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Jacobs Journal of Agriculture

Research Article

Agro-Geology and CHD in Finland

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Received: 06-01-2017

Accepted: 06-14-2017

Published: 06-18-2017

Abstract

Exceptional general and cardiac mortality of eastern Finland has been in focus of international interest, but not entirely explained. In environmental sciences the role of calcium (Ca), magnesium (Mg) and silicon (Si) in coronary heart disease (CHD) has been obscure. We compared CHD with groundwater (gw) Si (Si.gw), and variables associated with Si uptake: soil age, approximated by longitude (Long), temperature (Temp), soil type distribution and soil acidity (pH) in Finnish provinces (N = 11). Soil type proportions we assayed with proportions of coarse and finer mineral soils of cultivated fields (CoMS and FiMS, respectively) and effective cation exchange capacity of soil (CECe). Additionally we assayed soil and timothy (tim) Mg/Ca, gw hardness as (Ca+Mg) and latitude (Lat).

Results

CHD and Si.gw associated oppositely with following factors (R.CHD/R.Si.gw): Long (+0.93***/-0.70*), CoMS (+0.67*/-0.58), Lat (+0.49/-0.79**), Si.gw (-0.86***/+1.00), gw (Ca+Mg) (-0.67*/+0.71*), Temp (-0.59/+0.85***), CECe (-0.51/+0.63*) and FiMS (-0.49/+0.50) and negligibly with others. Combining increased the explanative strength: e.g. [Temp, Si.gw] explained 82 % (p = 0.001), [CoMS,Temp,Si.gw,CECe] 90 % (p = 0.004**) and [Lat,Long,Temp,pH] 98 % (p = 0.000) of CHD variation. In regressions by [Temp,pH] pH coefficient got positive value for CHD and negative for Si.gw. [Long,Temp] explained 95 % of CHD and Si.gw variation (p = 0.000, for both). Timothy Mg/Ca explained 71 % of soil Mg/Ca, but nothing (< 1 %) of CHD variance. Groundwater hardness explained 70 % (p = 0.001) of CECe and 54 % (p = 0.013) Si.gw variance.

Conclusions

Factors associated with plant Si uptake explained remarkably more CHD variation than the earlier reported. Approximate soil age (Long) together with temperature explained very significantly variation in CHD and gw Si. Timothy Mg/Ca ratio did not explain CHD variation. Groundwater hardness predicted soil fertility, Si.gw and possibly selenium content.

Introduction

Higher cardiac as also general mortality in eastern regions of Finland than in the west, documented since the 19th century [1], has been decades in the focus of international interest, but without satisfactory explanation. Only ca 40 % of the regional cardiovascular risk of the Eastern Finland was possible to explain by the conventional major and minor risk factors [2]. Carbonate associated Ca content of drinking water has been found to be highly significantly ($p < 0.0001$) negatively associated with cardiovascular mortality and significantly negatively with other mortality ($p < 0.01$) in the UK [3]. On the other hand Kousa et al. [4] have reported that Ca/Mg ratio in groundwater has been significantly positively associated with the acute myocardial infarction (AMI) in continental Finland. A dietary survey in Finland gave no east-west difference between dietary calcium and magnesium levels [5]. Loeper et al. [6] have reported that Si supplements could lessen the vascular atheroma formation in rabbits, administered intravenously or per os. Vegetable food rich in Si [7], is generally known to protect against CHD. Schwarz and colleagues [8] reported that the drinking water Si was highly significantly inversely correlated with the cardiovascular mortality in Finland. They listed seven studies, including five, where water Si was associated inversely with CHD. Ma and Takahashi wrote that Si uptake of rice was associated positively with temperature, negatively with pH, depending on Si content in soil solution [9]. This is on the other hand depending on soil type and soil age (soils derived from volcanic ash and shale were found to be rich in soluble Si, and soils derived from aged volcanic ash, quartz porphyry and granite, and peat are poor in soluble Si) [10]. According to Soil Atlas of Europe [11] soil ageing is generally associated with the reduction of calcium carbonate and clay material from the upmost soil layers. Effective cation exchange capacity (CECe), equivalent sum of calcium, magnesium and potassium, can also be benefited for evaluation of soil type, because the lowest values refer on sand soils and these values increase towards clay soils, i.e. with decrease of particle size [12]. In Finland, grossly speaking, soil ageing is increasing from west to east, opposite to the shift of the western coast of continental Finland during the last ca 10,000 years [13]. During this time the West was less affected by weathering and erosion and got more eroded minerals. Not only soil solutions, but the organic acids excreted by plant roots and soil micro-organisms can by disintegrating solid soil minerals liberate cations and silicon available to plants [14].

Materials and methods

Latitude (Lat), longitude (Long) and temperature (Temp) were determined by province capitals, i.e. roughly indicating their population maxima. Names and location of the provinces and province capitals were determined benefiting maps of Finland [15] and Wikipedia [16] and internet pages of these capitals.Provincial age adjusted CHD of 35-64 y. old men (1/100,000), (three years sliding means from 1964-84) were obtained from Valkonen and Martikainen [17] (Tabl. 1).

Table 1. Western and Eastern Finnish provinces, their capitals, latitude, longitude, mean annual temperature and age adjusted CHD mortality of 35-64 y. old men in 1964-84 and in five periods within 1964-83 [17].

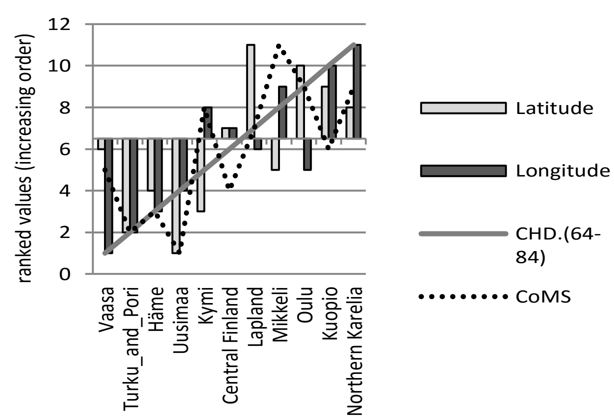
	Province	Capital	Latitude	Longitude	Temperature	CHD.(64-84)	CHD.(64-67)	CHD.(68-71)	CHD.(72-75)	CHD.(76-79)	CHD.(80-83)
			°N	°E	°C	1/100,000					
West	Vaasa	Vaasa	62.1	21.1	4.1	370	408	397	404	344	311
	Turku_and_Pori	Turku	60.5	22.3	5.2	386	423	409	387	393	338
	Häme	Hämeenlinna	61.0	24.5	4.5	414	461	457	433	410	328
	Uusimaa	Helsinki	60.2	24.9	5.2	447	526	502	443	434	360
East	Kymi	Kouvola	60.9	26.7	4.6	511	569	537	537	508	442
	Central Finland	Jyväskylä	62.2	25.8	3.6	515	525	575	517	528	461
	Lapland	Rovaniemi	66.5	25.7	0.5	529	564	572	552	526	448
	Mikkeli	Mikkeli	61.7	27.3	3.9	531	541	563	570	542	467
	Oulu	Oulu	65.0	25.5	2.2	553	577	591	599	580	454
	Kuopio	Kuopio	62.9	27.7	3.1	564	638	633	581	537	468
	Northern Karelia	Joensuu	62.6	29.8	3.0	622	708	706	633	564	519

Table 2. Agricultural and geologic variables. Soluble soil Ca, Mg and K and pH, [18], proportion of coarse mineral soils (CoMS) and finer mineral soils (FiMS), timothy Ca and Mg [19] groundwater Si, Ca and Mg [21].

		Ca soil	Mg soil	K soil	pH soil	CoMS	FiMS	Ca tim	Mg tim	Ground-water samples	Si.gw	Ca.gw	Mg.gw
	N	mg/L				%		(g/kg DW)		N	mg/L		
Vaasa	183	1283	155	75	5.43	47.5	12.6	2.60	1.32	50	8.3	15	3.7
Turku_and_Pori	158	1471	192	117	5.68	33.5	51.3	2.49	1.15	75	7.5	19	5.9
Häme	191	1434	223	126	5.64	34.0	56.5	2.41	1.10	72	7.4	16	5.5
Uusimaa	80	1750	346	151	5.67	12.5	82.5	2.26	1.16	70	7.6	21	6.6
Kymi	106	1482	147	122	5.61	61.3	24.5	2.42	1.02	65	6.9	16	3.8
Central Finland	162	1297	155	77	5.66	43.2	40.7	2.54	1.17	63	6.2	11	2.0
Lapland	244	998	201	116	5.33	58.6	7.4	2.86	1.60	86	4.9	11	2.8
Mikkeli	197	1281	104	81	5.61	74.1	7.6	2.54	1.03	51	6.6	18	3.3
Oulu	308	1168	225	83	5.45	67.1	11.7	2.58	1.57	87	5.5	15	3.1
Kuopio	133	1082	169	78	5.58	52.6	30.8	2.29	1.19	57	5.5	13	2.5
Northern Karelia	231	1278	109	87	5.66	67.1	11.7	2.69	1.11	53	5.6	11	2.2

Soluble mineral values of Ca, Mg and K from cultivated fields (soil), determined by using ammonium acetate acetic acid buffer, pH 4.65), are from Sippola and Tares [18]. Timothy mineral element contents (from the same fields as Sippola and Tares) and proportions of coarse and finer (clay and silt) mineral soils are from Kähäri and Nissinen [19]. Total number of samples of soil, timothy and soil-type (each) was 1993. Provincial temperature was determined with map of FMI [20] expressing mean annual temperatures combined with the map of Finland [15]. Provincial values of Si.gw, Ca.gw and Mg.gw from 11 provinces, total 729 captured springs and dug wells from 1999, was provided by Geological Survey of Finland (GSF) [21] (Tabl. 2). Åland was excluded because of small number of samples (6).

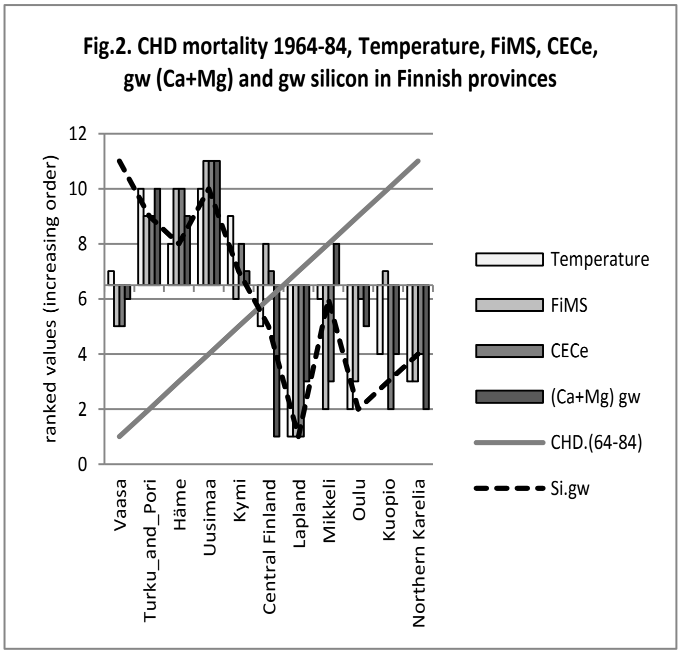
Fig. 1. CHD mortality 1964-84, latitude,longitude and propotion of coarse mineral soils in cultivated fields of Finnish provinces

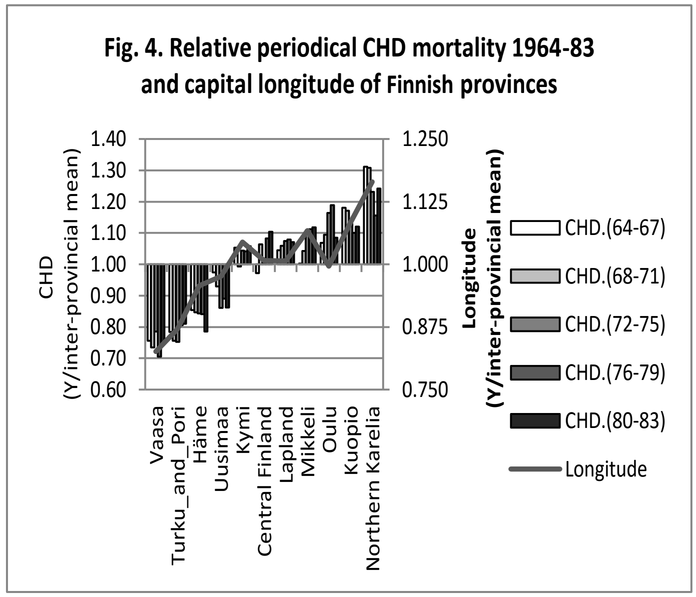


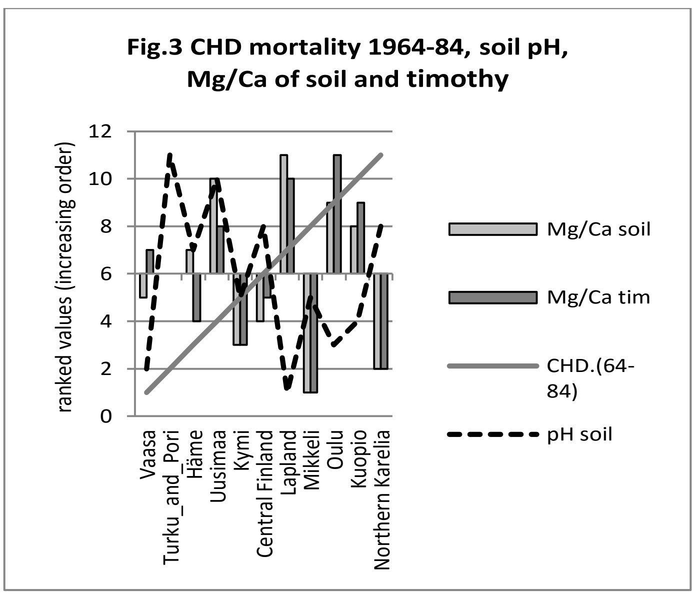
Results

By correlations the agro-geologic and geographic factors could be divided in three groups: "cardio-toxic" (Long, Lat and CoMS), "cardio-protective" (Si.gw, gw (Ca+Mg), Temp, CECe and FiMS) and obscure (pH, Mg/Ca of timothy and soil). (Figure. 1-3). In the Figures provinces are in order of increasing CHD mortality, from the left (West) to the right (East). Variables have got only ranked values (cf. Spearman correlations). Figure. 4 shows the stability of relative provincial CHD mortality in five periods and their close associations with longitude.

In Figure 1 we see the "cardio-toxic" variables: Lat, Long and CoMS, in Figure 2 "cardio-protective" variables: Temperature, FiMs, CECe, gw (Ca+Mg) and Si.gw. In Figure 3 are "obscure" environmental factors: pH, Mg/Ca of soil and timothy. In Figure. 4 shows relative provincial CHD mortality in five periods 1964-83 and longitude.







CHD and Si.gw associated oppositely with following factors (R.CHD/R.Si.gw): Long (+0.93***/-0.70*), CoMS (+0.67*/-0.58), Lat (+0.49/-0.79**), Si.gw (-0.86***/+1.00), gw (Ca+Mg) (-0.67*/+0.71*), Temp (-0.59/+0.85***), CECe (-0.51/+0.63*) and FiMS (-0.49/+0.50) and negligibly with others (Table. 3)

Because the eastern provinces are to the north of the western ones, geographic associations were determined by partial, standardized, (std) correlations, too. Then values for R.CHD/R.Si.gw of Long std were (+0.97***/-0.88***) and of Lat std (+0.82**/and -0.92***), respectively.

Other associations: Groundwater hardness associated significantly with CHD (-0.67*), Temp (+0.71*), CoMS (-0.63*), FiMS (+0.67*), Si.gw (+0.71*) and CECe (+0.83***). CECe showed negative trend with CHD (-0.51), associated significantly with Temp (+0.71*), CoMS (-0.81**), FiMS (+0.87***), Si.gw (+0.63*) and gw hardness.

Combination of agro-geological factors increased often their explanative variance. [CoMS,Temp] explained 51 % (p = 0.058), [CoMS,FiMS] 57 % (p = 0.033), [Temp,pH] 72 % (p = 0.006), [CoMS,Si.gw] 79 % (p = 0.002), [Temp, Si.gw] 82 % (p = 0.001), [CoMS,Temp,pH] 84 % (p = 0.004) and [CoMS,Temp,Si.gw,CECe] 90 % of CHD variance (p = 0.004**). Original Lat and Long fortified the "effect" of other factors: [Lat,Long,Temp,pH] explained 98 % of CHD variation (p = 0.000). In regressions by [Temp,pH] pH coefficient got positive value for CHD and negative for Si.gw. [Long,Temp] explained 95 % of CHD and Si.gw variation (p = 0.000, for both).

Timothy Mg/Ca explained 71 % (p = 0.001) of soil Mg/Ca, but nothing (less than 1 %) of CHD variance. Mg/Ca of soil showed positive trend with FiMS (+0.33) and negative with CoMS (-0.42). Timothy Mg/Ca associated negligibly with both of them.

Table 3. Agro-geologic and geographic variables and their associations – correlations ("R"), R square - and significances of associations with CHD and groundwater silicon.

	CHD			Si.gw		
	R	R Square	CHD.Sign.	R.Si.11	R Square	Si.Sign.
Long	+0.93***	0.86	0.000***	-0.70*	0.49	0.016*
CoMS	+0.67*	0.44	0.025*	-0.58	0.34	0.059
Lat	+0.49	0.24	0.122	-0.79**	0.62	0.004**
Si.gw	-0.86***	0.75	0.001**			
(Ca+Mg) gw	-0.67*	0.45	0.024*	+0.71*	0.51	0.013*
Temp	-0.59	0.35	0.056	+0.85***	0.72	0.001***
CECe	-0.51	0.26	0.105	+0.64*	0.41	0.035*
FiMS	-0.49	0.24	0.127	+0.50	0.25	0.118
pH soil	-0.04	0.00	0.902	+0.34	0.12	0.306
Mg/Ca soil	-0.13	0.02	0.728	-0.12	0.01	0.538
Mg/Ca tim	-0.02	0.00	0.948	-0.31	0.09	0.361

Discussion

Possibly this is the first agro-geological analysis, or one of them, concerning associations of CHD with CECe, soiltypes, soil pH, soil and timothy Mg/Ca. CHD associations with hard water [3,4] and temperature [3] has been reported earlier.

Several factors (Lat , Long, CoMS, Si.gw, Temp and FiMS, gw hardness, CECe) were observed to associate oppositely to CHD than to Si.gw. Three of them (Lat, Long and CoMS) can be labelled "cardio-toxic", five (Temp, FiMS, CECe, gw (Ca+Mg) and Si.gw, "cardio-protective". (Table. 3, Figure. 1 and Figure. 2). In the group of agro-geologic parameters Si.gw explained best of CHD variation and Temp best of Si.gw variation. Pure agro-geological parameters [CoMS, Temp,Si.gw,CECe] explained 90 % of CHD, which is more than in earlier studies [2]. Long std and Lat std associated very strongly with CHD and Si.gw. Our measure of soil age (Long) and Temp, together, explained 95 % of CHD and Si.gw variation. Variation of Si.gw can be understood so that Temp indicates speed of chemical and biologic processes and Long proportions of soil types and qualitative changes inside them.

Liberation of Si to soil solutions has been reported to associate negatively with pH [9]. Active carbonate buffer can reduce silicate liberation to soil solutions, when the carbonate buffer is active [22]. In this material pH showed positive trend with Si.gw (+0.34). This can be explained with strong association of pH with Temp (+0.75**)_and with FiMS [9] (+0.61*). After combining variable pH with Temp in CHD regression, the explanative strength of CHD variance increased from 35 to 72 %. Here pH coefficient got positive value for CHD and negative for Si.gw as expected [9]. Exceptionally low CHD in Vaasa was associated with low soil age, low longitude, high Si.gw and moderately low pH, but low CECe and gw (Ca+Mg) supporting the superiority of Si.gw to gw hardness as a prognosticating index (Figure. 2). Range of pH variation (5.33-5.68) was small, increasing risk of statistical error. Supposedly in less soaked (than paddy) soils pH differs in the colloidal micro-milieu of roots from that gained in standard soil analyses. So in carbonate soils (in higher pH) Si.gw obviously could not predict Si uptake.

Ground water hardness has been reported to associate with CHD in several studies [4]. In this survey associations of CECe and gw hardness were highly similar with other factors (Temp, Si.gw, soil-types), but the association of CECe with CHD (-0.51) was weaker. CECe is known to be associated with soil fertility [12] and obviously so with well-being of plants, animals and humans.

Inter-provincial mean Si.gw content was only ca 6.4 mg/L. In Finland major intake of Si (29 mg) comes from the food [23]. If we drink or take in our food 1 liter gw, our daily total intake would be ca 35 mg and proportion of Si.gw in total Si intake were ca 18 %. So most important in Si.gw could be its role as an indicator of Si uptake in this pH range. We suggest that in higher pH range Si.gw could decrease independently of Si uptake.

Effects of Si are suggested to be associated with its participation in collagen structures of arterial wall [24]. Thubrikar and colleagues [25] showed that artificial stabilization of arterial wall reduced atherosclerotic process, obviously by reducing local irritation/inflammation and possibly cholesterol synthesis in vascular walls [26]. But silicon has been shown to have effects on Mg uptake by cells, inflammation and blood pressure [27] and synergistic effects with copper (Cu) and antagonism with zinc (Zn) [28], with obvious benefits and harms.

Organic soils are not included supposing that their mineral values vary greatly depending on subsoil and subtypes of organic soils [10]. Proportion of CoMS varied from 13 to 74 %, FiMS from 7 to 83 %, their sum from 60 to 95 %, maximum ≤100. So they are not totally independent variables. Exclusion of organic soils explains why timothy Mg/Ca associated (slightly) negatively with CoMS and FiMS. Association of selenium with clay soils (FiMS) could explain some of their beneficial effects [29]. Surprising is that the increased inter-provincial and international food transport did not remarkably change the CHD east/west ratio during the 20th century. The authors have suggested that an additional explanation for geographic (Lat and Long) differences could be included in different vitamin D synthesis via skin [30].

Conclusions

Factors associated with plant Si uptake explained remarkably more CHD variation than the earlier reported. Approximate soil age (longitude) together with temperature explained very significantly variation in CHD and groundwater Si. Timothy Mg/Ca ratio did not explain CHD variation. Groundwater hardness predicted soil fertility, Si.gw and possibly selenium content.

Acknowledgements

We appreciate professor Simo Näyhä (Oulu) for kind comments and discussions.

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