AN INVESTIGATION REPORT
OF
WATER QUALITY IN JORDAN

1985.5.25～1985.6.3

Japan International Cooperation Agency

Water Supply and Environmental Sanitation Department
Ministry of Health and Welfare

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Member List of Survey Team

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Itinerary of Survey Team

May 25 (Sat) : Left Narita, Japan.

May 26 (Sun) : Arrived Amman, Jordan.

May 27 (Mon) : Visited Japanese Embassy.
Discussed with Water Authority of Jordan.
Discussed with Water Laboratories.

May 28 (Tue) : Surveyed at purification plant, water collection sites and along East Ghor Canal.

May 29 (Wed) : Tested and analysed samples at Water Authority and at Water Laboratories.

May 30 (Thu) : Continued test and analysis at same places.
Discussed with Planning Minister and others concerned.

May 31 (Fri) : Observed raw water and water supply conditions in Kerak, Petra, and Kodapa areas

June 1 (Sat) : Left Amman, Jordan.

June 3 (Mon) : Arrived Narita, Japan.

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1. Introduction

The Hashemite Kingdom of Jordan is constructing the Zay water purification plant for drinking water supply to the City of Amman, which is expected to complete in June, 1985.

According to the project, water will be taken from the East Ghor Canal, used now as agricultural irrigation waterway, and pumped to the plant which is located approximately 1,000 m higher than the point of intake. For transmission, a pipe line of 1,200 mm diameter will be laid down with a capability of 45 million cubic meters of water annually. Water purification process is adopted conventional rapid sand filtrations.

In connection with this project, the Jordan University warns in its investigation report that the East Ghor Canal water is hazardous to the health of the citizenes who drink its processed water and particularly the carcinogenic risk is high, because it contains much of precursor of trihalomethanes and other chlorinated organic matter and agricultural chemicals, therefore, the plant should be more effective to deal with such hazardous potentials or an alteration should be made of the project as much as necessary with a possibility of changing the water source.

In view of this, the Hashemite Kingdom of Jordan has made an inquiry to Canada, Britain, France, West Germany and Japan for second opinions as to how serious the problem is and how to cope with the situation.

In the waterworks engineering the problems which relate to trihalomethanes and other hazardous substances, etc., which is the main subject of our present investigation, is relatively new ones as Rook of the Netherlands discovered chloroform in drinking water for the first time in 1974. In Japan, it is no older than 1981 when a tentative target value was established for trihalomethanes in drinking water, and control was initiated then. However, none of the countries including Japan seems to have laid out a definite policy on this problem. As this is the case, it is considered most suitable to rely on the World Health Organization (WHO) Guide Lines for Drinking Water Quality (hereinafter DWQG) of 1984 as a reference about what concept is used for management over carcinogenic substances in drinking water.

However, the DWQG mentioned here differs in character from the previous Drinking Water Quality Standards of WHO which stipulate mainly of such impurities which can be proved the causal relation with disease pathologically or epidemiologically and give rise to disorders in the use of water. The Drinking Water Quality Standards did not also stressed carcinogenic substances which should be evaluated from the points of risk management.

Along with the scientific and technological developments, particularly of the research for cancer, it has been made clear that some of the chemical substances in the living environments including those in the drinking water are considered to be associated with cancer. In many countries, it is reported that the mortalities due to infections in the digestive system, disorders in the circulating system and tuberculoris have decreased, while the death rate due to cancer is contrarily increasing. Therefore, it is now highly important to formulate an effective measure to reduce the cancer-caused death rate. On the other hand, following the increase of living standards, man demands for a better quality of water to drink in addition to the safety against infections in the digestive system.

It is the DWQG, that responding to the changing situations as above, presents what level is desirable for the drinking water quality. The DWQG is, however, not the one which, like the Standards, sets up a quality level of drinking water that every drinking water supplier must observe. So, the DWQG should be understood as such that it is useful only for a reference which every country consults in the process of formulating a standard best applicable to its peculiar social, economic, cultural and other local conditions. Accordingly, in dealing with carcinogenic substances such as trihalomethanes (THM) it is not necessarily so that every country sets up a uniform quality level, but likely a different level by considering the local water and health conditions and others. So, the quality levels worldwide should inevitably be different.

In formulating the DWQG, there are several preconditions provided for determination of guidelines particularly for organic substances. Also, the footnotes given should be observed for the application of the DWQG.

Some of the preconditions are given below:

1) Drinking water quality can affect the health and well being of a community in a variety of ways. The importance of chemical contamination involving trace amounts of substances must be assessed in relation to the other health risks associated with drinking water (e.g., transmission of water borne deseases of bacteria and viral origines and parasites), and the relative importance attached to these risks must be decided by taking account the local or original situation.
2) For the majority of the substances for which guideline values are proposed, the toxic effect in man is predicted from studies with laboratory animals. Data on the toxicity of the chemicals are obtained from experiments in which the adverse effect occurs at considerably high dosage than would be experienced in man. When extrapolating from such animal data to man, therefore, a safety factor or risk factor must be introduced to provide for the unknown factor involved.
3) In view of the problem associated with the extrapolation of data from animals given high dose a guideline values for the carcinogenic substances were computed from a conservative, hypothetical, mathematical model and at the arbitrarily selected risk level of 1 in 100,000 per life time.
4) The linear multi-stage extrapolation model which is applied to calculate guideline values assumes that there is a finite risk from any exposure and the risk is proportional to the dose.
5) Chlorine is an effective water disinfectant and the hazards of desease caused by micro-biological contaminants resulting from incomplete disinfection are substantial and must be recognized.

   The World Health Organization support its use for water disinfection in developing countries.

The WHO's concept about carcinogenic substances as above is basically the same as that which Japan and other countries have applied in setting up a standard or target value against carcinogenic substances. Particularly regarding the treatment of chlorinated organic substances represented by THM which is formed by chlorination, a basic treatment in water purification system, the preconditions call for an effective measure against infection risks in the digestive system which might arise due to the abolition or mitigation of chlorination, and for an accurate assessment of costs to change water source for another one which includes no THM precursor or to provide a highly effective treatment facility for reducing the THM contents in drinking water. In view of this, it is considered such that the method of reducing THM contents in drinking water with best available technologies is a basic approach to the problem.

As regards our present investigation, we thought it most important to clearly formulate ways and means of reducing THM in the drinking water to be supplied from the plant without binding ourselves to the standard or target values such as $CHCl_3$ at 0.03 mg/ℓ in the DWQG or the total trihalomethane at 0.10 mg/ℓ in Japan or in the EPA of the United States. With this in mind, we conducted investigations at ZAY Purification Plant and the East Ghor Canal.

2. Water Quality Aspects of Raw Water

2-1 General Properties of Water Source

1) Outline of Data Analysis

The quality data used for analysis were those prepared by the Water Authority of Jordan (WAJ) and the Jordan Valley Authority (JVA).

By analysis we would like to know how contamination is progressing point by point in a range from upstream to downstream of the East Ghor Canal, how it is fluctuating from season to season, what element is playing a main role in quality variation and what is the reason for it.

The data of the Water Authority of Jordan covers a period generally from July, 1974 to December, 1984, with water samples collected at four sites of the main stream of the East Ghor Canal – Inlet (Tunnel Outlet), Adasiyyeh, Yabis and Deir Alla –, and at five sites of its tributary – Wadi Arab, Wadi Ziglab, Wadi El Yabis, Wadi Kufrinjeh and Wadi Rajib.

On the other hand, the data of the Jordan Valley Authority covers a period from June, 1979 to September, 1981 with water samples collected at two points – upstream of River Yarmuk and Deir Alla of the East Ghor Canal, during which measurement was made almost every month.

In the data analysis, we investigated about the total dissolved solid (TDS) at every sampling point and about correlation between water qualities among all the points. This was a preliminary investigation to know which correlation was strong. Also, we investigated about correlation between the sampling points from the upstream to the downstream of the East Ghor Canal. The purpose of this was to estimate a degree of relative contamination by measuring water quality variation individually at each of the sampling points as well as comparatively along the given range of the canal. The data sheets in Table 1 ~ 35 give the coefficients and the constants in correlation formula obtained by the statistical analysis, in which the mean values and the standard deviation values at the sampling points are given by division into whole season, dry season (June to September) and rain season (October to May), respectively. This chart enables one to visually comprehend the quality variation at each point, the quality variation in the rain and dry seasons and the relative quality variation between the upstream and downstream of the Canal.

Of the WAJ data obtained by measurement at Deir Alla, those obtained on September 23, and October 8 of 1978 and those obtained on May 1, July 11 and October 1 of 1979 were assumed to unusual data. In our analysis, however, we made it from two separate aspects – inclusive and exclusive of these data.

About the JVA data, however, it is noticed that the Potasium Permanganate Consumed (or $KHnO_4$ Cons.) dated of April 12, 1981, is extremely high as 69.52, a value being the same at Maqaren and Deir Alla. We thought this to be erroneous, so ignored it in our analysis.

Further, we plotted data on Normal Probability Paper and Logarithmic Normal Probability Paper in order to estimate distribution form of quality components. By this, we would be able to know quality distribution forms in the dry and rain seasons for comparison and, if a marked difference shows up, we would then presume the reason for it.

The correlation between qualitative variation and quantitative variation of water is very important. However, no mention is made in either data. Therefore, we made no analysis from that point of view.

In the followings we describe briefly the significance of the individual quality components in connection with our comments of the analysis results, which we trust that everybody concerned is well aware of.

2) **Results and Discussions of Data Analysis**

(1) Total Dissolved Solid (TDS)

The TDS means the total amount of the dissolved solid substance remaining in water after evaporation.

The TDS varies in amount by the rate of dissolution from area to area. Generally speaking, when the amount of the TDS varies considerably, it is suspected that there might be a large variation in any of the water zones concerned. This can be explained by identifying what substance is actually taking a major part in it.

Fig. 1 shows the mean values and the standard deviations at all the sampling points. From this, it is known that, although relatively high values are noted in the dry season at Yabis over the range from the Inlet to midstream at Yabis including Maqaren, the values in the whole data and the rain season data are nearly the same. So, it is understood that the quality variation is very small in this case. Comparison of Yabis and Deir Alla indicates that the TDS increases remarkably at Deir Alla. Even if those below the standard deviation value are discarded, the value at Deir Alla is 100 mg/ℓ, higher than at Yabis, suggesting that contamination in this range is advancing. According to the Deir Alla data of the JVA being similar to those of the WAJ, such a condition is endorsed.

When a view is given to the correlation of the TDS data between the upstream and downstream of the Canal, a high correlation is noticed in the whole season data and the rain season data (Tables 1, 3, 4 and 6) but no correlation is seen in the dry season data (Tables 2 and 5) from Inlet to Yabis. The correlation from Yabis to Deir Alla is weak in each of the whole data, the rain and dry season data (-0.50 to 0.53 in Tables 13, 14 and 15).

The TDS data of the WAJ are plotted on the probability paper as Figs. 2 and 3, from which it is known that the data from Inlet to Yabis stand generally in a line, form similar normal distribution, except those at Deir Alla which appears to be a logarithmic normal distribution, suggestive of a larger variation width with the values shifting to the high side. According to the TDS data of the JVA as shown in Figs. 4 and 5 on the other hand, although the variance between Maqaren and Deir Alla is very small, the TDS at the latter is somewhat higher than at the former. The distance between these two sites is more than 60 km, therefore, it is considered that there is little correlation between these.

From all the findings as above, we now summarize the results of TDS analysis. The water quality from Inlet and Yabis of the Canal is generally steady throughout the year including the rain season, excepting the dry season. On the contrary, the quality variation is large from Yabis to Deir Alla, indicating that there is little correlation between the upstream and the downstream of the Canal. From this, it is presumed that the canal water is used for various purposes and received miscellaneous waste water in this region, and consequently the contamination seems to be considerably developing. In the followings we attempt to find out what lies behind this phenomenon by checking individual substances.

(2) Calcium (Ca^{2+}) and Magnesium (Mg^{2+})

The most dominating factor of calcium is geology. Generally, the water that passes through lime stone strata contains much calcium, and the water that passes through igneous rock layers contains less.

The ratio of magnesium and calcium may be constant depending on the layers of passing. This is useful to assume the geological condition concerned. When the proportion is extensive, a thought should be given to some other factor rather than geology. In Jordan where the geology may be peculiar, it would be necessary to give a thought about the influence of sea water or salt water and the existence of greenstone when the ratio is high.

The calcium-magnesium ratio shows little variation from Adasiyyeh to Yabis, as in the case of the TDS. However, the concentration is seen as increasing 20 to 40 % at Deir Alla as shown in Figs 6 and 11. When the magnesium-calcium ratio is noted in the whole data, it is 0.55 at Adasiyyeh, 0.58 at Yabis, 0.52 at Deir Alla, indicating no variation throughout.

About the correlation between the upstream and the downstream of the Canal, there is nothing noticeable between Adasiyyeh and Yabis or between Yabis and Deir Alla (Tables 10, 11, 12, 19, 20, and 21). In Table 20, the correlation is inverse in the dry season, of which the correlation coefficiency is high, but this is inverse. As the number of samples is only six, and when examination is made on a confidence limit in this case, it is -0.3 to -0.90 in calcium and -0.10 to -0.90 in magnesium at a 0.10 significance level. From this, it is hard to say that there is a correlation.

Regarding the concentration increase from Yabis to Deir Alla, it can be assumed that calcium and magnesium accumulated in the water run out from the soil after repetitive use of the canal water.

The results of data plotting on probility paper are shown as Figs. 7, 8, 9, 10, 12, 13, 14 and 15. As seen from each of these sheets, the concentration distribution is extensive at Deir Alla as in the case of the TDS. According to the JVA data, though insufficient, variation is larger in the rain season than in the dry season and the concentration at Deir Alla is high. This data endorses the same.

(3) Sodium (Na^{+}) and Potassium (K^{+})

Like calcium and magnesium, sodium and potassium exist extensively in natural water.

Increase of sodium in water may be attributed to inclusion of sea water or salt water, water from rocky soil and hot spring water, and to contamination by human activities. The contamination by human activities is mainly due to the use of common salt and in this case the equivalence of chloride ion is considered to increase proportionally. (At a rate of 35 mg chlorine to 23 mg sodium).

Potassium also exists normally in natural water, though in low concentration. Potassium seems to originate mainly in rocks and soil. Since potassium is an important fertilizer, however, the extensive use of it is considered to contribute to increase the concentration of it in the water.

As shown in Figs. 16 and 21, there is no markable variation of sodium or potassium at each sampling point from Inlet to Yabis along the Canal. However, the variation width at Deir Alla is extremely large, which is, when compared by the mean value, 60 to 100 % higher than in the section to Yabis.

As the increase rates of magnesium and calcium are 20 to 40 % under geological conditions, such high rates of increase of sodium and potassium should not derive from flow change or from local geology but highly possible from human and/or agricultural activities.

As regards the correlation between the upstream and the downstream of the Canal, the value is relatively high between Adasiyyeh and Yabis (Tables 4, 5, 6, 10, 11 and 12) but is decreasing between Yabis and Deir Alla (Tables 13, 14, 15, 19, 20 and 21).

The plotting data on the probability paper (as Figs. 17, 18, 19, 20, 22, 23, 24 and 25) show the same tendency as in the case of the TDS, indicating that the inflow of sodium and potassium in the section of the Canal from Yabis to Deir Alla is much larger than in the upstream from Yabis.

(4) Ratio of Calcium+Magnesium and Sodium+Potassium

As aforementioned, calcium and magnesium derives mainly from geological features. Sodium and Potassium are affected by agricultural and/or human activities, besides geological features. Comparison of these is important to assume concentration variation.

The data of these substances are shown in Figs 26, 27 and 28. When the mean values at Adasiyyeh and Yabis are compared, sodium and potassium decrease and calcium and magnesium increase at Yabis, hence, the composition ratio at Yabis is higher than at Adasiyyeh. This is indicative of a condition that the inflow of sodium, potassium and other substances is not so variant in the range from Adasiyyeh to Yabis, from which it is considered that the contamination by human or agricultural activities is not so large a factor. Should there be no contamination factor from Yabis to Deir Alla, the water would flow down with more or less the same ratio as observed at Yabis. However, the fact is that the values at Deir Alla decreases on the contrary. This is because, according to the data given in the previous sections, the increase rate of sodium and potassium is larger than that of calcium and magnesium.

From the above, we presume that the contamination by human and/or agricultural activities is progressing in the section from Yabis to Deir Alla.

(5) Chloride Ion (Cl^-)

A principal source of supply of chloride ion is considered to be the human activity, or the salt carried by rain or wind from seas or hot spring, volcano or rock. The amount of supply seems to be constant in the locality concerned. At any rate, the variation of chloride ion is very little, so that it can serve as an index for contamination. From this, it is considered that a large variation of chloride ion in places like the East Ghor Canal where there is no influence of sea water or salt water is suggestive of contamination by human element.

As shown in Figs 29, 30, 31, 32 and 33, the chloride ion concentration at Maqaren on the upstream of River Yarmuk and in the section from Inlet to Yabis of the East Ghor Canal holds an annual mean value of approximately 80 mg/ℓ with no large variation width. As regards the condition at Deir Alla, there is some difference between the data of the WAJ and JVA. In the WAJ data, the variation width of chloride ion concentration is larger and the mean value of it is higher, the latter would still be large even if those large values outside the standard deviation are discarded. According to JVA data, on the other hand, the variation width of chloride ion concentration is somewhat smaller but the mean value is higher than those in the WAJ data.

Therefore, it can still be said from a viewpoint of chloride ion that there is a large possibility of contamination by human element in the section from Yabis to Deir Alla.

(6) Sulfate Ion (SO_4^{2-})

As sulfate ion is unstable, it is not so easy as in the case of chloride ion to designate its source of supply. There are, however, some sources of supply which may contribute to increase the amount of sulfate ion, besides geological features. These are the sewage including human waste, chemical fertilizer, waste water from mines with sulfide deposit, and factory drainage containing sulfuric acid.

The water containing human waste and sludge has a sulfide in it. When sulfide is oxidated it becomes sulfate. Some fertilizers has as its main ingredient a sulfate like ammonium sulfate. This substance, too, causes the sulfate ion concentration to increase. Sulfide deposits are oxidated by atmospheric oxygen and water which flows down as dissolved. Also, some chemical plants often use sulfuric acid in processing, and the drainage therefrom causes the sulfate ion concentration in the water to increase.

As a large variation of sulfate ion is observed in the Canal as shown in Figs 34, 35, 36, 37 and 38, it is considered to have derived from human waste or chemical fertilizer.

According to the data in Fig. 34, the variation of the sulfate ion concentration is small and the mean value of it is nearly the same as in the case of chloride ion in the section from Inlet to Yabis including Maqaren. According to the Deir Alla data, however, the variation of the sulfate ion concentration is large and the mean value of it shows a tendency of increase as other substances referred to in the previous sections.

As regards the correlation between the upstream and the downstream of the Canal (Tables 4, 5, 6, 13, 14 and 15), it is observed in both the whole season and the rain season between Adasiyyeh and Yabis but it is very low or none anywhere else.

The data on the probability paper show no large variation in the range from the TDS through chloride ion. Therefore, although it is difficult to clearly determine what causes the concentration variation, we assume that the contamination in the section between Yabis and Deir Alla might have been caused by human activity or by chemical fertilizer.

(7) Ratio of Chloride Ion and Sulfate Ion

Chloride ion is viewed as mainly existent in domestic waste water, while the variation of sulfate ion concentration is attributed to the oxidation of domestic waste water or chemical fertilizer.

Fig. 39 gives ratios of these substances from which it is observed that although the mean value is nearly constant the variation is large from the upstream to the downstream of the Canal. This evidents is also observed in Figs 40 and 41. As seen in Tables 7, 8, 9, 16, 17 and 18, there is no correlation observed between the upstream and the downstream.

As this is the case, we refrain from making a suggestion about this problem.

(8) Free Carbon Dioxide (CO_3^{2-}) and Bicarbonate Ion (HCO_3^-)

Free carbon dioxide and bicarbonate ion exist in water together with CO_2 and H_2CO_3 and the state of presence of each varies depending on the environmental condition involved.

There are several formation factors for these substances which include the dissolution of atmospheric carbonic acid gas, the consumption of CO_2 by the assimilation of water life, the discharge of CO_2 by respiration, the discharge of CO_2 by the decomposition of organic matters by bacteria, the transformation of CO_2 to bicarbonate ion by reaction with rock and soil. When dissolved in water, each changes its state of being by pH and temperature. Therefore, none of these is useful as a contamination index.

Of these substances, free carbon dioxide is an acidity dominating factor and bicarbonate ion is closely related to alkalinity. When a rapid sand filtration is employed, the presence of an adequate alkalinity is necessary for coagulation (about 30 to 100 mg/ℓ in Japan). However, when the pH is too high, it would be necessary to use acid or high dose of alum, and it needs a complicate water purification process operation.

The features of carbonate and bicarbonate ion are shown in Figs 42, 43, 44, 45, 46 and 47. Fig. 43 shows the measured data of bicarbonate ion. All the values shown stay on the high side and within a certain range from the upstream to the downstream. From these, it is considered that the alkalinity of free carbon dioxide is 200 mg/ℓ all year round, and it is recommended to control the pH at coagulation process in the purification plant.

(9) Nitrate Nitrogen (NO_3^-)

In quality analysis of water, values are normally expressed by nitrate nitrogen (NO_3^-–N) which represents the amount of nitrogen in nitrate ion. Accordingly, the amount of nitrate nitrogen is showen by using the following equation:

$$N/NO_3 = 14/(14 + 16 \times 3) = 0.226$$

Nitrate nitrogen is most stable form among the nitrogen compounds. Present in water are simple nitrogen (N_2), organic nitrogen compound deriving from animals and plants, inorganic nitrogen compound formed by decomposition by microorganisms, nitrogen in the form of ammonia deriving from nitrogenous fertilizers (such as ammonium nitrate, ammonium sulfate and urea) and the nitrogen in the form of ammonia deriving from waste water from homes and factories. Nitrate nitrogen is a final substance created by oxidation of these substances. Inclusion of this in a small amount in surface water is no problem. Deep underground water often contains ammonium nitrogen because of the shortage of oxygen in the water.

As regards the water with much nitrate nitrogen, the WHO has established a guide line level which limits the presence of it, inclusive of nitrate nitrogen, to no greater than 10 mg/ℓ (or approximately 44.3 mg/ℓ in the case of nitrate ion) for the reason that it cause metohemoglobinemia in babies.

The features of nitrate nitrogen are shown in Figs 48, 49, 50, 51 and 52. Fig. 48 shows the measured data of nitrate ion, in which it is seen that the variation width is large and fluctuated widely by the volume of water, the season and other factors. However, the average concentration of nitrate nitrogen is about 3 ~ 4 mg/ℓ, therefore it is assumed there is not any adverse effect to the health of people who use this water as a drinking purpose.

(10) Ammonium Nitrogen (NH_4^+–N)

Ammonia in water is normally expressed as ammonium nitrogen by the nitrogen content in ammonium ion. Ammonia exists in deep underground water, too, as mentioned previously. When its presence is observed in surface water, it is indicative of recent decomposition of animals and plants as well as of human waste, and it is suspected that the water might have been contaminated by waste matter. Unlike nitrate nitrogen, ammonia is not itself poisonous but the presence of it in water is regarded as a sign of feces contamination.

Fig. 53 shows the measured data of ammonium ion, in which some difference is seen between the data of the WAJ and the JVA. The difference is almost double between the two concerning Deir Alla. The reason is perhaps the difference in the number of samples, roughly nine of the WAJ against roughly 20 of the JVA. Take the JVA data now because of more samples, the mean values at Deir Alla are about 0.5 mg/ℓ for ammonium ion and about