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Sediments composition and pollution levels along the Kishon River and its drainage basin



Fish harvest, Kishon River, 1952

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**Sediment composition and pollution levels along
the Kishon River and its drainage basin**

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Abstract

Surface sediments from the Kishon river (west to the Kefar Baruch Reservoir), its harbors, estuary and drainage basin, were analyzed for major and trace elements, organic carbon content and mineralogical composition. Based on heavy metal concentrations, the studied part of the Kishon basin was divided into three main regions: (a) the upper river system with relatively low concentrations, (b) the lower Kishon system, adjacent to or downstream from heavy industrial complexes, with high concentrations, and (c) the estuary complex with concentrations decreasing seaward. The main mineralogical composition of the sediments is quartz, calcite and clay minerals, with some minor amounts of fluorite, introduced to the lower river system as CaF_2 particles from nearby industries. Organic carbon concentrations are low along the upper river system (<2%) and high along the lower system (up to 14%). The enrichment in organic matter content is regulated by two principal sources: the municipal sewage treatment plant and the oil refineries discharge. Quantification of the environmental impact on the composition of the river sediments resulted in the division of the elements into four groups: (a) elements which are significantly associated with pollution (Cd, Hg), (b) elements which are related to anthropogenic sources (Zn, Cr), (c) elements which are enriched only in part of the samples, originating both from anthropogenic and natural sources (V, Cu, Pb), and (d) elements derived from natural sources (Al, Fe, Ce, La, Mn, Ti). The interrelations between trace, minor and major elements reveal two main conditions: (1) during the winter, relatively clean sediments from the drainage basin are contaminated by industrial effluents (mainly trace elements related to phosphate products) along the lower river system, and downstream from the Gedora river the organic matter plays a major role in the accumulation of part of the trace elements; (2) during the summer, due to low energy conditions, most trace metals sink directly and via scavenging by organic matter along the entire lower river system. Thus, the scavenging of trace metals from the Kishon waters seems to be controlled by two factors: (a) the amount of organic matter input and (b) the hydrological regime of the river. An approximated mass balance for Cd and Zn showed that part of the amount of these elements introduced into the river does not stay in the system but is transported seaward.

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1. Introduction

The Kishon river, which empties into the Haifa Bay is one of the largest rivers in Israel, draining an area of approximately 1,100 km² (Fig. 1). Its discharge basin includes the north-eastern flank of the Carmel mountains, extending in a NW-SE direction, via the Izrael Valley to the Upper Galilee at the north. The drainage basin can be divided into three sub-drainage basins (Fig. 2): (1) the eastern basin which drains into the Kefar Baruch Reservoir (not discussed in this report), (2) the upper river system, from the Kefar baruch Reservoir up to the point where the Zipori river empties into the Kishon, and (3) the western, lower river system, from the Zipori river to the Kishon estuary, including the Zipori and Gedora rivers. The natural mean annual flow (for 1979-1989) in the upper river system is about 10 millions m³/y (Hydrological Year Book of Israel, 1990) and in the same order of magnitude for the lower river system. During the winter (January-April) the flow is about 5-fold higher than during the summer season.

The river is regarded as the most polluted coastal river in Israel. The river runs through the largest industrial area in the country and is subjected to considerable inputs of organic and trace metal contaminants from oil refineries, petrochemical and fertilizer plants, a sewage treatment plant, intensive agriculture in the recharge area and other sources. Except during rainy winters (particularly such as 1991-92), the river flow along the lower system is dominated by industrial effluents. The river is also subjected to frequent seawater penetration at least 3 km inland. As a result, there is only a minimal permanent flow to "wash" a limited amount of waste material through the estuary and out to the open sea. Due to these hydrological conditions, the lower river system serves as a trap for anthropogenic material. This pattern was detected by trace metal contamination in the sediments at the lower Kishon river system, and observed first in 1972 by Kronfeld and Navrot (1974, 1975) and later by Krumgalz et al. (1990) and Cohen et al. (1992). Organic contaminants in the lower reach of the Kishon river, its harbors and estuary were first determined in 1991: although pesticides, PCB's and dioxins were not detected in the sediments, they were highly polluted by petroleum derived compounds (Cohen et al., 1992).

Systematic studies in the Haifa Bay during the 1980's (Hornung et al., 1984, 1989; Herut et al., 1993) indicated that the Kishon is the major source contributing trace metals to the sediments of the southern part of the Haifa Bay, probably through bottom transport of river-borne sediment

particles which is enhanced during heavy river floods. The accumulation of contaminants in the sediments of the lower river system, the fishing and inner harbors, constitutes a potential hazard to the Haifa bay and the coastal marine environment. These pollutants can also reach the marine environment through periodic dredging of the harbors and the disposal of the resultant dredge spoils at sea.

The present study combines, for the first time, data on trace metals and mineralogical composition of sediments from the Kishon river, its drainage basin's stream sediments and its estuary sediments at the southern part of the Haifa Bay. The main objectives of this study are: (a) to document the variations of major and trace element concentrations in sediments along the Kishon river and its drainage basin, (b) to evaluate the fate of these elements, and (c) to assess the possible sources of the anthropogenic contaminants.

This research was carried out by the IOLR (Israel Oceanographic & Limnological Research) and the GSI (Geological Survey of Israel) with financial support of the Earth Science Research Administration, Ministry of Energy and Infrastructure.

Personal (Hava Hornung's) recollections on the earliest field surveys (1957) along the Kishon river are included in Appendix 1.

2. Methods and samples

Sampling and analytical procedures

The locations of the sampling stations along the Kishon river and its drainage basin are shown in Fig. 2. Two sampling phases were conducted along the river, the first during 24-25 of May 1992 and the second during 1-2 of November 1992. Stream (Wadi) sediments from the drainage basin were sampled during the period of September 1992 - March 1993, including only samples from the Zipori River and from small wadies draining from Mount Carmel into the Kishon.

River sediments: surficial sediment samples were collected by a small grab (Petite Ponar 6" Scoops - 008890) or by a plastic scoop (Table 1). In the lower reach of the Kishon river the sampling was done from a boat, while in the upper reach - from the river bank or bridges. Each sample was mixed and lyophilized for 50 hours and then sieved to pass 1000 μm .

Stream sediments: about one kg of stream sediment was sampled and packed in a marked

polyethylene bag. In the laboratory, the samples were dry sieved to pass 1000 μm . Wet samples underwent wet sieving through a 1000 μm sieve and oven drying at 80°C.

Chemical analysis

IOLR laboratory: For Hg, Pb, Cd, Zn, Cu and Fe determinations, approximately 1-2 g of dry sediment was digested for 3 hours at 140°C with concentrated nitric acid (65 wt%) in Uniseal, teflon-lined, high pressure decomposition vessels. For Hg analysis the digested samples were cooled, transferred to aerating flasks and diluted to volume with deionized distilled water (DDW). For other metals, similar digests were diluted to 25 ml in volumetric flasks with DDW and filtered through a Whatman #2 filter paper. Al and Mn concentrations were determined by total digestion with HF following the procedure of Jeffery (1975). Organic carbon concentrations were determined by the potassium dichromate method following the procedure of Walkley (1947) and Gaudette et al. (1974).

Each sample was digested and analyzed at least in duplicate and the average values are reported.

Total mercury was measured by cold vapour atomic absorption spectrometry on a Coleman Mercury Analyzer MAS-50A. The other metals were measured on an IL-951 and on a Perkin Elmer 1100B AAS. Mixed metal standards (Cd, Pb, Cu, Zn) and individual ones (Mn, Ni, Al, Fe), prepared from stock standard solutions of the elements, were used for calibration. The operating conditions for all elements using flame atomization are given in Table 2.

GSI laboratory: Major and trace elements were determined by Inductively Coupled Plasma - Atomic Emission Spectrometry (ICP-AES). 500 mg of the sample was mixed with 2.5 g Na_2O_2 in a Zirconium crucible and heated for 40 minutes in a muffle furnace (500°C). After cooling to room temperature, the crucible was rinsed in 50 ml water and 25 ml of 1+1 HCl (v/v) added rapidly in order to achieve clear solutions. Scandium was added to the solutions so that the final volume (100 ml) contained 5 mg/l Sc. Synthetic solutions were used for calibration, matched with Na_2O_2 and HCl. Scandium served as an internal reference and substantially reduced short-term variability. Arsenic and antimony were determined separately using a hydride generator with direct introduction into the Atomic Absorption instrument. Curves for multi-element determination

were established by calibration with composite standards prepared by stepwise dilution of stock solution made from pure metals or analytical grade salts. The operating conditions and limits of detection for the ICP are given in Table 2.

Organic matter content was determined by the potassium dichromat method (Allison, 1935; Emery, 1958).

Laboratories Quality control

The accuracy and precision of the methods were evaluated on the basis of analysis of several International Standard Reference Materials (Table 3). The standards were prepared (digested) and analyzed in a similar manner to those of the sediments. Table 3 indicates the recovery values of the elements analyzed. Relatively low recovery values were detected for Ni, Fe and Cd, therefore, concentrations of those elements represent minimum values.

3. Interlaboratory comparison of data

The accurate and precise determination of trace elements in sediment samples is an important aspect in pollution studies, especially regarding studies of human exposure to toxic elements through groundwater and sea food consumption. In the present intercalibration study the samples were analyzed simultaneously in two laboratories (IOLR and GSI) by different processes in order to calibrate the results, and compare surficial river sediments composition to those in the drainage basin of the river (sampled by GSI). Different sediment digestion procedures and instrumental techniques were compared and evaluated. The report presents the entire experimental data set and a statistical evaluation of the results. The aim of this exercise is to enable the laboratories to exchange data concerning environmental studies.

The data set which was used to compare between the two laboratories includes 47 surficial sediment samples from different parts of the Kishon river, with a considerable range of element concentrations. Each sample was analyzed for the content of Cd, Pb, V, Ni, Cu, Zn, Mn, Fe, Al and total organic carbon in the IOLR and GSI laboratories.

The main statistical parameters of the data for each laboratory are presented in Table 4. Since the distribution of the data is not normal, the nonparametric Wilcoxon test was used in order to

estimate the differences between the laboratories. The significance levels obtained by the Wilcoxon test are presented in Table 5: levels lower than 0.1 indicate a 90% probability of significant differences between the laboratories. Such significant differences were found only for Pb, Ni and Fe. The differences between the laboratories are also illustrated by the shift of the values from the 1:1 line (Fig. 3).

Organic carbon concentrations (analyzed by IOLR) and Easily Oxidizable Matter (EOM) concentrations (analyzed by the GSI) were determined practically by the same procedure. However, a factor of 1.69 was calculated for EOM/organic C relationship. This constant difference is probably a result of two main causes: (a) differences in conditions of digestion and concentration of the reagents, and (b) the use of a multiplying factor, as a recovery correction, by the GSI laboratory. In the present study, the organic carbon concentrations as determined by the IOLR laboratory are used.

4. Results

Major, trace elements and organic carbon concentrations in the surficial Kishon river sediments, collected during May and November 1992, are presented in Table 6. The sediments along the river are characterized by a wide heavy metal concentration range, up to two orders of magnitude. Major and trace elements concentrations in stream sediments of the Kishon drainage basin are presented in Table 7. Comparing the composition of the Kishon river sediments and that of the stream sediments of the drainage basin (selected metals are presented in Fig. 4), the elements were classified into the following three groups: (a) elements enriched in the Kishon river, (b) elements with similar concentrations, and (c) elements enriched in the drainage basin. Group (a) includes: Cd, Zn, Cu, Cr, Pb, P, S, Sr, Yb, Y; group (b): Al, Si, Ba, Sb, La, Mg, Ce, ~Ca, ~Fe, and group (c): Mn, As.

Spatial patterns

Based on the heavy metal concentrations, the Kishon river can be divided into three main regions (Fig. 5): (1) the upper river system and its drainage basin, with relatively low concentrations, (2) the lower river system with high concentrations, and (3) the estuary complex.

The spatial distribution of element concentrations in the upper river system and its drainage basin shows a constant similar composition for most elements. Along the Kishon lower system, much higher concentrations of Hg, Cd, Zn, Cu, and V are detected for almost all samples, while conservative elements (such as Al and Ce, which are derived from the natural environment), do not show major differences along the entire Kishon system. Moreover, in the lower Kishon system, significant variations in element concentrations are detected, in particular for those derived mainly from anthropogenic sources. These variations demonstrate the "anisotropic" distribution of elements along the lower Kishon river, and therefore, a single sampling station represents only a limited area. Variations in major elements content are usually sustained due to their relative high concentrations and the results indicate that the Ca content (representing mainly carbonates) exhibits a "mirror" behaviour opposite to the Al, Fe and Si concentrations, i.e. an increase in Ca is followed by a decrease in the contents of Al, Fe and Si in the same samples (Fig. 6). Calcium is positively correlated to P and organic carbon.

High concentrations of phosphorous and sulphur are recorded opposite and downstream the Deshanim fertilizer plant, at stations K57a (May), K57 (Nov.) and K58a (Nov.). The heavy metal concentrations in parts of the lower Kishon river system, downstream from the Zipori river junction, are higher than the 'background' concentrations in sub-recent Rhine sediments (Salomons and Forstner, 1984) or the EPA criteria for heavily polluted sediments (Nichols et al., 1991).

Time patterns

Generally, no significant differences were detected in metal concentrations in the sediments sampled in May 1992 and in November 1992 along the upper and lower river systems. This was statistically examined by using the Wilcoxon test. However, in the initial lower Kishon system, from the Zipori river (station K57) to station K2, higher concentrations were recorded for most of the metals and organic carbon in the November samples, except for conservative elements derived mainly from natural sources (Table 6). This behaviour is presented by selected metals in Fig. 7. It is important to emphasize that generally the composition of the sediments along the upper and lower Kishon river is similar in the time interval between the end of the winter to the end of the summer. In contrast to the Kishon upper system, sediments in the estuary (station K14)

showed considerable temporal variations (Fig. 8). These are controlled by various factors like bottom material transport in heavy flow events, dredging at the station area or at the Kishon Harbor and sand transport by waves and sea currents.

Mineralogical composition.

Qualitative XRD analyses have been carried out on 10 selected samples (stations K14, K12, K9, K4, K2, K57, K57a, K58, K51) along the Kishon river. The sediments consist mainly of: quartz, calcite and clay minerals. Organic matter is also a major component in most of the lower Kishon system samples. The samples contain minor amounts of fluorite, detected from station K57 (between Deshanim and Haifa Chemicals discharges) downstream to the Kishon harbor (station K12) (Fig. 9). No fluorite was detected in the estuary. It is known that CaF_2 particles are introduced into the Kishon as suspended particles within the Haifa Chemicals wastes (see Appendix II and Discussion). Two samples contain gypsum (K9 and to a smaller extent K12), probably derived as particles from the Deshanim phosphogypsum stack (near station K55). Some samples contained trace amounts of halite due to secondary precipitation during the drying of the sediments in the laboratory.

Three samples (K53, K57a, K4, May sampling) were examined by Scanning Electron Microscope (SEM). The composition of sample K53 (from the Kishon upper system) is mainly of clay minerals, quartz and calcite. In sample K57a, an unrecognized phase containing mainly Ca and P was detected (Fig. 10a), suggesting a poorly crystallized apatite. Some pyrite was detected as well. In K4, mainly clay minerals were detected, with appreciable amounts of pyrite (as framboids, Fig. 10b), with some Ca/P phase.

The relative concentrations of the major components vary along the river. However, the quartz/calcite ratios, as detected from the XRD diffractograms, show an increase towards the estuary. This may suggest sand (quartz) transport from the estuary upstream (Fig. 9). An approximate calculation based on the major elements chemical analysis shows that, for example, sediments from station K4 (May) contain ~30% quartz, ~25% clay minerals, ~25% calcite and ~12% organic matter, while sediments from station K10 (May) contain ~50% quartz, ~5% clay minerals, ~44% calcite and ~1% organic matter.

5. Discussion

The aerial distribution of selected elements is illustrated on single element maps (Fig. 11). Statistical definition of "high" and "very high" concentrations is given by the following categories:

1. "normal" concentrations: \leq mean drainage basin + 2SD.
2. "high" concentrations: between mean +2SD to mean+4SD.
3. "very high" concentrations: \geq mean +4SD.

For Cd, Hg and organic carbon, different statistical definition was applied, as Hg and organic carbon were not analyzed in sediments from the drainage basin and the use of Cd determinations in these sediments is restricted to values higher than 1 ppm, due to the analytical procedure. For these elements the categories are based on the 25, 75, 90 and 100 percentiles.

Some elements, such as Al, Ce, Mn and Ni (Fig. 11), show "normal" concentrations in the entire Kishon system, indicating no major differences between the drainage basin and the lower Kishon system. "High" and "very high" concentrations (indicating polluted sediments due to anthropogenic activity) along the lower Kishon system were found for Cd, Hg, organic C, Zn, Cu, P, Cr, V and Pb (Fig. 11), adjacent to or downstream from the heavy industry complexes.

Organic carbon concentrations in the sediments of the upper Kishon system are low (less than 2%), relatively to sediments from the lower Kishon system (up to 14%). The enrichment of organic matter is regulated by two main sources: the municipal sewage treatment plant and the oil refineries discharge. Contamination by petroleum derived organic compounds was detected by Cohen et al., (1992) in the area between the fishing harbor and the estuary (station K14).

The organic carbon distribution along the lower river system seems to be partly seasonal controlled, affected by the weaker flow during the summer (Nov.) and high flow pulses during the winter. Samples collected in May indicate horizontal bottom transport of organic matter towards the river mouth while in the summer time high concentrations are recorded along the entire lower system.

Quantification of environmental impact

The trace metal concentrations in sediments (Tr_s) exposed to a contaminated environment are given by:

$$(1) Tr = Tr_n + Tr_a$$

where the subscripts 'n' and 'a' designate the natural and anthropogenic sources in the sample, respectively.

In order to minimize the effects of grain size variations in the different natural 'clean' samples and hence provide a more precise identification and quantification of the anthropogenic heavy metals and their sources, the metal concentrations are normalized by a conservative element (Ackermann, 1980; Forstner and Wittmann, 1989). Aluminium was chosen as the normalizer because it is a major constituent of aluminosilicates and is generally not influenced by different environmental conditions and anthropogenic sources (Bruland et al., 1974; Loring, 1988; Windom et al., 1989). However, other potential reference elements, such as iron, are often also used as normalizers (Ackermann, 1980; Herut et al., 1993 and others). The same Fe-Al correlation line is detected for the sediments along the lower contaminated Kishon river as for the clean upper Kishon system, indicating a natural origin of these two major elements (Fig. 12). If, however the element examined is introduced by a mineralogical phase that is not related to the normalizer element, the latter will not compensate for the mineralogical natural variability.

An estimation of the natural 'background' of heavy metal to aluminum ratios can be derived from analysis of surface sediments in a relatively non-polluted area (Katz and Kaplan, 1981). In this study the 'background' ratios were calculated on the basis of sediments from the Mount Carmel part of the Kishon drainage basin. In those sediments, most of the trace metals were correlated with aluminium (selected elements are presented in Fig. 13) and the median of the ratio metal/Al was considered as the reference background ratio (Table 8). For most elements similar metal/Al ratios were found in the entire drainage basin although some stream sediments near the Bet Lehem river are subjected to minor pollution from nearby villages and agriculture fertilizers. Very similar metal/Al ratios were found also in deep sea sediments sampled in the Mediterranean sea (Table 8), 70 km from Atlit at ~1500 m water depth (Kress et al., 1993). Somewhat lower ratios are calculated for average shales composition (Wedepohl, 1968, Table 8). For Cd and Hg

the background ratios were estimated by the deep Mediterranean sea sediments, because of analytical limitations in the determination of Cd and Hg concentrations in the Kishon drainage basin.

Assuming that all the Al in the sediments is naturally originated, this fraction out of the total concentration of a trace metal is defined by:

$$(2) \text{Tr}_n = (\text{Tr}/\text{Al})_n \times \text{Al}_s$$

The subscript 's' stands for sediment. The anthropogenic fraction ($f\text{Tr}_a$) in the sediments is represented by:

$$(3) f\text{Tr}_a = \text{Tr}_a/\text{Tr}_s$$

Generally the calculated $f\text{Tr}_a$ for selected elements in the lower Kishon system results in four groups: (a) highly pollutant elements: Cd, Hg, in which the mean $f\text{Tr}_a > 0.8$, (b) moderate pollutant elements: Zn, Cr in which the mean $f\text{Tr}_a > 0.5$, (c) elements enriched in part of the samples: Cu, Pb, V, Ni, and (d) elements derived mainly from natural sources: Ce, La, Be, As, Co, Ti, Mn. Thus, more than 50% of the heavy metals from group (a) and (b) are discharged from municipal and industrial plants.

The calculated enrichment factors, $\text{EC} = (\text{Tr}/\text{Al})_s / (\text{Tr}/\text{Al})_n$, were found to be around three orders of magnitude for group (a), two orders of magnitude for group (b) and close to natural background for group (c).

Cadmium and mercury (group a) show an higher anthropogenic fraction in the November samples with $f\text{Cd}_a > 0.9$ and $f\text{Hg}_a > 0.7$. This behaviour is probably due to the following factors:

- (a) The lower natural flow, compared to the industries discharges during the late summer (~1:10), increases metal concentrations due to poor dilution.
- (b) Low natural/polluted discharge ratios during the late summer (~0.1) increase metal concentrations in the suspended matter, especially for cadmium (Salomons and De Groot, 1978).
- (c) As a result of poor flow during the summer, conditions are developed in which suspended sediments rich in cadmium and mercury are held back and sink more easily.

Trace metals fate along the Kishon lower system

Particulate bound and dissolved trace metals are introduced into the river by industrial effluents (see Appendix II). The distribution of these heavy metals in the sediments along the lower Kishon system and the calculated high anthropogenic fractions and trace metal enrichment in these sediments indicate that most of these metals sink and accumulate close to their sources. This behaviour is presented by the high metal/Al ratio peaks of the polluted trace metals along the lower river system (Fig. 14a). In general, these normalized concentrations increase downstream from the Zipori river, along the industrial zone in the lower system until the Fishing Harbor and then decrease seaward (station K14). This decreasing pattern, observed previously by Cohen et al. (1992), indicates a progressive dilution of the river borne sediments with relatively clean sandy sediments from the Haifa Bay (Fig. 14b), manifested also by the somewhat increasing quartz/calcite ratios from the drainage basin seaward. This trend, however, was not the same for all the enriched metals, probably due to differences in their geochemical behaviour, and was not observed for elements derived mainly from the natural environment (Fe/Al for example).

Minor concentrations of fluorite along the entire lower system also indicate immediate sedimentation and limited migration of fluorite particles toward the river mouth. These particles are mainly discharged as suspended matter within Haifa Chemicals effluents (see Appendix II). Krungalz et al. (1990) found very high levels (45-70%) of fluorite in sediments of the lower reach of the river (near stations K5-K8) and from the fishing harbor (around station K9). They suggested that coprecipitation with fluorite at the mixing border between seawater and river water (near station K5) is the main mechanism for the removal of trace metals from the river water. The present data do not support this hypothesis of fluorite being the major trace metal scavenger because (a) fluorite is present only in minor levels in the sediments at the lower reach of the river (indicated also by Cohen et al., 1992), and (b) fluorite was observed already close to its source, few kilometers upstream from station K5, where it is introduced intensively as fluorite particles. The amount of suspended matter in the acid effluents of Haifa Chemicals, which consists mainly of fluorite particles, was estimated to be 14 tons/day (4 g/l x 3600000 l/day, see Appendix II).

Many factors and mechanisms affect metals accumulation in sediments. The main accumulation processes observed in sediments from different environments are controlled by clay

minerals, hydrous Fe-Mn oxides and organic matter coating on particles (Salomons and Forstner, 1984). Direct precipitation may take place when external factors change and break barriers such as pH, oxidation potential or concentration of substances. The hydrological regime of the Kishon river is characterized by weak flow, except during the winter. Its bottom level along the entire lower system is below sea level. As a result, seawater penetrates into the river and a mixing gradient between seawater and river water is observed even at 3 km inland. This mixing increases the pH, the salinity and the oxygen content of the river water, and contributes to the removal of trace metals by adsorption and coprecipitation processes. Point source contamination by concentrated effluents streams combined with hydraulic and chemical properties of the depositional environment, are both the main factors that governs the behaviour of trace metals along the river system.

The interrelations between trace, minor and major elements was analyzed by means of factor analysis (Hintze, 1992). The analysis (varimax rotation) was carried out separately on the set of results from the May sampling phase and the November phase. For the May results, three factors were retained, explaining 73.3% of the variance:

Factor I (36.6%) includes organic C, Cd, Sb, V, Zn, S.

Factor II (25.5%) - Fe, Al, Ce, Ti, La, Mn, Eu, Ni.

Factor III (11.2%) - P, Cu, Hg, Pb, S, Cr, Zn.

For the November results, two factors were retained, explaining 61% of the variance:

Factor I (34.9%) - P, S, organic C, V, Pb, Zn, Y, Hg, Cd.

Factor II (26.1%) - Fe, Al, Ce, Ti, La, Ni, Cr, Mn, Eu.

These results can be interpreted as two main conditions varying seasonally:

(a) during the winter (based on the May analyses) two main sectors can be defined in the Kishon Lower System: 1. between the Zipory and Gedora rivers, in which relatively clean sediments from the drainage basin (Factor II) are contaminated mainly by near-by industrial effluents (Factor III); 2. between the Gedora and the Kishon Harbor, where the organic matter plays a major role in the accumulation of Cd, V, Zn in the sediments (Factor I).

(b) during the summer (based on the November analyses), due to low energy conditions, trace metals sink directly and via scavenging by organic matter along the entire lower Kishon system

(Factor I). Thus, the scavenging of trace metals from the Kishon waters seems to be controlled mainly by two factors: (a) the amount of organic matter input and (b) the hydrological regime.

Estimated mass balance for Cd and Zn

The annual amount of material discharged into the Kishon River by industrial complexes and the municipal sewage treatment plant is estimated to be in the order of ten thousands tons. For example: the yearly amount of Ca and suspended matter introduced by Haifa Chemicals is estimated to be 50,000 and 5,300 tons, respectively. The calculated mean annual discharge of Cd and Zn (dissolved + particulate) into the lower river system is ~ 7 ton and 50 ton, respectively (data from Appendix II). In cores (~2 meters long) sampled in the Kishon harbor, polluted sediments were detected up to a depth of few tens of centimetres (Kress and Herut, 1992). However, within the fishing harbor, the depth of the polluted sediments may reach a few meters, generally with higher concentrations than in the Kishon Harbor. It is assumed that the Kishon lower system bed maintains an almost constant level, and thus it is in balance with its downstream harbors.

The estimated yearly amount of sediments which accumulates in the Kishon harbors is: (a) about 10,000 tons in the fishing harbor, and (b) about 100,000 tons in the Kishon harbor. The estimation for the fishing harbor is based on dredging data between 1987 - 1991 (about 40,000 tons) and bathimetric maps (prior to the dredging) which demonstrate similar water depths in 1987 and 1991. For the Kishon harbor it was estimated (based on Kress and Herut, 1992) that about 30 cm of sediment is accumulating each year in the entire area of the Kishon harbor. Assuming that these sediments should contain the yearly discharge of Cd and Zn, we calculated the expected average concentrations of these elements in the sediments, in order to fulfil the above assumption. The values obtained, 64 ppm for Cd and 455 ppm for Zn, are much higher than the average measured concentrations in these sediments. For example, the Cd concentration in the fishing harbor sediments, which are about 10% of the total sediments volume is ~100 ppm. Thus, the Cd concentration in the Kishon harbor sediments (Y) was calculated ($64\text{ppm} = 0.1 \times 100\text{ppm} + 0.9 \times Y\text{ppm}$) and found to be ~60 ppm. No such concentrations were recorded in the Kishon harbor (Kress and Herut, 1992). It is thus feasible that not all the Cd and

Zn which are introduced into the Kishon river are trapped in the harbors, and part of the amount is transported seaward. Sediments originating in the Kishon river were found in the estuary (station 14), however the pathway of these sediments seaward is unclear at present.

It is assumed that equilibrium between the solution and the solid phases is achieved due to long enough residence time (more than 100 hours) because of low flow. Compared to other metals such as Pb and Cu, Cd is enriched in the more mobile fractions "cation exchange" and "easily reducible phases", and is, therefore, more mobile than most of the other heavy metals. In the Rhine river, for example, only 2% of the Cd was found in the residual fraction (Forstner et al., 1981).

Summary and Conclusions

1. Based on heavy metal concentrations, the Kishon River basin was divided into three main sectors: (a) the upper river system and its drainage basin, with relatively low concentrations; (b) the lower Kishon system, adjacent to and downstream from the heavy industry complexes, with high concentrations, and (c) the estuary complex with concentrations decreasing seaward.

2. The main mineralogical composition of the sediments is quartz, calcite and clay minerals. Along the lower Kishon system, minor amounts of fluorite, introduced mainly as CaF_2 particles, are detected.

3. Organic carbon concentrations in the sediments of the upper river system are low (<2%) relatively to sediments from the lower river system (up to 14%). The enrichment in organic matter content is governed by two main sources: the municipal sewage treatment plant and the oil refineries discharge.

4. The quantification of the environmental impact was studied by using Al as a normalizer element and the metal/Al ratios in sediments from the drainage basin as background ratios. As a result, four groups of selected elements were distinguished: (a) elements which are significantly associated with pollution and are found in high concentration in the lower Kishon river - Cd and Hg; (b) elements which are related to anthropogenic sources and are present in elevated concentrations in the river sediments - Zn and Cr; (c) elements enriched only in part of the samples - Cu, Pb and V; and (d) elements derived mainly from natural sources - Al, Fe, Ce, La,

Mn, Ti. More than 50% of the amount of metals from groups (a) and (b) is discharged from industrial complexes and a municipal sewage treatment plant.

5. The interrelations between trace, minor and major elements were studied qualitatively by means of factor analysis, revealing two main conditions: (1) during the winter, relatively clean sediments from the drainage basin are contaminated by industrial effluents (mainly trace elements related to phosphate products) along the lower river system, and downstream from the Gedora river the organic matter plays a major role in the accumulation of part of the trace elements; (2) during the summer, due to low energy conditions, it is suggested that most trace metals sink directly and via scavenging by organic matter along the entire lower river system.

6. The scavenging of trace metals from the Kishon waters seems to be controlled by two factors: (a) the amount of organic matter input and (b) the hydrological regime of the river.

7. An estimated mass balance for Cd and Zn showed that part of these elements is transported seaward.

Recommendations

Due to the possible adverse ecological impact of the Kishon river on the surrounding area and on the marine environment of the Haifa Bay, and in view of the plans to restore the river, it is of importance to continue this research and focus on the following issues:

1. Accomplishing a better understanding of the behavior of the main pollutants in the river sediments by conducting selective leaching procedures in the laboratory.
2. Studying the impact of seawater-river water interaction on the main pollutants.
3. Quantification of the main pollutants inputs into the Kishon river and their accumulation processes.
4. A study of the flux and composition of suspended matter into the Haifa Bay and its impact of the ecosystem.

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Appendix I

Personal recollections of the earliest field surveys (1957) along the Kishon river

Hava Hornung

Pollution was already a worldwide problem, and in January 1957 it was decided to survey the Kishon river. The nearby oil refinery was introducing its waste into the river and the surface water film looked oily, gray and carried an unpleasant smell. At that time the fishing harbor was established at the lower reach of the river, the commercial Kishon harbor and the Israeli shipyard were under construction and the quality of water brought in by the river was of great importance.

Weekly surveys took place from January 1957 to April 1958, and from May 1958 till July 1971 the river was surveyed once a month. The river water was analyzed for pH, chlorinity, dissolved oxygen and plankton samples were collected as well. Nine stations were selected along the river near the major industries waste discharges. Low pH levels (~3) were already recorded on July 1957 near the Chemical Fertilizers Plant (Deshanim), and on many occasions there was a complete oxygen depletion. On May 20 1952, 50 kg of grey mullet fish were caught by local fishermen along the Kishon river (Fig. 16). During the survey of April 1960 the first dead fish appeared, and later in 1969 an almost complete disappearance of the plankton communities and the bacterial flora occurred (Kimor et al., 1970).

Albert Schweitzer said: "*Man has lost the capacity to foresee and to forestall. He will end by destroying the earth.*"

Appendix II

Estimated inputs of contaminants from the major industrial plants

The following data on the estimated amounts and composition of discharged waste material from the major industries along the Kishon lower system are based on information contributed by the Haifa District Environmental Town Association, the Ministry of Environment and the Keren Kayemet L'eisrael. The following outlets are numbered on the maps in Fig. 11.

1. Deshanim Fertilizer Plant

Flow: 1000 m³/day, and unknown amount from the phosphogypsum stack.

Suspended Matter: 1 g/l

Chemical composition see Table 9.

2. Petrochemicals

Flow: 120-250 m³/day.

Suspended Matter: 0.03 g/l

Oils and Carbons: 12 mg/l

pH: 6-7

3. Petrochemicals - Polyethylene

Flow: 70 m³/day.

Particles of polyethylene.

4. Oil Refineries (Batei Zikuk) - cooling water of the ethylene apparatus

Flow: 300 m³/day.

NaCl, CaCl₂, MgCl₂

5. Haifa Chemicals

Flow: 6000 m³/day. The flow of the acid effluents is about 3600 m³/day.

Suspended Matter in acid effluents: 3-5 g/l. The Cd, Pb and Hg concentrations in suspended matter are (ppm): 0.66, 13.0 and 4.8, respectively. The major component of the suspended matter is fluorite (CaF₂).

Chemical composition see Table 9.

Cooling water and rainwater drainage outlet.

6. Sewage Treatment Plant

Flow: 80000 m³/day.

7. Oil Refineries (Batei Zikuk)

Rainwater drainage outlet.

8. Oil Refineries (Batei Zikuk)

Flow: 12400 m³/day.

Suspended Matter: 25 g/l

Oils: 10 mg/l

pH: 8-9

Detergents (MBAS): 22 mg/l

Alkalinity as CaCO₃: 350 mg/l

Chlorides: 450 mg/l

N- NH₃: 11 mg/l

N- Kjeldhal: 30 mg/l

Some industries discharge their cooling water into the Municipal Sewage Treatment Plant. The metals content of these cooling water is not known.

Table 1: Description of stations and sampling in the Kishon river.

Station	Description	Depth	pH	Grab	Plastic shovel	Grab	Plastic shovel
				May 92		November 92	
K14	Between Haifa and Kishon Harbors	12	7.0	+		+	
K13	Entrance of Kishon Harbor	10	6.5	+		+	
K12	Kishon Harbor, 150 m southern the chemical quay	9	6.5	+		+	
K11	Kishon Harbor opposite the Israel Shipyard	10	6.5	+		+	
1-2	Kishon Harbor opposite storehouse #1	9.5	nd	+		ns	
K10	Kishon harbor opposite quay 5	3	6.0	+		+	
K9	Middle of Kishon Fishing harbor	1.5	6.0	+		+	
K8	Entrance to the Fishing harbor	4.5	6.0	+		+	
K7	Kishon river ~250 m upstream from K8	2.7	5.5	+		+	
K6	~200 m upstream from K7	2.3	5.5	+		+	
K5	near the 'delta'	2.5	5.0	+		+	
K4	'Beili' bridge	4.5	5.0	+		+	
K3	~500 m upstream from K4 (Egaliptus tree)	1.5	5.0	+		+	
K2	~50 m upstream after railway bridge	nd	6.0	+		+	
K1	Kiryat Bialik bridge ("Batei Zikuk")	nd	5.0	+		+	
K59	~150m west of the "Lebeniot"	nd	6.0		ns	+	
K58	Opposite Haifa Chemicals (west of the domestic sewage outflow)	nd	6.0		+	+	
K58a	Opposite 'Haifa Chemicals'	nd	6.0		ns	+	
K57	concrete bridge ~500m upstream from K58	nd	6.0		+	+	
K57a	concrete bridge ~500m upstream from K58, from the side	nd	nd		+	ns	
K56	Opposite 'Dshanim'	nd	nd		+	ns	
K55	bridge few meters upstream from Tzipori and Kishon rivers junction	nd	nd		+	ns	
K55a	Tzipori and Kishon rivers junction (few meters upstream)	nd	6.5		ns	+	
K54	Yagur below the bridge of road #70	nd	6.3		+		+
K53	below bridge located ~800 m upstream from K54	nd	6.8		+	+	
K52	below bridge (road #75) 'Tzomet Haamakim'	nd	6.3		+	+	
K51	bridge Kiryat Haroshet	0.4	6.0		+		+
K50	bridge on road between Yokneam and Beit Shearim	nd	nd		+	+	

nd = not determined

ns = not sampled

Table 2. Operating conditions for (a) IL-951 and Perkin Elmer 1100B AAS, and (b) ICP

(a)

Metal	Wavelength (nm)	Background correction
Cd	228.8	+
Pb	283.3	
Cu	324.7	
Zn	213.9	+
Fe	248.3	+
Al	309.3	
Mn	279.5	+
Ni	232.0	+

(b)

		Wavelength (nm)	Background position (nm)	Analytical ranges as ppm in rocks	Limit of detection (3σ) as ppm in rocks
Sl	I	251.611	-0.092	0-99.9	200
Al	I	308.215	0.093	1.14-18.9	100
Fe	II	259.940	0.093	0.89-17.8	50
Ca	II	317.933		5.6-56.0	100
Mg	II	279.079		0.66-19.9	10
Tl	II	334.941	-0.092	0.10-3.34	50
P	I	177.499	0.093	0.10-30.0	1000
S	I	180.734	-0.092	0-4.0	1000
Ag	I	328.068	0.093	0-100	3
As	I	197.197		0-40	1
Ba	II	233.527	0.093	0-4000	1
Be	II	313.042	0.093	0-200	0.5
Bi	I	223.061	0.093	0-200	30
Cd	II	226.502	0.093	0-200	1.5
Ce	II	413.765	0.093	0-200	15
Co	II	228.616	-0.092	0-200	15
Cr	II	267.716	-0.092	0-4000	0.5
Cu	I	324.754	-0.092	0-200	1.5
Eu	II	381.967	-0.042	0-200	0.5
La	II	333.749	-0.042	0-200	3
Mn	II	257.610	0.093	0-4000	0.5
Mo	II	202.030	-0.092	0-200	5
Ni	II	231.604	-0.042	0-4200	5
Pb	I	220.353	-0.092	0-200	15

Table 3: Metals determination in standard reference material: (a) Cd, Pb, Cu, Zn, Ni, V, Fe, Mn and Al, (b) Hg.

(a)		IOLR								
Standard Reference Material	Value	Cd	Pb	Cu	Zn	Ni	V	Fe	*Mn	*Al
		ppm							%	ppm
MESS-1	certified	0.59±0.1	34±6.1	25.1±3.8	191±17	29.5±2.7	72.4±17	3.05±0.17	513±25	11.03±0.38
(NRCC)	found	0.53	36.69	24.12	207	24.03	64.11	2.57	522	10.66
		0.55	35.57	23.12	197	23.79	64.96	2.39	na	10.93
		0.53	34.68	23.03	na	23.89	na	2.55	517	11
		0.7	33.9	25.04	191	24.09	60.23	2.63	518	11.12
		0.69	35.5	24.76	189	24.31	61.28	2.69	na	na
	mean	0.60	35.27	24.01	196	24.02	62.65	2.57	519	10.93
	recovery (%)	102	104	96	103	81	87	84	101	99
River Sediment	certified	10.2±1.5	714±28	109±19	1720±169	45.8±2.9	23.5±6.9	11.3±1.2	765±97	2.26±0.04
1645 (NIST)	found	7.04	734	104.44	1820	36.29	22.56	8.31	785	2.21
		7.16	754	109.76	1792	31.84	23.74	8.45	791	2.18
		7.84	715	109.13	1656	33.94	28.09	9.6	769	2.5
		8.21	743	112.98	1746	34.29	26.96	9.81	800	2.5
		7.56	736.50	109.08	1754	34.09	25.34	9.04	786	2.35
	mean	7.56	736.50	109.08	1754	34.09	25.34	9.04	786	2.35
	recovery (%)	74	103	100	102	74	108	80	103	104
Estuarine Sediment	certified	0.36±0.07	28.2±1.8	18±3	138±6	32±3	94±1	3.35±0.1	375±20	6.25±0.2
1646 (NIST)	found	0.31	31.34	16.31	145	25.51	77.82	2.86	370	6.3
		0.32	32.71	16.21	139	25.93	79.66	2.68	368	5.99
		0.26	30.31	16.8	na	22.71	71.32	2.61	377	6.42
		0.31	28.6	17.72	139	24.97	72.87	2.9	382	6.33
		0.30	30.74	16.76	141	24.78	75.42	2.76	374	6.26
	mean	0.30	30.74	16.76	141	24.78	75.42	2.76	374	6.26
	recovery (%)	83	109	93	102	78	80	82	100	100

(a)		GSI								
Standard Reference Material	Value	Cd	Pb	Cu	Zn	Ni	V	Fe	*Mn	*Al
		ppm							%	ppm
MESS-1	certified	0.59±0.1	34±6.1	25.1±3.8	191±17	29.5±2.7	72.4±17	3.05±0.17	513±25	11.03±0.38
(NRCC)	found	2	56	23	210	43	90	3.78	589	5.82
		339	165	92	110	146	124	124	115	53
	recovery (%)	10.2±1.5	714±28	109±19	1720±169	45.8±2.9	23.5±6.9	11.3±1.2	765±97	2.26±0.04
River Sediment	certified	10.2±1.5	714±28	109±19	1720±169	45.8±2.9	23.5±6.9	11.3±1.2	765±97	2.26±0.04
1645 (NIST)	found	5	1000	107	1295	59	38	11.96	759	2.59
		49	140	98	75	129	162	106	99	115
	recovery (%)	0.36±0.07	28.2±1.8	18±3	138±6	32±3	94±1	3.35±0.1	375±20	6.25±0.2
Estuarine Sediment	certified	0.36±0.07	28.2±1.8	18±3	138±6	32±3	94±1	3.35±0.1	375±20	6.25±0.2
1646 (NIST)	found	1	60	13	113	39	106	4.27	420	6.35
		277	213	72	82	122	113	127	112	102
	recovery (%)	277	213	72	82	122	113	127	112	102

(b)		Value	11g ppm
Standard Reference Material			
Buffalo River	certified	1.47±0.07	
Sediment 2704 (NIST)	found	1.465	
		1.523	
		1.566	
		1.465	
	mean	1.50	
	recovery (%)	102	

na = not analysed
* IIF digestion

Table 4: Statistical parameters for elements analysed in IOLR and GSI laboratories (concentrations in ppm and Fe, Al in %)

Station	Cd		Pb		V		Ni		Cu		Zn		Mn		Fe		Al	
	IOLR	GSI	IOLR	GSI	IOLR	GSI	IOLR	GSI	IOLR	GSI	IOLR	GSI	IOLR	GSI	IOLR	GSI	IOLR	GSI
N	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Mean	11.87	9.64	56.51	67.35	145.6	137.4	56.92	82.67	236.3	229.0	472.3	417.6	700.7	641.3	3.36	4.21	5.07	5.11
Std Dev	20.52	13.02	45.38	53.69	89.8	53.8	16.93	26.69	749.3	748.1	516.9	410.6	572.4	426.3	1.29	1.48	1.63	1.86
Median	3.77	4.28	43.56	53.73	110.6	126.0	59.28	76.64	70.7	67.4	266.2	248.9	545.8	552.4	3.74	4.68	5.26	5.70
75%	17.84	17.80	66.17	77.34	204.1	174.8	64.91	107.94	148.2	142.1	743.0	690.4	828.6	787.8	4.31	5.34	6.26	6.48
25%	0.83	1.07	29.54	38.36	92.0	108.8	52.74	64.92	32.2	35.3	144.9	128.1	342.4	314.9	2.59	3.26	4.14	4.06
Max	101.51	72.93	251.68	323.53	534.4	334.8	110.07	129.67	4982.6	4896.9	2374.7	1886.8	2969.9	2060.2	5.76	6.42	7.53	8.53
Min	0.16	0.00	22.40	15.11	28.4	30.3	11.85	15.06	19.5	17.0	61.6	51.1	153.1	142.6	0.61	0.77	1.04	1.05

Table 5: Significance levels in comparison between IOLR and GSI laboratories analyses:

	Fe	Ni	Pb	V	Cu	Zn	Al	Mn	Cd
significance level	0.001	0.0001	0.07	0.24	0.99	0.63	0.83	0.88	0.94

Table 6: Chemical composition of sediments from the Kishon river.

Station	Month	Hg ppm	Cd ppm	Pb ppm	V ppm	Ni ppm	Cu ppm	Zn ppm	Mn ppm	Fe %	Al %	Org C %	Si %	Ca %	Mg %	Ti %	P %	S %
K14	5	0.17	0.40	24.3	28	12.7	20	75	334	1.06	1.92	0.48	23.35	11.18	0.91	0.15	0.09	0.40
K13	5	0.28	3.02	51.5	114	59.9	80	270	489	5.66	6.48	2.03	21.61	9.75	2.16	0.63	0.10	0.97
K12	5	0.28	4.38	51.5	111	59.3	91	312	579	5.47	6.27	1.51	22.16	9.00	2.06	0.62	0.16	0.88
K11	5	0.33	4.98	49.2	128	66.4	99	362	502	6.23	6.79	2.22	22.49	9.76	2.22	0.63	0.10	1.14
1-2	5	0.48	2.88	37.5	83	33.0	67	239	411	ns	ns	1.37	ns	ns	ns	ns	ns	ns
K10	5	0.26	2.07	30.7	41	12.0	28	147	342	1.07	1.34	0.58	29.67	18.15	0.80	0.11	0.62	0.49
K9	5	0.70	19.40	66.2	175	60.8	155	571	397	5.38	5.86	3.68	17.43	13.99	2.11	0.60	0.92	1.63
K8	5	0.32	5.96	48.2	107	65.1	65	311	708	5.68	6.59	2.61	21.37	8.33	2.00	0.65	0.05	0.55
K7	5	0.16	2.32	35.5	103	62.5	49	256	628	5.89	6.91	1.59	22.24	8.81	1.99	0.67	0.21	0.68
K6	5	1.23	25.97	68.7	248	60.5	165	1017	236	3.06	3.80	10.13	12.07	8.51	1.69	0.38	0.39	1.08
K5	5	1.28	23.95	69.1	213	53.1	148	846	254	3.26	4.11	11.16	13.01	8.28	1.73	0.40	0.83	1.05
K4	5	0.88	16.82	53.5	204	56.0	124	829	459	5.51	6.89	7.27	21.12	9.99	2.37	0.63	0.12	1.41
K3	5	1.88	41.04	76.2	284	54.0	227	1277	154	1.92	2.40	14.07	7.65	5.74	1.34	0.26	0.51	1.06
K2	5	0.09	0.60	31.2	92	64.9	36	166	688	4.36	5.70	1.36	3.87	15.08	1.30	0.55	2.08	1.03
K1	5	0.09	0.53	28.8	111	59.7	34	147	1067	6.19	8.07	0.71	23.39	5.16	1.96	0.70	0.10	0.61
K59	5	ns	ns	0.0	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K58	5	0.76	1.47	45.4	103	60.3	71	327	762	4.16	5.62	1.35	21.58	8.95	1.54	0.60	0.14	0.68
K58a	5	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K57	5	0.09	0.84	27.0	93	63.0	37	151	927	5.13	6.69	1.03	23.55	7.98	1.79	0.72	0.09	1.28
K57a	5	14.87	18.34	251.7	244	54.4	4983	2027	186	1.32	1.05	9.67	2.79	24.32	1.58	0.08	7.26	2.89
K56	5	0.38	17.84	73.8	239	64.0	98	834	704	5.76	8.53	1.87	22.29	5.72	1.93	6.85	0.20	0.87
K55	5	0.06	2.25	28.2	107	53.6	32	145	951	4.87	6.17	0.92	25.41	7.04	1.61	0.81	0.75	0.17
K55a	5	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K54	5	0.02	0.22	29.4	81	69.8	30	110	1107	4.84	5.97	0.80	24.47	7.38	1.67	0.78	0.14	0.17
K53	5	0.07	0.16	22.4	69	46.6	24	83	670	3.87	4.51	1.43	29.61	5.86	1.22	0.82	0.14	0.13
K52	5	0.04	0.33	33.3	81	110.1	36	105	2247	2.38	2.76	0.69	13.58	3.27	0.58	0.41	0.05	0.04
K51	5	0.04	0.44	27.1	94	64.2	24	81	2970	3.99	4.06	0.55	17.46	18.92	1.31	0.60	0.09	0.17
K50	5	0.09	0.19	28.5	85	58.0	33	125	1272	6.42	7.32	1.34	28.91	7.62	1.99	0.93	0.11	0.29

ns = not sampled

Table 6: Cont.

Station	Month	Ag ppm	As ppm	Ba ppm	Be ppm	Ce ppm	Co ppm	Cr ppm	Eu ppm	La ppm	Mo ppm	Sb ppm	Sr ppm	Y ppm	YB ppm
K14	5	bdl	2.02	207	0.61	31.3	6.1	73	0.81	15.1	bdl	0.20	650	16.1	1.01
K13	5	bdl	3.47	288	2.43	76.3	28.9	297	1.85	43.9	bdl	0.46	270	43.9	4.62
K12	5	bdl	3.67	282	2.20	59.9	29.3	214	1.34	42.8	bdl	0.49	242	50.1	3.67
K11	5	bdl	4.75	292	2.61	79.6	38.0	234	2.02	49.9	bdl	0.48	233	57.0	4.75
1-2	5	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K10	5	bdl	3.05	249	0.71	32.5	8.1	289	0.81	17.3	bdl	0.61	1208	23.4	2.03
K9	5	bdl	5.83	396	2.45	90.9	32.6	328	3.50	74.6	18.65	1.40	340	125.9	9.32
K8	5	bdl	3.43	320	2.40	74.3	26.3	218	2.06	44.6	bdl	0.34	206	45.7	4.57
K7	5	bdl	3.66	286	2.44	72.0	28.1	233	2.32	42.7	bdl	0.49	181	39.0	3.66
K6	5	bdl	4.49	393	2.13	52.8	13.5	301	1.91	46.0	11.23	1.35	320	87.6	6.74
K5	5	bdl	3.58	422	2.15	56.1	25.1	311	1.79	45.4	bdl	0.60	307	83.6	5.97
K4	5	bdl	6.79	509	2.99	82.8	27.1	338	2.58	59.7	bdl	1.22	353	93.6	6.79
K3	5	bdl	3.17	308	2.01	43.3	10.6	249	1.69	41.2	22.18	2.11	250	81.3	5.28
K2	5	bdl	4.54	641	2.27	65.8	27.2	471	1.93	39.7	bdl	1.13	638	60.1	5.67
K1	5	bdl	5.82	314	2.56	76.8	26.8	199	2.33	43.1	bdl	0.47	158	36.1	3.49
K59	5	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K58	5	bdl	5.31	476	1.91	74.3	34.0	391	1.59	41.4	bdl	0.21	325	43.5	4.25
K58a	5	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K57	5	bdl	6.38	356	2.23	82.9	41.5	270	1.91	43.6	bdl	0.21	221	35.1	4.25
K57a	5	bdl	5.24	272	1.05	37.7	10.5	597	2.09	31.4	13.61	0.94	1099	66.0	5.24
K56	5	bdl	8.01	272	2.97	81.2	32.0	260	2.17	50.3	bdl	0.34	151	38.9	4.57
K55	5	bdl	6.42	530	2.14	89.9	43.9	346	1.93	43.9	bdl	0.21	338	37.5	4.28
K55a	5	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K54	5	bdl	6.38	642	2.13	90.4	46.8	186	1.81	41.5	bdl	0.21	224	34.0	4.26
K53	5	37.26	3.19	366	1.60	75.6	33.0	181	1.49	34.1	bdl	0.11	192	29.8	3.19
K52	5	bdl	8.51	271	1.06	62.8	36.2	121	1.06	26.6	bdl	0.21	89	22.3	2.13
K51	5	bdl	5.19	872	1.56	105.9	55.0	295	2.28	55.0	bdl	0.21	226	44.6	4.15
K50	5	bdl	4.90	517	2.57	104.1	47.8	206	2.08	49.0	bdl	0.24	250	38.0	3.67

bdl = below detection limit

Table 6: Cont.

Station	Month	Hg ppm	Cd ppm	Pb ppm	V ppm	Ni ppm	Cu ppm	Zn ppm	Mn ppm	Fe %	Al %	Org C %	Si %	Ca %	Mg %	Ti %	P %	S %
K14	11	0.48	3.61	45.8	126	53.1	87	277	546	5.14	6.48	2.38	20.36	7.73	1.48	0.57	0.09	1.14
K13	11	0.42	3.35	45.3	108	52.5	90	282	570	5.34	6.69	2.65	20.14	8.01	1.54	0.59	0.18	1.18
K12	11	0.45	8.52	38.9	96	34.5	87	300	330	2.99	4.14	2.97	24.48	10.18	1.04	0.36	0.31	0.98
K11	11	0.34	4.42	43.4	114	55.7	79	266	410	5.47	6.92	2.83	20.70	7.14	1.55	0.60	0.09	1.28
1-2	11	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K10	11	0.19	4.37	40.5	40	11.8	31	172	393	0.77	1.17	0.85	20.65	19.88	0.73	0.10	0.66	0.60
K9	11	0.95	31.43	77.7	299	68.3	194	1041	277	3.57	4.59	5.36	14.31	9.34	1.29	0.43	0.53	1.27
K8	11	0.47	21.73	48.5	161	61.8	83	641	412	4.71	5.84	2.83	19.09	7.44	1.54	0.56	0.13	1.27
K7	11	0.21	3.39	34.5	121	53.3	50	222	552	4.95	6.24	2.49	20.13	7.33	1.48	0.59	0.09	1.07
K6	11	0.22	3.77	37.9	144	65.1	48	232	539	5.16	6.59	2.13	20.95	6.93	1.53	0.61	0.09	1.01
K5	11	1.18	27.04	65.3	256	69.1	169	998	259	3.61	4.64	7.25	14.75	7.96	1.43	0.45	0.27	1.28
K4	11	1.77	90.42	87.4	534	75.4	241	2375	186	2.73	3.48	11.96	11.28	8.44	1.42	0.36	0.90	1.23
K3	11	0.85	21.51	48.6	227	67.5	115	729	466	4.19	5.73	4.08	18.33	7.08	1.43	0.55	0.23	0.95
K2	11	0.27	101.51	83.0	107	43.3	179	146	153	3.99	4.79	1.91	25.68	9.09	0.98	0.66	0.09	1.43
K1	11	0.25	5.46	32.0	143	56.2	53	193	1718	5.05	6.39	2.45	22.67	7.52	1.24	0.71	0.05	1.24
K59	11	0.35	2.50	43.6	102	41.1	25	115	744	4.73	5.07	1.45	25.75	8.65	1.03	0.70	0.35	2.06
K58	11	3.49	14.32	180.0	164	65.1	577	1515	344	2.55	2.79	9.01	8.53	11.24	1.22	0.29	1.95	2.15
K58a	11	2.41	8.38	137.5	276	60.8	563	743	297	2.14	1.78	12.88	7.64	12.11	0.55	0.16	4.46	2.66
K57	11	1.69	4.97	178.7	218	94.7	1598	863	468	4.68	4.90	3.95	13.84	15.80	1.24	0.43	2.15	2.39
K57a	11	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K56	11	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K55	11	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K55a	11	0.14	1.79	29.4	110	50.2	42	145	829	5.23	6.15	1.95	23.51	6.35	1.04	0.73	0.31	1.05
K54	11	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K53	11	0.08	0.29	24.0	75	44.4	25	77	723	4.37	5.07	1.48	28.40	5.40	0.97	0.85	0.18	0.16
K52	11	0.19	0.48	25.9	83	52.7	29	119	1008	4.37	5.02	1.70	23.33	9.23	1.03	0.74	0.18	0.44
K51	11	0.03	0.83	28.2	92	50.2	21	62	2213	3.45	3.30	0.63	14.31	20.16	0.91	0.48	0.09	0.24
K50	11	0.11	0.28	28.1	91	57.2	31	110	868	5.31	6.43	1.42	25.32	5.43	1.28	0.77	0.13	0.20

Table 6: Cont.

Station	Month	Ag ppm	As ppm	Ba ppm	Be ppm	Ce ppm	Co ppm	Cr ppm	Eu ppm	La ppm	Mo ppm	Sb ppm	Sr ppm	Y ppm	YB ppm
K14	11	bdl	5.10	241	2.24	66.3	26.5	244	2.14	41.8	bdl	0.41	270	43.9	4.08
K13	11	bdl	5.09	238	2.24	69.3	28.5	227	1.83	41.8	bdl	1.02	260	44.8	4.08
K12	11	bdl	4.07	238	1.63	51.9	15.3	182	1.83	40.7	bdl	0.81	554	71.2	5.09
K11	11	bdl	4.12	217	2.37	70.0	27.8	196	2.06	45.3	bdl	0.62	214	51.5	4.12
1-2	11	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K10	11	bdl	3.01	292	0.60	26.1	6.0	60	0.70	16.1	bdl	30.12	1632	24.1	2.01
K9	11	bdl	4.08	218	2.55	65.3	22.5	335	2.76	60.2	15.31	2.55	344	122.5	9.19
K8	11	bdl	5.11	236	2.55	65.4	25.5	315	1.94	42.9	bdl	0.51	295	55.1	5.11
K7	11	bdl	3.08	211	2.15	65.6	24.6	197	1.64	37.9	bdl	0.51	197	35.9	3.08
K6	11	bdl	4.22	254	2.11	64.3	28.5	264	1.79	39.0	bdl	0.53	180	38.0	3.16
K5	11	bdl	6.19	417	2.37	60.8	18.6	353	2.27	49.5	bdl	1.55	357	87.6	6.19
K4	11	bdl	7.19	317	2.67	61.6	19.5	387	2.77	58.5	28.76	2.05	388	123.3	8.22
K3	11	bdl	7.22	332	2.27	66.0	25.8	219	2.06	46.4	11.35	1.14	277	69.1	5.16
K2	11	bdl	5.09	335	1.63	64.1	24.4	142	1.73	32.6	bdl	0.20	405	31.5	3.05
K1	11	bdl	6.19	272	2.27	80.5	32.0	166	2.48	44.4	bdl	0.41	259	52.6	5.16
K59	11	bdl	5.04	311	1.72	76.7	34.3	370	1.61	38.3	bdl	0.61	343	35.3	4.04
K58	11	bdl	3.04	320	1.32	51.7	17.2	340	1.83	39.6	bdl	1.62	409	84.2	6.09
K58a	11	bdl	8.17	245	0.82	37.8	30.6	152	1.02	30.6	17.36	2.35	394	62.3	4.08
K57	11	bdl	3.09	502	1.95	71.0	33.9	477	2.57	40.1	11.31	0.72	486	49.4	5.14
K57a	11	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K56	11	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K55	11	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K55a	11	bdl	4.04	525	1.82	77.8	41.4	201	1.62	40.4	bdl	0.20	310	37.4	4.04
K54	11	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K53	11	bdl	2.02	381	1.61	74.6	34.3	201	1.41	35.3	bdl	0.20	212	31.2	4.03
K52	11	bdl	2.02	358	1.61	81.7	35.3	303	1.82	38.3	bdl	0.20	262	32.3	4.03
K51	11	bdl	3.02	642	1.41	108.8	42.3	373	2.92	54.4	bdl	0.30	241	44.3	4.03
K50	11	bdl	3.04	370	2.03	82.0	42.5	213	1.82	38.5	bdl	0.20	206	31.4	4.05

Table 7: Chemical composition of sediments from the Kishon river drainage basin.

Station	Cd	Pb	V	Ni	Cu	Zn	Mn	Fe	Al	Si	Ca	Mg	Ti	P	S	Ag	As	Ba	Be	Ce	Co	Cr	Eu	La	Mo	Sb	Sr	Y	YB
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4540	bdl	19	139	141	38	81	601	5.74	5.98	15.9	10.51	1.57	0.935	0.131	0.080	3	6	115	1.5	62	40	157	1.8	32	2	0.3	95	20	2
4542	bdl	8	75	54	52	92	173	2.03	3.02	8.2	26.30	0.30	0.294	0.305	0.160	1	9	174	0.8	37	9	153	0.5	21	4	0.7	465	24	2
4545	bdl	26	137	63	33	91	768	5.32	7.36	20.1	6.65	0.84	0.725	0.044	0.080	5	8	192	2.2	82	25	143	1.8	43	1	0.7	83	30	3
4546	bdl	18	122	39	30	83	663	4.41	6.24	18.1	9.22	0.72	0.623	0.044	0.080	6	9	166	1.9	75	19	129	1.6	40	2	0.3	100	27	3
4549	bdl	9	82	24	30	53	425	2.59	3.70	11.8	19.87	1.15	0.372	0.044	0.160	8	17	114	1.2	47	14	82	0.7	21	3	0.6	156	16	2
4550	bdl	23	101	56	36	113	547	3.50	5.03	13.9	14.87	1.87	0.438	0.044	0.120	10	8	132	1.6	76	16	105	1.2	31	3	0.6	105	21	3
4539	bdl	22	63	14	36	54	434	2.73	3.70	10.3	20.37	3.56	0.336	0.131	0.160	1	6	126	1	36	11	98	0.7	26	1	0.3	95	17	2
4543	bdl	29	86	36	33	79	605	4.06	4.76	14.2	12.79	1.69	0.528	0.742	0.120	bdl	7	192	1.6	53	15	120	1.5	42	2	0.6	190	35	4
4547	bdl	33	93	55	36	83	606	3.78	4.29	14.7	17.44	0.78	0.492	0.175	0.160	3	6	149	1.5	50	14	126	1.6	36	1	0.4	135	24	3
4681	bdl	13	36	20	19	45	167	0.91	1.22	5.3	25.51	4.40	0.132	0.044	0.080	2	4	38	0.4	12	10	33	0.3	8	7	0.3	220	6	1
4683	bdl	25	91	40	48	120	520	2.87	3.65	13.7	14.15	2.17	0.408	0.087	0.080	1	6	343	1.1	40	17	82	0.8	24	5	0.4	173	18	2
4684	bdl	27	85	40	26	70	385	2.31	2.91	10.3	12.22	1.81	0.306	0.044	0.120	3	7	97	0.9	32	13	69	0.7	19	2	0.4	109	14	1
4685	bdl	22	62	25	24	55	253	1.40	1.85	6.4	7.43	1.15	0.180	0.087	0.120	3	3	73	0.6	22	7	41	0.4	13	1	0.3	87	9	1
4686	bdl	30	119	50	61	90	693	3.85	4.82	15.5	3.50	0.96	0.498	0.087	0.080	4	5	151	1.7	53	21	111	1.3	32	7	0.4	74	22	2
4687	bdl	32	114	50	48	85	472	3.71	4.66	14.3	10.22	1.81	0.468	0.087	0.080	4	5	118	1.5	45	18	101	1	25	4	0.5	139	17	2
4688	bdl	28	64	25	24	55	308	1.82	2.38	10.0	19.08	2.23	0.258	0.044	0.120	8	4	77	0.8	27	11	59	0.6	17	3	0.4	216	12	1
4695	bdl	43	123	60	53	90	674	4.13	5.19	17.5	9.58	1.93	0.534	0.087	0.080	4	8	300	1.8	55	22	115	1.3	34	5	0.4	154	24	3
4693	bdl	36	110	45	47	98	740	4.13	5.08	17.9	5.00	1.39	0.534	0.175	0.120	2	6	169	1.8	58	19	109	1.2	35	3	0.2	81	24	3
4699	bdl	53	170	70	41	104	988	6.29	7.41	24.1	2.36	1.27	0.767	0.087	0.040	4	9	236	2.9	86	32	167	2	53	11	0.8	87	35	4
4700	bdl	87	56	120	44	156	367	2.17	2.75	20.5	17.94	1.57	0.300	0.087	0.080	7	4	177	1	38	13	75	1.2	22	3	0.3	436	16	2
4706	bdl	37	99	85	70	109	846	4.90	5.50	28.6	2.29	0.90	0.540	0.087	0.080	3	5	1518	2.3	63	27	183	1.6	49	1	0.2	122	43	4
4734	bdl	161	44	na	36	187	205	1.54	1.32	7.0	33.73	2.11	0.174	0.131	0.200	3	2	108	0.6	16	11	55	0.3	10	7	2	274	7	1
4837	3	78	48	28	57	269	299	1.75	2.80	13.4	20.30	0.72	0.270	0.218	0.120	bdl	3	262	0.8	22	8	51	0.3	16	4	1	376	12	1
7682	1	26	107	69	31	92	1374	4.55	5.56	25.8	7.58	1.27	0.737	0.044	0.200	bdl	7	398	1.9	83	31	163	1.9	38	bdl	0.3	238	33	4
7683	1	12	90	41	20	52	1866	1.75	1.53	7.6	34.81	0.72	0.192	0.000	0.280	bdl	7	308	0.9	121	26	83	3.6	71	bdl	0.3	244	53	4
7684	bdl	23	103	68	36	92	1336	4.34	5.13	22.9	12.22	1.15	0.683	0.087	0.200	bdl	6	311	1.7	89	36	283	2.3	44	bdl	0.2	190	34	3
7685	bdl	39	115	79	34	85	1380	5.18	6.09	23.4	9.22	1.21	0.719	0.044	0.120	bdl	8	248	2.1	98	39	212	2.6	45	10	0.3	136	34	4
7686	bdl	77	102	82	40	90	956	4.34	4.60	22.2	14.44	1.75	0.647	0.044	0.160	bdl	8	240	1.4	55	34	162	1.8	29	bdl	0.3	216	23	2
7687	bdl	32	110	63	32	85	1012	4.48	5.45	21.9	11.29	1.15	0.635	0.044	0.200	bdl	7	306	1.9	82	29	482	2.2	41	bdl	0.2	158	33	3
7688	bdl	24	98	62	27	73	1182	3.92	5.24	20.9	12.86	1.21	0.570	0.000	0.160	bdl	6	323	1.7	77	30	100	1.9	37	bdl	0.2	177	30	3
7689	bdl	25	105	63	29	85	1100	4.20	5.50	23.9	10.36	1.03	0.659	0.044	0.160	bdl	7	347	1.8	78	29	144	2	37	bdl	0.3	159	31	3
7690	1	24	102	62	33	109	816	3.99	5.45	22.4	11.51	1.03	0.635	0.000	0.200	bdl	5	368	1.7	71	27	123	1.9	34	bdl	0.3	186	29	3
7690	bdl	29	94	62	38	145	741	3.92	5.13	19.1	7.65	1.09	0.552	0.087	0.320	bdl	5	245	1.7	66	25	143	1.7	31	bdl	0.4	132	27	3
7691	1	25	87	56	30	94	800	3.71	4.92	22.3	13.29	1.27	0.576	0.087	0.200	bdl	4	342	1.6	76	26	107	1.9	36	bdl	0.3	206	30	3
7693	bdl	26	123	73	34	107	1140	5.25	6.88	28.0	3.14	1.09	0.767	0.087	0.160	bdl	4	307	2.6	89	34	172	2.1	42	bdl	0.2	124	34	4

bdl = below detection limit

Table 7: Cont.

Station	Cd ppm	Pb ppm	V ppm	Ni ppm	Cu ppm	Zn ppm	Mn ppm	Fe %	Al %	Si %	Ca %	Mg %	Ti %	P %	S %	Ag ppm	As ppm	Ba ppm	Be ppm	Ce ppm	Co ppm	Cr ppm	Eu ppm	La ppm	Mo ppm	Sb ppm	Sr ppm	Y ppm	YB ppm
7694	1	41	124	77	64	155	1261	5.32	7.04	25.8	7.58	1.21	0.719	0.044	0.120	bdl	6	326	2.3	89	33	157	2.1	41	bdl	0.2	122	33	4
7695	2	12	49	23	22	64	409	1.68	2.22	10.1	31.02	0.66	0.246	0.044	0.240	bdl	4	171	0.7	31	9	66	1	18	bdl	0.2	164	16	2
7696	bdl	20	55	38	54	147	431	2.10	2.80	13.1	15.22	0.78	0.306	0.218	0.360	bdl	2	212	0.9	31	13	72	1.3	18	bdl	0.3	135	15	2
7697	1	36	95	54	34	184	470	3.92	5.34	21.6	14.08	1.09	0.582	0.131	0.280	bdl	5	257	1.7	65	21	110	1.8	35	bdl	0.3	153	29	3
7698	bdl	38	84	53	35	123	528	3.78	4.97	21.0	10.22	1.09	0.534	0.087	0.360	bdl	3	217	1.6	65	18	112	1.8	30	bdl	0.3	128	25	3
7700	bdl	25	112	67	32	89	1094	4.62	6.03	23.9	10.43	1.33	0.671	0.131	0.280	bdl	4	326	2	91	32	140	2	40	bdl	0.3	173	33	4
22001	bdl	43	108	60	31	124	908	4.06	5.19	25.8	6.36	0.72	0.713	0.000	0.040	bdl	7	516	1.3	75	28	319	0.9	36	bdl	0.6	167	32	3
22002	bdl	41	121	66	31	105	1150	4.62	5.93	26.5	5.15	0.72	0.743	0.000	0.040	bdl	15	469	1.5	86	32	136	1	41	bdl	0.5	125	35	4
22003	bdl	39	89	50	54	112	767	3.08	4.13	26.3	8.22	0.48	0.695	0.000	0.040	bdl	6	465		66	24	131	0.6	32	bdl	0.3	177	32	3
22004	bdl	48	133	67	24	93	1161	5.18	6.51	28.9	2.50	0.60	0.809	0.000	0.000	bdl	8	425	1.7	91	32	153	1.1	43	bdl	0.3	106	36	4
22005	bdl	45	114	65	32	121	1020	4.34	5.66	25.4	6.07	0.54	0.659	0.044	0.040	bdl	8	454	1.5	75	27	169	1	40	bdl	0.3	141	34	4
22006	bdl	30	93	56	29	86	947	3.15	4.07	25.8	10.15	0.48	0.677	0.000	0.040	bdl	15	497	0.9	67	25	175	0.6	33	bdl	0.3	192	32	3
22007	bdl	25	80	49	46	111	665	2.59	3.44	25.6	11.36	0.48	0.647	0.044	0.080	bdl	4	530	0.5	56	21	152	0.3	29	bdl	0.2	199	30	3
22008	bdl	42	88	51	57	111	697	3.01	3.86	25.1	11.01	0.60	0.653	0.000	0.080	bdl	8	489	0.7	66	25	182	0.5	32	bdl	0.3	185	32	3
22008	bdl	38	95	61	25	94	722	3.43	4.71	20.4	12.44	0.66	0.504	0.000	0.080	bdl	8	356	1.2	60	21	245	0.8	32	bdl	0.3	261	30	3
22009	bdl	42	94	53	27	91	568	3.36	4.71	18.9	13.15	0.54	0.468	0.044	0.040	bdl	8	308	1.1	56	20	129	0.6	31	bdl	0.4	262	28	3
22010	bdl	34	82	58	55	130	582	2.38	3.49	21.4	14.01	0.54	0.516	0.000	0.120	bdl	5	570	0.6	53	20	146	0.3	28	bdl	0.3	224	31	3
22011	bdl	44	111	65	34	106	865	4.06	5.50	22.7	8.58	0.60	0.588	0.000	0.040	bdl	10	412	1.5	75	23	136	1.2	38	bdl	0.3	210	34	3
22012	bdl	39	113	73	49	119	945	4.34	5.72	25.2	6.65	0.60	0.641	0.000	0.040	bdl	30	438	1.6	76	27	203	1.2	40	bdl	0.4	181	36	4
22013	bdl	42	125	75	31	99	1490	4.83	5.82	31.8	1.43	0.54	0.977	0.000	0.000	bdl	9	498	1.5	111	38	240	1.3	43	bdl	0.2	106	39	5
22014	bdl	43	120	76	32	113	1015	4.69	6.14	26.6	4.29	0.54	0.671	0.000	0.040	bdl	12	423	1.7	81	27	227	1.2	43	bdl	0.3	127	39	4
22015	bdl	37	113	55	23	97	813	4.20	5.72	23.3	8.22	0.48	0.623	0.000	0.040	bdl	9	474	1.6	74	25	128	1.1	38	bdl	0.3	171	33	3
22016	bdl	43	83	40	24	99	620	2.66	3.76	16.8	18.15	0.42	0.432	0.000	0.080	bdl	7	337	0.7	49	18	97	0.4	27	bdl	0.3	361	24	2
22017	bdl	32	50	35	30	76	345	1.40	1.85	17.5	21.94	0.36	0.384	0.000	0.080	6	6	328	0.1	36	12	102	bdl	20	bdl	0.3	281	20	2
22019	bdl	45	105	56	46	369	785	4.20	5.24	19.6	5.79	0.72	0.647	0.000	0.160	bdl	5	314	1	66	25	125	0.6	32	bdl	0.2	124	27	3
22020	bdl	51	84	52	71	131	595	2.80	3.76	24.5	11.44	0.54	0.570	0.087	0.080	bdl	7	515	0.8	59	19	158	0.6	30	bdl	0.4	196	31	3
22021	bdl	31	78	61	24	95	578	3.01	4.13	20.1	13.44	0.72	0.438	0.000	0.080	bdl	11	443	0.9	50	19	114	0.5	28	bdl	0.3	202	27	3
22022	bdl	29	78	54	43	109	505	2.31	3.33	21.8	15.72	0.48	0.504	0.000	0.120	bdl	5	596	0.5	52	17	124	0.3	29	bdl	0.3	239	33	3
22023	bdl	47	116	69	29	80	978	4.34	5.29	23.8	8.58	0.84	0.719	0.000	0.000	bdl	13	389	1.4	73	28	168	1.3	36	bdl	0.3	167	30	3
22024	bdl	43	98	66	67	165	682	3.78	5.08	23.0	9.86	0.48	0.611	0.175	0.080	bdl	7	467	1.3	71	22	141	1.2	36	bdl	0.3	169	35	3
22025	bdl	51	125	66	29	81	1420	4.48	5.45	30.1	4.29	0.48	0.893	0.000	0.000	bdl	11	443	1.4	93	32	155	1.1	39	bdl	0.2	123	36	4

Table 8: Metal/Al mean ratios in sediments from the Kishon drainage basin, Carmel stream sediments, deep sea sediments and average shales.

Ratio	Kishon drainage basin	Kishon Carmel drainage	*Deep sea sediments (Atlit)	**Shale and clays
Fe/Al	0.763	0.787	0.764	0.55
Cu/Alx1000	0.73	1.01	1.01	0.51
Zn/Alx1000	2	1.9	1.7	1.1
Pb/Alx10000	7.2	6.9	5.9	2.3
Ni/Alx1000	1.2	1.1	-	0.8
Cd/Alxe6	-	-	2	3
Hg/Alxe7	-	-	8.9	4.5
V/Alx1000	2	2.3	1.4	1.5
As/Alx10000	1.5	1.5	-	1.1
Be/Alxe5	3.1	3.2	4.2	3.4
Co/Alx10000	4.8	3.9	3.4	2.2
Cr/Alx1000	2.7	2.3	-	1
Mn/Alx100	1.5	1.3	2.4	1
Ti/Al	0.11	0.1	-	0.05

* Kress et al., 1993

** Wetepohl, 1968

Table 9: Chemical composition of effluents from Haifa Chemicals and Deshanim plants.

Material	Fertilizer Plants Deshanim*	Haifa Chemicals*
Discharge flux (m ³ /day)	1000?	3600
pH	2	0.5-1
HCl (g/l)	?	3-8
Ca (g/l)	?	30-50
Cl (g/l)	?	60-100
Na (g/l)	1.3	1-3
K (g/l)	0.3	4-7
Mg (g/l)	0.1	0-1
F (g/l)	1	0.5-1.5
P ₂ O ₅ (g/l)	5	1-4
NO ₃ (g/l)	?	2-5
SO ₄ (g/l)	7	0.5-5
Cd (mg/l)	1-3.5	1.4
Cu (mg/l)	0.3-0.7	3.8
Zn (mg/l)	14-19	38
Cr (mg/l)	1.4-1.7	9.2
Fe (mg/l)	56	90
Ni (mg/l)	3	?
V (mg/l)	3	?
Hg (ppb)	bdl	20-30

bdl = below detection limit

* Data from Haifa District Environmental Town Association & Keren Kayemet LeIsrael.

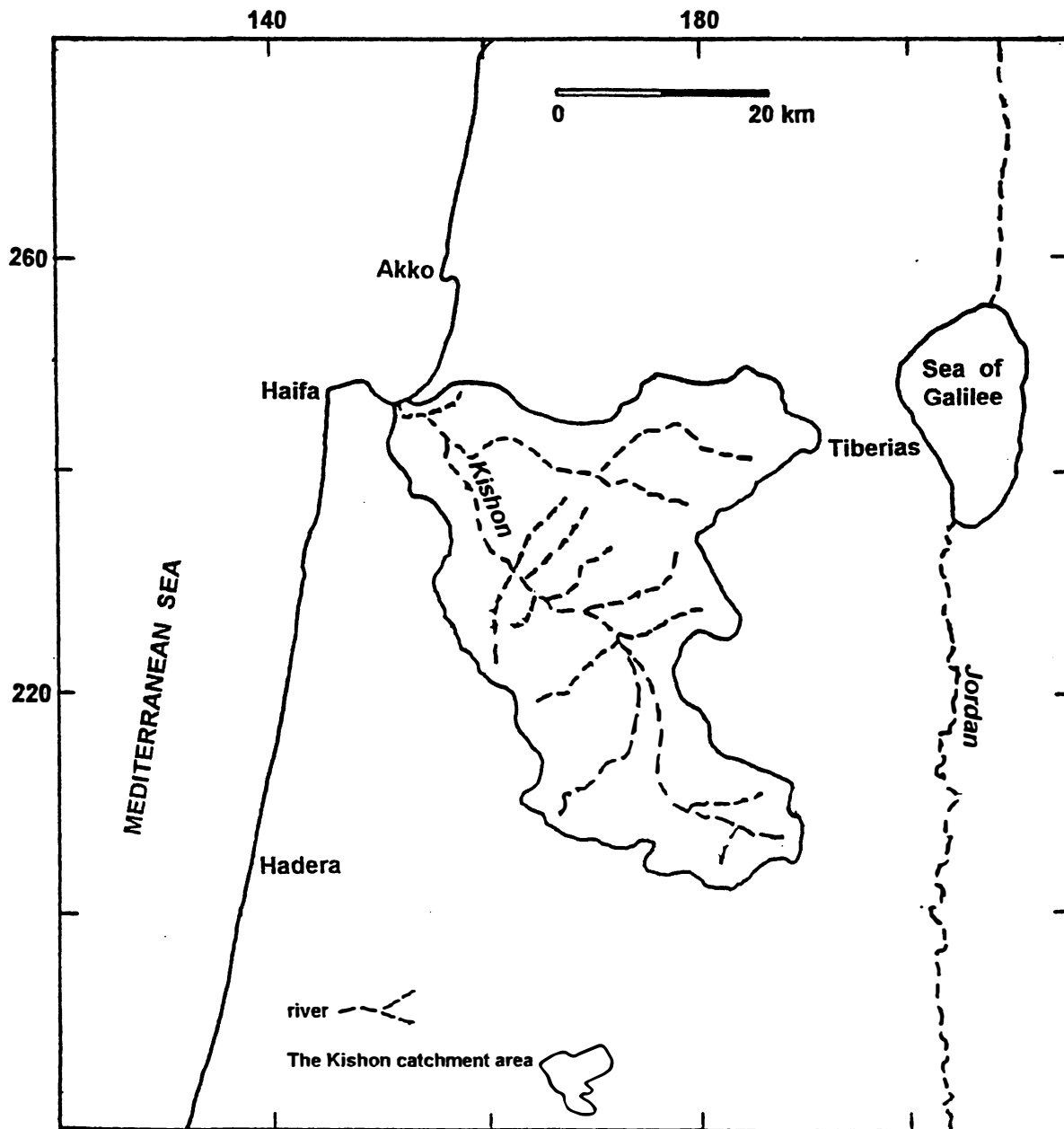
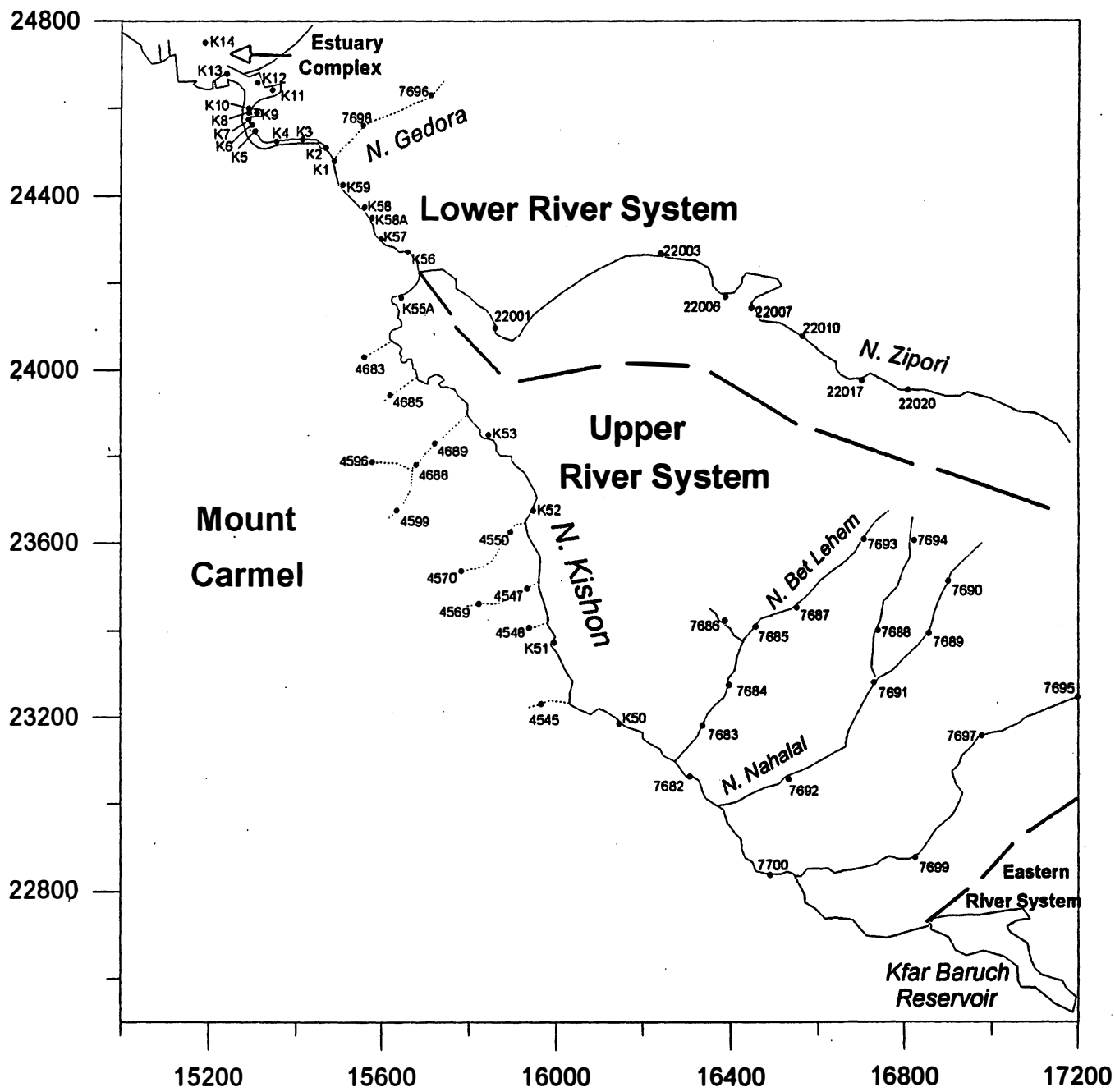


Fig. 1: The Kishon drainage basin.

Fig. 2: Location map of sampling sites and sub - division of the Kishon river basin.



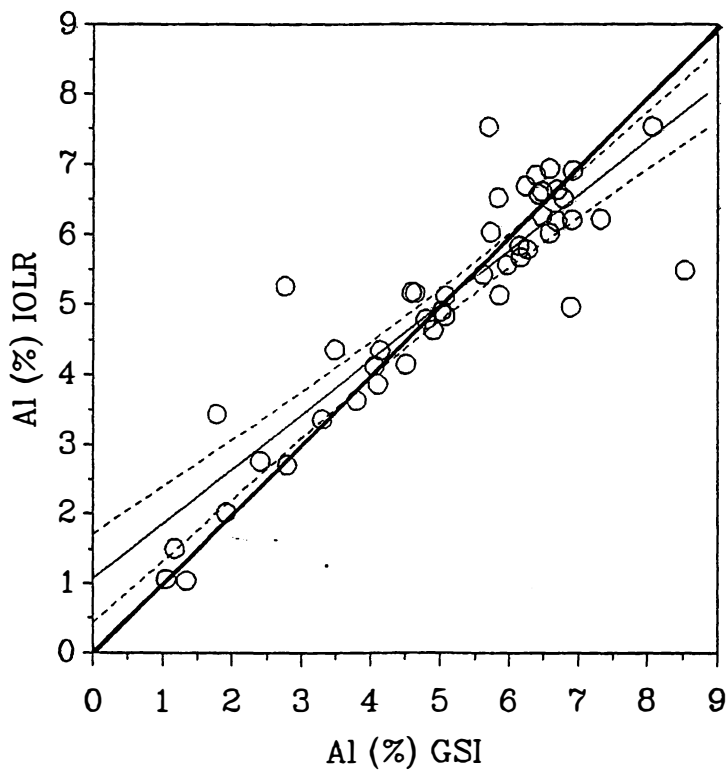
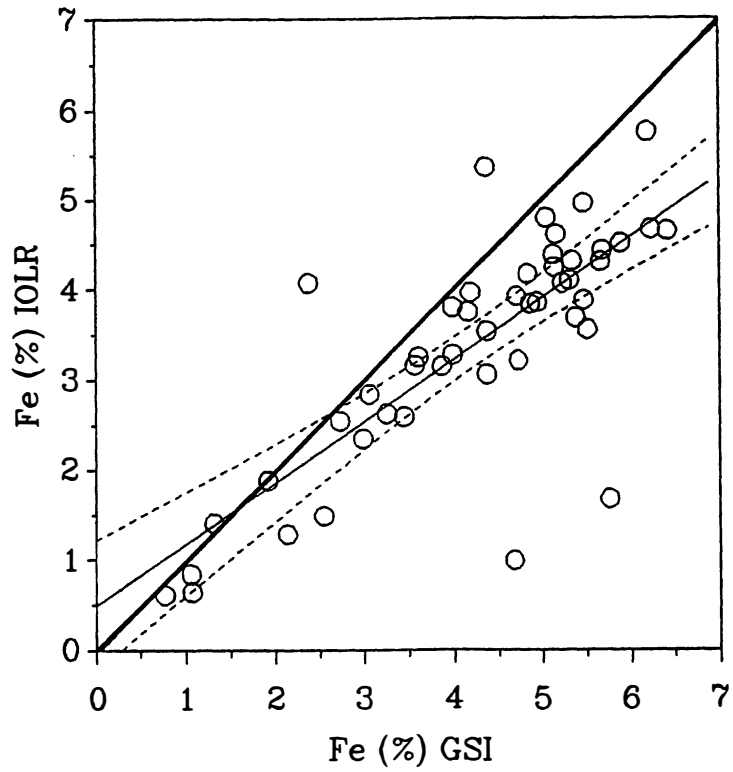


Fig. 3: Comparison between IOLR and GSI results for Al and Fe. The bold line denotes ratio 1:1.

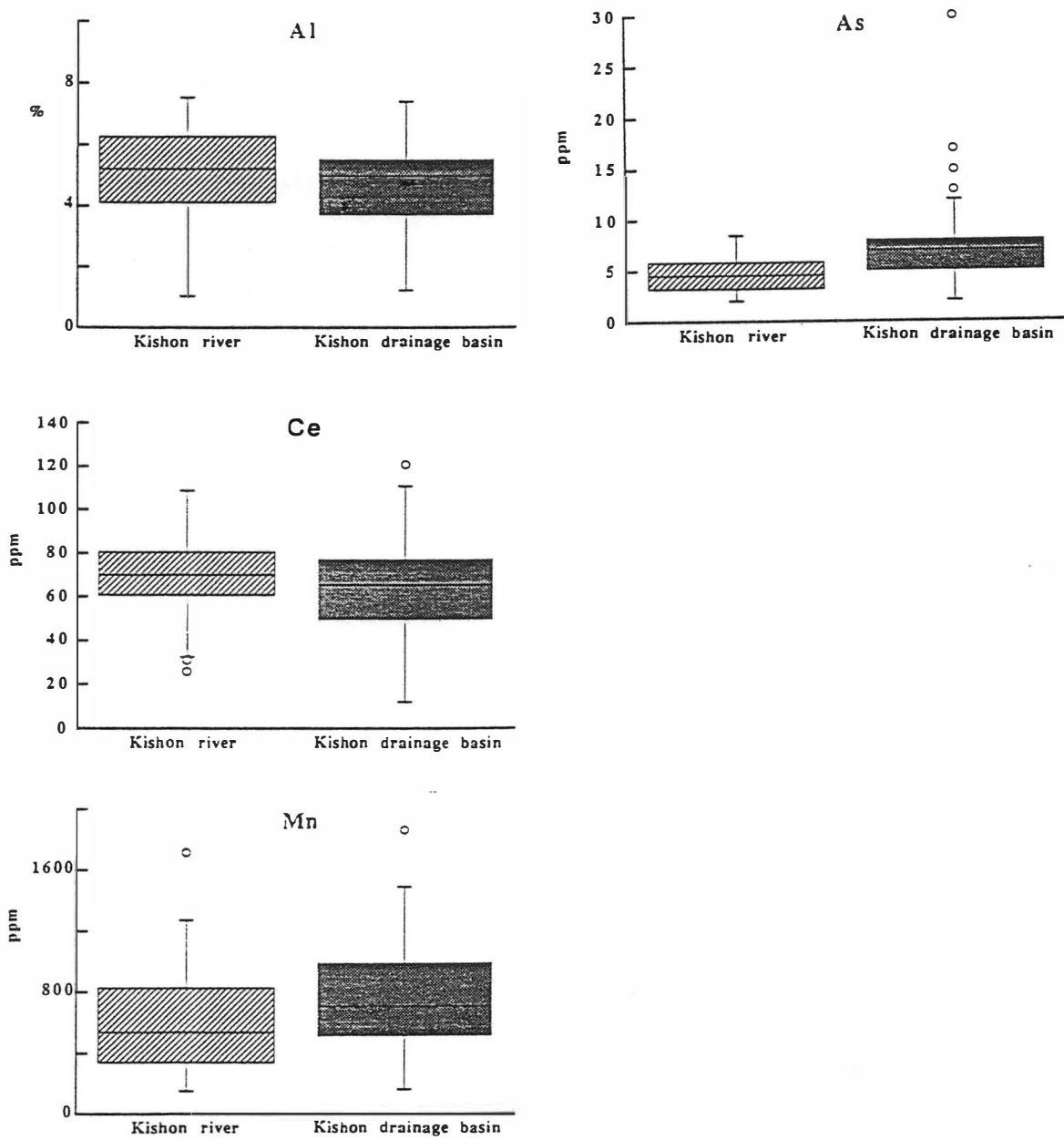


Fig. 4: Concentrations of selected elements in the Kishon river and drainage basin, represented by box plots. The box represents the values of the 25 - 75 percentiles, the inside line is the median (50%-ile) and the whiskers represent the 10 and 90 percentiles.

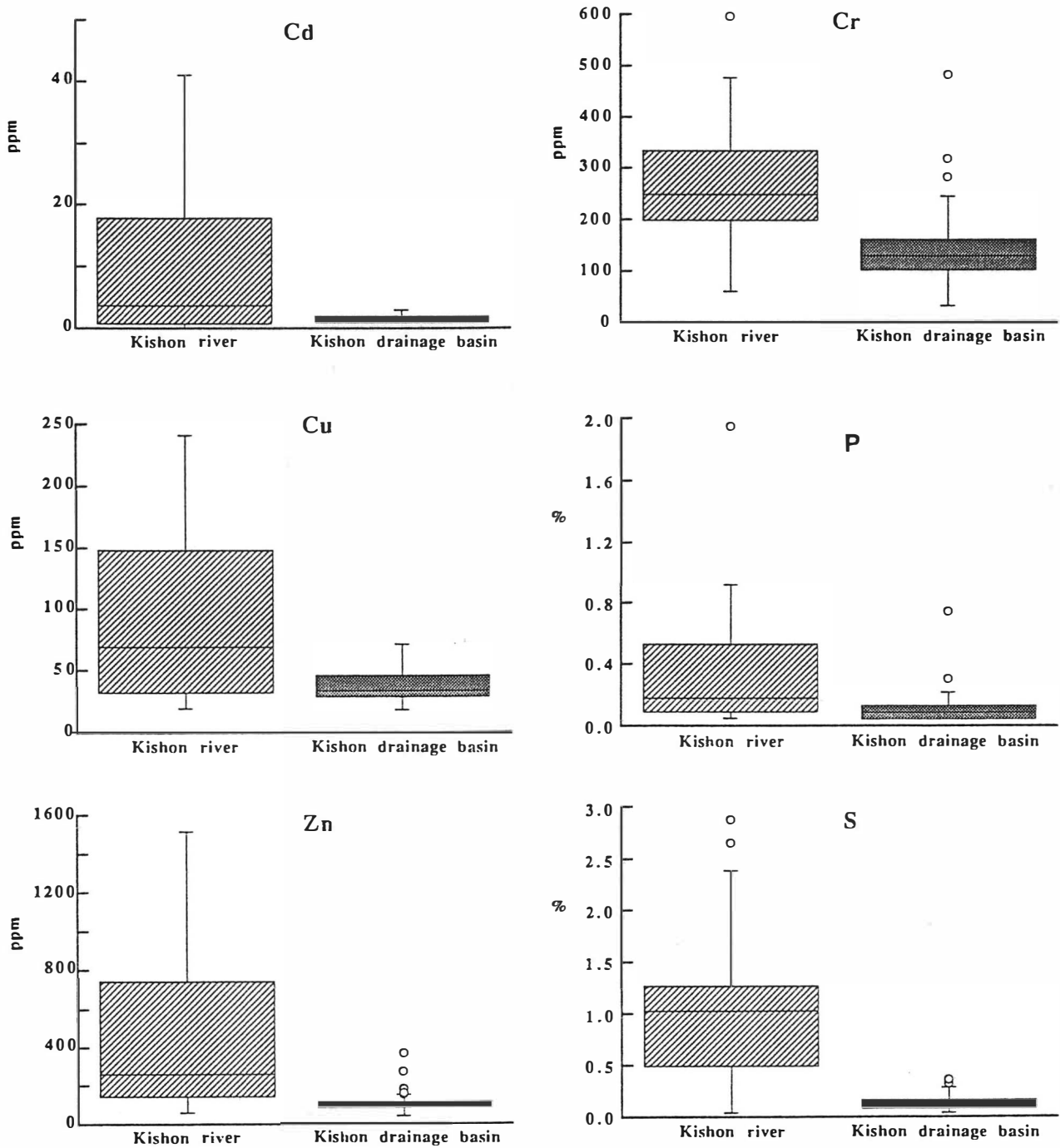


Fig. 4: Cont.

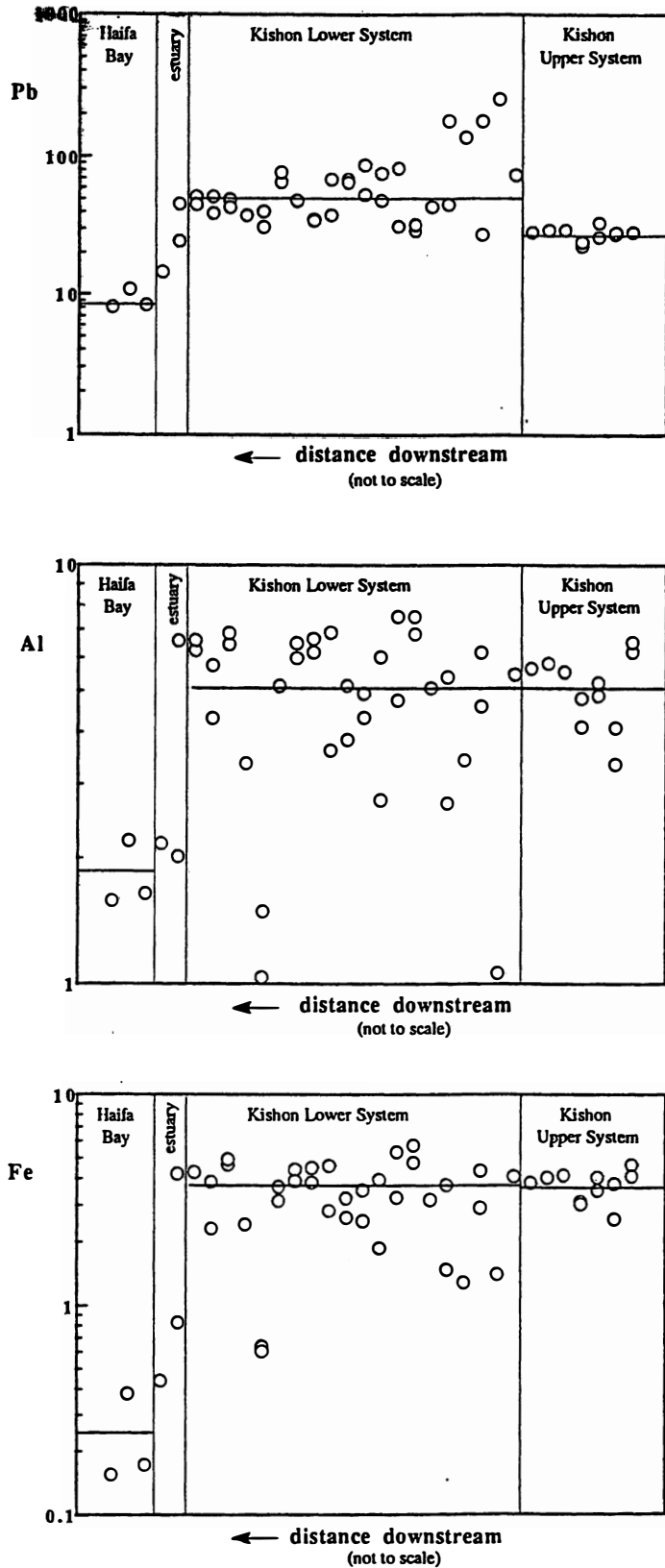


Fig. 5: Concentrations of selected elements along the entire Kishon system and Haifa Bay. Horizontal lines represent the median values in each sub-system.

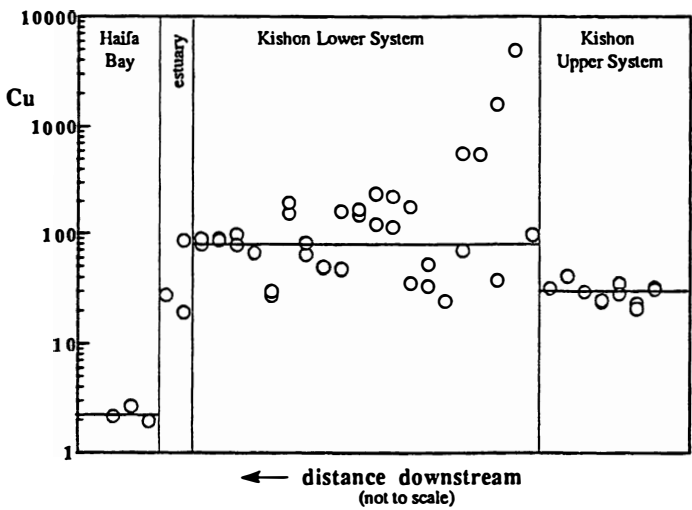
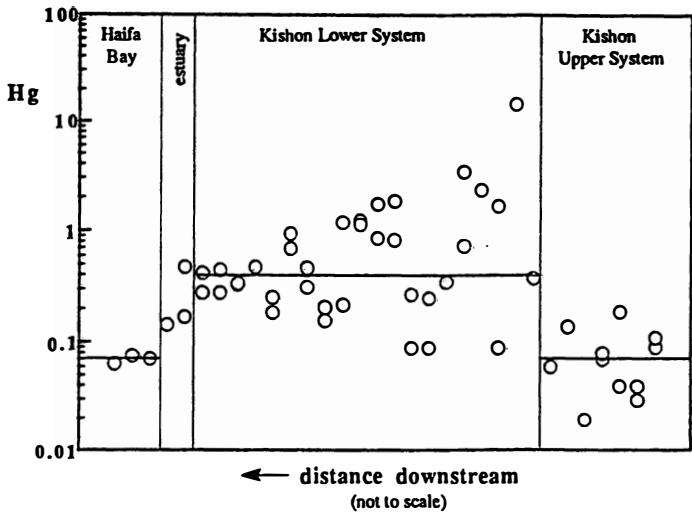
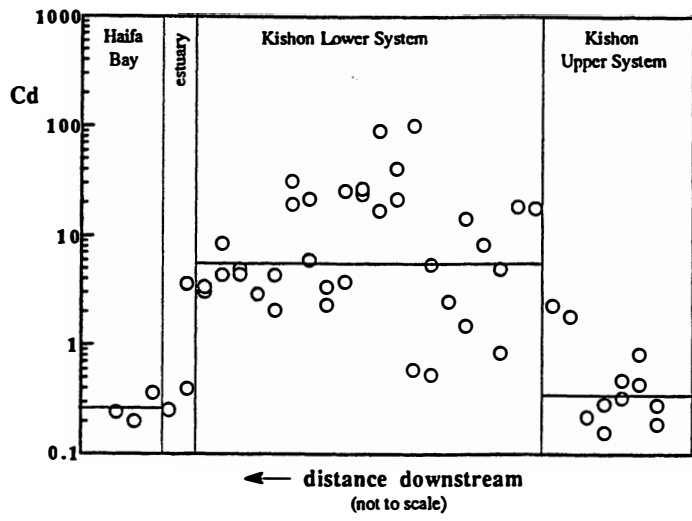


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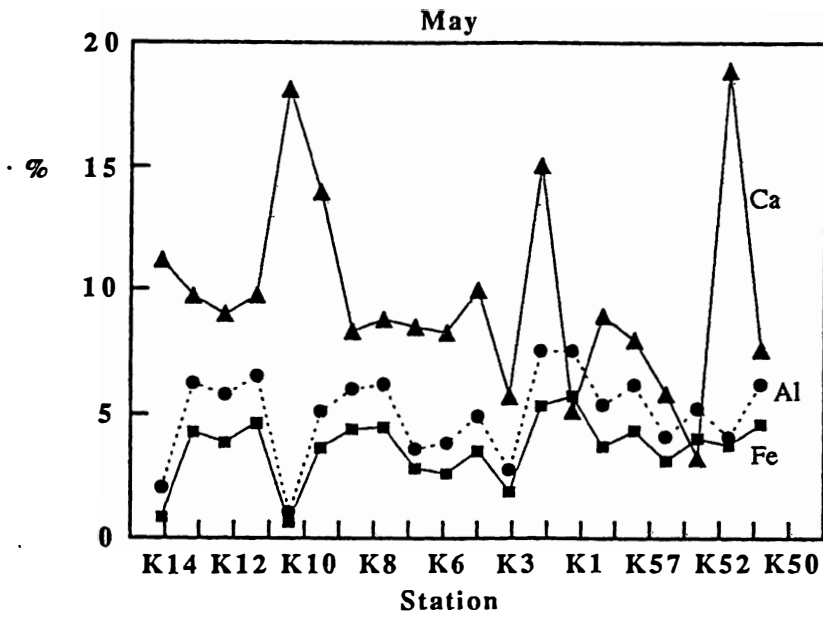
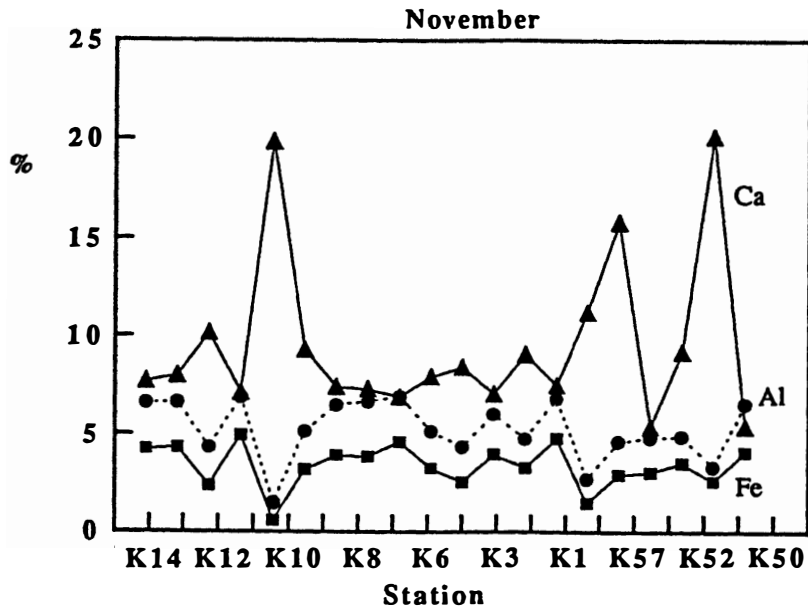


Fig. 6: Concentrations of Ca, Al and Fe in sediments along the Kishon river.

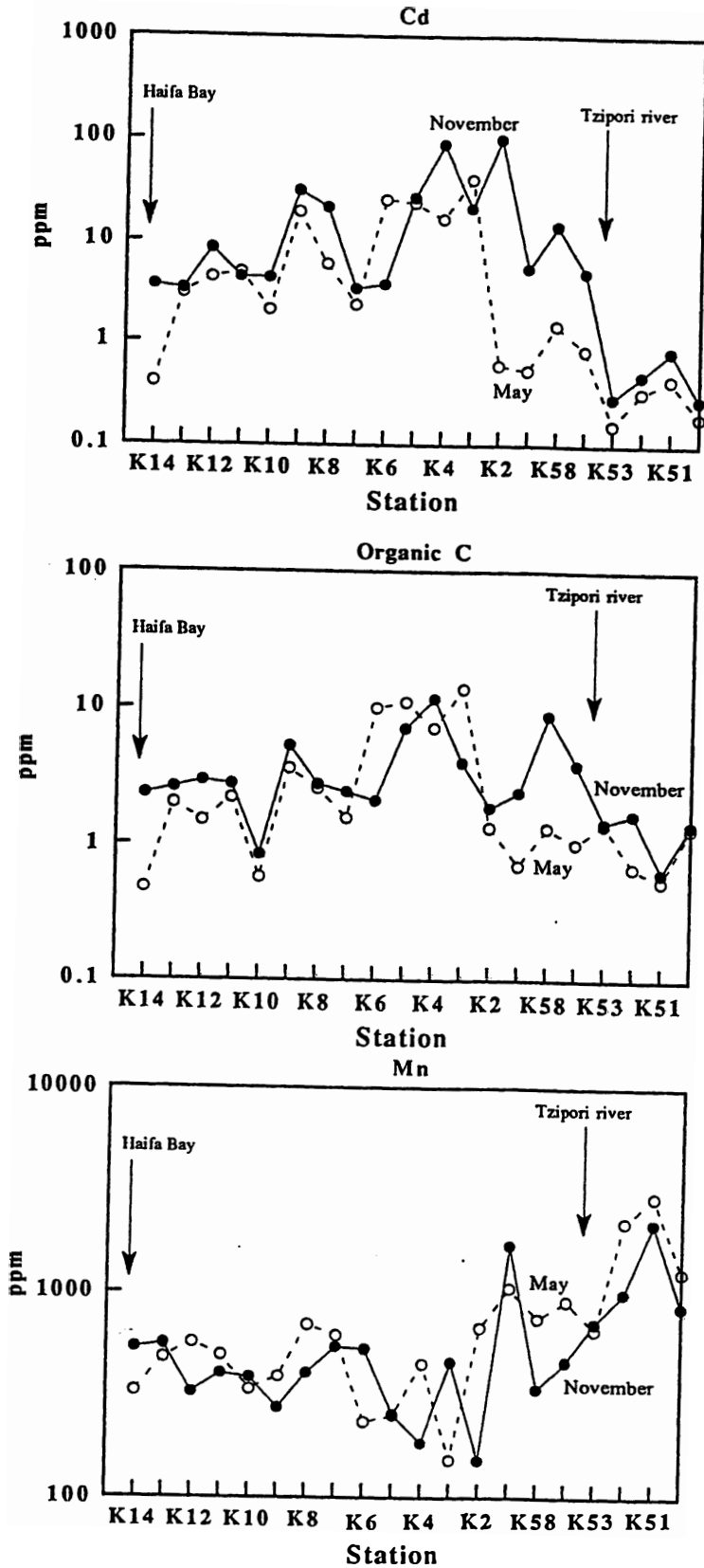


Fig. 7: Concentrations of Cd, organic C and Mn in sediments of the Kishon river in May and November 1992.

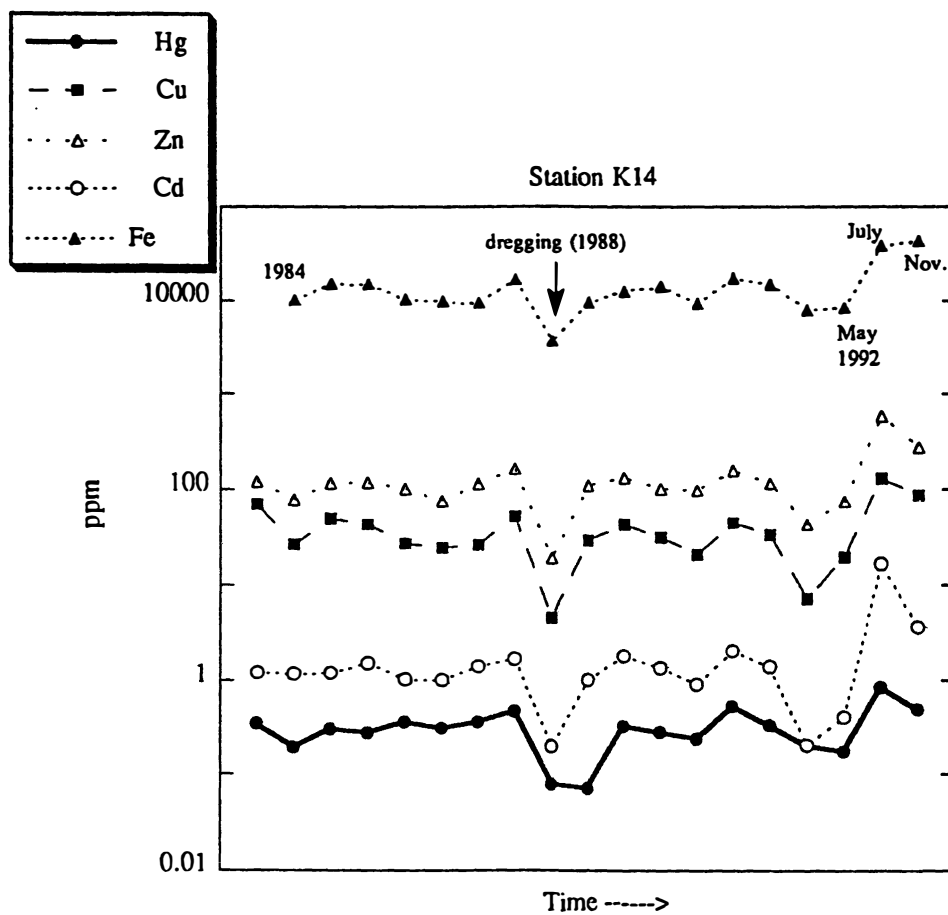


Fig. 8: Temporal variations in Hg, Cu, Zn, Cd and Fe concentrations.

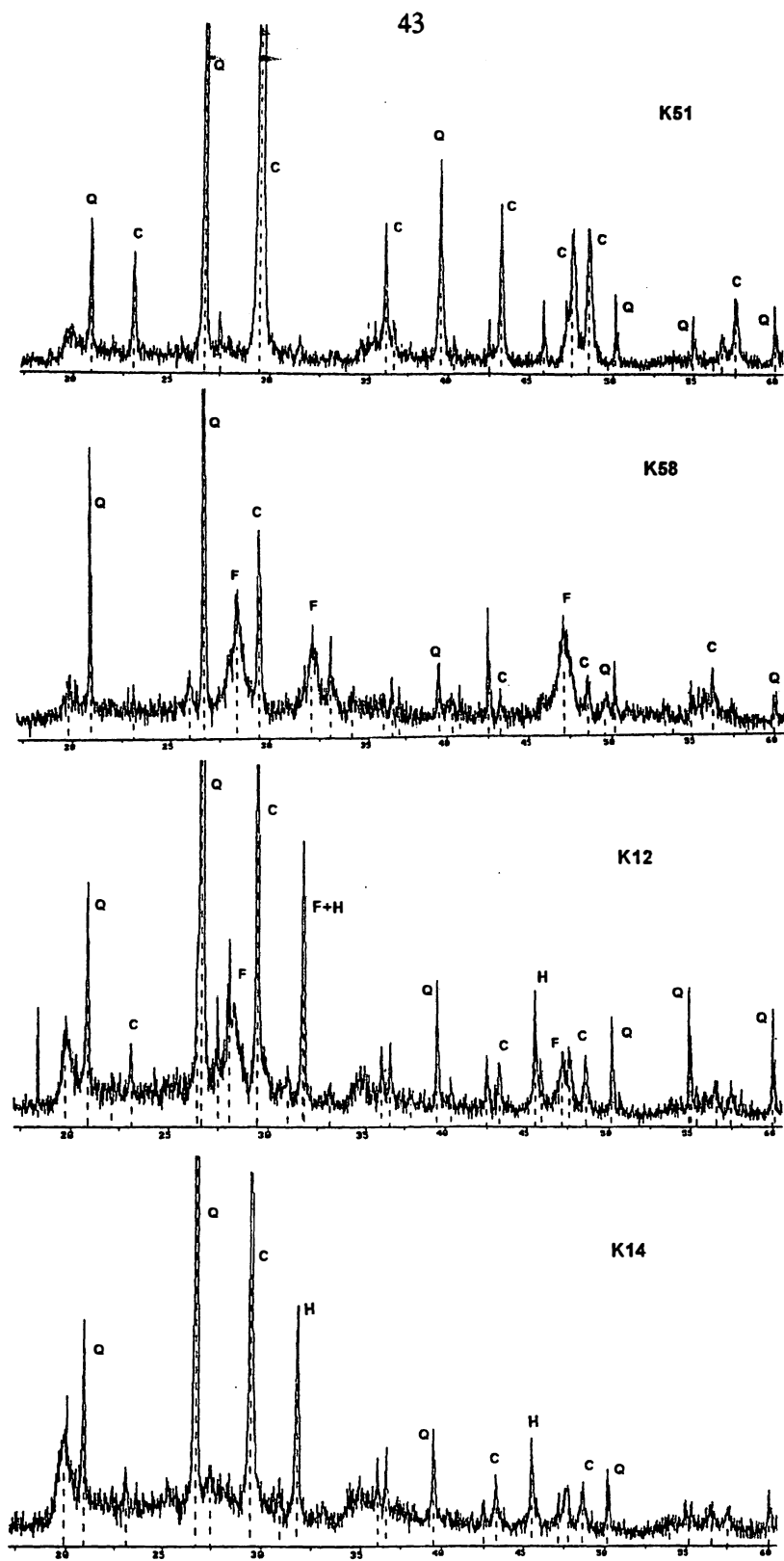


Fig. 9: XRD diffractograms of sediments from the Kishon river. C - Calcite; Q - Quartz; F - Fluorite; H - Halite.

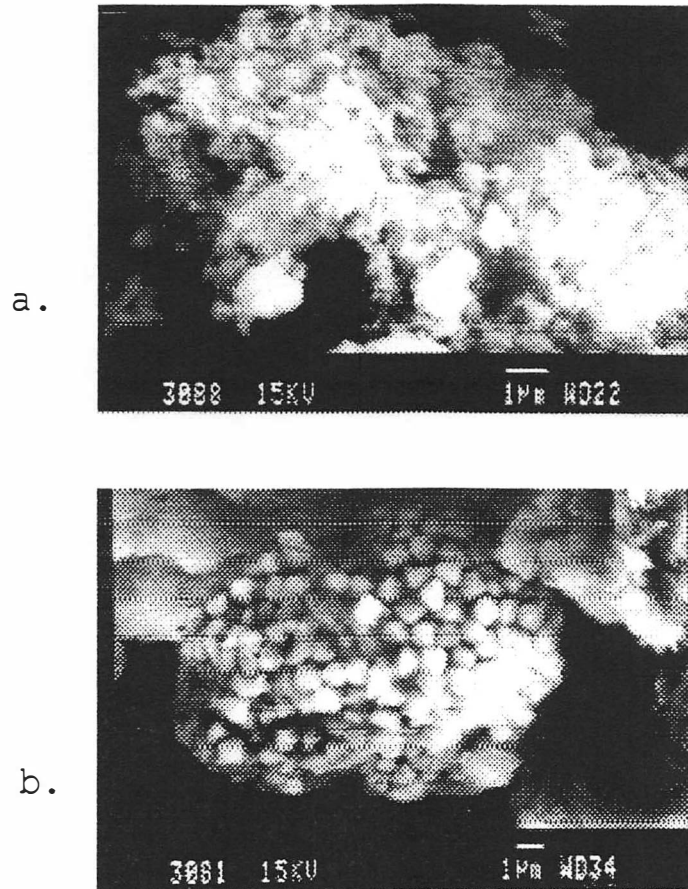


Fig. 10: (a): SEM photos; (a) - a Ca-P phase, probably poorly crystallized apatite.
(b) - a pyritic framboid.

Fig. 11: Single element maps, the Kishon river system.

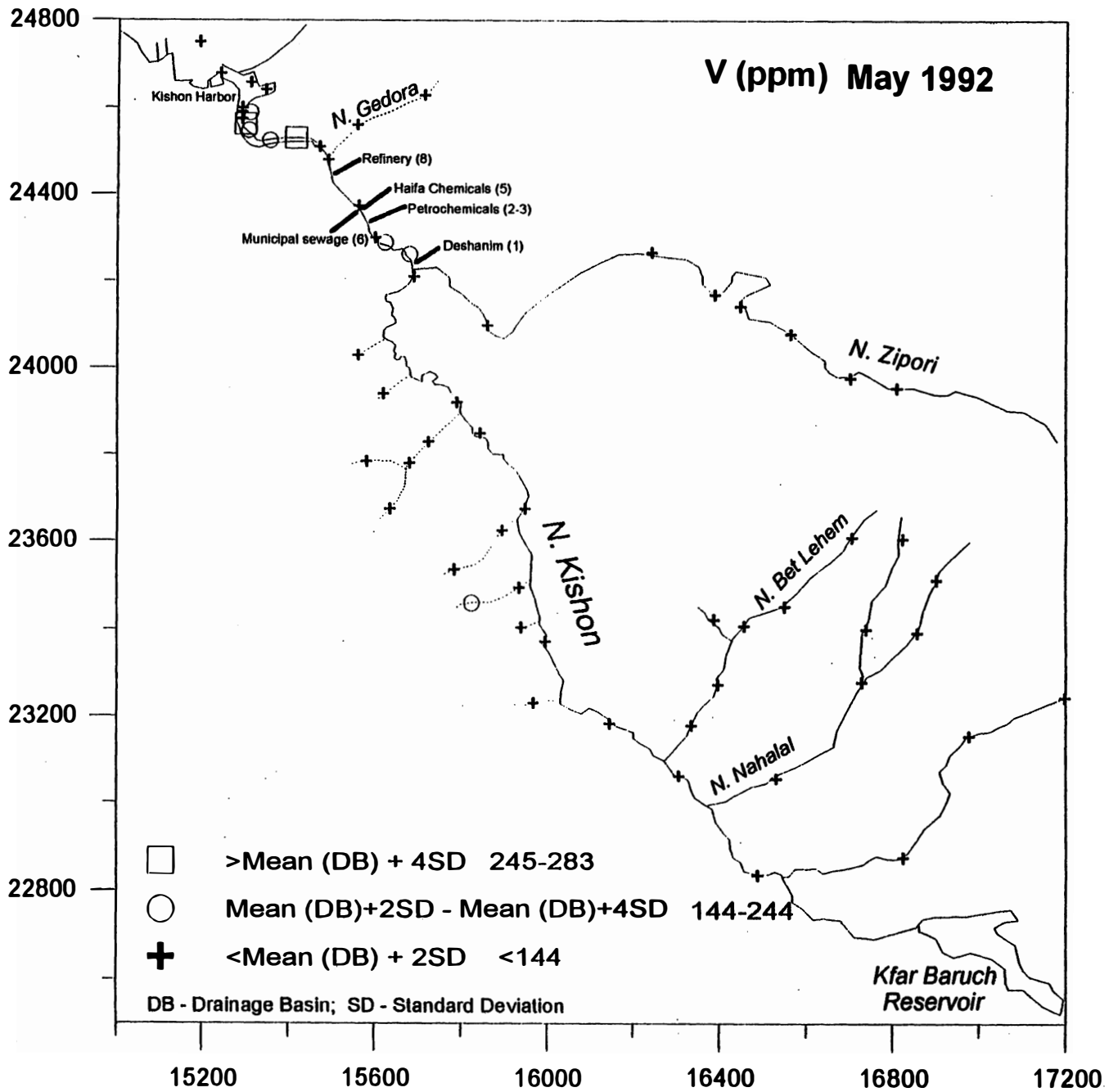


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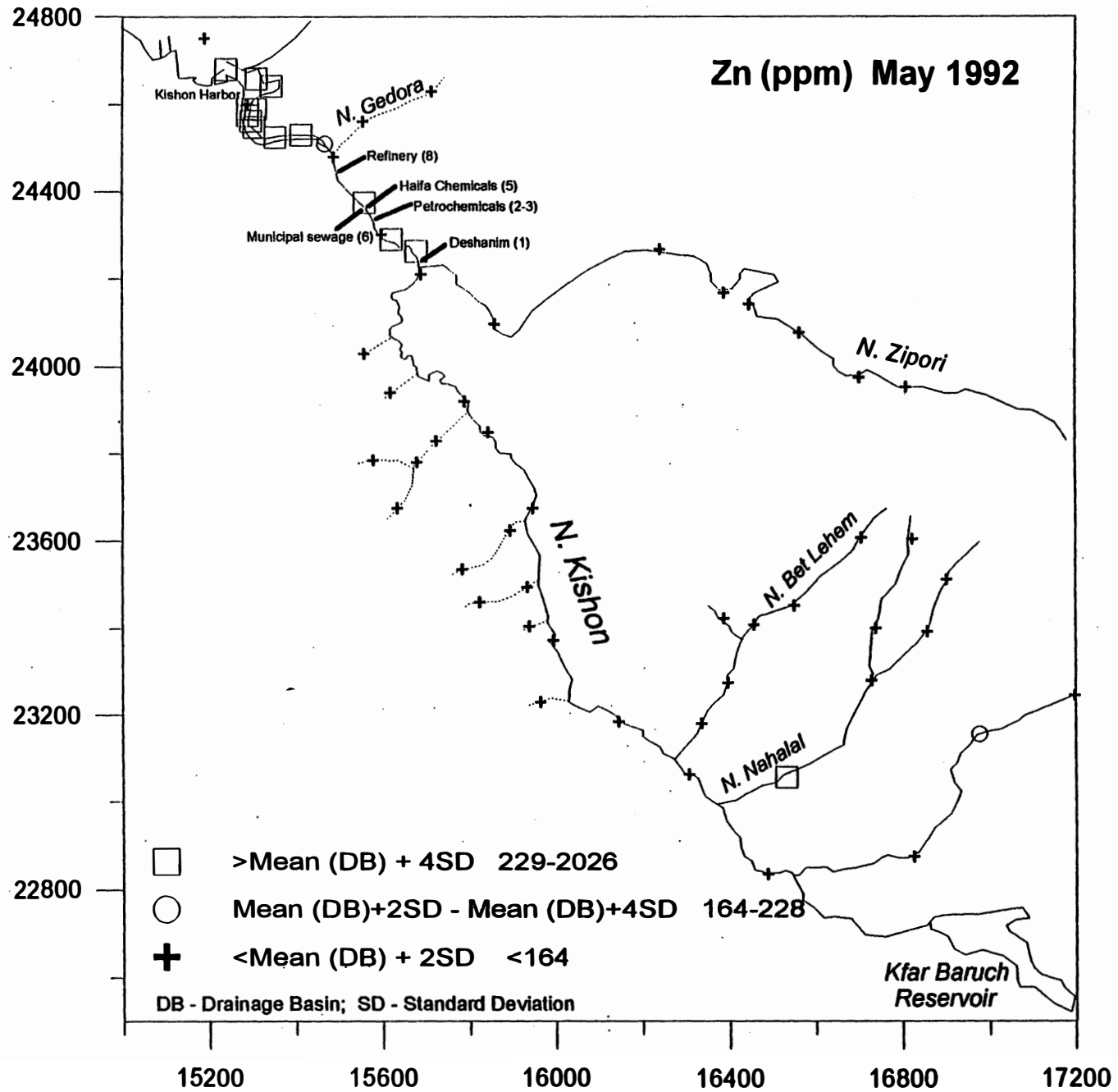


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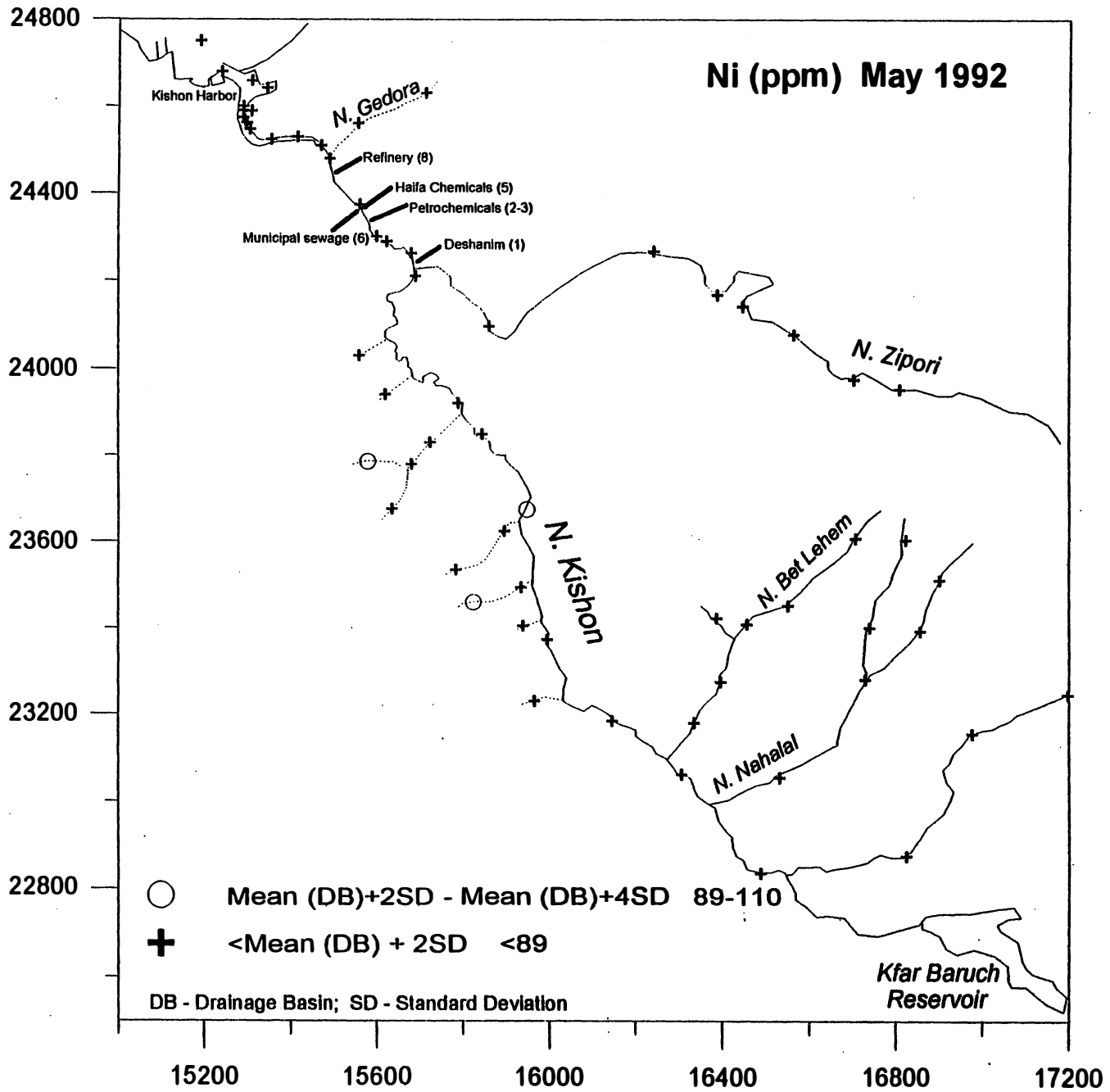
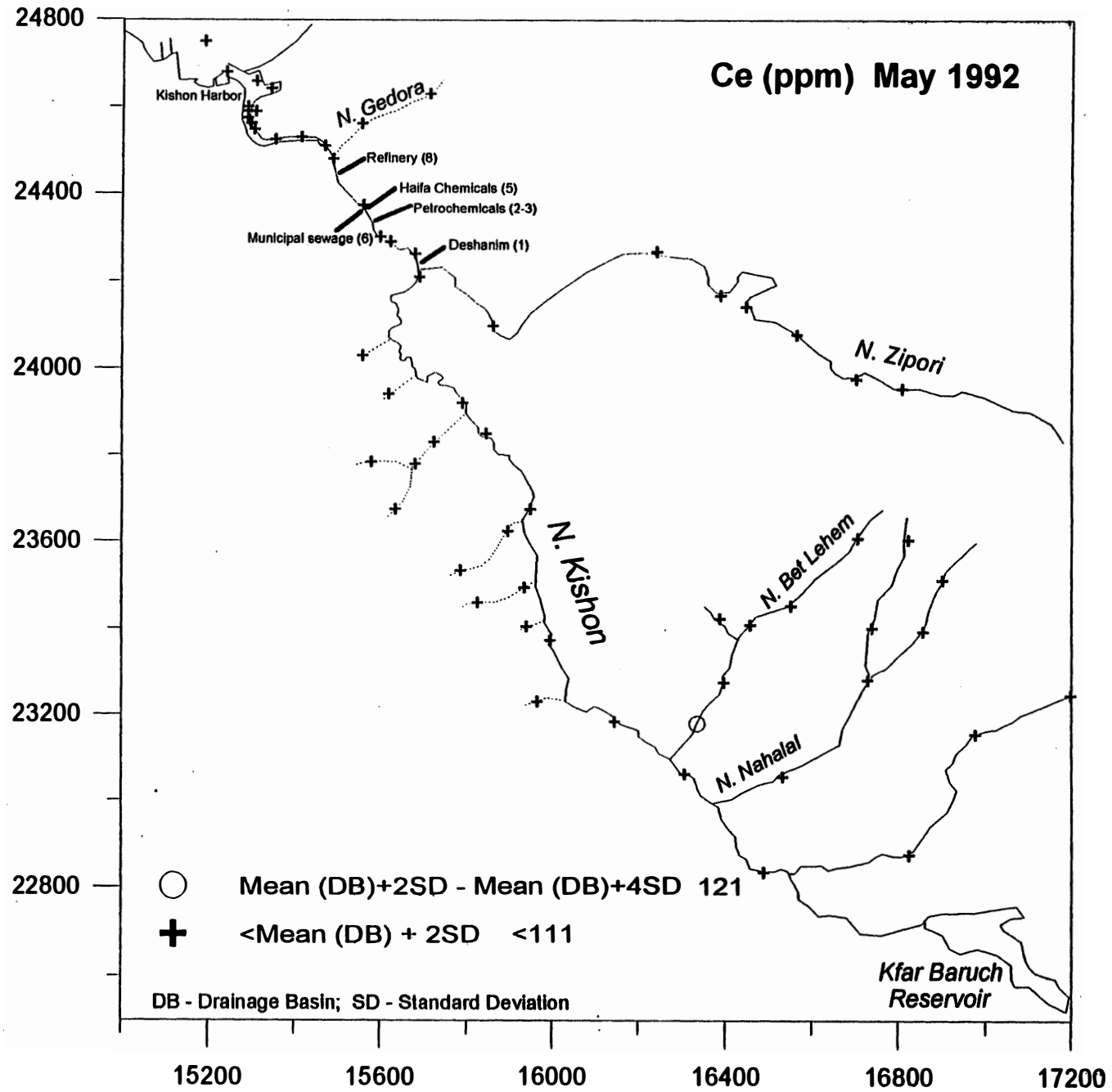


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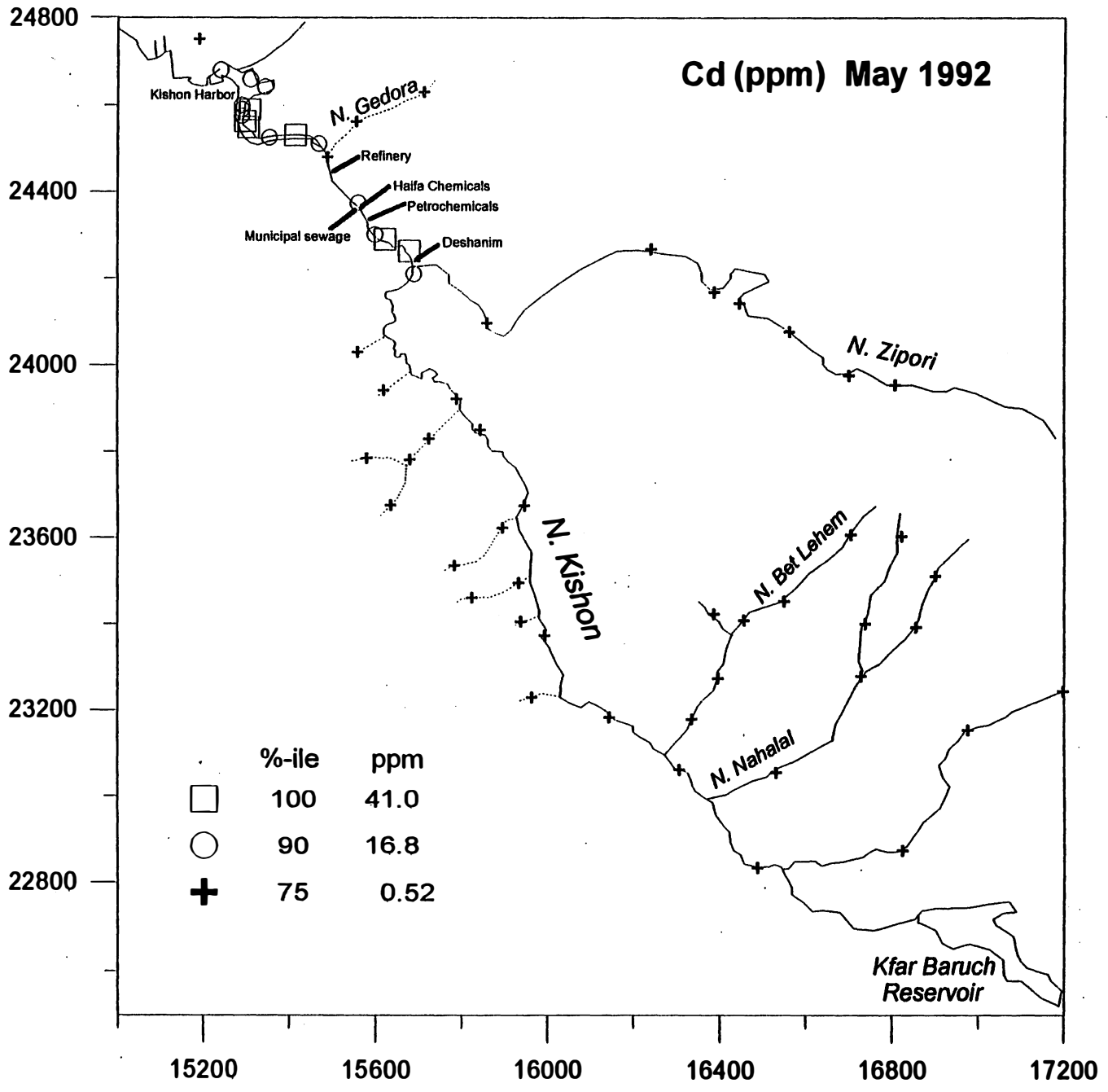


Fig. 11: Cont.

Fig. 11: Cont.

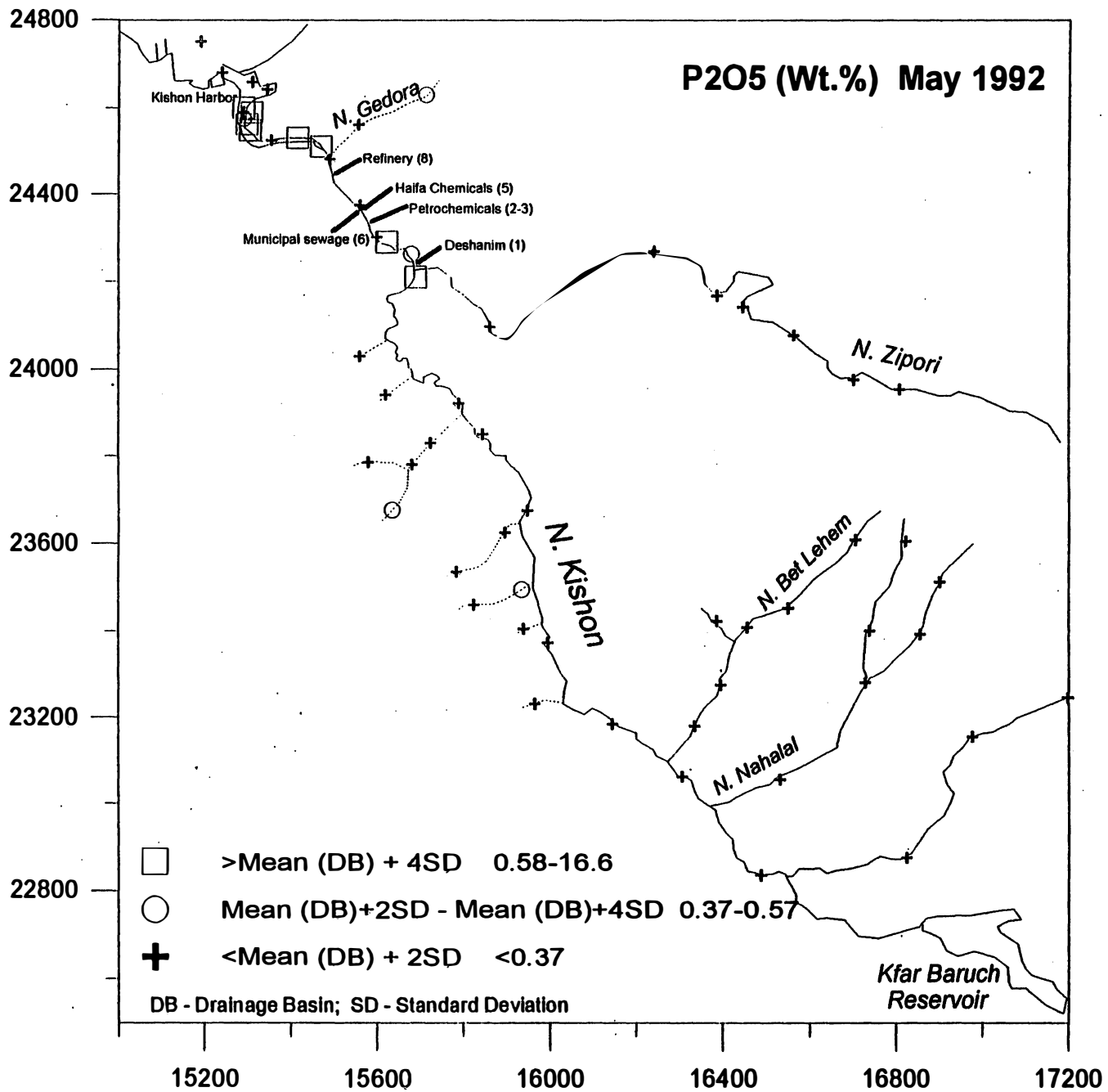


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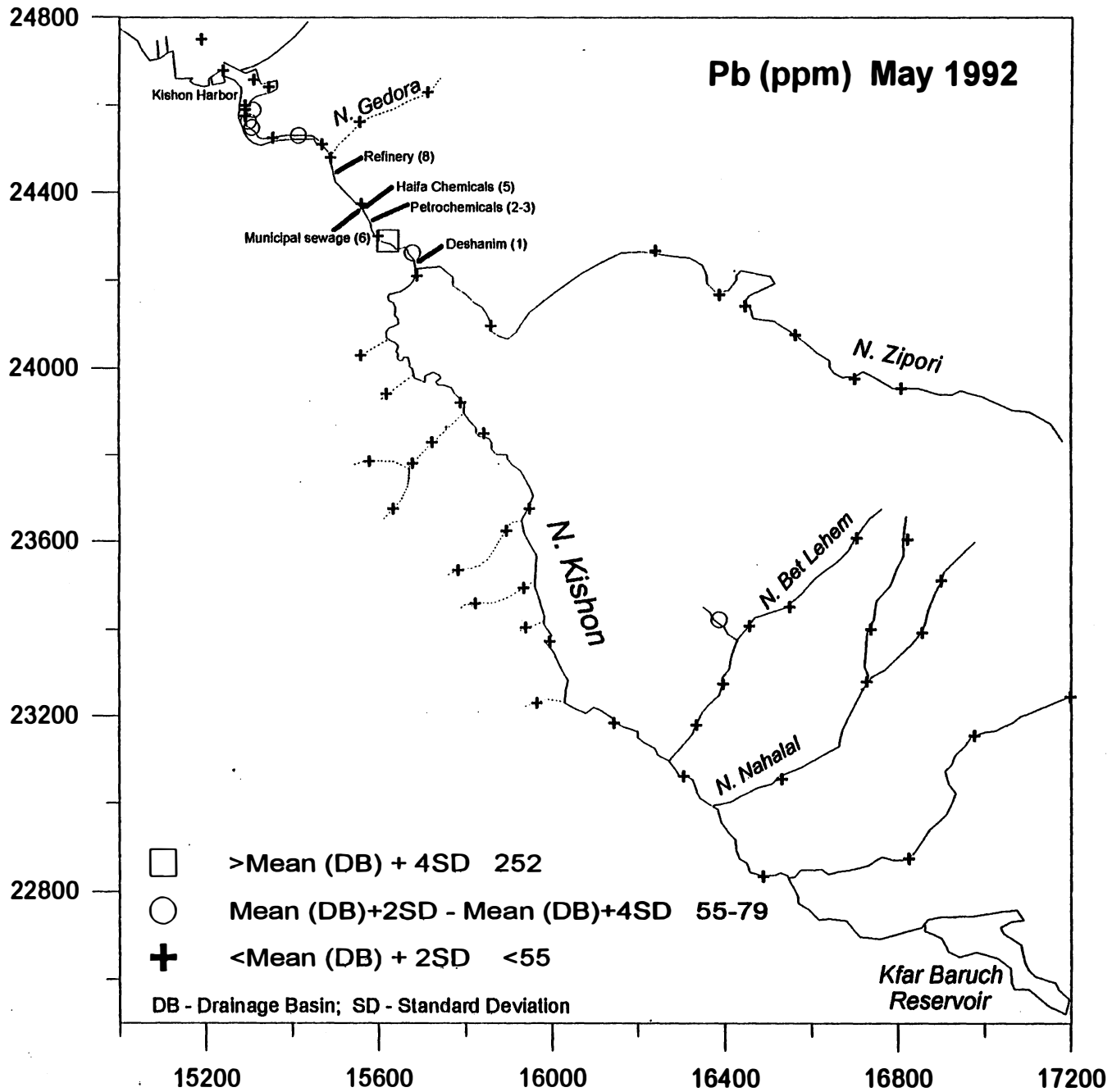


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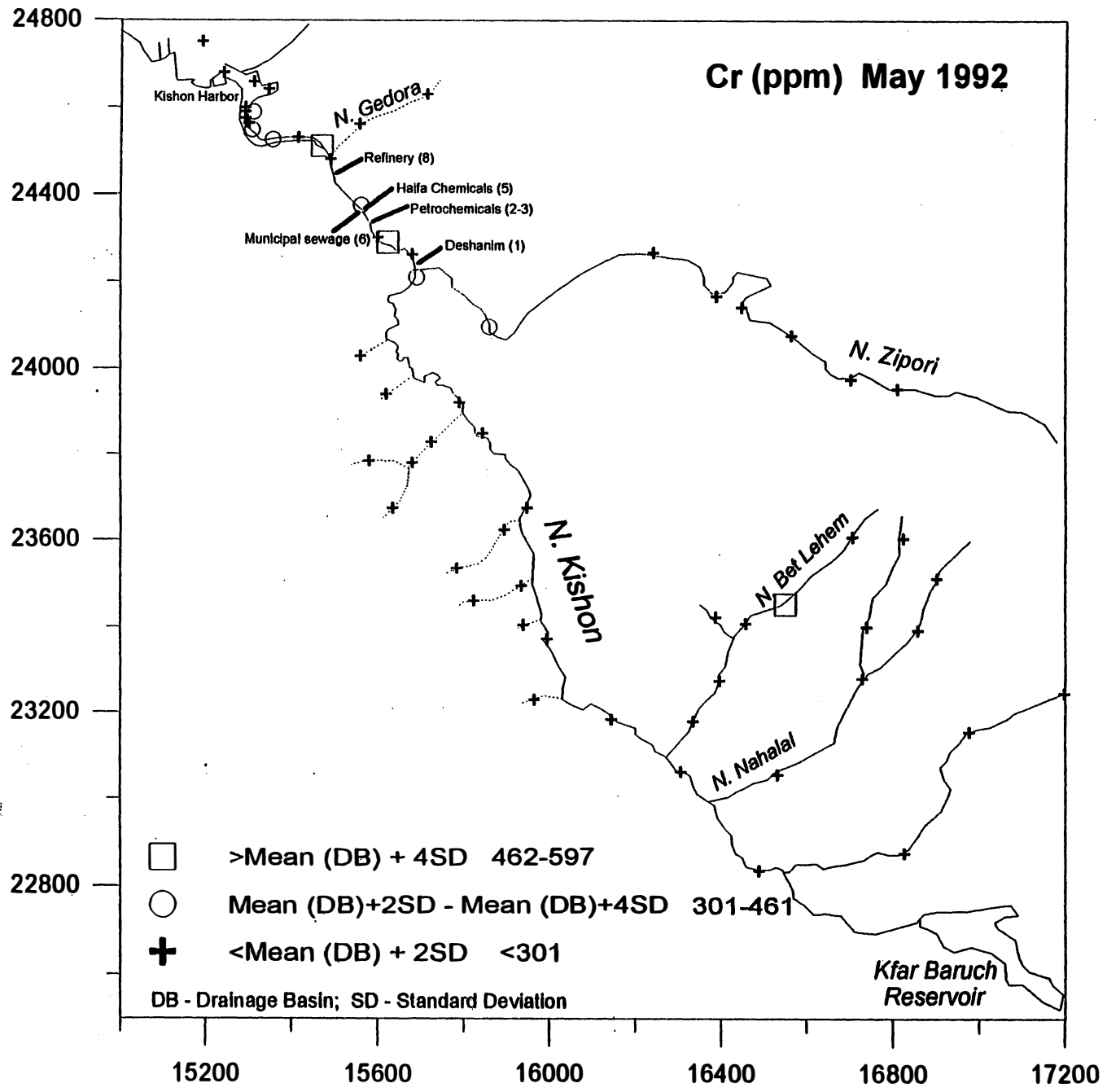
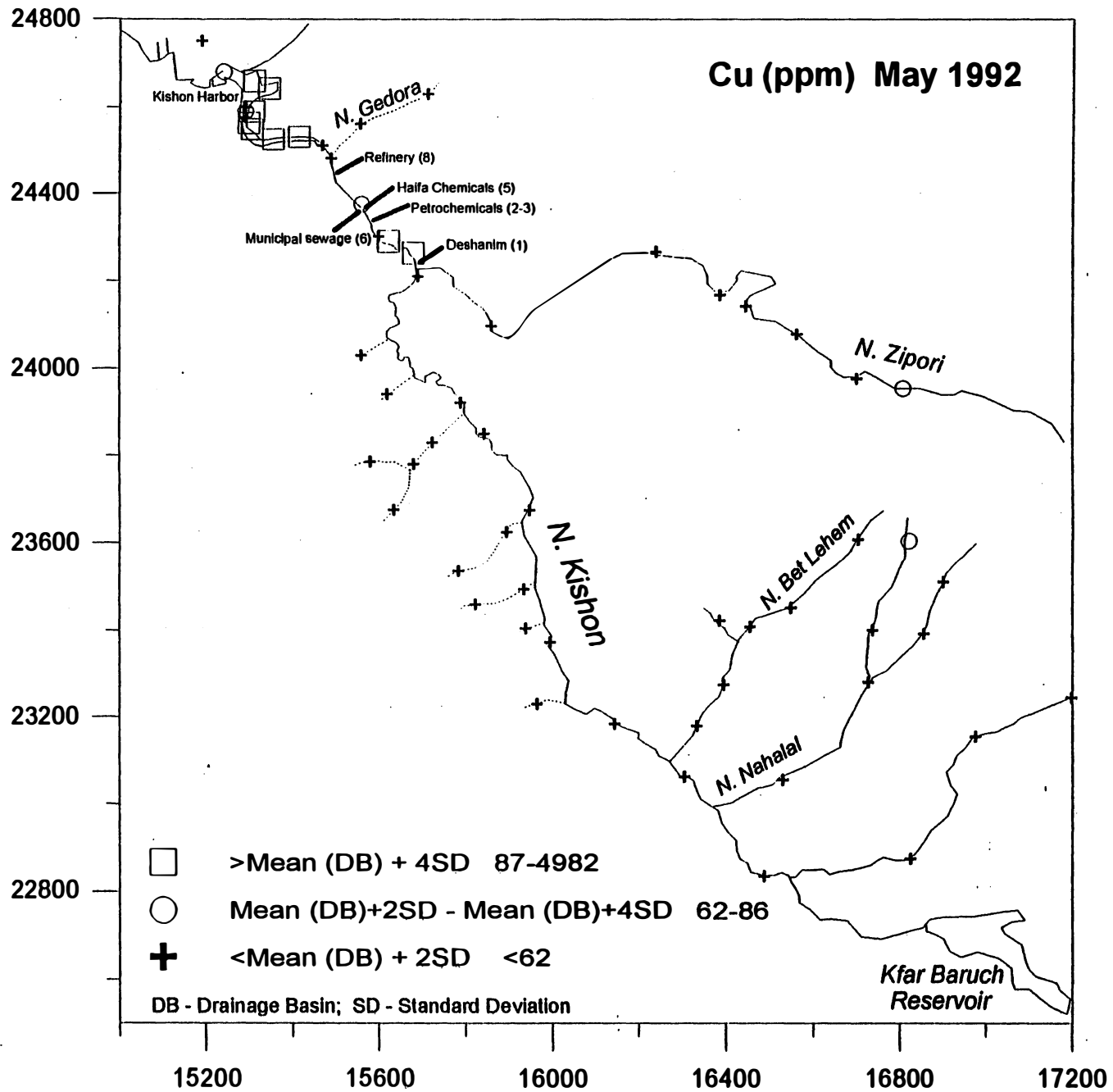


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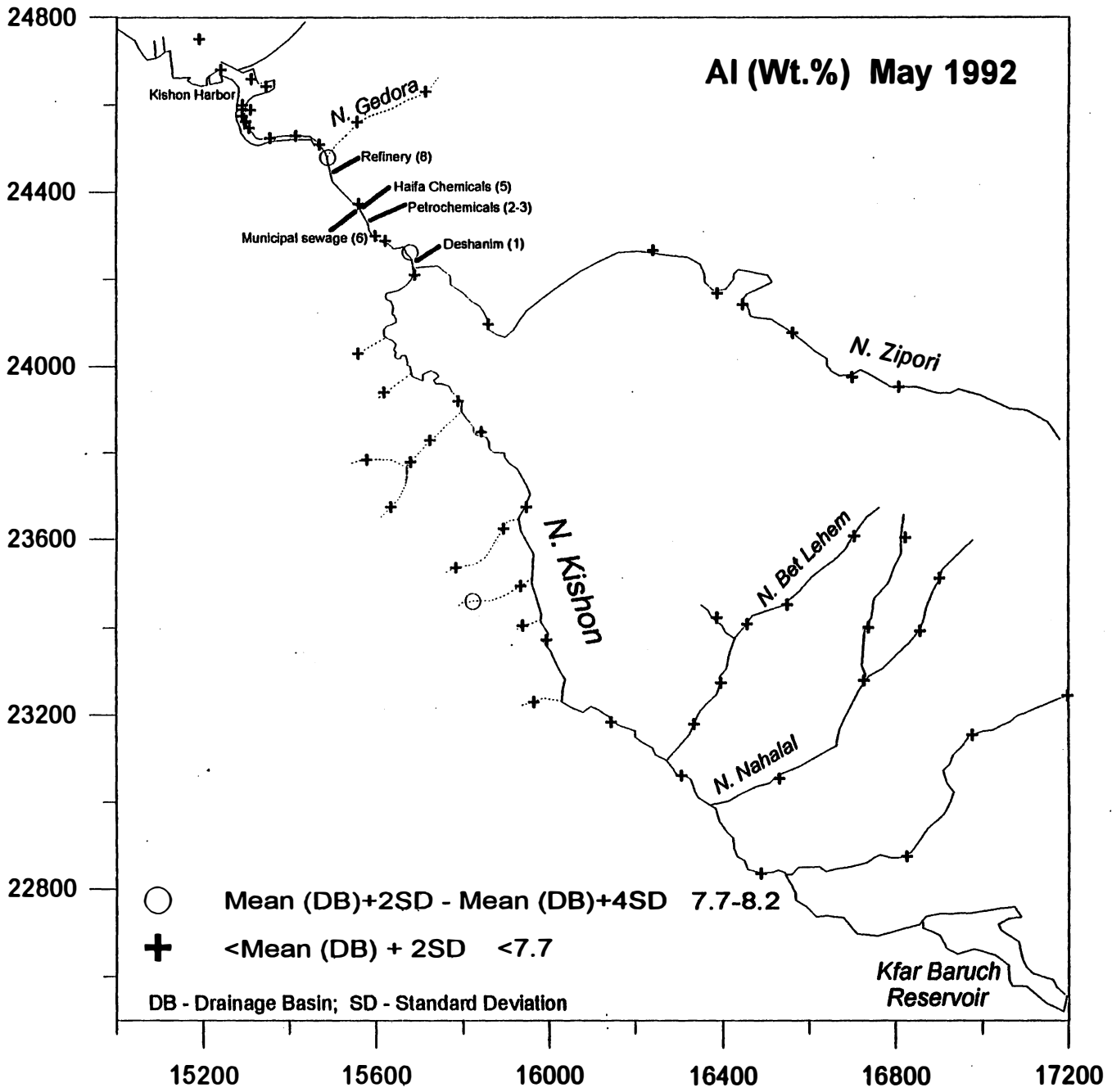


Fig. 11: Cont.

Fig. 11: Cont.

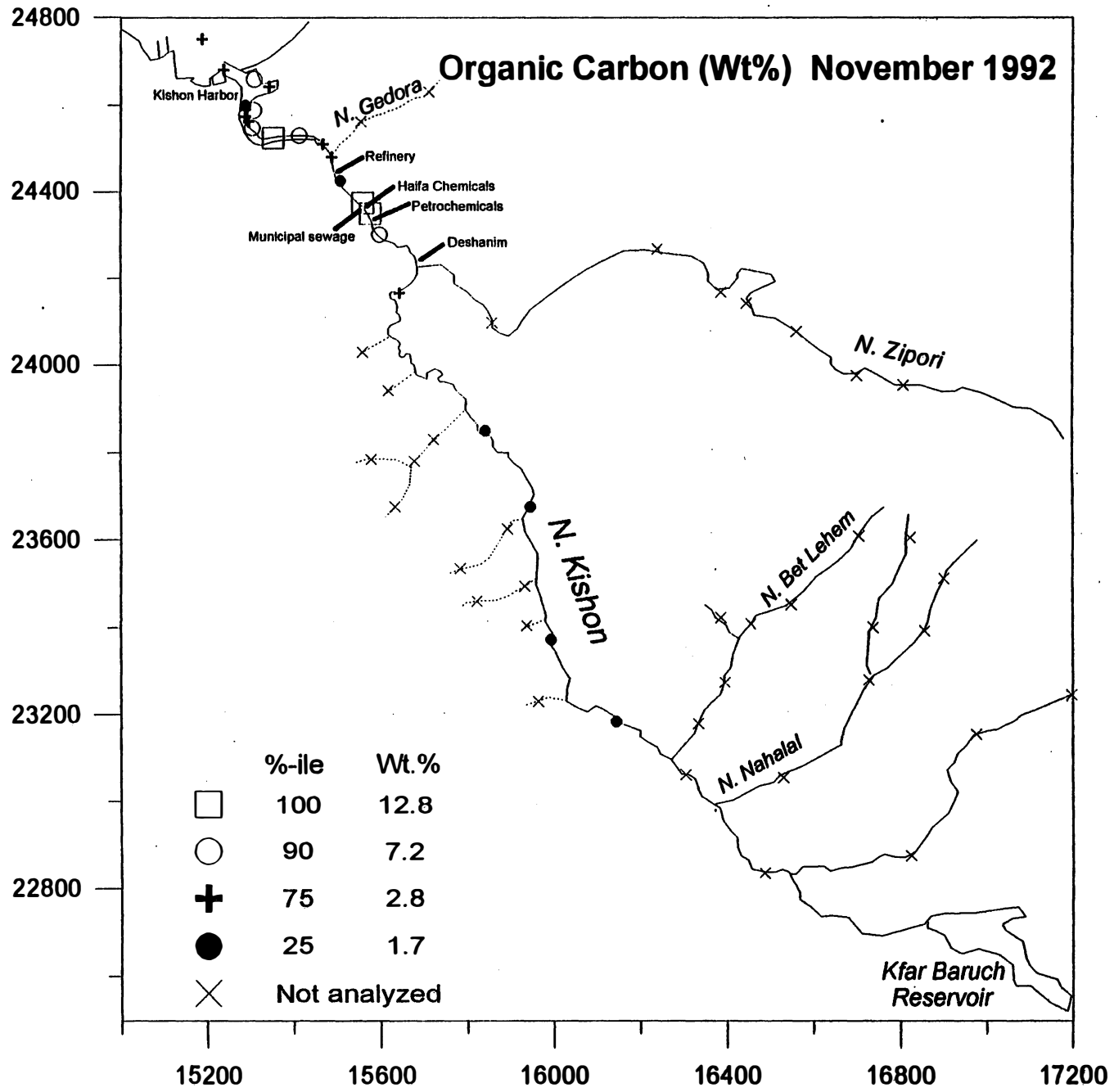
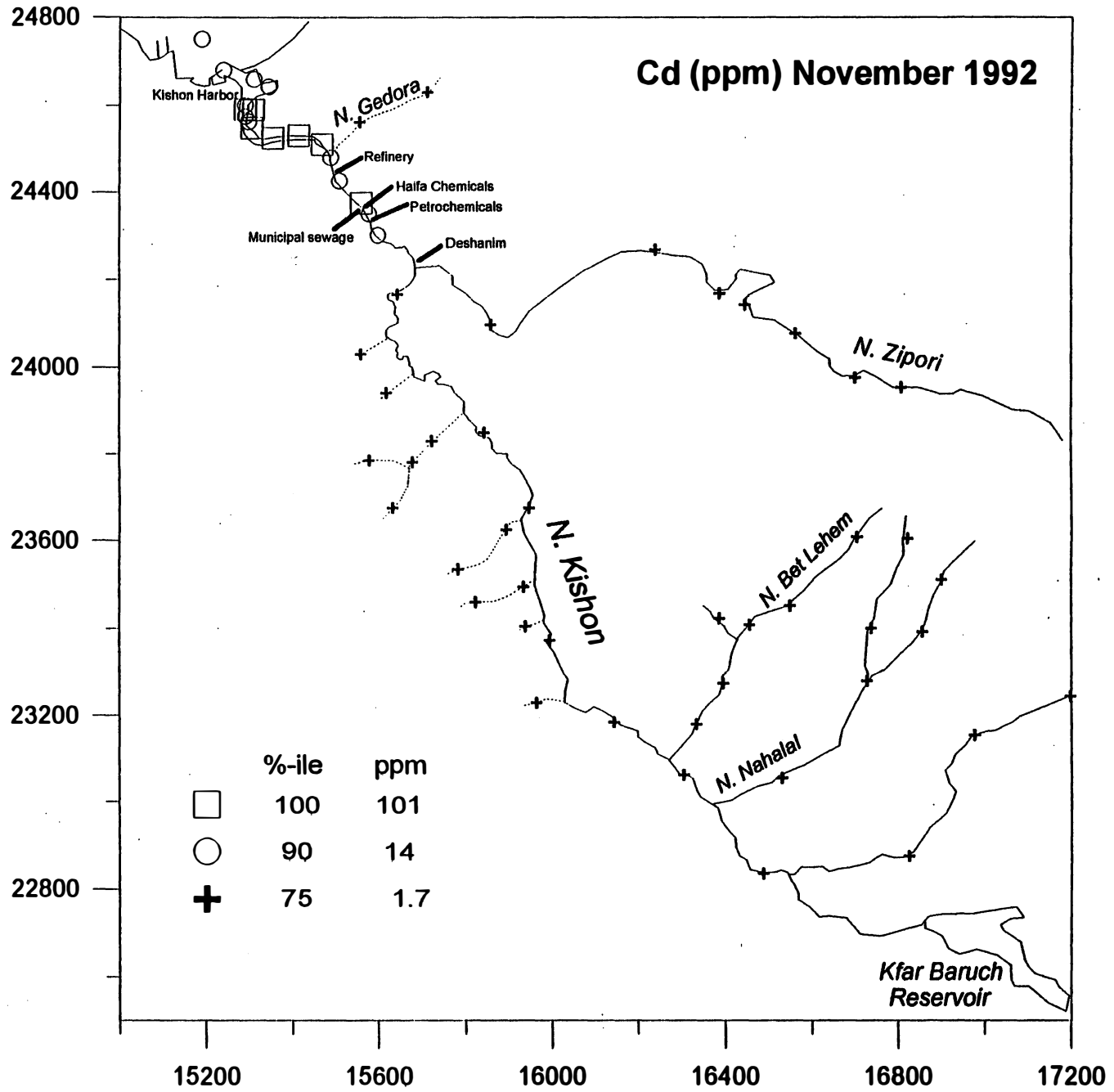


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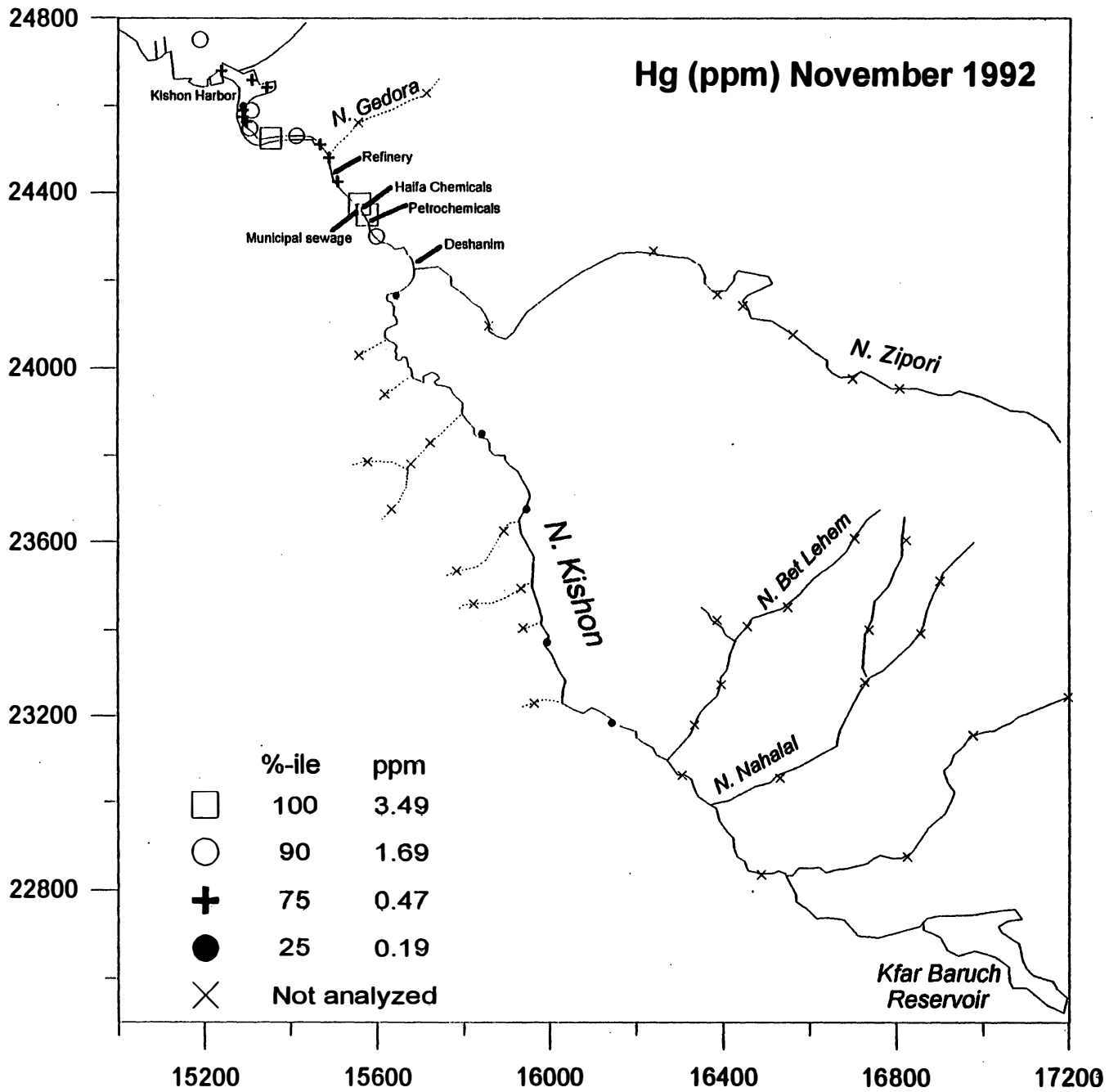
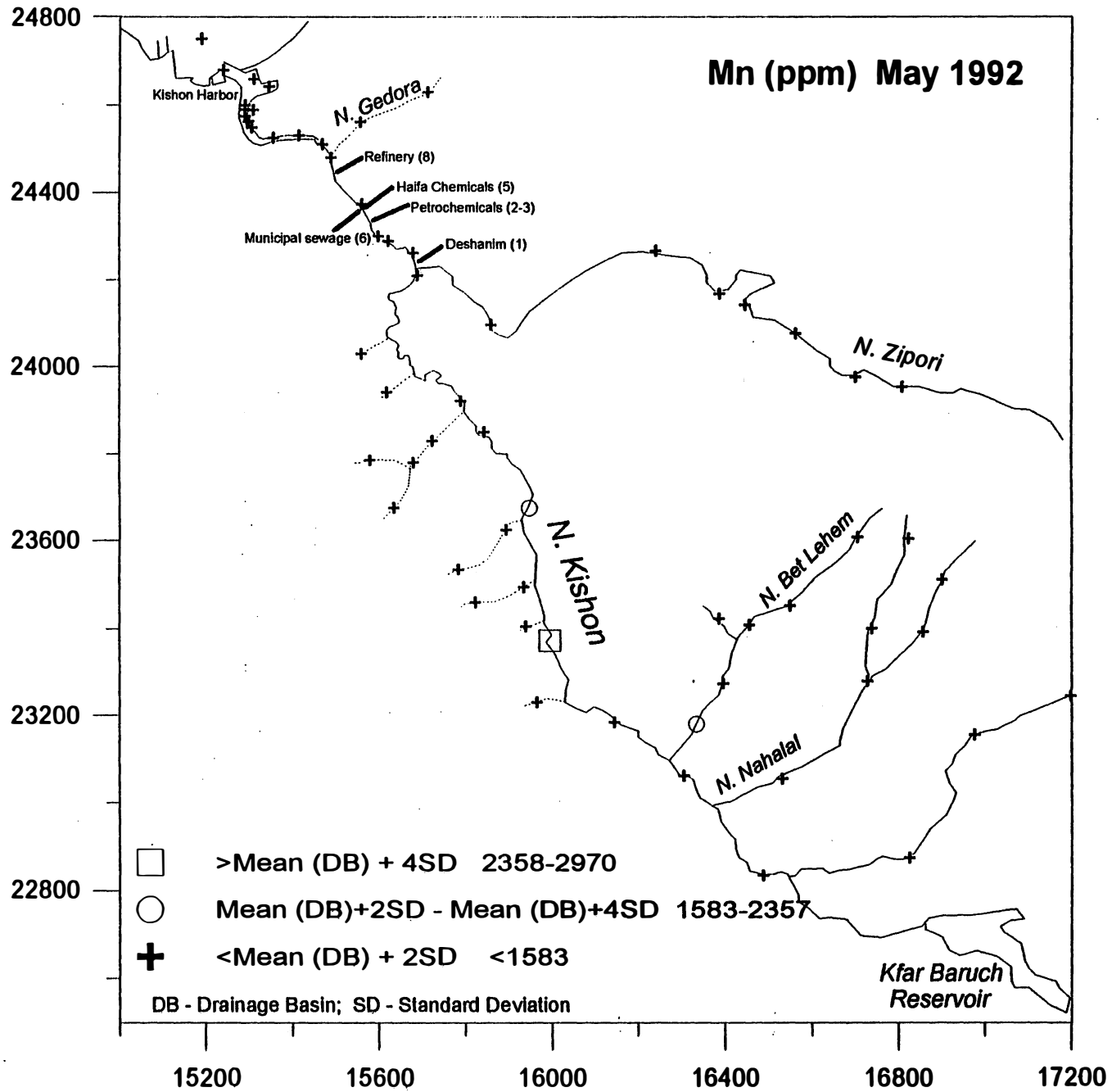


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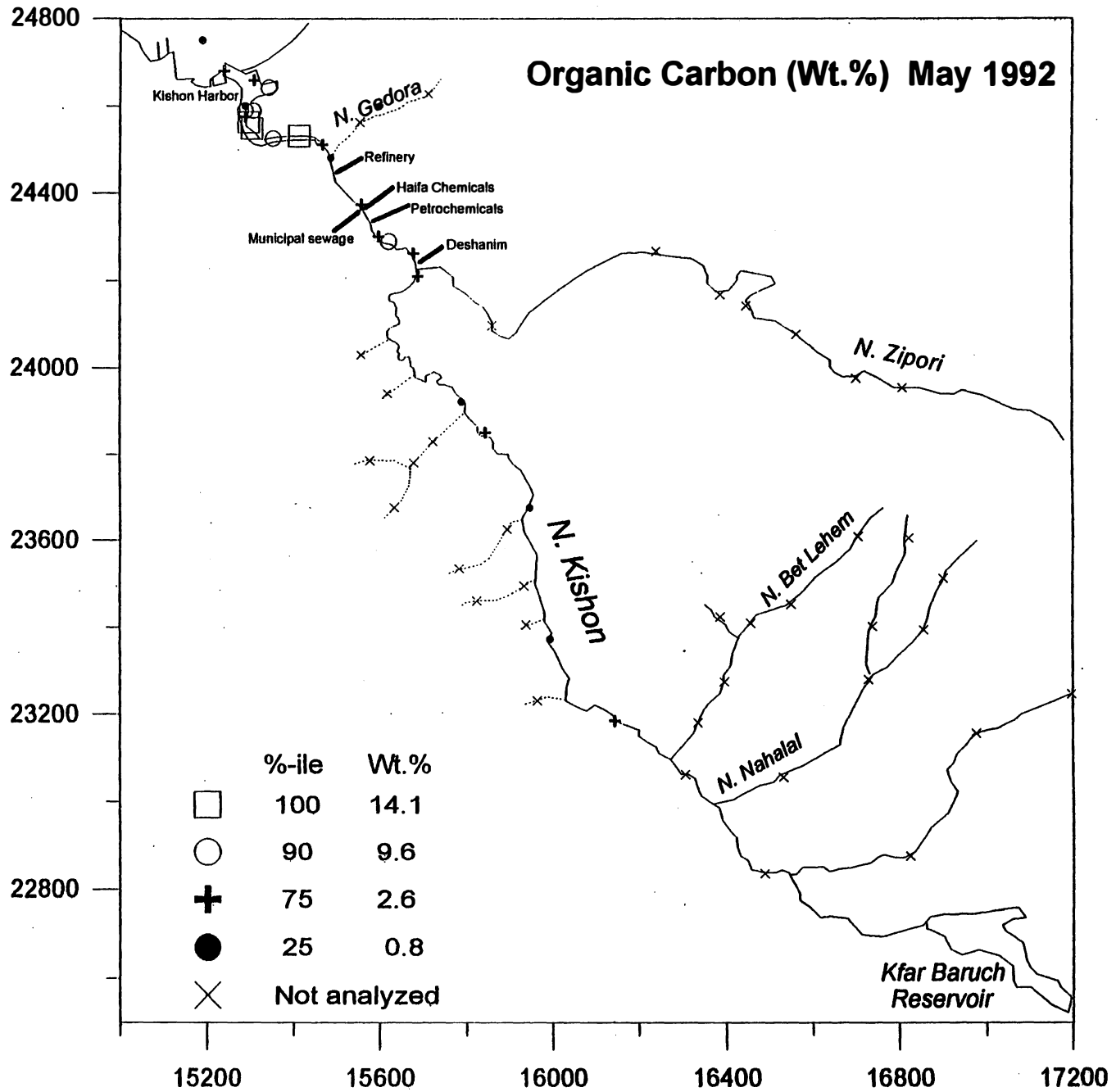


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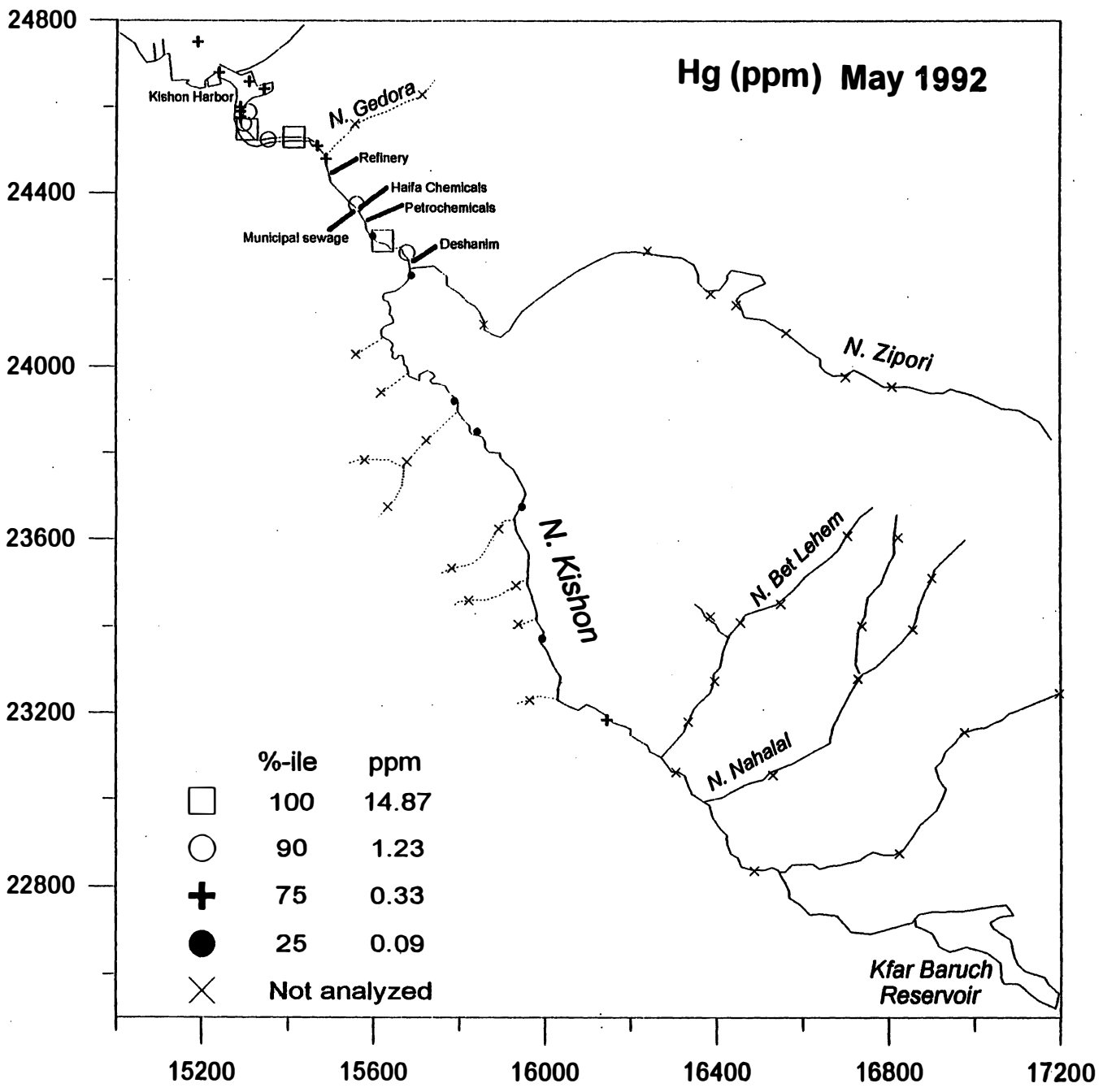


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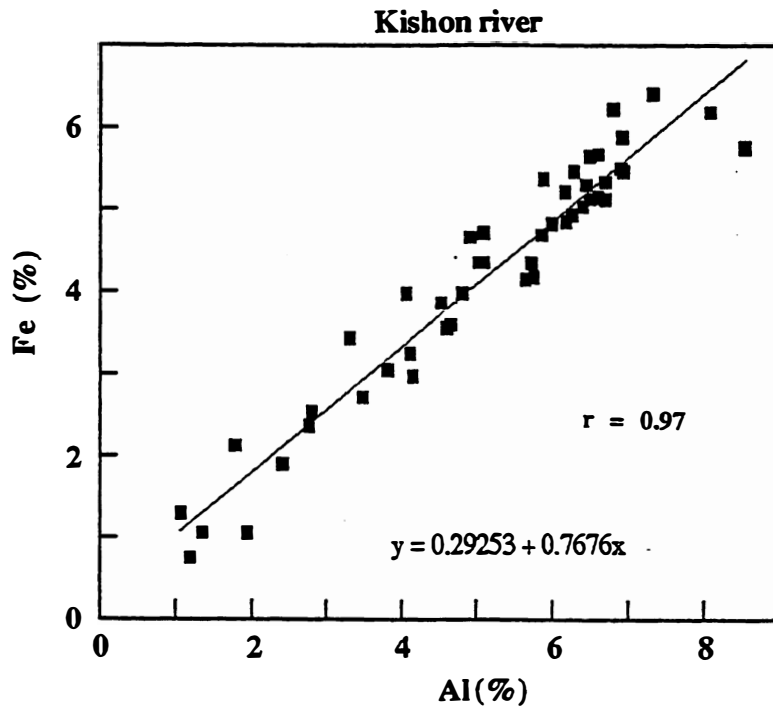
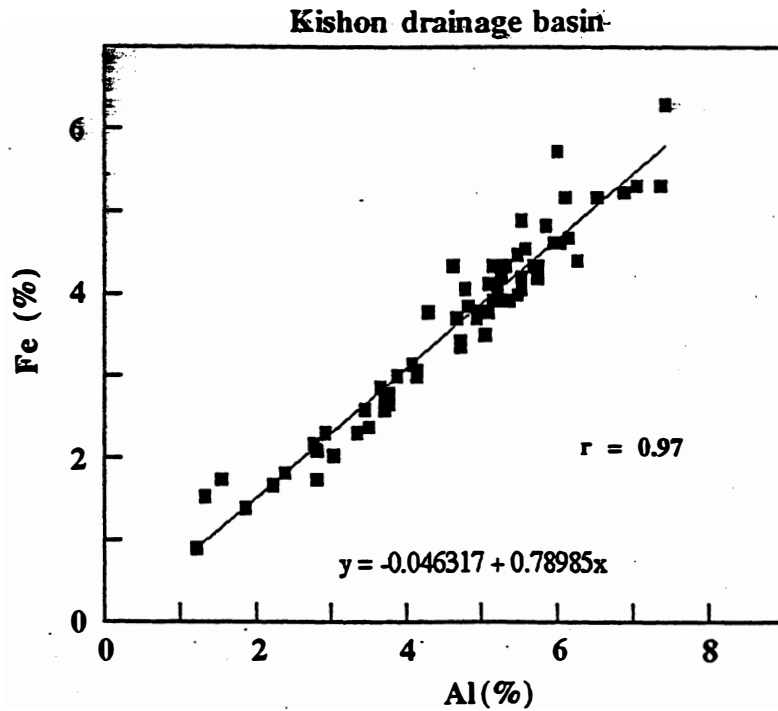


Fig. 12: Fe vs. Al in sediments from the Kishon river and the Kishon drainage basin.

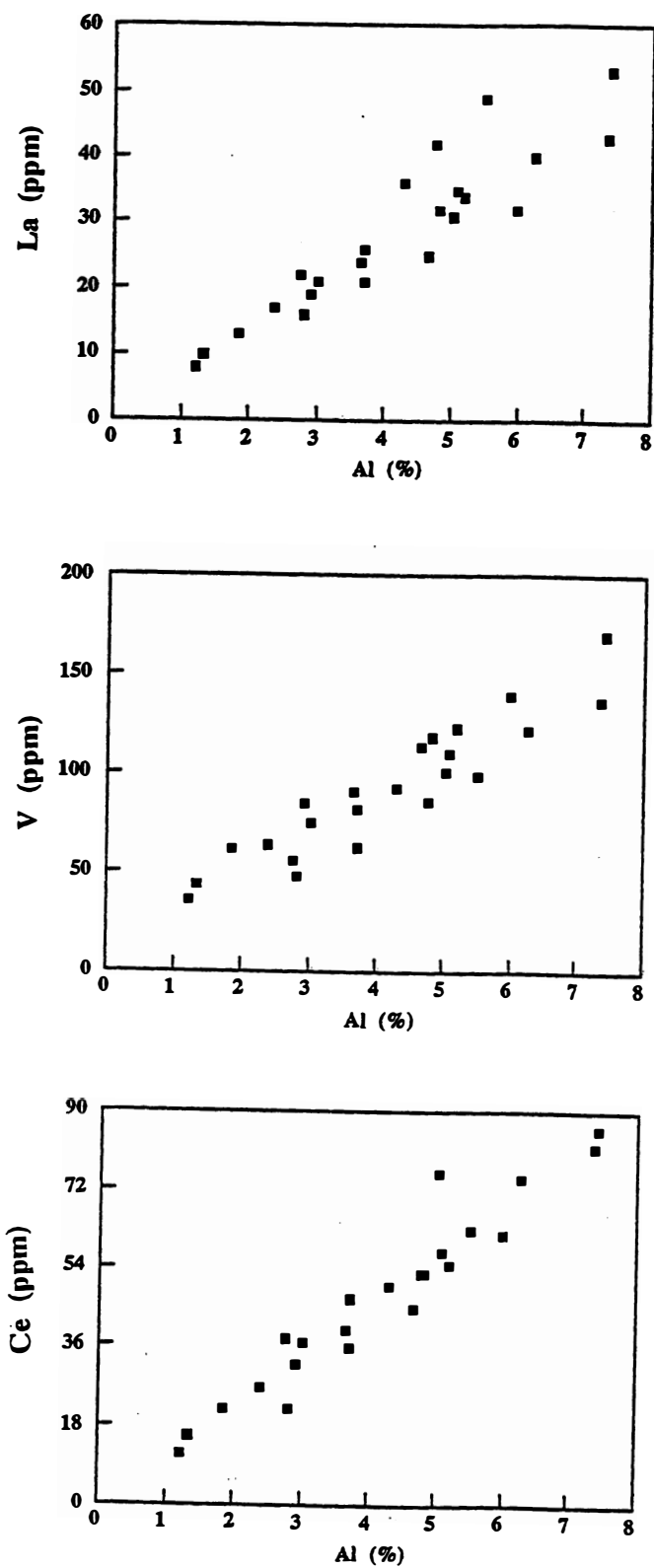


Fig. 13: Ce, V and La vs. Al in stream sediments from the Mount Carmel area of the Kishon drainage basin.

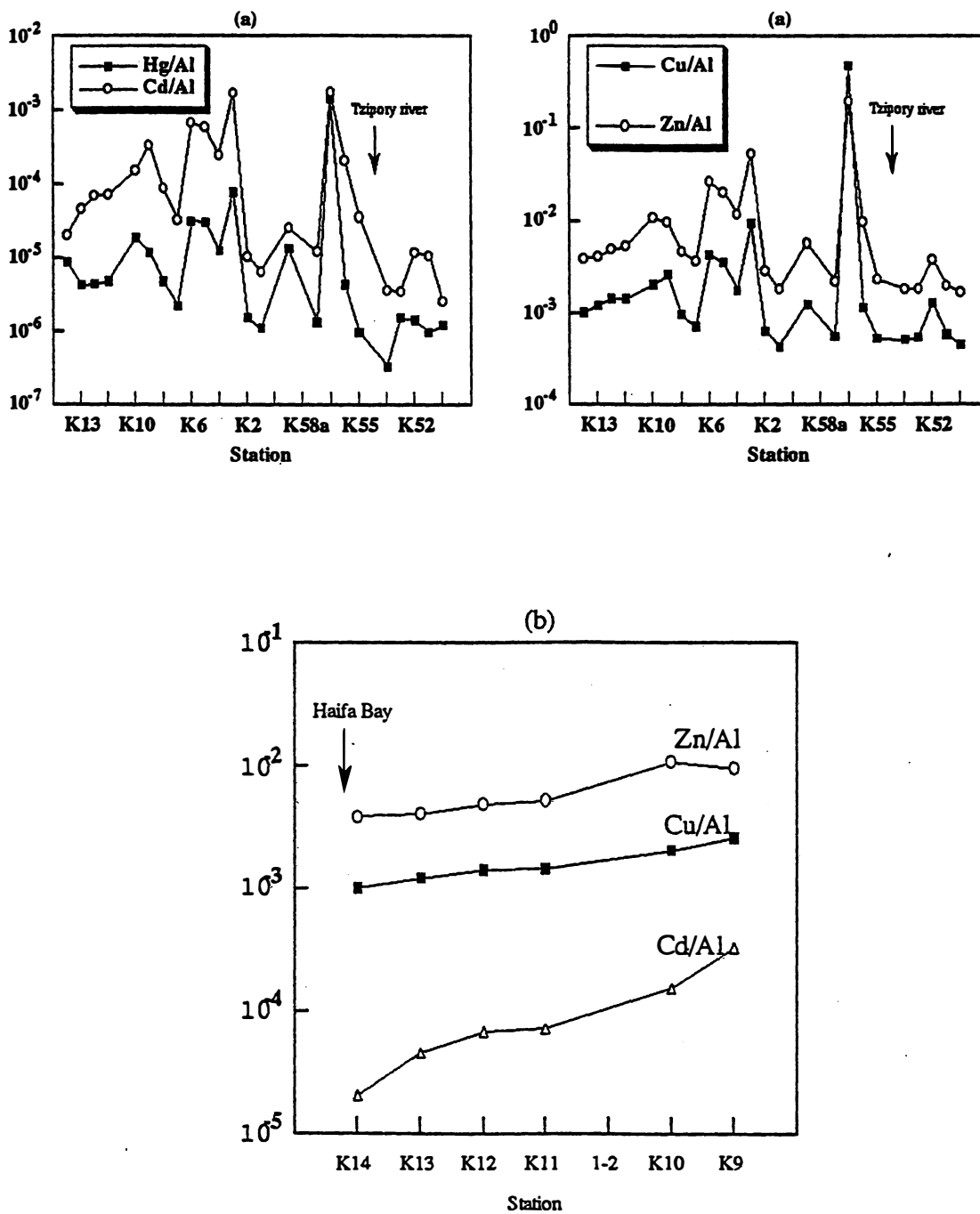
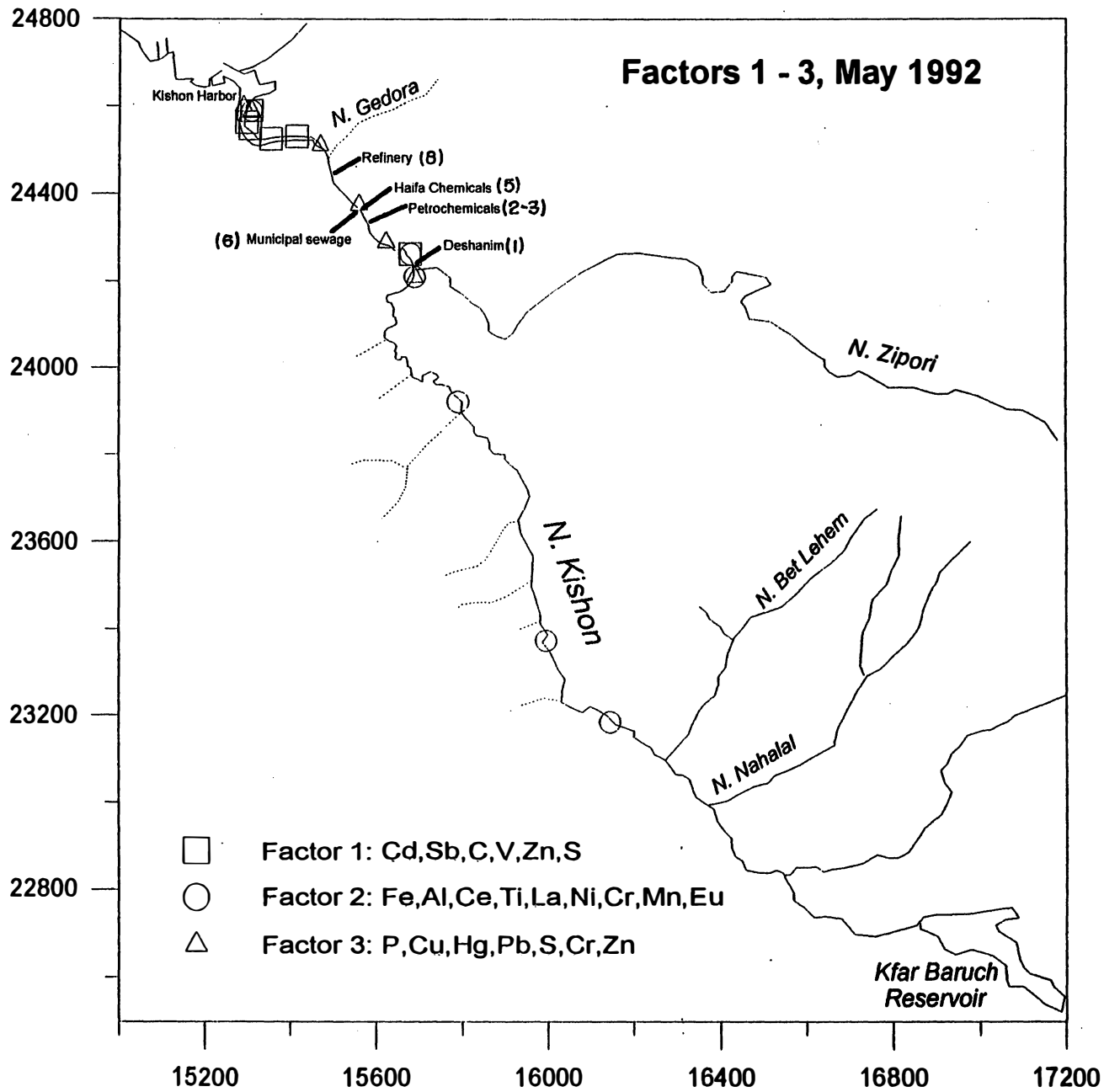


Fig. 14: Ratios of selected metals/Al. (a) along the Kishon river; (b) from the Kishon anchorage to the estuary.

Fig. 15: Single element factor scores (upper 25%) for samples of the Kishon river.



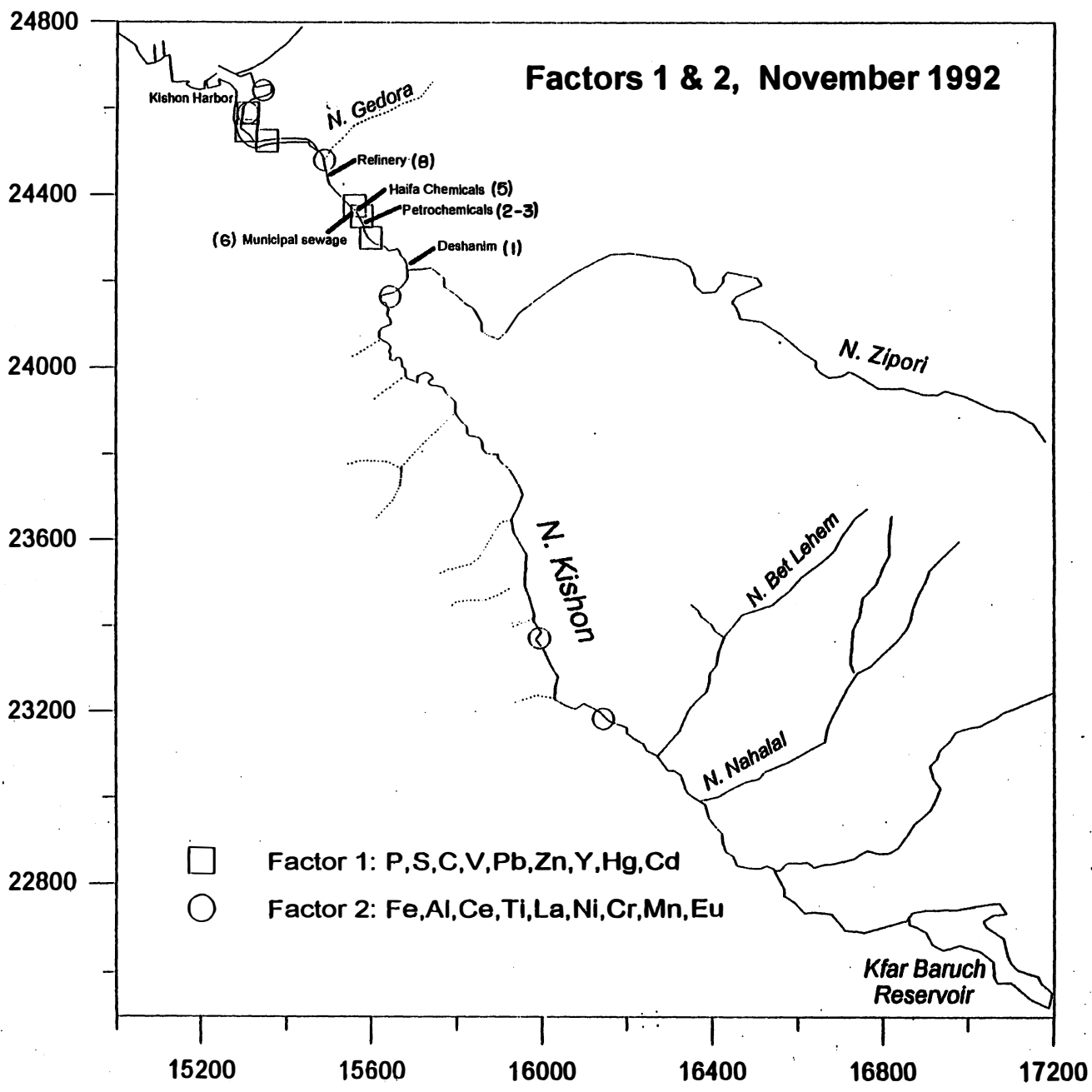


Fig. 15: Cont

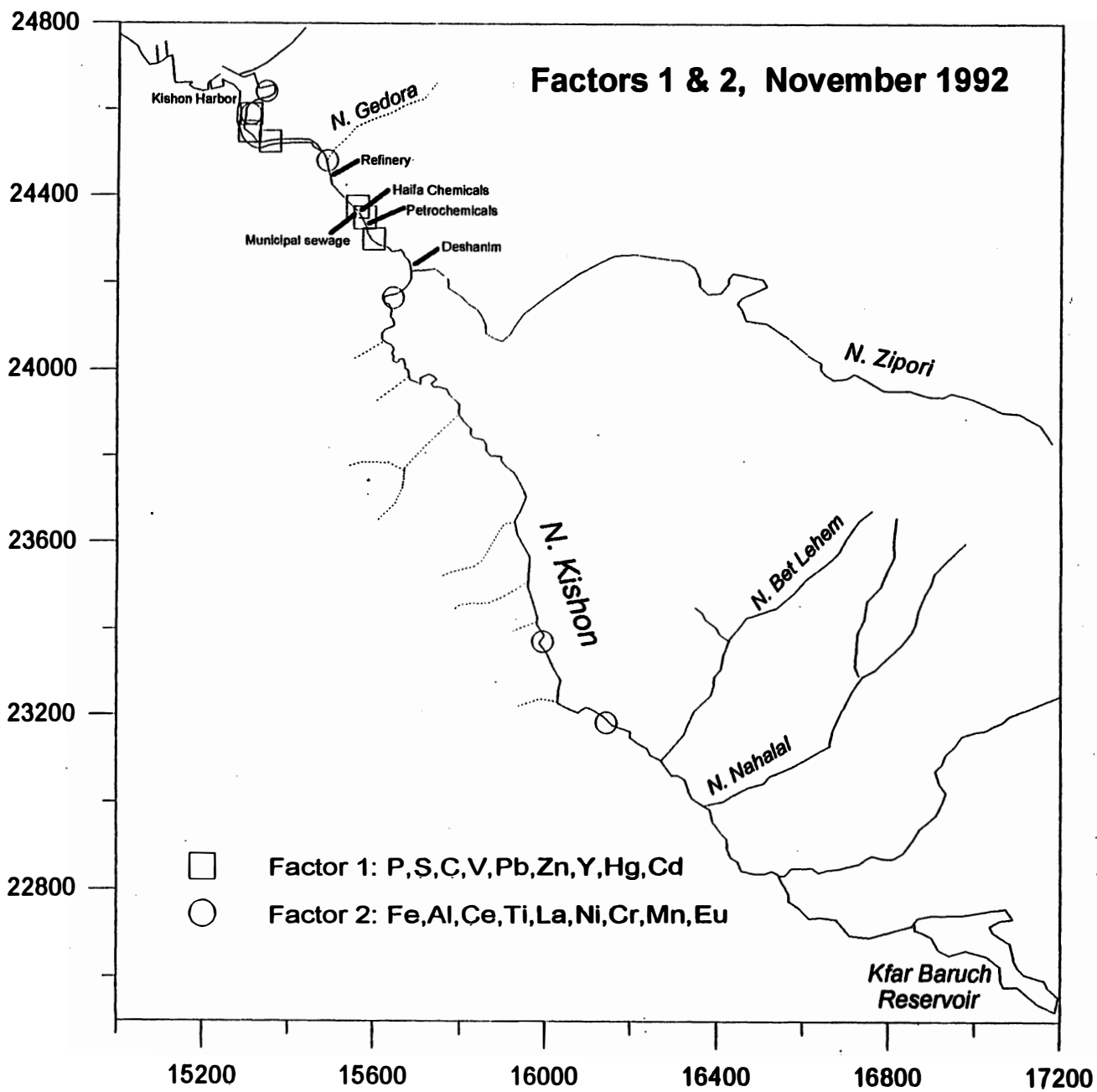


Fig. 15: Cont.

