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HEAVY METAL POLLUTION IN DRAINAGE NETWORK OF COLOMBO CITY AND SUBURBS OF SRI LANKA

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ABSTRACT

Lack of pollutant level data on aquatic ecosystems of major cities is a major setback in environmental monitoring and management of Sri Lanka. Pollutant levels in the drainage network of Colombo city and suburbs were studied as a part of the long term monitoring program. Water and sludge samples were collected from the entire drainage network of Colombo and suburbs covering three seasons with different rainfalls within a period of 18 months. Samples were collected from 33 locations and water samples were analysed for physical properties (pH, EC), anions (nitrate, sulphate and phosphate) and heavy metals (Cd, Cr, Pb) while sludge samples were analysed for Cd, Cr and Pb.

The results show that water in the drainage system is acidic to neutral and at most of the locations nitrate, sulphate and phosphate values exceed the Sri Lanka portable water standard levels. In contrast to nitrate levels, phosphate levels decrease with increasing rainfall. Major source of nitrate can be household wastes. In many locations Pb, Cd and Cr levels are also higher than the above portable and effluent standard levels. Similar to nitrate levels, Pb levels also increase with increasing rainfall and may be originated from unleaded fuel used during past few decades. Sludge also contains very high content of Pb, Cr and Cd particularly in downstream locations of streams. A detailed study to identify the point sources and pollutant dispersion pattern will be an added advantage in formulating an appropriate mechanism to prevent pollution.

INTRODUCTION

Long term environmental monitoring programs are essential for the present day environmental management projects of major cities. Identifying base levels of pollutants in the drainage systems of cities is vital in this respect and is commonly practiced throughout the world. For Sri Lanka long term monitoring of pollutant levels in urban drainage systems is still a new practice. However various water quality parameters such as BOD, COD, DO and anions such as nitrate, phosphate have been occasionally measured by various scientists and institutes in selected drainage systems particularly in Beira Lake, Lunawa Lagoon Hamilton Canal etc. (Dassanayake et al., 1997, Dassanayaka, 1993). Some studies have focused on heavy metal pollution of these waterways (De Silva et al., 1997).

However no detailed water quality surveys in the entire channel network of Colombo have been carried out covering different climatic seasons. This study aims at monitoring the variation of pollutant levels of the drainage network in Colombo city and its suburbs. Colombo. Colombo is the commercial capital city of Sri Lanka and is densely populated (377,396 population in 2001) and many industries as well as commercial institutes (95311 building units by 2001) are located within the city and its suburbs. Recently declared administrative capital city, Sri Jayawardhanapura Kotte, located adjacent to the Colombo, does not bear such a large population (115826 population in 2001) except for several administrative institutes.

Drainage network

Drainage network of Colombo and its suburb area is mainly fed by two main water bodies. Kolonnawa Ela and Diyawanna Oya streams originate from Diyawanna lake while Attidiya canal originates from the Boralasgamuwa tank (Fig. 1). There are several artificial canals constructed under land reclamation projects interconnecting major streams. Water in the entire drainage network is either slowly flowing or stagnant. Low gradient of the drainage system and blocking the estuaries by sand accumulation prevent continuous water flow within them.

Rainfall

Annual rainfall of the area is greatly influenced by the south-western monsoonal and inter-monsoonal rains. During May-September, the area gets rain from southwest monsoonal winds. During November-December period it also gets considerable amount of rainfall from thunderstorms and hurricanes and inter-monsoonal rains brings rain during March-May and August-October.

Methodology

Thirty three sampling locations were selected representing the entire drainage network. Distance between sampling locations, joining of sub streams to the main were considered in selecting sampling locations (Fig. 1). Repeated sampling was done in three phases representing different climatic seasons during the period March 2004-August 2005 (Table 1). Water samples collected from the middle and edges of the streams were later mixed and bulked together to provide a composite sample. Two samples were collected in to polyethylene bottles in which one sample was preserved with three drops of conc. nitric acid to use for heavy metal analysis. The unacidified portion was used to analyze pH, conductivity, nitrate, sulphate and phosphate.

Table 1: Sampling seasons and total rainfall during the study period

Phase	Sampling period	Total rainfall/mm
1	Mar-June 2004	452.7
2	Feb-Mar 2005	1.4
3	Aug-05	214.2

A steel auger was used to collect sludge samples. Several sludge samples were collected from different points of the channel profile and were bulked together to make composite samples and stored in polyethylene bags.

Chemical analysis

pH and electrical conductivity were measured immediately after the sampling using Jenway 3015 pH meter and Orion 160 EC meter in the laboratory. Samples were filtered through No. 42 filter paper before other chemical analysis was preformed.

Sulphate concentration was determined turbidimetrically by using $BaCl_2$ method and the total nitrate concentration was determined using a spectrophotometric method. Total phosphate concentration was determined colorimetrically by adding ammonium. Water samples were heated with conc. HNO_3 and the filtered samples were analysed for Pb, Cd, Cr using Graphite furnace Atomic Absorption Spectrophotometer (GBC 933AA). Elements bound to suspended colloidal and silt fractions can be extracted by acid treatment, hence the total element concentration in the sample can be determined.

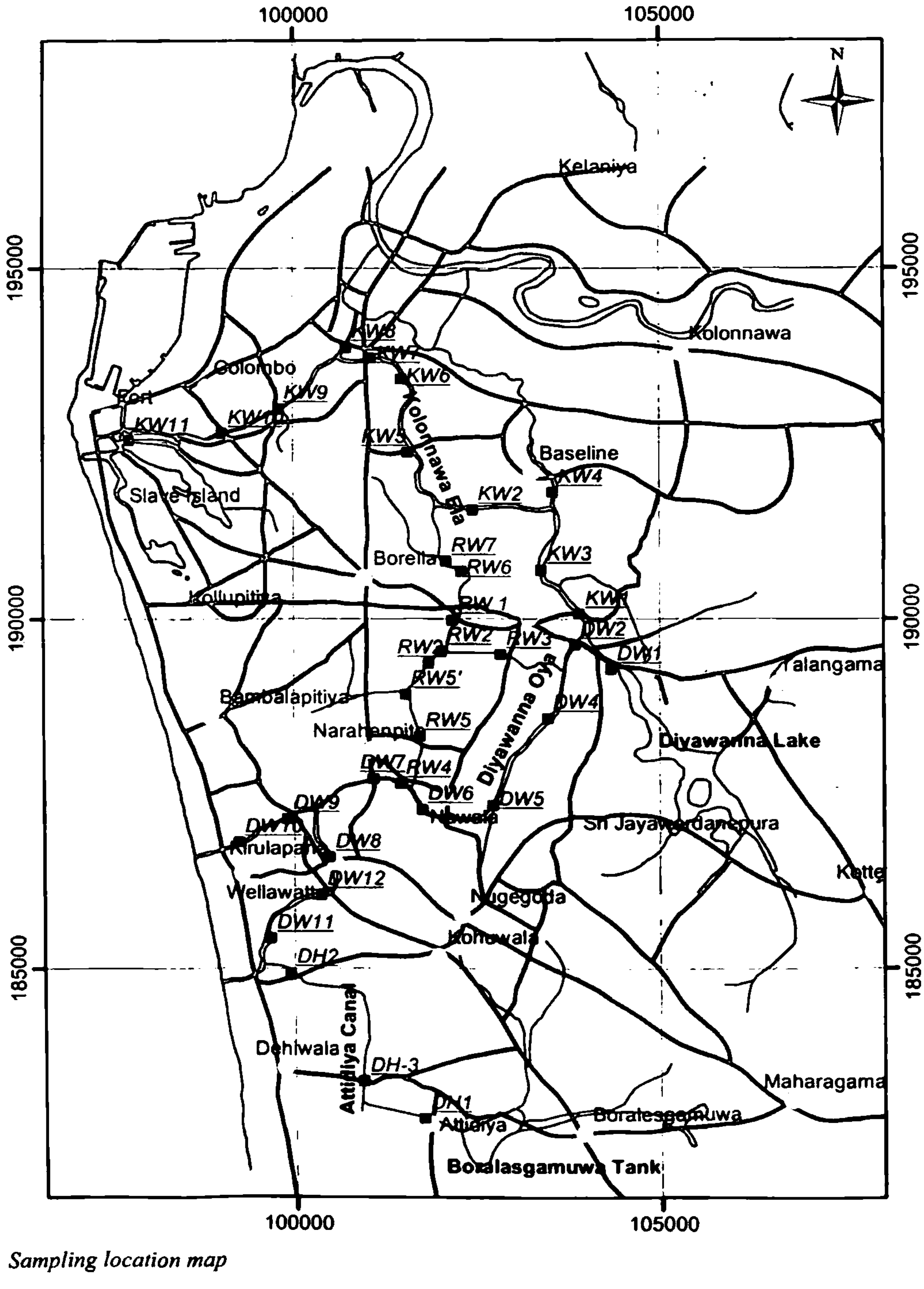

Fig: 1. Sampling location map

Collected sludge samples were pre-concentrated by wet sieving method. Then the samples were shaken overnight at room temperature with 0.5N hydrochloric acid to extract the weakly bonded metal fraction which believed to be of anthropogenic origin (Agemian and Chau, 1976). Filtrates were used for the analysis of toxic heavy metals (Pb, Cr, and Cd) using Atomic Absorption Spectrophotometry (GBC 933AA).

Results

Physical properties

pH value of the water in the entire drainage system is varying between 5.8-7.8. During first two seasons water in the system is slightly acidic to neutral (pH 5.8-7.0) (Table 2). But during the last sampling season, water in some areas became slightly basic (pH 7-7.8). Conductivity of the water varies in a wide range (186 – 25000 μScm^{-1}). Down stream locations close to the sea indicated higher EC values (>1000μscm^{-1}) (Table 2).

Table 2: *Physical properties, anion and heavy metal concentrations of water samples and standard levels (LD-less then the detection limit).*

	Phase	Min	Max	Ave	World avergae[1] in stream water	SL effluent[2] standards	SL portable water[3] standards
	1	5.9	7.0	6.6			
pH	2	6.2	7.4	6.6	-	6.0-8.5	6.5-9.0
	3	5.8	7.8	6.8			
	1	296	7460	801			
EC(μS/cm)	2	189	5740	995	-	-	3500
	3	186	25000	1909			
	1	4.3	55	16			
NO_3 (ppm)	2	2.5	11	6	50	-	10
	3	4.0	33	10			
	1	12.0	1125	64			
SO_4 (ppm)	2	7.4	413	48	500	-	400
	3	3.7	1000	85			
	1	1.0	6	3			
PO_4 (ppm)	2	0.8	12	4	-	-	2
	3	0.03	10	2			
	1	2	9	3			
Cd (ppb)	2	1	43	4	0.08	100	5
	3	0.14	15	3			
	1	10	189	49			
Cr (ppb)	2	3	317	41	0.70	100	50
	3	LD	19	4			
	1	12	585	99			
Pb (ppb)	2	2	174	15	0.079	100	50
	3	0.4	94	19			

[1] *Gaillarder et al. (2004)*
[2] *General Standards for discharge of effluent in to inland surface waters - National Environmental (Prtotection & Quality) regulations No 1 of 1990*
[3] *Sri Lanka Standards 614:1983 Maximum permissible level (SLSI, 1983)*

Anions

Nitrate in water varies from 4.3 -54.5 ppm (1st Phase), 2.5-10.8 ppm (2nd Phase), and 4.0-33.1 ppm (3rd Phase). There is an increase in nitrate levels at some locations during the first sampling phase. Narahenpita and Rajagiriya areas (RW5, RW5', RW7, KW2, KW1) showed a significantly high nitrate content (Fig. 2). A remarkable contrast in mean values of Nitrate between first (16.4 ppm) and second (5.6 ppm) phase was noted. Correlation coefficients between nitrate level and rain fall at many locations are over +0.8. This strong positive correlation indicates an increase in nitrate levels with increasing rainfall. Anthropogenic pollutants, especially household waste, mixing with runoff water may contribute to increasing nitrate levels during rainy periods. This phenomenon is prominent in both Kolonnawa canal and Rajagiriya canal except at a few locations. During rainy periods nitrate levels of most of the locations exceed the maximum permissible level of nitrate for portable water in Sri Lanka (SLSI, 1983).

Sulphate levels in water range from 12-96.4 ppm (1st Phase), 7- 413 ppm (2nd Phase), and 4-1000 ppm (3rd Phase) (Table 2). During the first phase, 1125 ppm sulphate value was obtained at the intercept of the Kolonnawa canal and Beira lake (KW11). Sulphate levels at Wellawatta and Narahenpita areas (DW9, DW7) are much higher particularly during the 3rd Phase (Fig. 3). These values are well above the maximum potable water standard levels of Sri Lanka (400 ppm).

Phosphate concentrations were 1.0 - 6.1 ppm (1st Phase), 0.8 -11.5 ppm (2nd Phase), 0-9.8 ppm (3rd Phase) in water samples (Table 2). A general increase of phosphate levels can be observed (mean value 4.1 ppm) during the 2nd phase of sampling. This is probably due to low rainfall which concentrated the phosphate. It indicates that in contrast to the nitrates, phosphate mixes with canal water from point sources rather than runoff water. At Orugodawatta and Dehiwala (KW7, KW8, KW9 and DW12) areas high phosphate values can be observed during the 2nd phase (Fig. 4). At most of the locations phosphate values exceed the maximum permissible level in Sri Lanka (2 ppm).

Heavy metals

Cd concentration in water changes from 2-9 ppb (1st phase), 1-43 ppb (2nd phase), <1-15 ppb (3rd phase). Almost at all locations Cd levels are several times higher than the world average level of 0.8 ppb in stream water (Gaillardet et al., 2004). High Cd levels were recorded from Wellawatta and Dehiwala areas (Fig. 5). These levels are higher than the maximum permissible levels for portable water in Sri Lanka (5 ppb) but lower than standard level of 100 ppb described for effluents. Industrial sources such as metal plating workshops may contribute Cd in to the drainage network that increasing the levels at isolated locations (Fig. 5). A previous study by De Silva and Goonasekere (1997) has recorded 0.2-28.4 ppb Cd level in Beira lake to which Kolonnawa Canal joins (DW11, DW12).

Cr levels in the drainage system were 10-189 ppb (1st phase), 3-317 ppb (2nd phase), and <1-19 ppb (3rd phase) (Fig. 6). These values are far higher than the world average Cr content of 0.7 ppb in stream water. An increase of Cr level downstream can be observed at both Diyawanna Oya and Kolonnawa canal during the first phase. During the second phase high concentrations (over 50 ppb) were recorded from several locations in Diyawanna Oya around Nawala, Pitakotte and Kirulapana areas (DW4, DW5). Point discharge sources and slow flow rates at different locations may account for this sharp local increase of values. A significant decrease in mean Cr levels during the 3rd phase was recorded. A 12.5-92 ppb Cr level has been recorded from Beira lake in 1996 (De Silva and Goonasekere 1997).

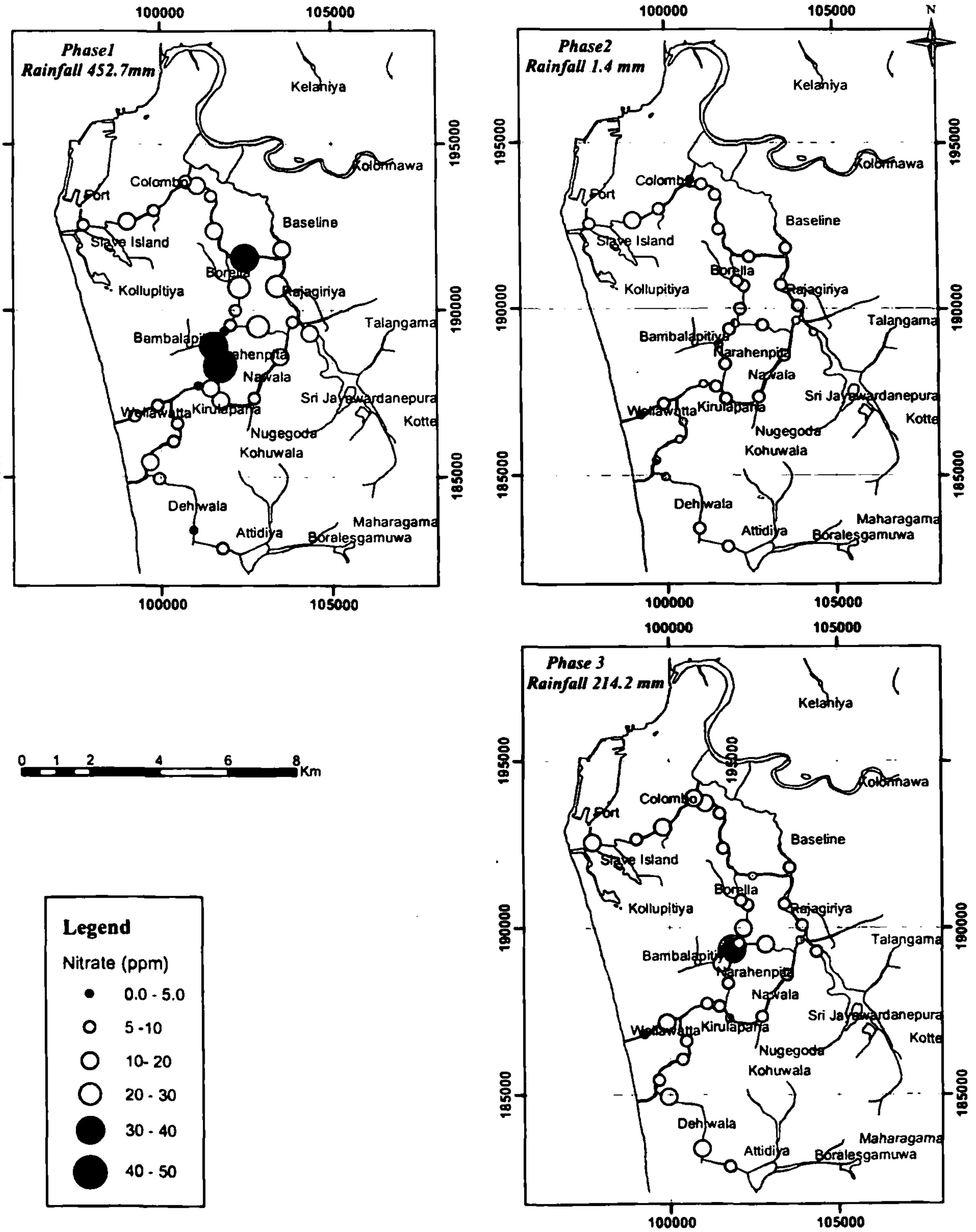

Fig: 2. Nitrate concentrations of water in the drainage network during different climatic seasons in the drainage network in different climatic seasons

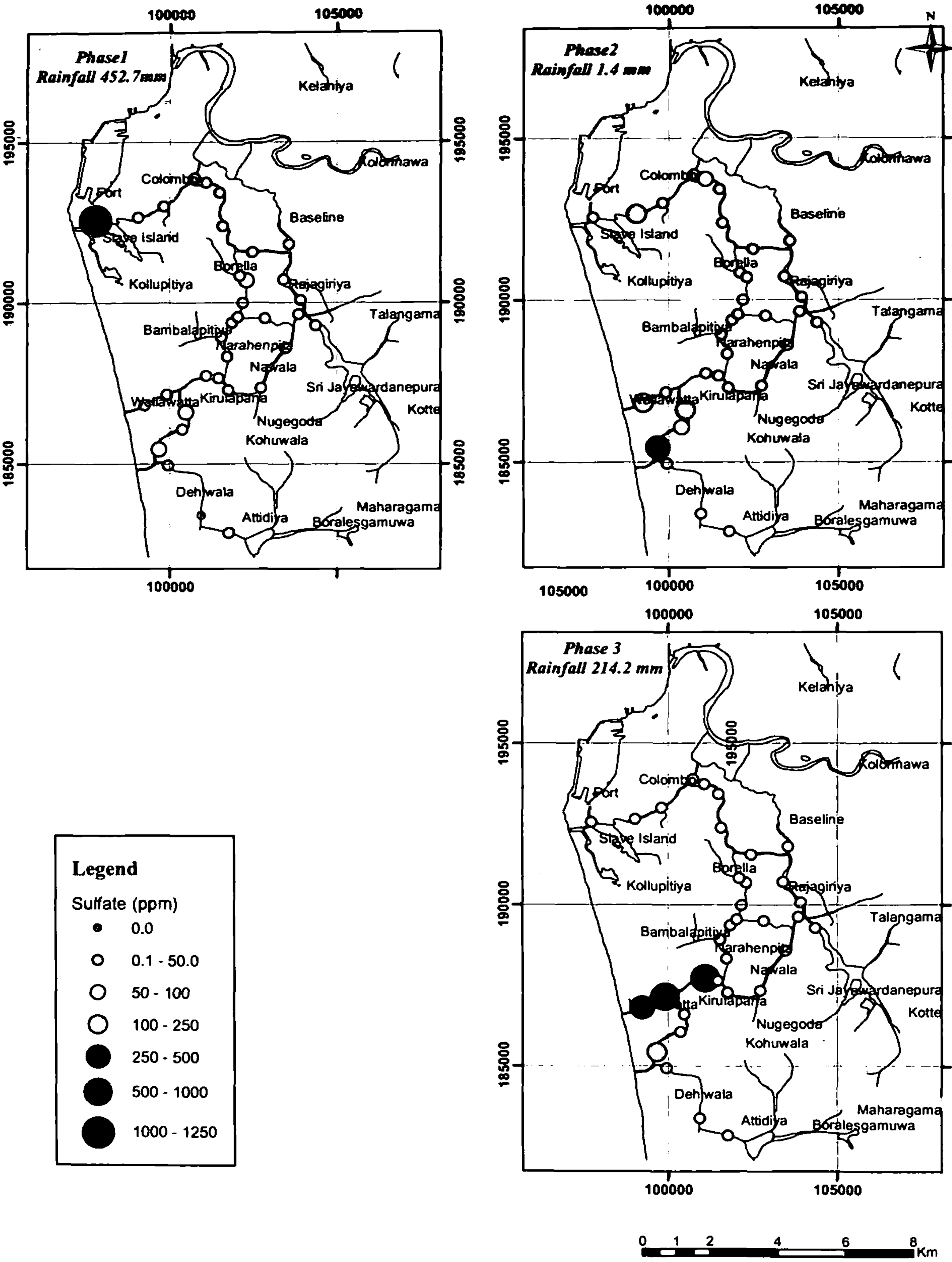

Fig: 3. Sulphate concentrations of water in the drainage network during different climatic seasons

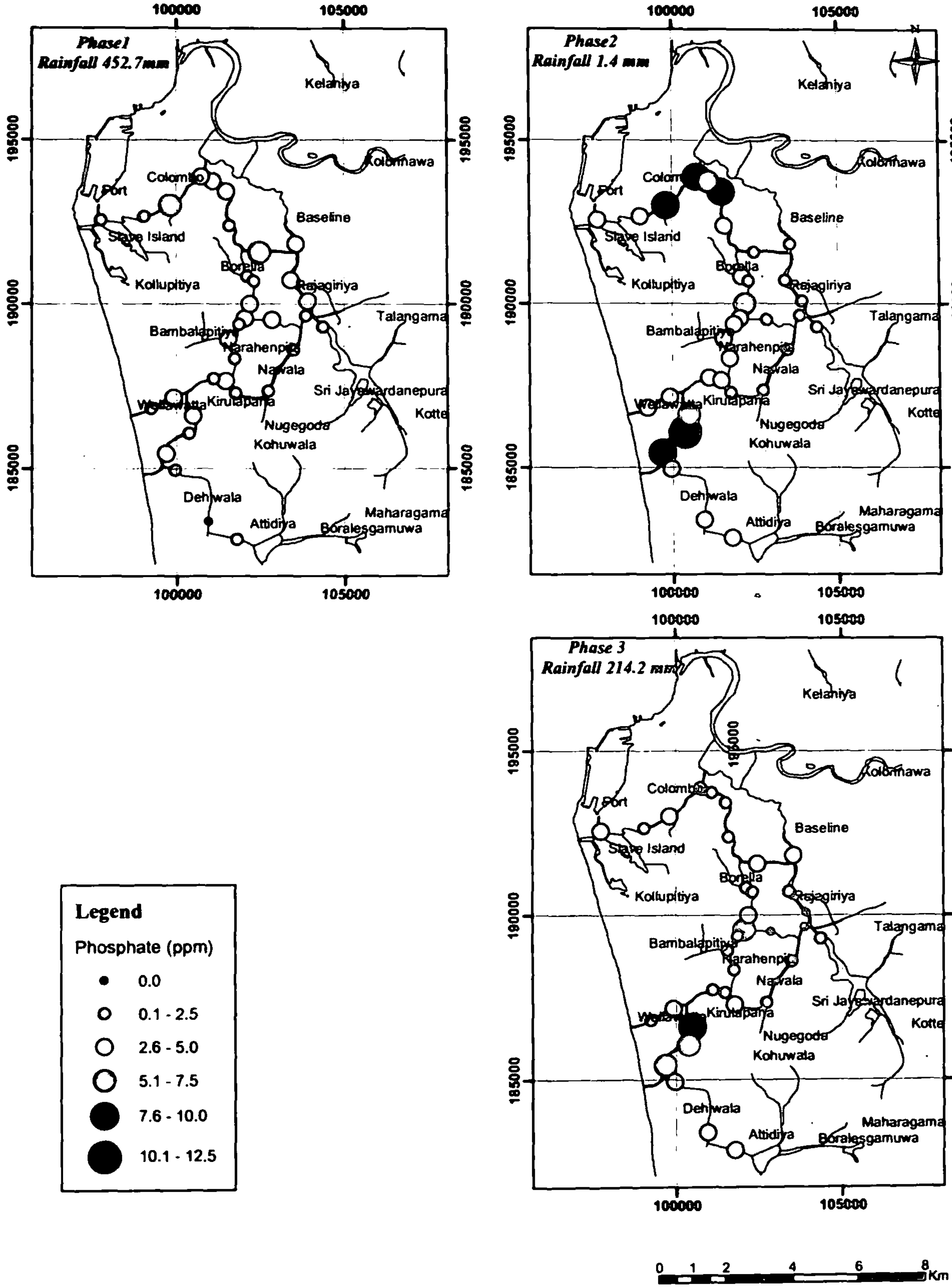

Fig: 4. Phosphate concentrations of water in the drainage network during different climatic seasons

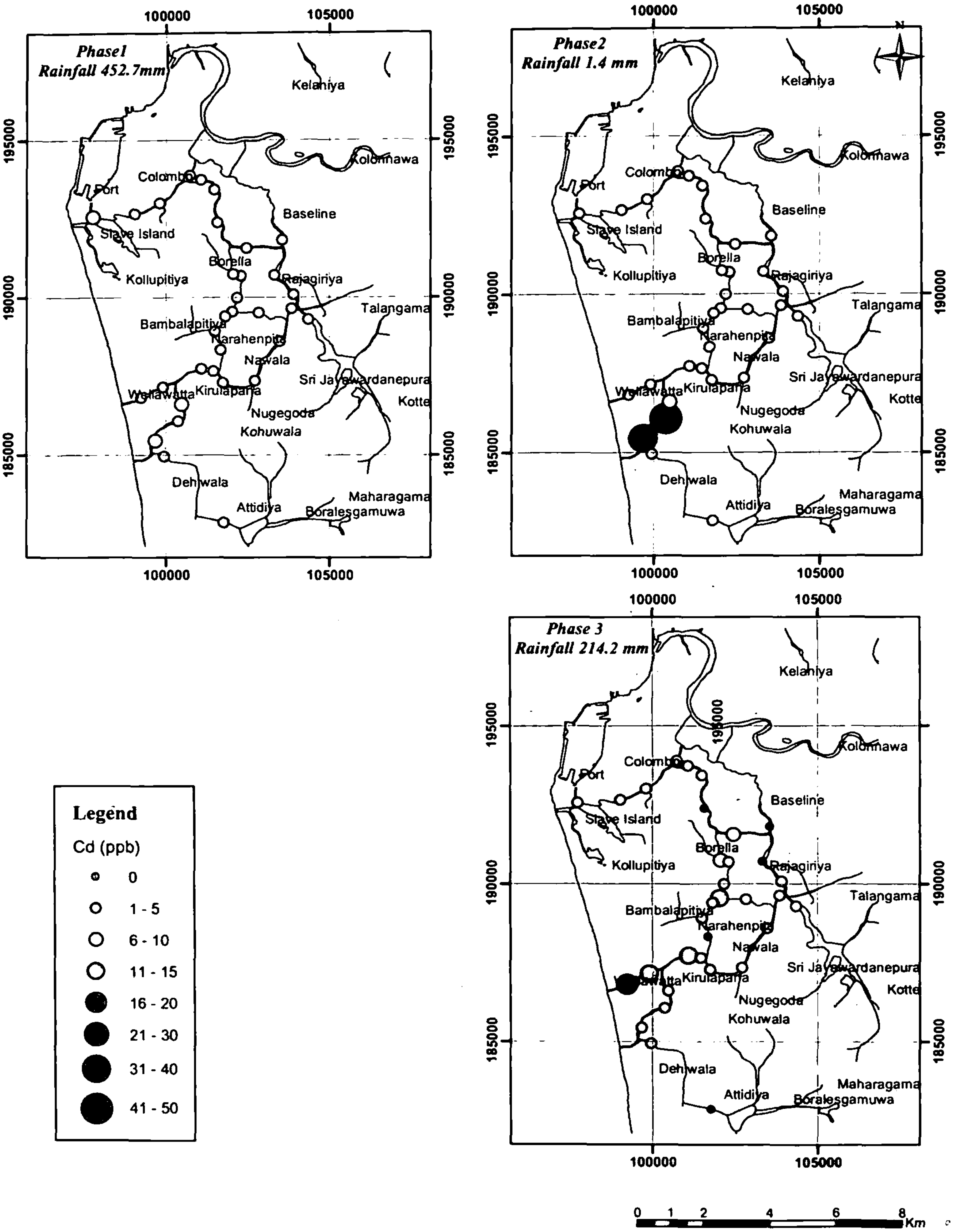

Fig: 5. Cd concentrations of water in the drainage network during different climatic seasons

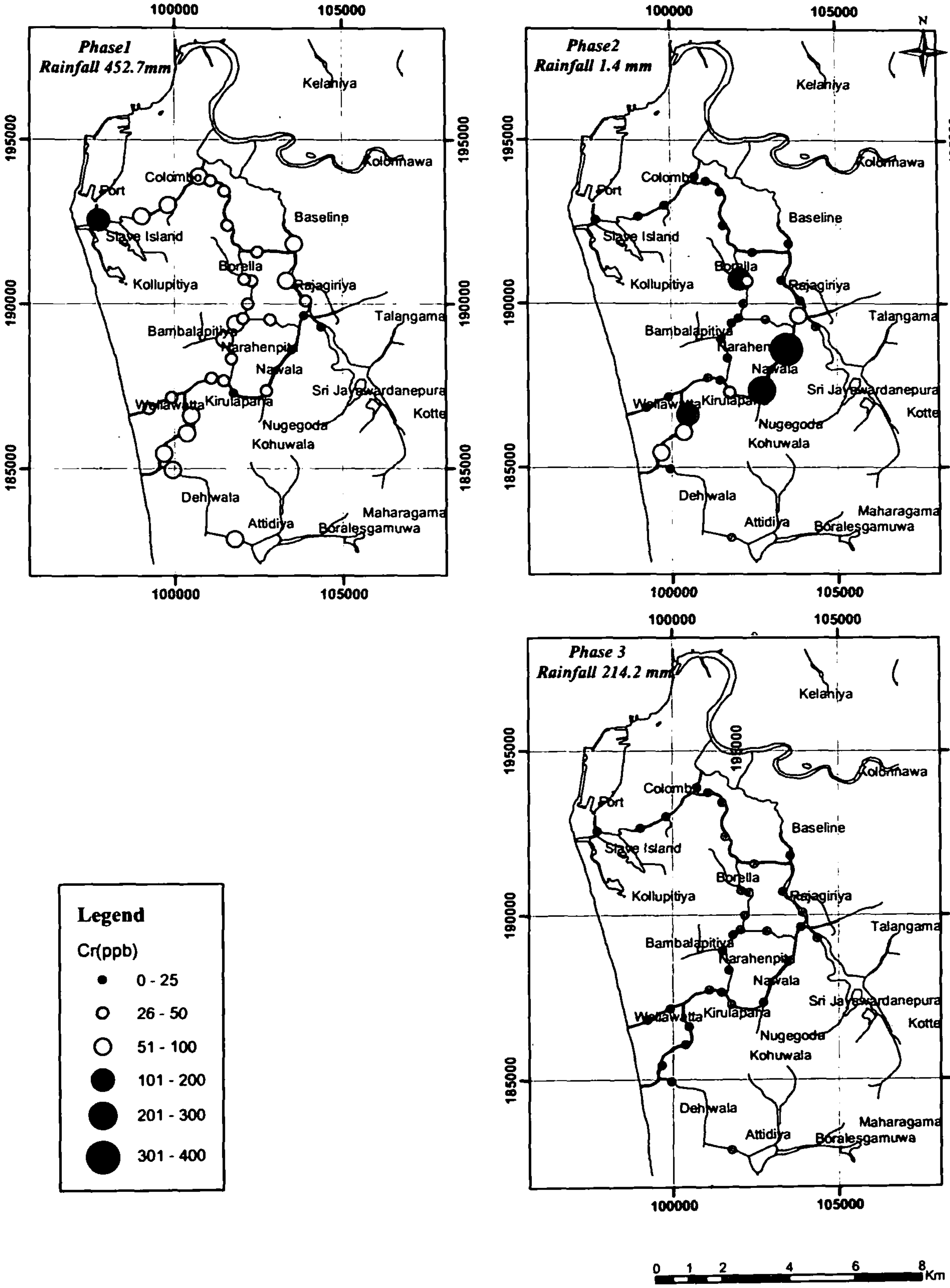

Fig: 6. Cr concentrations of water in the drainage network during different climatic seasons

Pb is mainly transported with suspended sediments, both silt and colloid, because of its strong hydrophorbic nature. Pb levels in water varies from 12-585 ppb (1st phase), 2-174 ppb (2nd phase), <1-94 ppb (3rd phase). Similar to Cd and Cr, Pb values are also much higher than the world average value of 0.079 ppb in stream waters. The average Pb value (99 ppb) during the 1st phase is markedly higher than that of the 2nd and 3rd phases. Pb values at many locations especially in Kolonnawa Canal exceed the standard values for portable water (50 ppb) and effluent (100 ppb). Pb concentration in Beira Lake to which the Kolonnawa canal frees its water was in the range <0.25 ppb-8.0 ppb in March-July period of 1996 (De Silva and Goonasekere 1997). Increasing rainfall and resulting runoff may be a main source of Pb in streams. A significant increase in the Pb level can be observed downstream of Kolonnawa canal and Diyawanna Oya especially around Maradana, Panchikawatta (KW7-KW11), Dehiwala and Kirulapana areas (DW8, DW12, DW11) (Fig. 7). This downstream increase and the relationship between the rainfall indicate that the road network with heavy traffic at these areas strongly contribute to the increase of the Pb in water. Unleaded petrol used for vehicles in Sri Lanka until 2005 may responsible for Pb pollution in waterways. Similar increase in Pb levels in water ways associated with highways is recorded in many parts of the world. Untreated storm water from low-traffic highway site in western Washington likely exceeds the maximum allowable aquatic life concentrations for Pb during more than half of the rains for moderate to low hardness conditions and would require removal of more than 90% of the Pb to meet the drinking water (Horner and Mar 1984). A study in Lagos, Nigeria revealed increased Pb levels in surface waters, 0.324±0.089, 0.030±0.046, and 0.346±0.389 ppm for high, medium and low traffic density areas (Sridhar 2005). Dramatic increase in Pb content downstream of Kolonnawa canal (KW7-KW11) may be attributed to the petroleum effluents released from Kolonnawa oil storage tank system.

Sludge samples of the drainage system contained Cd levels varying from 0.03-2.10 ppm (1st phase), 0.3-7.31 ppm (2nd Phase), 4.38-146.9 ppm (3rd Phase) (Table 3). A remarkable increase in Cd levels during 3rd phase (mean value 30.64 ppm) and decrease during the first phase (mean value of 0.54 ppm) could be observed. Kolonnawa canal had higher Cd concentrations (>3ppm) at its downstream locations around Baseline, Maradana, and Pettah areas (KW7-KW11) during 2nd and 3rd phases (Fig. 8). However it is interesting to note that there is no relationship between this elevated Cd levels in sludge with that of water samples. Also lower concentrations during the period with high rainfall (1st Phase - 452mm) are characteristic. Deposition of suspended load which carries highest portion of Cd, at stagnant or slow flowing downstream stretch of Kolonnawa canal, may account for the high Cd values.

Table: 3. Heavy metal concentrations of sludge samples

Element	Phase	Min	Max	Ave
Cd (ppm)	1	0	2	1
	2	0	7	1
	3	4	147	31
Cr (ppm)	1	4	43	14
	2	4	30	13
	3	3	41	12
Pb (ppm)	1	6	414	90
	2	2	458	79
	3	11	583	90

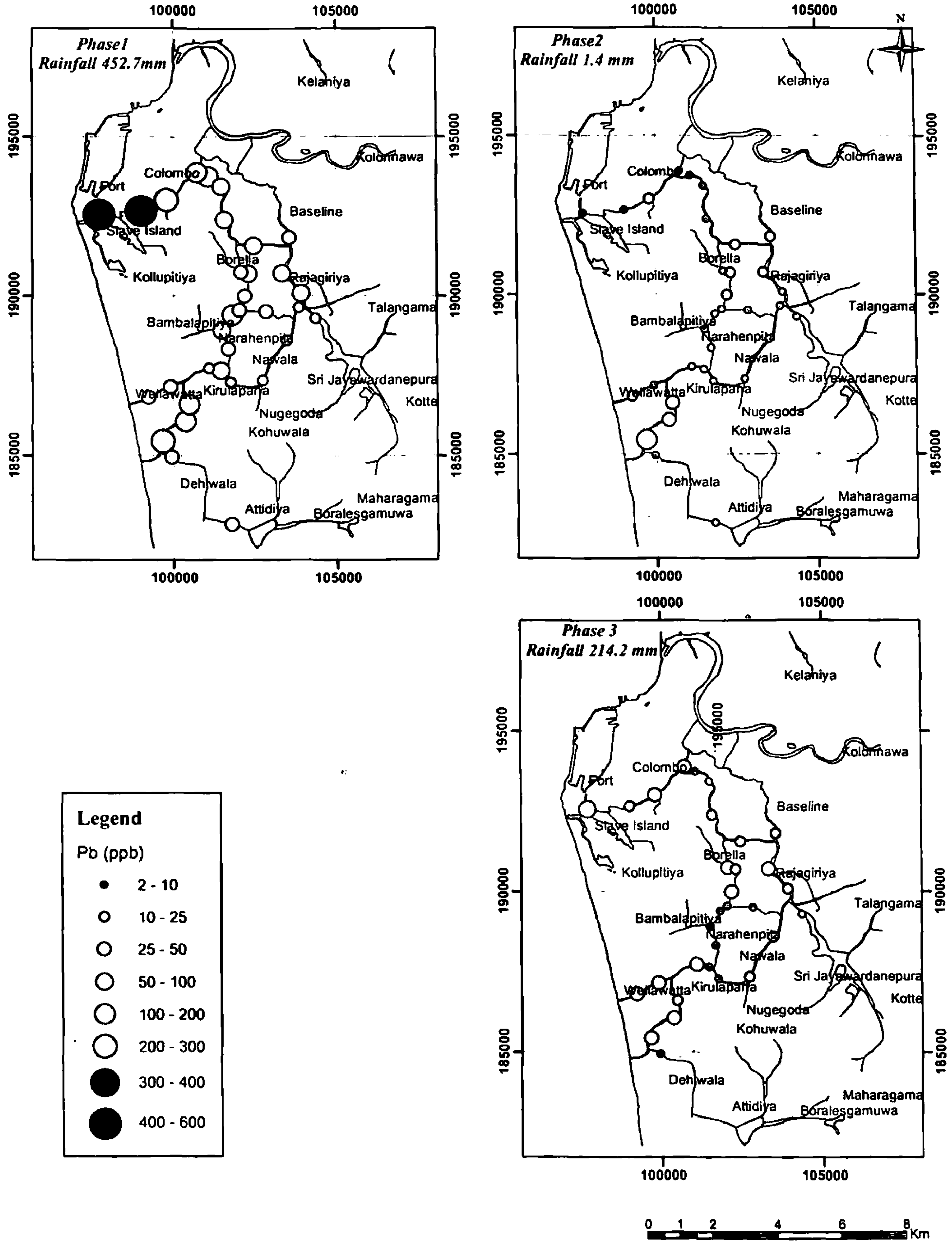

Fig: 7. Pb concentrations of water in the drainage network during different climatic seasons

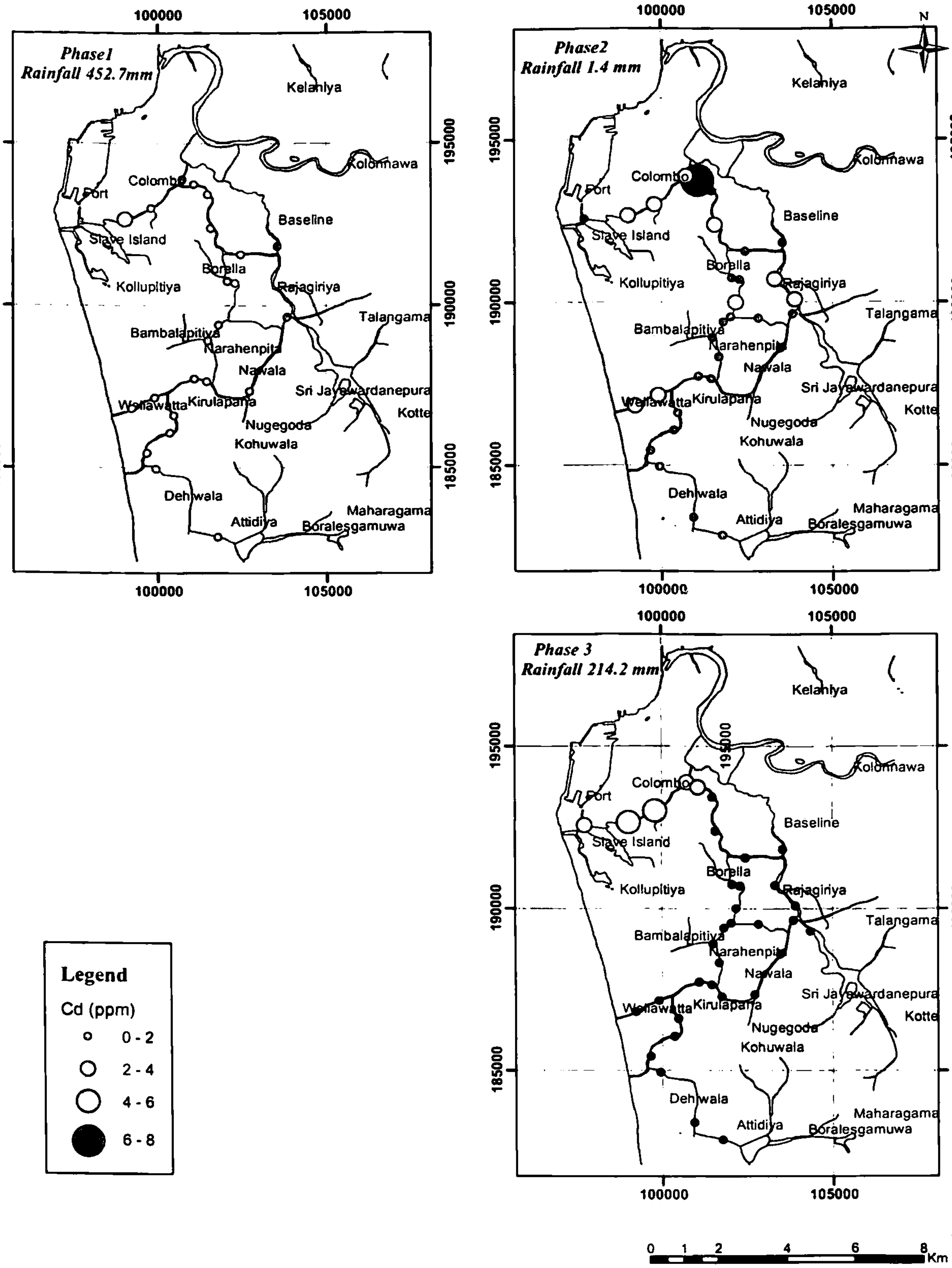

Fig: 8. Cd concentrations of sludge in the drainage network during different climatic seasons

Leachable Cr levels in sludge do not show any significant difference between sampling periods. The Cr levels varies from 4.4 – 42.8 ppm (1st phase), 3.8-29.9 ppm (2nd Phase), and 3.1-40.9 ppm (3rd phase) (Table 3). However it can be clearly observed that Cr levels downstream of Diyawanna Oya canal are higher than the upstream locations during the first phase in which the rain fall is higher. Deposition of bottom sediments and suspended load, brought to the canal by runoff water of the high rainfall period, due to slow flow rates at downstream locations close to the sea, may produce these high values. Isolated higher Cr values at upstream locations such as Wellawatta, Pettah, and Baseline (DW9, KW7, and KW10) during other periods probably represent point pollutant sources (Fig. 9). No difference in anthropogenic Pb concentrations of sludge samples could be observed between sampling periods. Variation of Pb values was 5.8-414 ppm in 1st phase, 2.5-457.8 ppm in 2nd phase11.4 - 583 ppm in 3rd phase (Table 3). High Pb levels (>80ppm) were recorded from downstream of both Kolonnawa and Diyawannawa canals (Fig. 10). Similar distribution pattern of Pb in water could be observed during the 01st sampling period with the highest rainfall. Deposition of suspended load, containing high Pb contents, at low flow velocities at downstream areas may account for this anomalously high Pb values.

CONCLUSIONS

From this study it is obvious that water ways of Colombo and its suburbs are considerably polluted with Pb, Cd, Cr, nitrate, phosphate and sulphates. Road network, household waste, and local industries are the major pollutant contributors. However it can be expected that use of unleaded petrol at present may decrease Pb pollution level in water ways. A detailed study to identify the point sources and an appropriate mechanism to prevent pollution are suggested.

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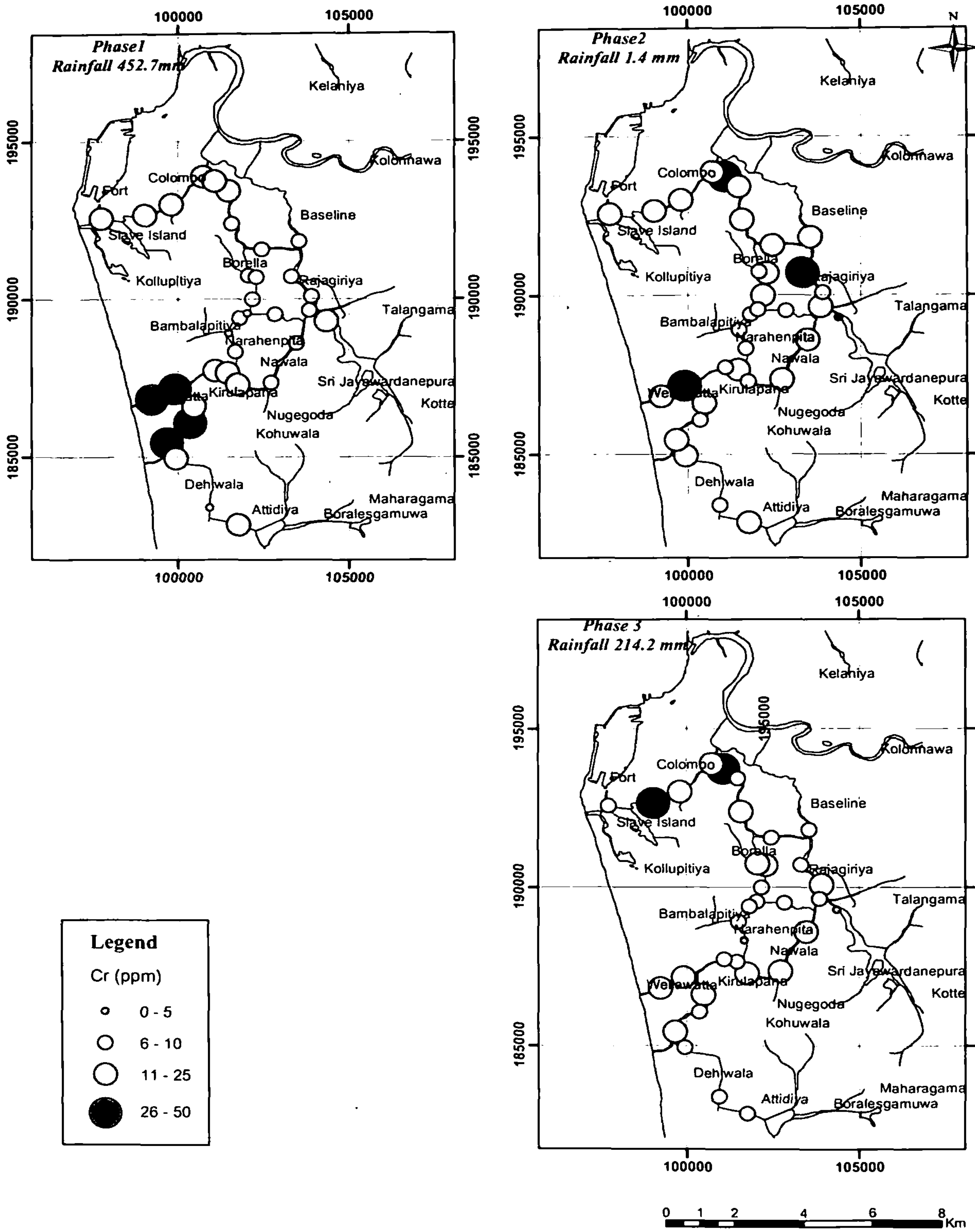

Fig: 9. Cr concentrations of sludge in the drainage network during different climatic seasons

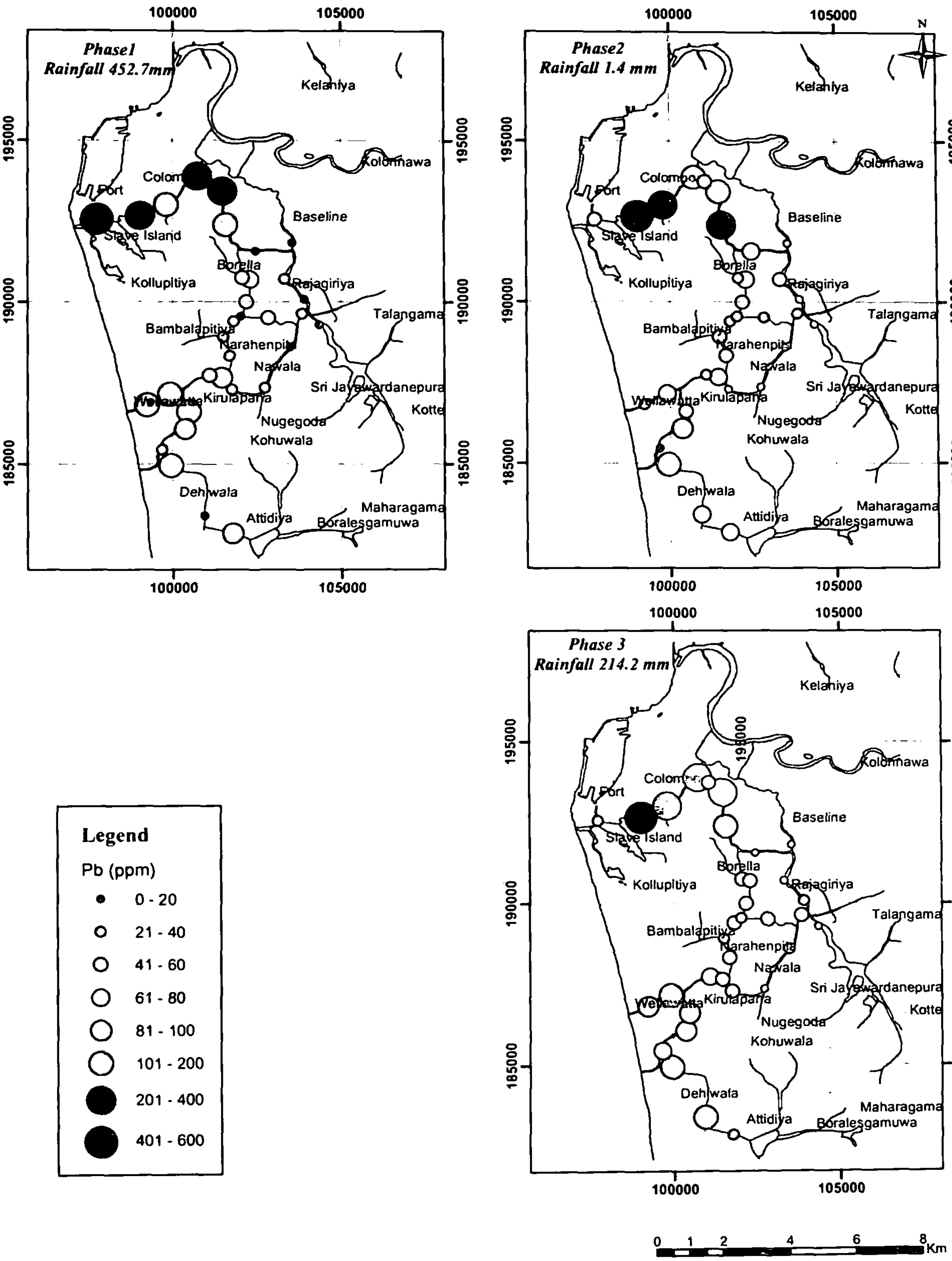

Fig: 10. Pb concentrations of sludge in the drainage network during different climatic seasons

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