicated that more than half of the water samples during the particular years exceeded the maximum allowable value prescribed in the drinking water quality standard (Appendix A). The year 1998 recorded 54.05% and the year 2000 recorded 51.11% respectively. The maximum violation recorded was 94.44% in 1999. This record in 1999 translates to 34 samples violation out of 36 water samples taken. The violation was less between 2001 and 2002, with 16.33% and 18.67% respectively.

Figure 15 indicates the maximum value for manganese in 1999 was 36.06 mg/L. Similarly, the average value of manganese in the particular year recorded 0.6 mg/L. The maximum allowable limit prescribed in the standard is 0.1 mg/L (Table 17, Appendix A). The year 1998 and 2000, recorded the same average value of 0.18 mg/L, which was above the requirement of drinking water quality standards (Table 17, Appendix A).

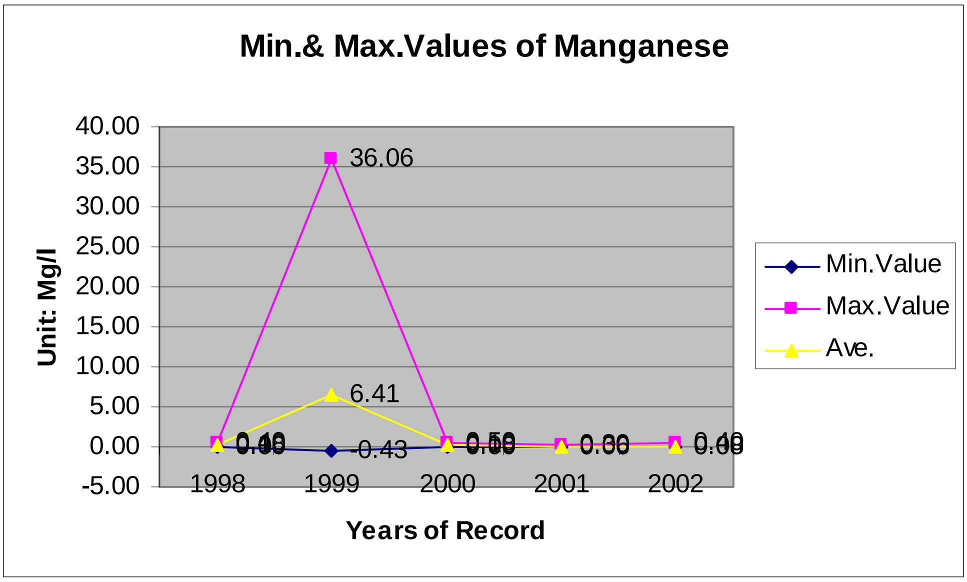


Figure 15 - Manganese: minimum, maximum & average values

(c) Gravity-feed Systems in Betong District

Year	Total PG sample locations	Physical (Turbidity) % samples exceeded max.allowable value of NDWQS	Physical (Conductivity) % samples exceeded max.allowable value of NDWQS	Microbiological (Feacal Coli.) % samples exceeded max.allowable value of NDWQS	Chemical % samples exceeded max.allowable value of NDWQS		
					(Nitrate)	(Iron)	(Manganese)
1998	44	0	0	11.36	0	4.54	0
1999	39	0	2.56	0	0	0	0
2000	42	2.38	0	0	2.38	2.38	0
2001	27	3.70	0	11.11	0	0	3.70
2002	37	0	0	56.76	0	5.41	2.72

Note: (1) NDWQS denotes National Drinking Water Quality Standard (Rev.2000)
(2) GFS denotes gravity-feed system
(3) PG denotes piped-gravity water

Table 20 – Betong PG: Percentage samples exceeded NDWQS

The same as previously, the interpretation of data for the minimum and maximum values from 1998 to 2002 will refer to the results of data analysis on water quality for gravity-feed system in Betong listed in the appendixes (Appendix E-1B, Appendix E-2B, Appendix E-3B, Appendix E-4B, Appendix E-5B). These results are used to produce the following graphs in Figure 16, Figure 17, Figure 18, Figure 19, Figure 20 and Figure 21.

Table 20 is derived using the results of summary rural water sample analysis in the appendixes (Appendix E-1A, Appendix E-2A, Appendix E-3A, Appendix E-4A, Appendix E-5A) to calculate the percentage of samples exceeded the maximum allowable values of the National Drinking Water Quality Standard (Appendix A, Table 17).

Based on Table 20, the data observation indicated that the violations of water quality parameters in Betong piped-gravity water are sparsely distributed amongst the water properties. The presence of faecal coliform in the water samples was most significant especially in 2002. Other water quality parameters that violate the national water quality standard are the turbidity, conductivity, nitrate, iron and manganese.

(i) Physical Property: Turbidity Measurement

Table 20 shows that the violations of turbidity levels only occurred in 2000 and 2001, with 2.38% and 3.70% respectively. No detection of turbidity level violates the drinking water quality standard during 1998, 1999 and 2002.

Figure 16 shows that before the year 2000, the trend was on the increase from 3.60 NTU in 1999 to the highest maximum value of 10.6 NTU. After 2000, the declining trend shows the maximum value drop to 6.50 NTU in 2001 and 4.9 NTU in 2002. The turbidity measurements in 1998, 1999 and 2002 were below the maximum limit of 5 NTU of the drinking water quality standard (Table 17, Appendix A). This is the reason of no violation being shown in Table 20 for 1998, 1999 and 2000. Also, Figure 16 shows the average values are less than the allowable limit in the national drinking water quality standard (Table 17, Appendix A).

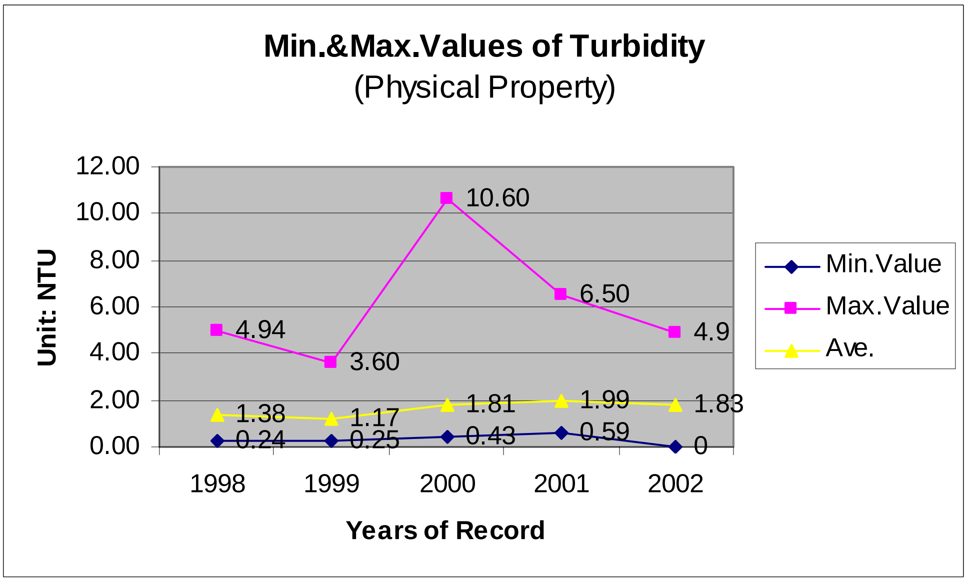


Figure 16 - Turbidity: minimum, maximum & average values

(ii) Physical Property: Conductivity Measurement

Table 20 shows that the violation of conductivity measurement only occured in 1999 with 2.56% samples exceeded the maximum allowable value of the drinking water quality standard (Table 17, Appendix A). This translates to one sample violation only in 1999.

In addition, Figure 17 shows the highest maximum value of 116 ms/cm was recorded in 1999, which is beyond the maximum allowable standard of 100 ms/cm (Table 17, Appendix A). The average values highlighted in Figure 17 shows the conductivity levels are much lower than the prescribed national standard throughout the five-year records.

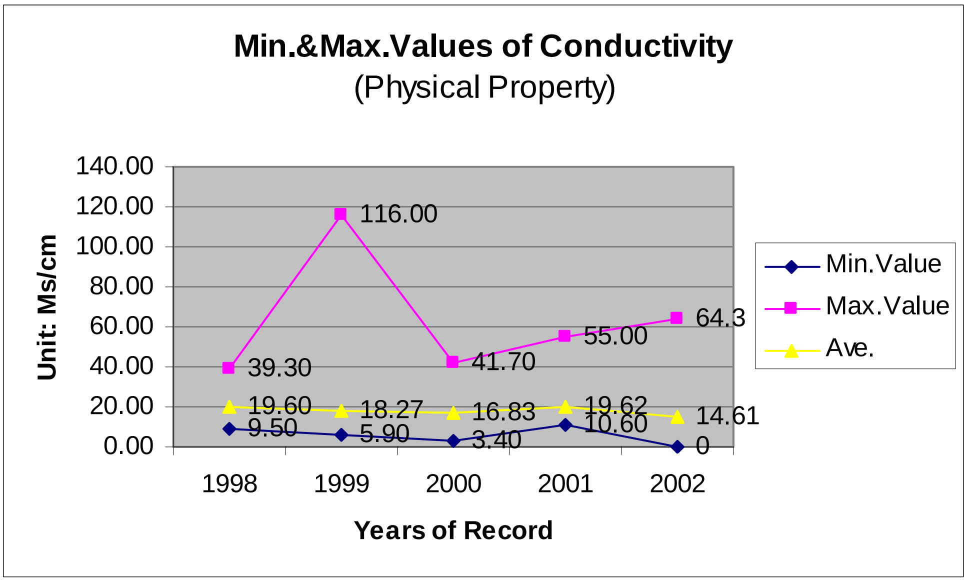


Figure 17 - Conductivity: minimum, maximum & average values

(iii) Microbiological Property: Faecal Coliform

Table 20 shows the detection of faecal coliform presence in 1998, 2001 and 2002. The highest recorded of violation was 56.76% in 2002. The violations in 1998 and 2001 were 11.36% and 11.11% respectively. No violation was detected in 1999 and 2000.

Figure 18 indicates the maximum value of 200 MPN/100Ml was recorded in 1998. Although the presence of faecal coliform was significant in 2001 and 2002, the values were slightly reduced from 100 MPN/100 mL to 86 MPN/100 mL respectively. The average values for the five-year records ranging from 7.14 MPN/100 mL to 18.18 MPN/100 mL.

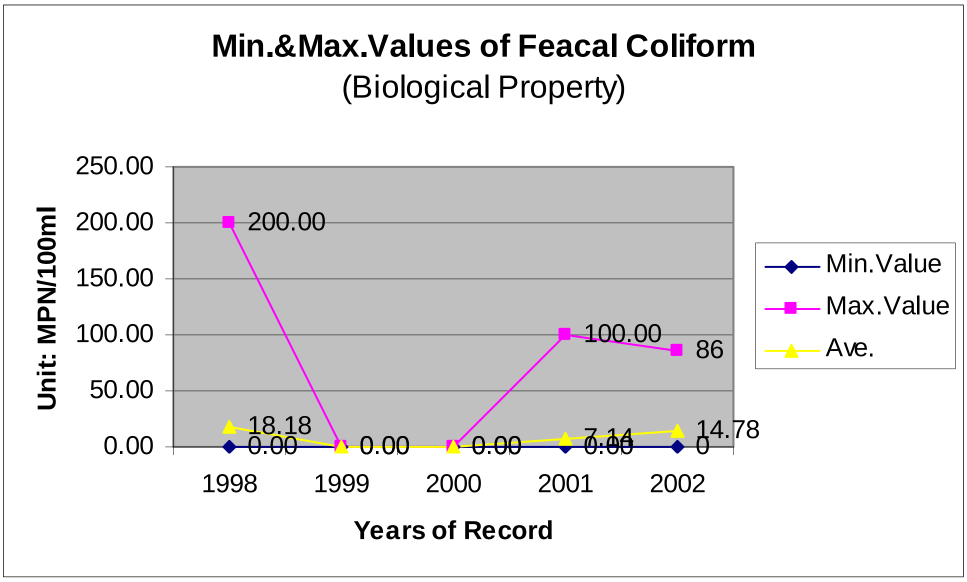


Figure 18 – Faecal Coliform: minimum, maximum & average values

(iv) Chemical Properties: Nitrate/Iron/Manganese

Table 20 shows the violation of nitrate occurred only in the year 2000 with 2.38%. This translates to one sample violation in 2000.

Figure 19 supports the presence of nitrate with the highest maximum value of 12.60 mg/L in 2000, above the maximum acceptable limit of the drinking water quality standard of 10 mg/L (Table 17, Appendix A). The values in other years are lower than the requirement set in the standard. The average values of the five-year records also indicated the lower measurement ranging from 0.54 mg/L to 1.04 mg/L.

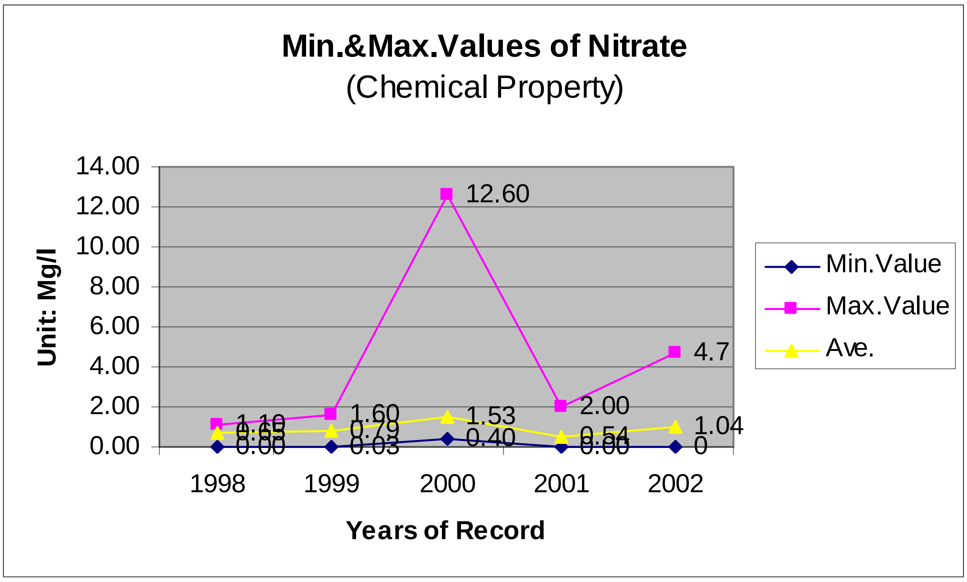


Figure 19 – Nitrate: minimum, maximum & average values

Table 20 shows that the violations of iron were recorded in 1998, 2000 and 2002, with the 4.54%, 2.38% and 5.41% respectively. No violation of iron was recorded in 1999 and 2001.

Figure 20 shows the highest maximum value being recorded was 21 mg/L in 2000, above the requirement of drinking water quality standard of 0.3 mg/L (Table 17, Appendix A). The maximum value of iron in 1998 and 2002, recorded the values of 1.09 mg/L and 0.4 mg/L respectively. The average value in 2000 indicated a high average of 0.65 mg/L compared with the others.

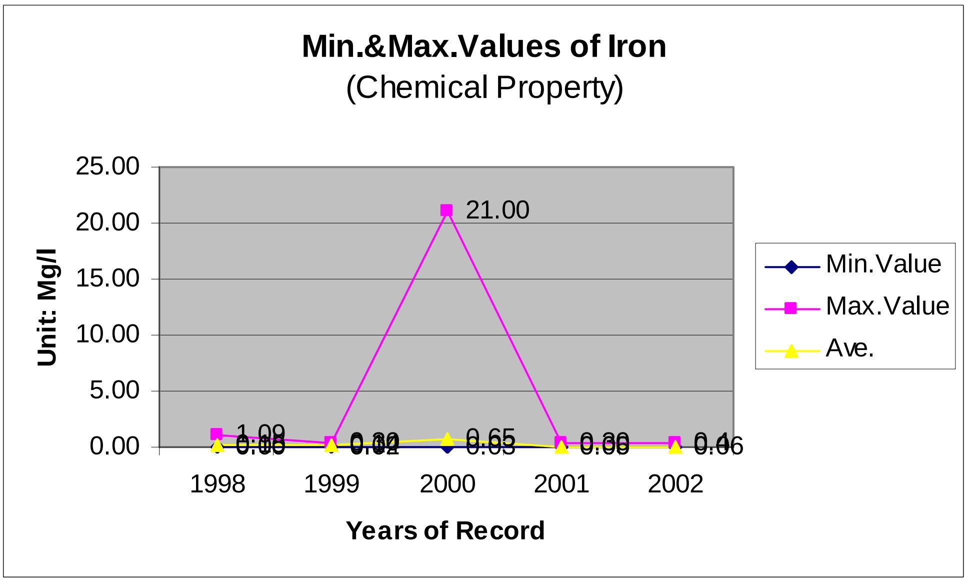


Figure 20 – Iron: minimum, maximum & average values

Table 20 indicates manganese recorded only two violations in 2001 and 2002, with the 3.7% and 2.72% respectively.

Figure 21 shows the incremental maximum value from 0.40 mg/L in 2001 to 0.60 mg/L in 2002, which support the violation of manganese parameter exceeded the 0.1 mg/L of the drinking water quality standards (Table 17, Appendix A). No detection of manganese was recorded in 1998, 1999 and 2000. The average values for 2001 and 2002 were 0.02 mg/L and 0.08 mg/L respectively, which were below the permissible limit of drinking water quality standard.

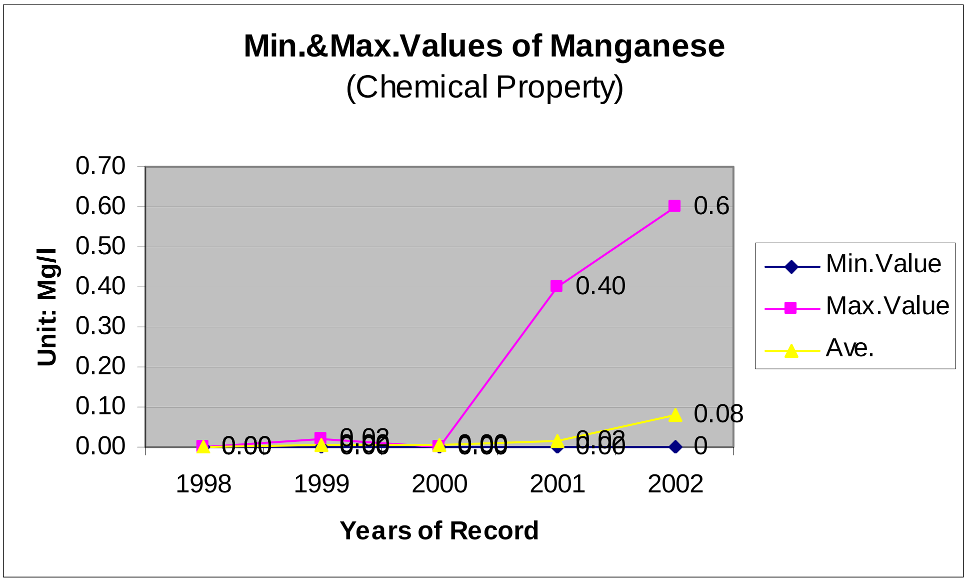


Figure 21 - Manganese: minimum, maximum & average values

5.1.3. Public Works Department Water Quality Data

To determine the effectiveness of treatment for the raw water from the selected water treatment plants under the Water Supply Authorities, a five-year water quality records, from 1998 until 2002, were compiled from the Water Supply Branch of Public Works Department for the purpose of data analysis.

Although, majority of the water quality records for the physical and chemical properties have already being key-in into Microsoft Excel format, some adjustments are required to be made to the water quality records. This is to comply with the standard presentation format in this study by following Table 17. The tedious task is to split and compile the water quality parameters into two groups of database, namely, the raw water quality parameters file and the treated water quality parameters file. This will enable a digital data processing could be made on the water quality to detecting significant changes to the raw water after undergoing the treatment processes.

Despite the aforementioned exercises of adjusting the water quality formats (water physical and chemical properties) are already challenging, carrying out the manual conversion of the five-year records of bacteriological data into softcopy format has added to the burden. Lastly, the whole water quality parameters database was successfully converted into Microsoft Excel format to simplify the analysis study.

5.1.4. Public Works Water Quality Data Results & Analysis

The *Summary Rural Water Sample Analysis* reports and the *Results of Data Analysis on Water Quality for Gravity-feed System* reports for Muara Tebas, Lundu and Triboh water supply authorities are grouped according to the following systems, namely, Muara Tebas water quality data are grouped from Appendix F-1A to Appendix F-5D, Lundu water quality data from Appendix G-1A to Appendix G-5D and Triboh water quality data from Appendix H-1A to Appendix H-5D.

For interpretation of the water quality data, the sample mean value of each water quality parameter is used. These mean values are generated using the Microsoft Excel Data Analysis Tool. The results of mean values for Muara Tebas, Lundu and Triboh water supply authorities are annexed in a report in Appendix C as *Mean Values for Water Quality for Gravity-feed System for Water Supply Authorities (Raw Water & Treated Water)*. The mean values are also used to produce Figure 22, Figure 23, Figure 24, Figure 25, Figure 26, Figure 27, Figure 28 and Figure 29.

Besides using the mean values to interpret the results, the maximum values are sometimes referred to support the argumentation. Both data for each of the mean value and maximum value can be referred in the appendixes for raw water and treated water according to the year of records in the appendixes (Muara Tebas - Appendix F-1B, Appendix F-1D; Appendix F-2B, Appendix F-2D; Appendix F-3B, Appendix F-3D; Appendix F-4B, Appendix F-4D, Appendix F-5B, Appendix F-5D; Lundu - Appendix G-1B, Appendix G-1D; Appendix G-2B, Appendix G-2D; Appendix G-3B, Appendix

G-3D; Appendix G-4B, Appendix G-4D, Appendix G-5B, Appendix G-5D; Triboh - Appendix H-1B, Appendix H-1D; Appendix H-2B, Appendix H-2D; Appendix H-3B, Appendix H-3D; Appendix H-4B, Appendix H-4D, Appendix H-5B, Appendix H-5D).

The following figures show the results on the effectiveness of water treatment processes from the three water supply authorities that use different conventional water treatment systems. The discussions on the water quality parameters from those water supply authorities will follow the headings based on the water characteristics, namely, the physical, microbiological and chemical properties:

(a) Physical Property

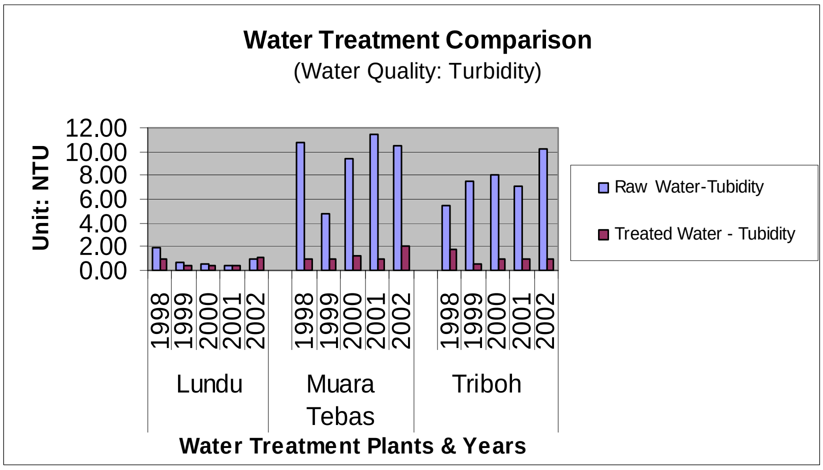


Figure 22 – Turbidity (Mean) for Lundu, Muara Tebas & Triboh

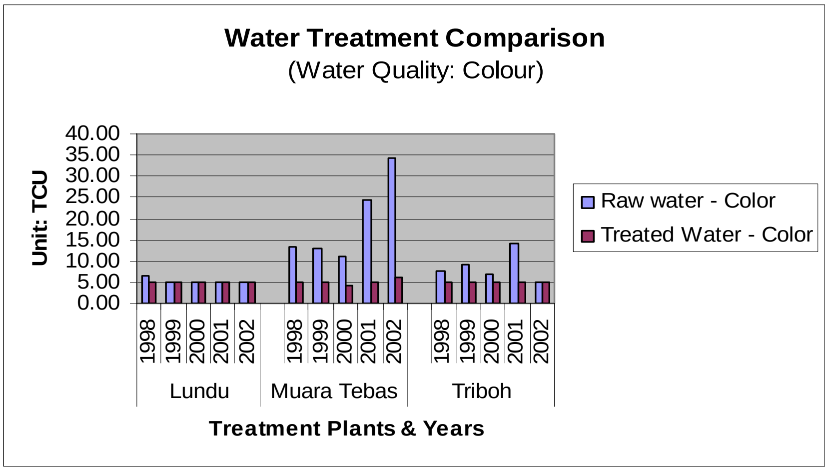


Figure 23 – Colour (Mean) for Lundu, Muara Tebas & Triboh

(i) Turbidity Measurement

Figure 22 shows a reduction of turbidity values below 5 NTU in the treated water, after going through the water treatment processes for Lundu, Muara Tebas and Triboh from 1998 to 2002. According to the drinking water quality standards, the turbidity level in drinking water must not exceed 5 NTU (Table 17, Appendix A). Similarly, the turbidity values of these raw water sources are still far below the acceptable limit of 1000 NTU in the recommended raw water quality criteria (Appendix B).

Observed in Figure 22, the turbidity levels in raw waters from Muara Tebas and Triboh are much higher as compared to the raw water in Lundu for the five-year records. The raw water in Muara Tebas recorded the maximum turbidity values 29 NTU in 2001 (Appendix F-4B). Triboh raw water recorded 30 NTU in 2002 (Appendix H-5B) and Lundu recorded 6 NTU in 1998 (Appendix G-1B). Since the raw water in Lundu is naturally low in turbidity level, the results of the water treatment process is considered not that significant in reducing turbidity in this type of water.

Overall, the data in Appendix C shows the turbidity levels between the raw waters and treated water from the respective water supply authorities have been reduced successfully to an acceptable drinking water quality standard of not above 5 NTU (Table 17, Appendix A).

(ii) Colour Measurement

Figure 23 shows the colour measurements for the raw water in Lundu, Muara Tebas and Triboh are still below the acceptable limit in the recommended raw water quality criteria of 300 TCU. Similarly, these colour measurements are below the requirement in the drinking water quality standard of 15 TCU (Appendix A, Appendix B). Although the chart shows the values for the colour measurement in Muara Tebas raw water are slightly higher, with the maximum value of 107 TCU in 2002 (Appendix F-5B), as compared to the colour of raw water in Lundu and Triboh, Figure 23 shows after the water treatment process, the overall values of the treated waters are reduced to 5 TCU (Appendix C).

(b) Microbiological Property

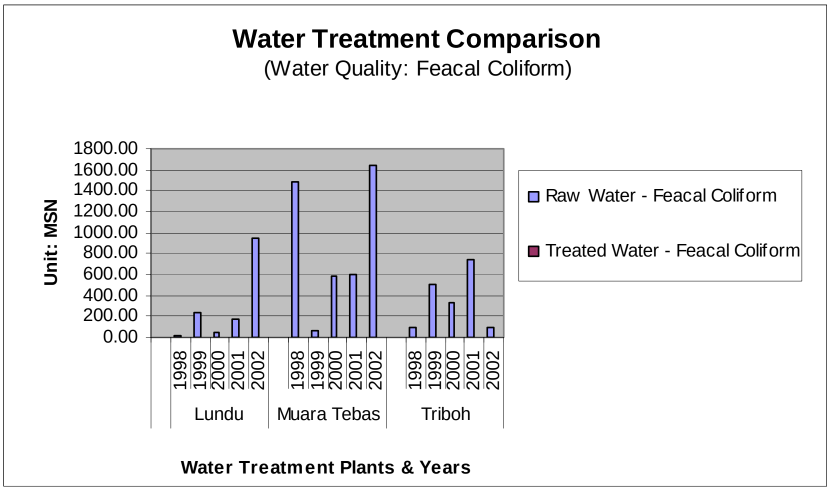


Figure 24 – Faecal Coliform (Mean) for Lundu, Muara Tebas & Triboh

Generally, Figure 24 shows the raw water sources from the respective water supply authorities are polluted with faecal coliform. Some years recorded as high as 1600 MPN/100mL. After the treatment process, the presence of faecal coliform in the treated waters were not detected during the water sampling throughout the five-year records. The drinking water quality standard requires the faecal coliform must not be detected in any of 100 ml sample using the MPN method (Appendix A).

The chart illustrates the effectiveness of water treatment processes using the conventional water treatment systems to remove the presence of microbiological contaminants in the raw water to produce safe drinking water.

(c) Chemical Property

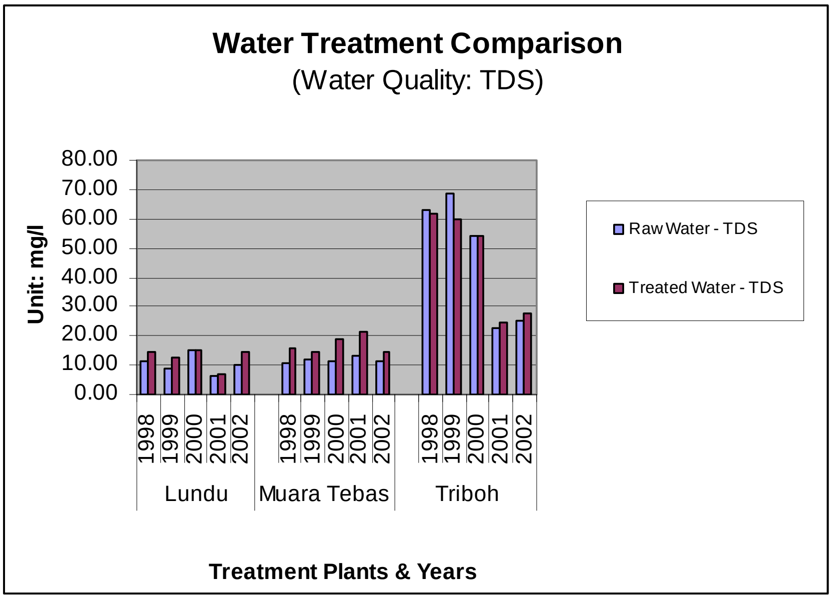


Figure 25 – Total Dissolved Solid (Mean) for Lundu, Muara Tebas & Triboh

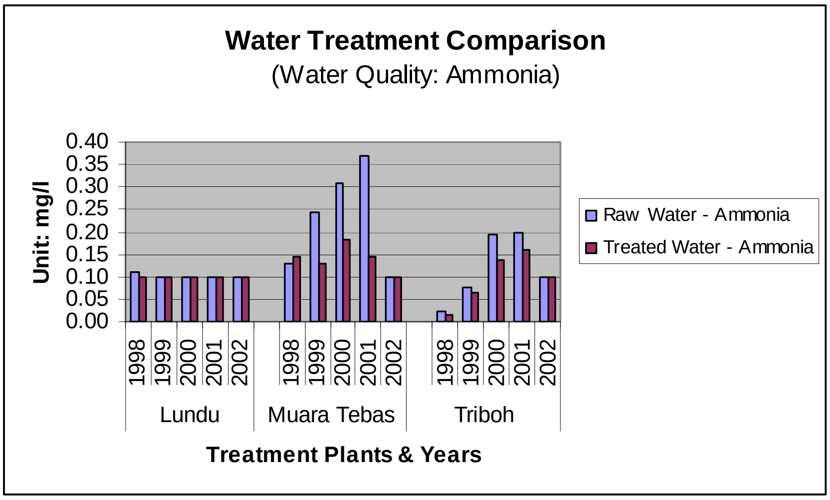


Figure 26 – Ammonia (Mean) for Lundu, Muara Tebas & Triboh

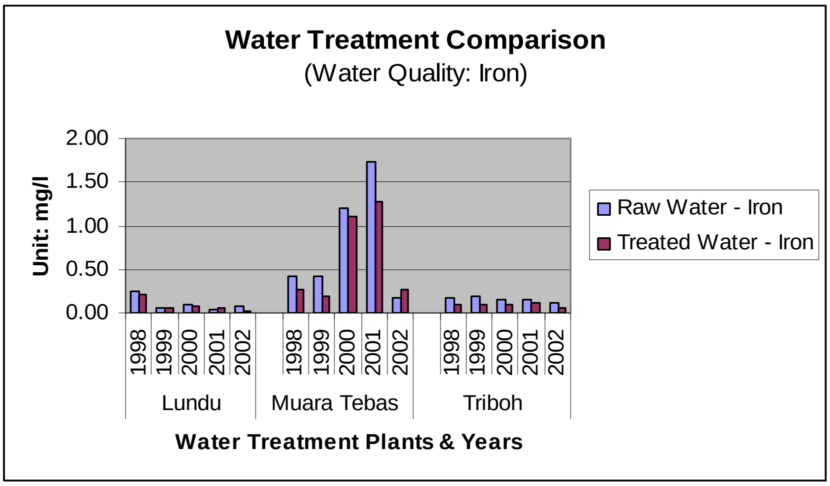


Figure 27 – Iron (Mean) for Lundu, Muara Tebas & Triboh

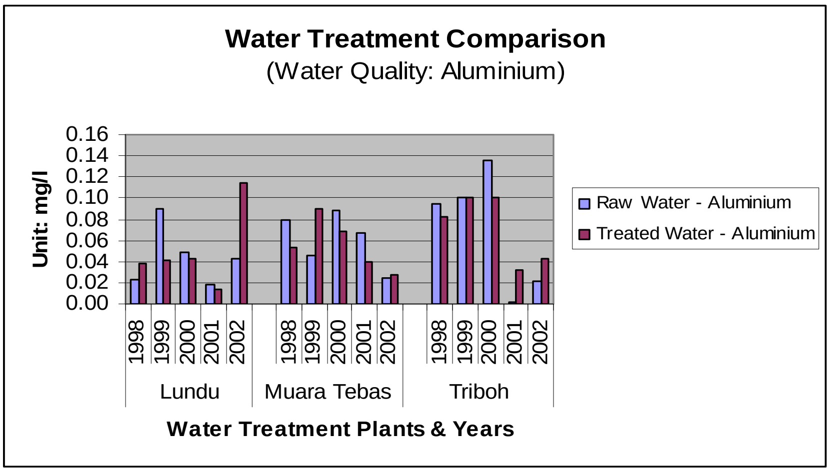


Figure 28 – Aluminium (Mean) for Lundu, Muara Tebas & Triboh

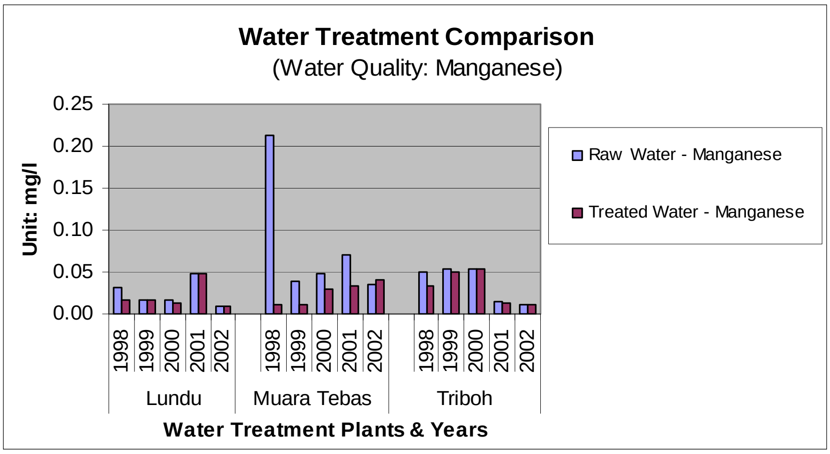


Figure 29 - Manganese (Mean) for Lundu, Muara Tebas & Triboh

(i) Total Dissolved Solid (TDS) Measurement

Figure 25 shows that the mean values of TDS in the treated water for Lundu and Muara Tebas are not successfully reduced after the water treatment process. Similarly, the treated water for Triboh indicates the same results in 2001 and 2002.

Although the results of treated water are not satisfactory, the TDS values in Appendix C shows the mean values of raw water and treated water for the five-year records are less than the maximum acceptable value of 1500 mg/L in the recommended raw water quality criteria and less than 1000 mg/L in the drinking water quality standard. Overall, the TDS values for most of the treated waters are less than 22 mg/L for Lundu and Muara Tebas water supply authorities, and less than 70 mg/L for treated water for Triboh water supply authority.

(ii) Ammonia Measurement

Figure 26 shows the results of water quality after treatment are generally reduced for all the treatment plants Lundu, Muara Tebas and Triboh. Except in the raw water in Muara Tebas, a slight increase of ammonia after the treatment from 0.1 mg/L in the raw water to 0.15 mg/L was detected in the treated water in 1998. However, the amount of ammonia presence in the treated water was still below the drinking water quality standard of 1.5 mg/L. This indicates that ammonia is successfully reduced to an acceptable limit for safe drinking water.

(iii) Iron Measurement

Figure 27 shows that the iron measurements in Muara Tebas raw water from 1998 to 2002 are much higher compared to Lundu and Triboh. The Muara Tebas raw water recorded the highest levels of iron measurement in 2000 and 2001, with the mean value of 1.11 mg/L and 1.28 mg/L respectively. Generally, the iron contents in other water supply authorities are below 0.5 mg/L.

Since the most significant presence of iron constituents are in Muara Tebas treated water. The recorded maximum values of iron in Muara Tebas are as follows: 0.76 mg/L in 1998 (Appendix F-1D), 0.31 mg/L in 1999 (Appendix F-2D), 10 mg/L in 2000 (Appendix F-3D), 10 mg/L in 2001 (Appendix F-4D) and 0.41 mg/L in 2002 (Appendix

F-5D). All of these values are above the acceptable value allowed in the drinking water quality standards of 0.3 mg/L.

Accordingly, the treated water in Lundu and Triboh also exceeded the acceptable limit of 0.3 mg/L. The iron levels in Lundu recorded a maximum value of 0.37 mg/L in 1998 (Appendix G-1D) and Triboh recorded a maximum value of 1.63 mg/L in 2001 (Appendix H-4D).

(iv) Aluminium Measurement

Figure 28 shows the removal of aluminium contents in the raw water are not successful in certain years, in all the treatment plants. Generally, the aluminium levels in the treated water were still on the increase after the water treatment process for Lundu in 1998 and 2002, Muara Tebas in 1999 and Triboh in 2001 and 2002.

According to Appendix C, the aluminium measurements in both raw water and treated water for Muara Tebas in 2002 are actually having the same value of 0.03 mg/L.

Generally, the mean values for raw water and treated water for the water treatment plants are below the maximum acceptable limit for the drinking water quality standard is 0.2 mg/L. However, some significant maximum values of aluminium contents in the treated water were detected in Lundu with a measurement of 1.43 mg/L in 2002 (Appendix G-5D), Muara Tebas at 0.24 mg/L in 1999 (Appendix F-2D) and Triboh at 0.52 mg/L in 2002 (Appendix H-5D).

(v) Manganese Measurement

Figure 29 shows that the manganese contents in all treated waters for the five-year records were reduced after the treatment process. The manganese levels are below the drinking water quality standards of 0.2 mg/L.

Although Muara Tebas raw water demonstrated a significant presence of highest manganese content in 1998 of 0.2 mg/L, after the treatment process, the maximum value of 1.0 mg/L (Appendix F-1B) in the raw water was reduced to a maximum value of 0.02 mg/L (Appendix F-D) in the treated water for 1998.

Similar case with aluminium, the ambiguity of chart display actually indicates no increase of manganese levels in both the raw water and treated water of Muara Tebas in 2002. The data of the mean values in Appendix C shows the manganese measurement for both raw water and treated water is 0.04 mg/L .

5.2 The Comparative Study Results

After analyzing the water quality parameters from the selected gravity-feed systems under the jurisdiction of the State Health Department and the effective treatment of raw water using various convention water treatment systems and treatment processes by the Public Works Department, the results of the comparative study are derived in a matrix for illustration.

Table 21 shows the design of a simple matrix to highlight the selections of water treatment processes that could effectively remove the specific water quality problems from the studied piped-gravity water of the State Health Department. The selected water treatment processes are based from the knowledge acquired in the literature review. The water quality parameters listed in the matrix are those water properties that posed significant threats to the rural communities consuming the piped-gravity water provided by the State Health Department. In addition, the chosen water quality parameters are those that exceeded the maximum allowable values of the drinking water quality standards. In bracket underneath the specific type of treatment processes, indicated the name of respective water supply authorities, which used that particular treatment processes in their water treatment plants.

Violated Water Quality Parameters (Medical PGS)	Water Treatment Processes						
	Pre-Sedimentation (Muara Tebas)	Aeration (Lundu)	Coagulation (Lundu)	Flocculation (Lundu)	Sedimentation (Lundu)	Filtration (Lundu) (Muara Tebas) (Triboh)	Disinfection (Lundu) (Muara Tebas) (Triboh)
Physical Property							
Turbidity	√		√	√	√	√	
Microbiological Property							
Faecal Coliform	√		√		√	√	√
Chemical Property							
Iron		√				√	
Manganese		√				√	
TOTAL	2	2	2	1	2	4	1

Note: PGS denotes Piped-Gravity System

Table 21- Results of comparative study on conventional water treatment processes

CHAPTER SIX: DISCUSSION

6.1. State Health Department: Water Quality from Gravity-Feed System

Using the calculated percentage of samples exceeded the maximum allowable value prescribed in the National Drinking Water Quality Standard (Rev.2000), an observation of annual violations from a particular group of water quality parameters could be detected based on the amount of water samples being taken (Table 18, Table 19, Table 20). In addition, to support the interpretation of results, the maximum and minimum values derived from the statistical analysis for a particular water quality parameter assists in defining the violation magnitudes of water samples that exceeded the allowable drinking water quality standard.

Based from the water quality analysis of the water samples from the piped–gravity systems in Lundu, Serian and Betong, the most significant water quality parameters that exceeded the drinking water quality standard in all the sampled waters are due to contamination by turbidity, faecal coliform, iron and manganese presence. The percentage of violations for these water quality parameters in the five-year records shown in Table 22 indicated an average amount of violations above 70%. Hence, these water quality parameters shall be the focus in the comparative study, to find out the best water treatment process options that are economical and feasible to remove the persisting problems. Above all, the average value of other water quality violations is below 14%.

Although the violation of chemicals such as ammonia and fluoride are detected in water samples from gravity-feed systems in Lundu, while conductivity and nitrate being detected in Betong, however, the numbers of violation from these chemicals or water quality parameters are not profoundly significance throughout the five-year records. As discussed in earlier chapter on results and analysis, sometimes only one or two water samples out of the total amount of water samples taken in a particular year, actually exceeded the drinking water quality standard. Therefore, these water quality parameters are insignificant threat in low concentration in drinking water and shall not be elaborated in the discussion.

Table 22 depicts the summary on percentage of violations for the various water quality parameters during the five-year record periods, above the drinking water quality standard from the piped-gravity waters in Lundu, Serian and Betong. In addition, the Table 22 provides the answers to the research question in Chapter One on conditions of the water quality from the various studied gravity-feed systems:

Piped-gravity systems Locality	Percentage Violations of Water Quality in a five-year record (1998-2002)							
	Turbidity (%)	Conduct-ivity (%)	Faecal Coliform (%)	Ammonia (%)	Nitrate (%)	Iron (%)	Fluoride (%)	Manganese (%)
Lundu	100	-	100	40	-	80	20	100
Serian	80	-	100	-	-	80	-	100
Betong	40	20	60	-	20	60	-	40
Average	73	6.7	86.7	13.3	6.7	73.3	6.7	80

Table 22 –Summary on percentage violations of water quality parameters during the five-year records

Accordingly, based on the outcome of the water quality results from the gravity-feed systems in Lundu, Serian and Betong Districts, a conclusion could be derived that the drinking water from these gravity-feed system are considered not safe for direct consumption in the long-term due to presence of microbial risks and toxic chemicals that are harmful to human health when ingested. To reduce the potential health impacts, some forms of water treatment process options are required to improve the drinking water quality standard. On the other hand, the study proves the hypothesis is correct.

6.2. Public Works Department:

Water Quality from Gravity-Feed System

After carrying out the data analysis of the raw water and treated water from Lundu, Muara Tebas and Triboh based on the available data provided by the Public Works Department, the study of conventional water treatment processes system to treat the raw water quality have successfully proven to reduce levels of pollutions caused by degraded water qualities. This successful treatment of applying convention method encompasses the physical parameters, microbial and inorganic constituents. This shows the treated water for public water supply complies with the requirements in the drinking water quality standards.

The charts presentation derived from the mean values of specific water quality parameters (Figure 22, Figure 23, Figure 24, Figure 25, Figure 26, Figure 27, Figure 28, Figure 29) and the maximum values generated from statistical analysis are used to support the results of contaminants reduction in the raw water after the water treatment processes.

Amongst the chemical constituents, only the presence of iron and aluminium in the treated water are deemed significant. Although in the case of Muara Tebas treated water indicated the quantity of iron constituents are still detectable during several sampling periods (Figure 27), using only the filtration system for the treatment process could be the reason of not able to remove entirely the high level of iron presence in the raw water. Comparing with raw water in Lundu and Triboh, the mean values of iron in the water are much lesser than in Muara Tebas (Figure 27).

Similarly, the problems of aluminium in treated water in Muara Tebas and Triboh detected during certain sampling periods (Figure 28) could be due to the failure of current water treatment process of only having the filtration system to remove the aluminium constituents. Although Lundu treatment plant has more complete treatment processes, the presence of aluminium in treated water could be contributed to over-dose of residual alum (aluminium sulphate) during coagulation process with the residual being carried over into the drinking water.

6.3 Choices of Water Treatment Processes

According to the water treatment process matrix in Table 21 on page 109, the most exceptional option of water treatment process that is practical to remove the contaminants in the raw water from the gravity-feed systems in the rural area is the filtration system. Effectively, this system is able to remove the majority of water quality problems encountered by the various gravity-feed systems under studied, namely, to resolve the issues of high turbidity, faecal coliform, iron and manganese detection in the raw water. Additional advantages of using filtration system are discussed comprehensively in the literature review.

Definitely, to prevent any harmful threat of faecal contamination, the most significant treatment process that is essential to remove the presence of microbiological property found in the water from gravity-feed system is by having a proper set-up of disinfection system injected into the piped-gravity water delivery system. As described earlier in the chapter two on literature review, severe microbial contamination is considered a primary concern to human health as compared with the impacts caused by chemical contamination. Therefore, the detection of excessive faecal coliform contamination in drinking water from the gravity-feed systems indicates adequate disinfection process is necessary for the piped-drinking water supplies. Unless the toxic nature of the chemicals detected in the water could cause severe health risks, then the matter must be taken seriously.

In addition, it is considered practical to provide a sedimentation system as a backup system to remove the turbidity and faecal coliform contamination in the raw water. Since the rural areas still have plenty of land area, the sedimentation basin could be designed and constructed appropriately. Further details on the effectiveness of the sedimentation system can be referred in chapter two on literature review.

A simple aeration system could also be constructed for the rural water supply that has excessive problems of iron and manganese contents in the raw water. This system could act as a backup to reduce the chemical presence before the filtration process started.

Hence, having a strategic approach in systematically combining the selected water treatment process options from this study, namely, aeration, sedimentation, filtration, and disinfection processes could assist in reducing specific water quality problems faced by the rural communities to ensure safe supply of drinking water in the long-term.

Table 8 on page 46, provides data as general indicator for general guideline to determine the range of costing that could be incurred to implement the suitable treatment method for a small community water supply. The guidelines includes the matrix on construction cost, operation and maintenance cost, reliability of the system, construction skill requirement, and operation and maintenance skill requirement of the systems.

6.3.1 Appropriate Technology for the Community

The application of an appropriate technology to help enhances the livelihood of the rural community has always been a challenge. According to Kerr (1989), the success of a community water supply is very much dependent on a systematic approached of implementation a project through participation and self-help. Strongly advocated in one of the article (Kerr,1989), the importance of familiarization to understand the community, emphasis of community participation and adaptation of the intermediate technology suitable to serve the local needs are the essential ingredient of success in the rural community water supply programmes.

Therefore, it is viewed that the use of sophisticated technology that could certainly produce high quality drinking water is not acceptable or even practical for use to solve the local conditions having water quality problems that are treatable by using a simple conventional treatment process, whereby the technology is readily available locally. Unless the water quality standard is highly polluted and freshwater sources are limited, then there is no other choice to opt for the best technology. However, the factor such as costing is still significant to determine the cost-effective system that is appropriate to the local conditions.

Unless the communities are willing to pay a high price of having a high standard superior finished water quality for their drinking water, then it is appropriate to adopt a more reliable system for the water treatment process. In the case of the population in the United States of America, the raw water quality conditions demanded increasingly stringent water quality regulations, diminishing freshwater supplies and uprising multi-contaminant compliance problems of the treatment systems. Hence, the production of potable water supply in the United States of America preferred the option of using the advance technology of membrane filtration and ultrafiltration for their future water treatment system. The US regarded the membrane filtration system as a competitive alternative to conventional treatment processes being practiced to produce safe drinking water supplies (Duranceau,2001).

6.3.2. A Pilot Study: Use of Chlorine Dispenser Unit

A pilot study for testing the use of a commercially available disinfectant unit viz., the Klorman Chlorine Dispenser Unit, was implemented in one of the villages in Lundu.

One unit was installed onto the piped-gravity distribution system in the village. This study was conducted by the Environmental Health Unit/BAKAS in Lundu District with the purpose of improving the microbiological quality from exceeding the prescribed level in the raw water.

Besides trying to improve the raw water quality, the pilot project was trying to prove the claim by the supplier of system's simplicity in terms of long-terms operation, maintenance and design (MOH, 1995). Figure 30 depicts the Klorman Chlorine Dispenser unit tested by the Medical Department.

Figure 30 – The Klorman Chlorine Dispenser Unit

Source: Photograph by Omar Ali Sepian

The principle of operation for this unit was determined by the contact-time period between the calcium hypochlorite tablets and the water available in the piped-gravity water at preset concentration level. The study results concluded that after the cartridge was installed and operational, the system has proven the disinfection process was very successful, with indication of negative detection of coliform and faecal coliform organisms from the field-testing and monitoring results.

However, the major setback of this project is on the economic of scale for the statewide implementation. The following shortcomings were discovered during the study period (Unit BAKAS, 1995):

(a) The use of cartridge required frequent changes thus become very costly for bigger scale implementation.

(b) Shortage of water supply from the catchment thus causing inconsistent flow rate in the pipeline system, thus reduced the effectiveness of the infectant.

(c) Depending on the length of pipeline system, the level of residual chlorine detected at the end-point of the distribution system varied and was affected due to the distance travel.

(d) The running cost is very expensive to be borne by the villagers in the long-terms.

6.4. Issues and Challenges of Sarawak Gravity-Feed System

The growing concern over water quality degradation in the rural areas has becoming a profound issue in Sarawak. Among the main reasons that contributes to this environmental problem is due to land transformation from arable forested area to agriculture development and exploitation of timber resources for timber industries to generate economic incomes for the state. The situation is further aggravated by the land developers who are unaware on the existence of the designated small gravity-feed water catchment's buffer zone in the locality they operated; thus, the encroachment of heavy field machineries and workers into the water catchment boundaries disturbed the catchment ecosystem and polluted the streams that serve as sources of fresh drinking-water, sometimes are unavoidable. In some instances, the high demand to exploit indiscriminately the natural resources within the catchment by the local residents for their economic interest also affects the flow regime in the catchment areas (Shakeran, 2000).

In the year 2000, a total of 119 gravity-feed water catchments across the State was reported to the Sarawak Water Resources Council that were critically affected by the land use development activities. Amongst the immediate actions initiated by the Sarawak Water Resources Council was by directing the Natural Resources and Environment Board to review the preparation of guidelines for the Environmental Impact Assessment Study and the prescribed activities list to regulate the activities for this type of catchment areas (Shakeran,2000).

Likely, more gravity-feed water catchments will experience the encroachment of development activities into the sources of freshwater. One of the main problems being encountered in monitoring the gravity-feed water catchments is because of the smaller size catchment as compared with the catchments for urban water supply. The variation in catchment sizes that ranges from about 500 hectares to only 30 hectares in acreages also cause difficulty to identify in the map. This has been experienced by the Water Supply Branch of Public Works Department that is entrusted with the responsible to carry out the digitizing task for water supply catchment areas. Adopting the base-map of 1:50,000 scale as template to demarcate the water supply catchment areas in Sarawak in digital format, the department is not able to digitize the gravity-feed catchment sites because these gravity-feed catchments have not been accurately identified on map and no proper boundary survey of gravity-feed catchments on the ground have been carried out for the purpose of detailed mapping (Shakeran,2000).

Generally, the perspectives of the health staff members at both headquarters and district levels that are responsible with the drinking water quality surveillance programme indicated as follows (Boon,L.K.Personal Communication.15 Feb.2003):

(a) Minor water quality problems will occur during the hunting seasons that encourage the hunters encroaching into the gravity-feed catchment areas.

(b) Some of the gravity-feed catchments that originated in the highland consisted of limestone caves. These are the places of collecting bird-nests as sources of income to the local. Among others, this could be the contributor to the high faecal counts in the raw water. During the bird-nests harvesting seasons, these locals will stay in the caves to collect the bird nests.

(c) Depending on the locality and altitude of the gravity-feed systems, those catchments situated on much higher ground and not easily accessible by the public will be quite protected from contamination. This is because the plantation and logging activities normally being carried out on the lower ground that is to easy to access and mobilize the machineries.

(d) Normally, the villagers elected their own committee members to manage the gravity-feed system; therefore, less dispute is encountered on the ownership of land situated within the gravity-feed catchment. In the case of Lundu District, the communities imposed strict conditions to the villagers from carrying out any activities within a defined radius upstream from the intake of their gravity-feed.

CHAPTER SEVEN: CONCLUSION AND RECOMMENDATION

7.1 Conclusion

The study of the raw water quality data based on the five-year records, from various gravity-feed systems encompassing the administrative districts in Western Sarawak has strongly indicated that the piped-gravity water supplied to the rural communities must undergo some sorts of water treated processes. This is to eliminate the agents of water borne diseases through water transmission, and remove the harmful inorganic presence at concentration that exceeded the allowable limit set forth in the drinking water quality standard. Without any doubt, the rural water supplies provided by the State Health Department gravity-feed systems are already showing signs of water quality deterioration and this supports the hypothesis of the study.

Although the State Health Department has recommended the rural communities to boil their water as a basic mean of protecting their health before ingestion, the presence of chemical constituents with high traces above the permissible drinking water quality standard such as iron and manganese, still perceive as inadequate to sustain good health. In some cases, additional water treatment process is deemed essential to alleviate the persisting water quality problem caused by the chemical presence. The advantage of applying a filtration process as one of the option could enhance the rural water quality standard. Several treatment processes have been deliberated in the earlier chapter as preferences. However, the economic feasibility study to implement the choice of system required must be adequately carried out.

Evaluating the effectiveness of different water treatment systems from the Public Works Department, the results of the comparative study provide the tool to evaluate the performance of conventional treatment methods to treat the raw water. The details on water treatment process options deliberated in the literature review is a precursor of determining the most practical approach to implement the system that is technologically feasible to deal with the specific raw water quality condition of a particular site. The system of operation and maintenance is simple enough to be managed by the rural communities with proper supervision by the authority.

Having the same objective of providing safe drinking water to the rural community, the State Health Department could learn and utilize the technical experiences of the staff from Water Supply Authority for development of skill and knowledge on water treatment processes. The knowledge can be shared and disseminated to the rural inhabitants through proper training programmes. The integrated working approach between different departments could prove to be beneficial to the government in optimizing the expertises of human resources and local knowledge to achieve a successful outcome.

Considering the high cost of buying and maintaining the highly sophisticated gadgets that are available in the markets to improve the water quality problems of a small community, added with the requirements of developing the technical skills to manage the system, it is considered not economical as well as practical for implementation in Sarawak rural water supply. On the other hand, it is more economical to use a reliable regional raw water source to serve a bigger population than setting up a scheme of expensive instruments to serve about 2,730 gravity-feed systems scattered throughout the State (BAKAS Negeri,2001).

Despite the State Health Department has initiated the planning and selecting only the first-priority water catchment areas for the gravity-feed system to supply the piped-gravity water to designated rural communities, seemingly in the long-term, the water sources are not continuously free from potential harmful impacts due to contaminants discharged into the waterways. Hence, the set forth first-priority gravity-feed catchments endorsed by the State Health Department should be reviewed accordingly, based on types of contaminants significantly detected in the water as pollution indicator. This will allow development of stringent mitigation measures to improve the drinking water quality as soon as the deterioration level of raw water becomes apparent.

The State government must be aware that the most economical means of providing safe drinking water to the rural communities in the long-term is by controlling anybody from disturbing the natural environment of the gravity-feed water catchments. Stringent protection of the small gravity-feed water catchments from any human activity within its boundary should be favoured and conservation of these catchment areas is the best practice. Since the size of gravity-feed catchment is smaller as compared with water catchment for urban supply, hence the environmental impacts due to any development activity within the catchment might be irreversible. This is very much depending on the extent of catchment carrying capacity to sustain the pollution loads.

In terms of addressing the needs to develop and apply a simple and economical water treatment methods to reduce the health risks of the rural communities that still dependence on the gravity-feed systems as the main sources of water supply for their daily intake, the findings and recommendations of the study are beneficial to the State of Sarawak in devising better mechanism of protecting the gravity-feed systems in the future.

7.2 Recommendations

The following recommendations are pertinent to improve the current and future management of State Health Department gravity-feed systems in order to protect the health of the rural communities consuming directly these natural freshwater sources:

(a) Water Quality Database Network System

A central system of water quality database network based at the State Health Department headquarters to archive all the water quality results across the State of Sarawak should be developed. Through this network system, accessibility to the data, working on-line as well as carrying out the data analysis could be done spontaneously. Data transmission can be speed-up and results being transferred at any time between various districts.

A decentralized database network system could be developed at the district levels, which is linked to the headquarters database. The appointed health inspectors at the district health offices could do the data input. The quality of data in this database will be more reliable since the role of these health inspectors at the district levels include to collect the water samples, check, edit and validate the water quality data before sending to the headquarters.

(b) Development of Geographical Information System (GIS)

The development the Geographical Information System is essential to keep records and update the ever-increasing numbers of gravity-feed systems, locality plans and the changing trends of raw water quality parameters for the entire Sarawak. Availability of this GIS application in the designated department will enhance the effectiveness of monitoring as well as managing the development of rural gravity-feed systems.

In addition, other available systems for rural water supply such as the rainwater harvesting schemes, community wells, boreholes networks and pipeline distribution systems could be integrated and input into the GIS application. Likewise, critical indicators and priorities could be developed using the GIS softwares as a warning system to alert the authority.

(c) Filtration System as Basic Water Treatment

Based on the study of water treatment processes, the filtration process has produced an outstanding result compared with the other water treatment process options, besides the importance of disinfection system to remove the pathogen. Therefore, it is recommended that for drinking water from the gravity-feed system that exhibits some form of degradation in water quality standard, to be provided with an independent conventional filter system. Nevertheless, the adoption of the filtration system to treat the water must take into account the limitation of water quality conditions that a filter system could effectively operate. Adequate training must be provided to the locals to run the system and to carrying out the operation and maintenance services.

(d) Community Water Quality Surveillance Programme

Selected group of volunteers from the villages could be trained to carry out a routine water quality surveillance programme in their respective gravity-feed systems. Essential tools such as water quality monitoring instruments must be provided to equip them with the field job. Adequate training on the use of the instruments and recording procedures must be provided to them by the authority. Their supports will be able to complement the shortage of work force to carryout the field works in the district levels. At least, with the increasing numbers of gravity-feed systems being established yearly, the human resources to carry out the task of the surveillance programme could be maintained without putting the burden on the State government of increasing the workforce. Lets the locals have pride to look after their waters.

(e) Guidelines for Sustainable Gravity-Feed Catchment Management

It is essential the guidelines for management of a sustainable gravity-feed catchment to be developed by the State government. Currently, each community has their own set of unwritten rules that are only good to their requirements. The government should initiate a forum to bring together these community leaders of various rural areas using piped-gravity water to come together, communicate and share their approach of managing their water catchments. The outputs of this meeting will be beneficial to the State government as well as to the rural communities, in delivering the resolutions. Supplemented with the modern knowledge on catchment management, the final guidelines will provide as a standard for application of future generation that still depend on the piped-gravity water.

(f) Education and Environmental Awareness Programmes

The government must provide continuous environmental awareness programmes and education to the public on the importance of protecting the gravity-feed system. The responsibility of environmental protection should not rest only in the hand of the environmental authority, but a responsibility of the whole community both the public and private sectors. Particular focus should be emphasized to those agencies that are directly involved with land-use development with activities that could potentially affect the gravity-feed catchment ecosystem. Among others, the programmes must be carried out concurrently with an imbedded objective that the community will become a self-regulating society in taking care of the environment in the future.

(g) Participation of NGOs

The involvement of responsible NGOs in promoting catchment protection should be encouraged. Besides providing a hand in educating the locals, their function can be extended in providing findings or aids to the locals living in the rural areas. Close liaison with the medical department should be promoted for knowledge-transfer. Knowledge and experiences accumulated from other parts of the world can be shared and adopted for better management of the gravity-feed catchments in Sarawak.

(h) Extension Study on Gravity-Feed Systems of Eastern Sarawak

To complement the current study, it is encouraged that someone to take up the future study of the State Health Department gravity-feed systems in Eastern Sarawak. This is to complete my work and accumulate the knowledge as well as understanding on the conditions of water quality parameters in State of Sarawak. Depending on the period, because of the ever-changing nature of land-use development in the State of Sarawak, the outcomes of the water quality results might be different for Eastern Sarawak.

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MAP OF SARAWAK – AREA OF STUDY

Appendix A

Drinking Water Quality Standards and Frequency of Monitoring

PARAMETERS	COLUMN I	COLUMN II				COLUMN III
	Max.Acceptable Value Mg/l (unless otherwise stated)	Frequency To Be Monitored				Source of Reference
		Treatment Plant Outlet	Service Reservoir Outlet	Distribution System	Well/Spring	
MICROBIOLOGICAL Total Coliform	MPN Method/ Membrane Filtration Method Must not be detected in any 100 ml. sample	W	W	W	W	MAL
E.Coli or Thermotolerant Coliform Bacteria	Absent in 100 ml sample	W	W	W	2Y	WHO2
Faecal Streptococci	Membrane Filter Method: Absent in 100 ml. sample MPN Method: < 1 in 100 ml. sample	WN	WN	WN	WN	EEC
Clostridium Perfringens	Absent	WN	WN	WN	WN	MAL1990
Viruses	Absent in 100 L	WN	WN	WN	WN	NZ
Protozoa	Absent in 100 L	WN	WN	WN	WN	NZ
Helminths	Absent in 100 L	WN	WN	WN	WN	NZ
PHYSICAL-GROUP I Turbidity	5 NTU	W	W	M	2Y	WHO2
Colour	15 TCU	W	W	M	2Y	WHO2
Ph	6.5 – 9.0	W	W	M	2Y	MAL
Free Residual Chlorine	Not Less Than 0.2	W	W	M	2Y	WHO3
Combined Residual Chlorine	Not Less Than 1.0	W	W	M	2Y	MAL1990
Monochloramine	3	WN	WN	WN	WN	WHO2
INORGANIC-GROUP II Total Dissolved Solids	1,000	M	M	Y/2	2Y	WHO2
Chloride	250	M	M	Y/2	2Y	WHO2
Ammonia (as N)	1.5	M	M	Y/2	2Y	WHO2
Nitrate (as N)	10	M	M	Y/2	2Y	WHO3
Iron	0.3	M	M	Y/2	2Y	WHO2
Fluoride	0.5 – 0.7	M	M	Y/2	2Y	MAL
Hardness	500	M	M	Y/2	2Y	WHO3
Aluminium	0.2	M	M	Y/2	2Y	WHO2
Manganese	0.1	M	M	Y/2	2Y	WHO2
GROUP III Mercury (Total)	0.001	Y/4	Y/2	Y	2Y	WHO2

PARAMETERS	COLUMN I	COLUMN II				COLUMN III
	Max.Acceptable Value Mg/l (unless otherwise stated)	Frequency To Be Monitored				Source of Reference
		Treatment Plant Outlet	Service Reservoir Outlet	Distribution System	Well/Spring	
Cadmium	0.003	Y/4	Y/2	Y	2Y	WHO2
Arsenic	0.01	Y/4	Y/2	Y	2Y	WHO2
Cyanide	0.07	Y/4	Y/2	Y	2Y	WHO2
Lead	0.01	Y/4	Y/2	Y	2Y	WHO2
Chromium	0.05	Y/4	Y/2	Y	2Y	WHO2
Copper	1.0	Y/4	Y/2	Y	2Y	WHO3
Zinc	3	Y/4	Y/2	Y	2Y	WHO2
Sodium	200	Y/4	Y/2	Y	2Y	WHO2
Sulphate	250	Y/4	Y/2	Y	2Y	WHO2
Trihalomethane: The sum of the ratio of the concentration of each of the guideline value should not exceed 1						
Chloroform	0.2	Y/4	Y/2	Y	2Y	WHO1
Bromoform	0.1	Y/4	Y/2	Y	2Y	WHO2
Dibrohochloromethane	0.1	Y/4	Y/2	Y	2Y	WHO2
Bromodichloromethane	0.06	Y/4	Y/2	Y	2Y	WHO2
Selenium	0.01	Y/4	WN	WN	WN	WHO2
Silver	0.05	Y/4	WN	WN	WN	MAL1990
Magnesium	150	Y/4	WN	WN	WN	MAL1990
Antimony	0.005	WN	WN	WN	WN	WHO2
Barium	0.7	WN	WN	WN	WN	WHO2
Boron	0.5	WN	WN	WN	WN	WHO1
Molybdenum	0.07	WN	WN	WN	WN	WHO2
Nickel	0.02	WN	WN	WN	WN	WHO2
Uranium	0.002	WN	WN	WN	WN	WHO1
Hydrogen Sulfide	0.05	WN	WN	WN	WN	WHO2
Mineral Oil	0.3	WN	WN	WN	WN	MAL1990
Phenol	0.002	WN	WN	WN	WN	WHO3
Bromate	0.025	WN	WN	WN	WN	WHO2
Chlorite	0.2	WN	WN	WN	WN	WHO2
2-Chlorophenol	0.0001	WN	WN	WN	WN	WHO2
2,4 Dischlorophenol	0.0003	WN	WN	WN	WN	WHO2
2,4,6 Trichlorophenol	0.2	WN	WN	WN	WN	WHO2
Formaldehyde	0.9	WN	WN	WN	WN	WHO2
Dichloroacetic Acid	0.05	WN	WN	WN	WN	WHO2
Trichloroacetic Acid	0.1	WN	WN	WN	WN	WHO2
Chloral hydrate (Trichloroacetaldehyde)	0.01	WN	WN	WN	WN	WHO2
Dichloroacetonitrile	0.09	WN	WN	WN	WN	WHO2
Dibromoacetonitrile	0.1	WN	WN	WN	WN	WHO2
Trichloroacetonitrile	0.001	WN	WN	WN	WN	WHO2
Cyanogen chloride (as CN)	0.07	WN	WN	WN	WN	WHO2

PARAMETERS	COLUMN I	COLUMN II				COLUMN III
	Max.Acceptable Value Mg/l (unless otherwise stated)	Frequency To Be Monitored				Source of Reference
		Treatment Plant Outlet	Service Reservoir Outlet	Distribution System	Well/Spring	
GROUP IV						
Aldrin/Dielrin	0.00003	Y/4	WN	WN	WN	WHO2
DDT	0.002	Y/4	WN	WN	WN	WHO2
Heptachlor & Heptachlor epoxide	0.00003	Y/4	WN	WN	WN	WHO2
Methoxychlor	0.02	Y/4	WN	WN	WN	WHO2
Lindane (BHC)	0.002	Y/4	WN	WN	WN	WHO2
Endosulfan	0.03	Y/4	WN	WN	WN	AUS
Alachlor	0.02	WN	WN	WN	WN	WHO2
Aldicarb	0.01	WN	WN	WN	WN	WHO2
Ametryn	0.05	WN	WN	WN	WN	AUS
Atrazine	0.002	WN	WN	WN	WN	WHO2
Bentozone	0.3	WN	WN	WN	WN	WHO1
Carbofuran	0.007	WN	WN	WN	WN	WHO1
Chlorotoluron	0.03	WN	WN	WN	WN	WHO2
Chlordane	0.0002	WN	WN	WN	WN	WHO2
Cyanazine	0.0006	WN	WN	WN	WN	WHO1
2,4-Dichlorophenoxyacetic acid (2,4D)	0.03	WN	WN	WN	WN	WHO1
Diquat	0.01	WN	WN	WN	WN	WHO1
1,2-Dibromo-3-chloropropane	0.001	WN	WN	WN	WN	WHO2
1,2-Dichloropropane	0.04	WN	WN	WN	WN	WHO1
1,3-Dichloropropene	0.02	WN	WN	WN	WN	WHO2
1,2- Dibromoethane	0.0004	WN	WN	WN	WN	WHO1
Hexachlorobenzene	0.001	WN	WN	WN	WN	WHO2
Isoproturon	0.009	WN	WN	WN	WN	WHO2
MCPA	0.002	WN	WN	WN	WN	WHO2
Metolachlor	0.01	WN	WN	WN	WN	WHO2
Molinate	0.006	WN	WN	WN	WN	WHO2
Pendimethalin	0.02	WN	WN	WN	WN	WHO2
Pentachlorophenol	0.009	WN	WN	WN	WN	WHO1
Permethrin	0.02	WN	WN	WN	WN	WHO2
Propanil	0.02	WN	WN	WN	WN	WHO2
Pyridate	0.1	WN	WN	WN	WN	WHO2
Simazine	0.002	WN	WN	WN	WN	WHO2
Trifuralin	0.02	WN	WN	WN	WN	WHO2
2,4 DB	0.09	WN	WN	WN	WN	WHO2
Dichlorprop	0.1	WN	WN	WN	WN	WHO2
Fenoprop	0.009	WN	WN	WN	WN	WHO2
Mecoprop	0.01	WN	WN	WN	WN	WHO2
2,4,5 T	0.009	WN	WN	WN	WN	WHO2
Terbuthylazine	0.007	WN	WN	WN	WN	WHO1
Carbon Tetrachloride	0.002	WN	WN	WN	WN	WHO2
Dichloromethane	0.02	WN	WN	WN	WN	WHO2

PARAMETERS	COLUMN I	COLUMN II				COLUMN III
	Max.Acceptable Value Mg/l (unless otherwise stated)	Frequency To Be Monitored				Source of Reference
		Treatment Plant Outlet	Service Reservoir Outlet	Distribution System	Well/Spring	
1,2 Dichloroethane	0.03	WN	WN	WN	WN	WHO2
1,1,1 Trichloroethane	2	WN	WN	WN	WN	WHO2
Vinyl Chloride	0.005	WN	WN	WN	WN	WHO2
1,1 Dichloroethene	0.03	WN	WN	WN	WN	WHO2
1,2 Dichloroethene	0.05	WN	WN	WN	WN	WHO2
Trichloroethene	0.07	WN	WN	WN	WN	WHO2
Tetrachloroethene	0.04	WN	WN	WN	WN	WHO2
Benzene	0.01	WN	WN	WN	WN	WHO2
Toulene	0.7	WN	WN	WN	WN	WHO2
Xylene	0.5	WN	WN	WN	WN	WHO2
Etylbenzene	0.3	WN	WN	WN	WN	WHO2
Styrene	0.02	WN	WN	WN	WN	WHO2
Benzo (A) Pyrene	0.0007	WN	WN	WN	WN	WHO2
Monochlorobenzene	0.3	WN	WN	WN	WN	WHO2
1,2 Dichlorobenzene	1	WN	WN	WN	WN	WHO2
1,4 Dichlorobenzene	0.3	WN	WN	WN	WN	WHO2
Trichlorobenzene (Total)	0.02	WN	WN	WN	WN	WHO2
DI (2-Ethylhnexyl) Adipate	0.08	WN	WN	WN	WN	WHO2
DI (2-Ethylhnexyl) Phthalate	0.008	WN	WN	WN	WN	WHO2
Edetic Acid (EDTA)	0.6	WN	WN	WN	WN	WHO1
Acrylamide	0.0005	WN	WN	WN	WN	WHO2
Epichlorohydrin	0.0004	WN	WN	WN	WN	WHO2
Hexachlorobutadiene	0.0006	WN	WN	WN	WN	WHO2
Microcystin-LR	0.001	WN	WN	WN	WN	WHO1
Nitrilotriacetic Acid (NTA)	0.2	WN	WN	WN	WN	WHO2
Tributylin Oxide	0.002	WN	WN	WN	WN	WHO2
GROUP V-Radioactivity Gross α	0.1 Bq/l	WN	WN	WN	WN	WHO2
Gross β	1.0 Bq/l	WN	WN	WN	WN	WHO2

W - Indicates parameters to be monitored at least once a week
M - Indicates parameters to be monitored at least once a month
Y/2 - Indicates parameters to be monitored at least once in 6 months
Y - Indicates parameters to be monitored at least once a year
2Y - Indicates parameters to be monitored at least once in 2 years
WN - Indicates parameters to be monitored at when necessary
WHO1 - Indicates WHO Guidelines for Drinking Water Quality (Addendum to Vol.1) 1998
WHO2 - Indicates WHO Guidelines for Drinking Water Quality 1993/96
WHO3 - Indicates WHO Guidelines for Drinking Water Quality 1984
AUS - Indicates Australian Drinking Water Quality Guidelines,1996
NZ - Indicates Drinking Water Standard for New Zealand 1995
MAL - Refers to values adapted for Malaysia Conditions
EEC - Indicates EEC Standard Council Directive (80/778/EEC)

Note: Any toxic substances not listed shall be deemed as not allowable in drinking water

Appendix B

Recommended Raw Water Quality Criteria and Frequency of Monitoring

PARAMETERS	COLUMN I	COLUMN II			COLUMN III
	Acceptable Value Mg/l (unless otherwise stated)	Frequency To Be Monitored			Source of Reference
		Surface	Ground	Direct Impounding	
Total Coliform	5000 cfu/100ml	W	M	M	WHO1
Turbidity	1000 NTU	W	M	M	WHO2
Colour	300 TCU	W	M	M	WHO1
Ph	5.5 – 9.0	W	M	M	MAL
Total Dissolved Solids	1,500	M	Y/4	Y/4	WHO1
Biological Oxygen Demand	6	M	Y/4	Y/4	WHO1
Chemical Oxygen Demand	10	M	Y/4	Y/4	WHO1
Chloride	250	M	Y/4	Y/4	MAL
Anionic Detergent MBAS	1.0	M	Y/4	Y/4	WHO1
Ammonia (as N)	1.5	M	Y/4	Y/4	WHO1
Nitrate (as N)	10	M	Y/4	Y/4	MAL
Total Nitrogen N (-NO3)	1.0	M	Y/4	Y/4	WHO1
Iron (as Fe)	1.0	M	Y/4	Y/4	WHO1
Fluoride	1.5	M	Y/4	Y/4	WHO1
Hardness	500	M	Y/4	Y/4	MAL
Mercury	0.001	Y/4	Y/4	Y/4	MAL
Cadmium	0.003	Y/4	Y/4	Y/4	MAL
Selenium	0.01	Y/4	Y/4	Y/4	WHO1
Arsenic	0.01	Y/4	Y/4	Y/4	MAL
Cyanide	0.07	Y/4	Y/4	Y/4	MAL
Lead	0.05	Y/4	Y/4	Y/4	MAL
Chromium	0.05	Y/4	Y/4	Y/4	WHO1
Silver	0.05	Y/4	Y/4	Y/4	MAL
Copper	1.0	Y/4	Y/4	Y/4	MAL
Manganese	0.2	Y/4	Y/4	Y/4	MAL
Magnesium	150	Y/4	Y/4	Y/4	MAL
Sodium	200	Y/4	Y/4	Y/4	MAL
Zinc	3	Y/4	Y/4	Y/4	MAL
Sulphate	250	Y/4	Y/4	Y/4	MAL
Mineral Oil	0.3	Y/4	Y/4	Y/4	MAL
Phenol	0.002	Y/4	Y/4	Y/4	WHO1
Organochlorine Pesticides:		Y/4	Y/4	Y/4	MAL
Aldrine/Dieldrin	0.00003	Y/4	Y/4	Y/4	MAL
Chlordane	0.0002	Y/4	Y/4	Y/4	MAL
DDT	0.002	Y/4	Y/4	Y/4	MAL

PARAMETERS	COLUMN I	COLUMN II			COLUMN III
	Acceptable Value Mg/l (unless otherwise stated)	**Frequency To Be Monitored**			Source of Reference
		Surface	Ground	Direct Impounding	
Heptachlor & Heptachlor Epoxide	0.00003	Y/4	Y/4	Y/4	MAL
Hexachlorobenzene Lindane	0.001	Y/4	Y/4	Y/4	MAL
Lindane	0.002	Y/4	Y/4	Y/4	MAL
Methoxychlor	0.03	Y/4	Y/4	Y/4	MAL
Herbicides: 2,4-D (Dichlorophenoxyacetic Acid)	0.03	WN	Y/4	Y/4	MAL
Radioactivity:					
Gross α	0.1Bq/l	WN	WN	WN	MAL
Gross β	1.0 Bq/l	WN	WN	WN	MAL

W - Indicates parameters to be monitored at least once a week
M - Indicates parameters to be monitored at least once a month
Y/4 - Indicates parameters to be monitored at least once in 3 months
Y - Indicates parameters to be monitored at least once a year
WHO1- Refers to WHO International Standards for drinking water 1963
WHO2- Refers to WHO Guidelines for drinking water quality Volume 1 & 2 1984
MAL - Refers to values adapted for Malaysia Conditions

Note: Collection of samples of both raw and treated water for examination for toxic substances should be carried out more frequency if values above the acceptable values are known to be present in the source of supply, or where such potential pollution exits.