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Cohort profile: the Geoscience and Health Cohort Consortium (GECCO) in the Netherlands

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ABSTRACT

Purpose In the Netherlands, a great variety of objectively measured geo-data is available, but these data are scattered and measured at varying spatial and temporal scales. The centralisation of these geo-data and the linkage of these data to individual-level data from longitudinal cohort studies enable large-scale epidemiological research on the impact of the environment on public health in the Netherlands. In the Geoscience and Health Cohort Consortium (GECCO), six large-scale and ongoing cohort studies have been enriched with a variety of existing geo-data. Here, we introduce GECCO by describing: (1) the phenotypes of the involved cohort studies, (2) the collected geo-data and their sources, (3) the methodology that was used to link the collected geo-data to individual cohort studies, (4) the similarity of commonly used geo-data between our consortium and the nationwide situation in the Netherlands and (5) the distribution of geo-data within our consortium.

Participants GECCO includes participants from six prospective cohort studies (eg, 44 657 respondents (18–100 years) in 2006) and it covers all municipalities in the Netherlands. Using postal code information of the participants, geo-data on the address-level, postal code-level as well as neighbourhood-level could be linked to individual-level cohort data.

Findings to date The geo-data could be successfully linked to almost all respondents of all cohort studies, with successful data-linkage rates ranging from 97.1% to 100.0% between cohort studies. The results show variability in geo-data within and across cohorts. GECCO increases power of analyses, provides opportunities for cross-checking and replication, ensures sufficient geographical variation in environmental determinants and allows for nuanced analyses on specific subgroups.

Future plans GECCO offers unique opportunities for (longitudinal) studies on the complex relationships between the environment and health outcomes. For example, GECCO will be used for further research on environmental determinants of physical/psychosocial functioning and lifestyle behaviours.

Strengths and limitations of this study

- The main strengths of the Geoscience and Health Cohort Consortium (GECCO) are the centralisation of a variety of objectively measured geo-data on the address-level, postal code-level and neighbourhood-level and the linkage of these environmental-level data to individual-level data from six longitudinal cohort studies in the Netherlands.
- The large number of respondents in GECCO are spread out over all municipalities in the Netherlands and, consequently, the variation in environmental exposures is large.
- The geo-data could be successfully linked to almost all respondents of each participating cohort study, with successful data-linkage rates ranging from 97.1% to 100.0%.
- Although the collaboration between the cohort studies in GECCO increases power of analyses and enables nuanced analyses on specific subgroups, procedures are required to harmonise variables between cohort studies.

INTRODUCTION

The exposome encompasses the life-course environmental exposures from the prenatal period onwards and receives growing attention in medical research with respect to its relationship with health behaviours and health outcomes.[1–3] Multidisciplinary and longitudinal research combining individual-level data with environmental-level data is urgently needed to identify and better understand the environmental determinants of behaviours and health and to optimally inform policymakers. In the Netherlands, a great variety of objectively measured geo-data is available (eg, air pollution, traffic noise and area demographics), but these data are currently scattered and measured at varying spatial and temporal scales. The centralisation of these geo-data and the linkage of these data to individual-level data from longitudinal cohort studies would stimulate

large-scale epidemiological research on the impact of the environment on public health in the Netherlands.

In the Geoscience and Health Cohort Consortium (GECCO), a variety of existing geo-data has been brought together and databases of six large-scale, ongoing cohort studies in the Netherlands have been enriched with these geo-data. GECCO stimulates large-scale studies on environmental determinants of health and well-being in the Netherlands. In particular, the collaboration between cohort studies within this consortium increases power of analyses, provides opportunities for cross-checking and replication, ensures sufficient geographical variation in environmental determinants and allows for analyses on specific subgroups.

In this cohort profile, we introduce GECCO and provide an overview of the collected geo-data and their sources. Furthermore, we describe the methodology that was used to link the collected geo-data to the individual cohort studies. We examine the similarity of commonly used geo-data (eg, air pollution, traffic noise and area demographics) between our consortium and the nationwide situation in the Netherlands. We investigate the variability in geo-data within GECCO by examining the distribution of geo-data within our consortium and by assessing differences in geo-data between urban and rural areas of residence.

COHORT DESCRIPTION

Cohort studies

GECCO involves six cohort studies, affiliated with Vrije Universiteit Amsterdam and/or VU University Medical Center in Amsterdam, the Netherlands. Here we focus on the linkage of geo-data to the cohort studies in 2006, because most cohort studies (five out of six) had a measurement around this year. The geo-data could be successfully linked to almost all respondents of each cohort study. The successful data-linkage rates ranged from 97.1% to 100.0% between cohort studies. Missing geo-data or postal code information (eg, as a result of living abroad) were the main reasons for unsuccessful data-linkage. The six cohort studies are described below.

The Generations^2-study (http://www.generaties2.nl) is a longitudinal cohort study following first-time pregnant women during the transition to parenthood. The Generations^2-study was started in 2009 and the inclusion of pregnant women ended in 2015. By following women from the first trimester of pregnancy until 6 years after birth, the study aims to obtain more insight in the adaptation of mothers to parenthood and the development of the parent-child relationships.[4] Participants were recruited via midwifery practices in the Amsterdam area and via a website. Data were collected by using a variety of questionnaires, interviews and observations. Women were eligible to participate in the Generations^2-study if they were pregnant of their first child and if their Dutch or English proficiency was good enough to complete the questionnaires. In total, 2000 women took part in the Generations^2-study. In 2009, data were collected for 208 participants in this cohort study. Geo-data could be linked to 202 (97.1%) participants in 2009. For the Generations^2-study, we show data for the year 2009 in this cohort profile.

The Longitudinal Aging Study Amsterdam (LASA; http://www.lasa-vu.nl) is a longitudinal, multidisciplinary cohort study that aims to study the determinants, trajectories and consequences of physical, cognitive, emotional and social functioning in relation to ageing.[5 6] The study is based on a nationally representative sample of older adults aged 55–84 years at baseline, living in three different geographical areas in the Netherlands, covering protestant, roman-catholic and secularised areas of the country as well as urbanised and rural areas. The baseline measurement included 3107 respondents. The baseline data collection was conducted in 1992/1993, with 3 yearly follow-up waves. Additional respondents from later birth cohorts were recruited from the same sampling frame in 2002/2003 and 2012/2013. Data were collected by trained interviewers, who visited respondents at home. The main data collection was done by means of face-to-face, computer-assisted interviews. Additionally, respondents were asked to fill out a written questionnaire and to participate in a medical interview, entailing a separate visit to administer clinical measurements and ask additional questions. In 2005/2006, data were collected for 2165 participants in this cohort study. Geo-data could be linked to 2150 (99.3%) participants in 2005/2006, of which 2123 persons lived at individual addresses.

The Netherlands Longitudinal Study on Hearing (NL-SH; http://www.hooronderzoek.nl) is an ongoing prospective cohort study and focuses on the relationships between hearing impairment and several aspects of life of adults, including psychosocial functioning, work and use of healthcare. The NL-SH comprises a convenience cohort of Dutch adults between 18 and 70 years with and without hearing loss at the start of the study. The aim of the NL-SH is to compare groups of participants with and without hearing impairment on a range of aspects. This longitudinal cohort study commenced in 2006. The first follow-up wave took place 5 years after the initial measurement. A 10-year follow-up wave is currently underway. The NL-SH is a web-based study, with the entire data collection processed via the internet. The NL-SH website is used to recruit participants and to collect data.[7–9] Before enrolment, participants have to perform a Dutch online speech-in-noise test and subscribe themselves to the study by completing an online registration form. Hereafter, they receive the NL-SH questionnaire. In 2006, data were collected for 1015 participants in this cohort study. Geo-data could be linked to 1012 (99.7%) participants in 2006, of which 995 persons lived at individual addresses.

The Netherlands Study of Depression and Anxiety (NESDA; http://www.nesda.nl) is a national ongoing, longitudinal study designed to investigate the long-term course and consequences of depressive and anxiety disorders and to integrate biological and psychosocial research paradigms within an epidemiological approach

in order to examine (interaction between) predictors of the long-term course and consequences.[10] Briefly, six assessment waves have been completed between 2004–2006 (baseline) and 2014–2016 (9 year follow-up). The study started with 2981 participants aged 18–65 years, including healthy controls and subjects with a past or current depressive and/or anxiety disorder. To represent various settings and stages of psychopathology, participants were recruited in the general population, in general practices and in mental health organisations. In NESDA, geo-data could be linked to 2974 (99.8%) participants in 2006.

The Netherlands Twin Register (NTR; http://www.tweelingenregister.org) is an ongoing cohort study and was established around 1986. The NTR examines the contribution of genes and environment to development, lifestyle, health and personality.[11] The cohort study was established by recruiting young twins and multiples at birth and by approaching adolescent and young adult twins through city councils. The Young Netherlands Twin Register (YNTR) collects data from twins and multiples from birth onwards, by parent and teacher report and as of age of 14 by self-report.[12] The Adult Netherlands Twin Register (ANTR) started data collection in adolescent and young adult twins and their parents and was extended to include older twins as well as siblings, spouses and adult children of twin participants.[13] Survey data are collected every 2–3 years, since 1986 and 1991 for the YNTR and ANTR, respectively. Selected groups of participants are invited for specific research projects and DNA collection. In addition, biological samples and data for adult participants were obtained in a large-scale biobank effort.[14] Approximately 98 000 twins and multiples are registered with the NTR. In total, over 200 000 individuals (twins, multiples, parents, siblings, spouses, etc) take part. To ensure an unrelated sample in the current project, one NTR-participant within a family was selected who was 18 years or older in 2006 and for whom a Dutch residence in 2006 was known. In total, 35 574 unrelated participants were selected. Geo-data could be linked to 35 556 (99.9%) individuals in 2006.

The New Hoorn Study (NHS; http://www.emgo.nl/research/lifestyle-overweight-and-diabetes/research-projects) is an ongoing population-based study focusing on the prevalence of impaired glucose regulation and determinants of type 2 diabetes mellitus in the city of Hoorn, the Netherlands.[15] The baseline measurement took place in 2006/2007 and included 2807 participants, aged 40–65 years. Participants were invited to visit the Diabetes Research Center in Hoorn and data were collected using questionnaires and physical examinations. A follow-up measurement has been conducted in 2014/2015. In the NHS, geo-data could be linked to all 2807 (100.0%) participants in 2006/2007.

Patient and public involvement

Patients and public were not involved in the design of this study.

Cohort data

The richness of the GECCO database is based on the cohort data and the geo-data that have been linked to these cohorts. The phenotypes of the individual cohort studies within GECCO are summarised in table 1. In most of these cohort studies, data on demographics, socioeconomic status (SES), lifestyle factors, healthcare use, biomaterial measurements and various domains of functioning have been repeatedly measured over time (table 1).

Environmental data

A variety of existing geo-data on address-level, 6-digit postal code-level, 4-digit postal code-level as well as neighbourhood-level from different sources were collected. In the Netherlands, 6-digit postal code areas (average area size: 0.0025 km^2), 4-digit postal code areas (average area size: 8.3 km^2) and neighbourhoods (average area size: 3.1 km^2) are geographically delineated areas within municipalities and include, on average, approximately 15, 1870 and 630 households, respectively.[16–21] Data were available for several years, depending on the source database used. For the data-linkage between geo-information and participants of each specific cohort study, 4-digit postal codes or, if possible, 6-digit postal codes were used as identifier. All collected geo-data within GECCO can thus be linked to the postal codes of respondents. In this cohort profile, we highlight geo-data that are commonly used in exposome research (table 2). A complete list of collected geo-data is available online (http://www.emgo.nl/research/international-collaborations/longitudinal-cohort-studies/emgo-cohort-booster-project).

Population and households

Statistics Netherlands provided data regarding population and households in 4-digit postal code areas in the Netherlands (table 2).[19 22–37] These data describe the population in terms of sex and age. Furthermore, the data include the proportions of Western and non-Western immigrants and also include household characteristics (eg, average household size). These data are described in more detail elsewhere.[19 22–37]

Socioeconomic status

The Netherlands Institute of Social Research provided SES scores for each 4-digit postal code area in the Netherlands for specific years (table 2).[38 39] The SES score has been modelled using several sources of nationwide survey data on the residents' educational level, income and position in the labour market. The SES score is based on mean income, percentage of low incomes, percentage of low educated residents and percentage of unemployed residents as determined by a principal component analysis. A higher score represents a better SES.[38] More information on the SES-score is available elsewhere.[38 39]

Air pollution

In the European Study of Cohorts for Air Pollution Effects (ESCAPE-project), the Institute for Risk Assessment

Table 1 The phenotypes of the individual cohort studies within GECCO

	Generations[2]-study		Longitudinal Aging Study Amsterdam		Netherlands Longitudinal Study on Hearing		Netherlands Study of Depression and Anxiety		Netherlands Twin Register		New Hoorn Study	
Period	2009–2015		1992-ongoing		2006–ongoing		2004–ongoing		1986–ongoing		2006/2007 and 2014/2015	
Number of measurement waves	7		8*		3		6		12*		2	
Cohort data												
	Assessed in cohort?	In multiple waves?	Assessed in cohort?	In multiple waves?	Assessed in cohort?	In multiple waves?	Assessed in cohort?	In multiple waves?	Assessed in cohort?	In multiple waves?	Assessed in cohort?	In multiple waves?
Demographic and socioeconomic factors												
Age	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Sex	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Educational level	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Marital status	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N
Income	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N
Occupational status	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N
Physical functioning												
Auditory functioning	N	N	Y	Y	Y	Y	N	N	N	N	N	N
Body mass index	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
Chronic diseases	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Functional limitations	N	N	Y	Y	N	N	Y	Y	Y	Y	N	N
Physical activity	N	N	Y	Y	Y†	Y	Y	Y	Y	Y	Y	Y
Physical limitations and performance	N	N	Y	Y	N	N	Y	Y	Y†	Y†	N	N
Lifestyle factors												
Alcohol use	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
Nutrition	N	N	Y	Y	N	N	Y	Y	Y†	N	Y	N
Sleeping behaviour	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Smoking	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Cognitive functioning												
Executive functioning	N	N	Y	Y	N	N	Y	Y	Y†	Y†	N	N
General cognitive functioning	N	N	Y	Y	N	N	Y	Y	Y†	Y†	N	N
Intelligence	N	N	Y	Y	N	N	N	N	Y†	Y†	N	N
Memory	N	N	Y	Y	N	N	N	N	Y†	Y†	N	N

Continued

Table 1 Continued

	Generations[2]-study		Longitudinal Aging Study Amsterdam		Netherlands Longitudinal Study on Hearing		Netherlands Study of Depression and Anxiety		Netherlands Twin Register		New Hoorn Study	
Emotional functioning												
Anxiety	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Depression	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Life events	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Personality traits	Y	N	Y	Y	N	N	Y	Y	Y	Y	N	N
Quality of life	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Social functioning												
Personal network	Y	Y	Y	Y	Y	N	Y	Y	N	N	N	N
Loneliness	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N
Social participation	N	N	Y	Y	Y	N	Y	Y	Y†	Y†	N	N
Healthcare use												
Use of care	Y	Y	Y	Y	Y	Y	Y	Y	Y†	Y†	Y	Y
Medication use	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Biomaterial measurements												
Blood biomarkers	N	N	Y†	Y†	N	N	Y	Y	Y†	Y†	Y	Y
DNA	Y	N	Y†	Y†	N	N	Y	Y	Y†	Y†	Y	N

*Number of measurement waves depends on cohort.
†Limited information or information only available in subgroups.
DNA, DNA acid; GECCO, Geoscience and Health Cohort Consortium; n, No; Y, Yes.

Table 2 Collected geo-data within GECCO*

Geo-data	Spatial scale	Period	Source
Population and households	PC4	1998 till 2014	Statistics Netherlands[19 22–37]
Socioeconomic status	PC4	1998, 2002, 2006, 2010, 2014	The Netherlands Institute of Social Research[38 39]
Air pollution	Address/PC6	2009	Institute for Risk Assessment Sciences[40–43]
Road-traffic, rail-traffic and air-traffic noise	Address/PC6	2000, 2004, 2005, 2007, 2008	Netherlands Environmental Assessment Agency[47]
Liveability	PC4	1998, 2002, 2006, 2008, 2010, 2012	The Netherlands Ministry of the Interior and Kingdom Relations[48 49]
Neighbourhood environment	Neighbourhood	1995, 1997, 1999, 2001, 2003 till 2014	Statistics Netherlands[20 21 50–63]
Urbanisation grade	Neighbourhood	1995, 1997, 1999, 2001, 2003 till 2014	Statistics Netherlands[20 21 50–63]

*A complete list of the collected geo-data within GECCO is available online (http://www.emgo.nl/research/international-collaborations/longitudinal-cohort-studies/emgo-cohort-booster-project).
GECCO, Geoscience and Health Cohort Consortium; PC4, 4-digit postal code area; PC6, 6-digit postal code area.

Sciences of the Utrecht University has measured the spatial variation of residential concentrations of air pollutants in 2009 in the Netherlands (table 2).[40–43] Land Use Regression (LUR) models were developed to predict air pollution concentrations at the address-level.[40 42] Residential exposure to air pollutants was assessed as annual average concentrations of particulate matter with diameters≤2.5 µm (PM2.5) and 2.5–10.0 µm (PM_{coarse}). Furthermore, air pollution was assessed as annual average concentrations of nitrogen dioxide (NO_2), nitrogen oxides (NO_x) and the reflectance of PM2.5 filters, which is a proxy for elemental carbon (soot). Detailed information on the assessment of exposure to air pollution is described elsewhere.[40–43] Although the data on air pollution were obtained in 2009, several studies have documented that the LUR models represent the spatial contrast in long-term average air pollution concentrations over periods of 10 years or more.[44–46] In GECCO, the address-level concentrations of air pollutants were aggregated to mean values of 6-digit postal code areas. This aggregation of data facilitated the linkage of these data to individual-level data of the various cohort studies.

Road-traffic, rail-traffic and air-traffic noise

The Netherlands Environmental Assessment Agency modelled daily average noise levels of road-traffic, rail-traffic and air-traffic for specific years in the Netherlands by using the Empara Noisetool with a resolution of 25 by 25 m (table 2).[47] Noise is measured in Level day-evening-night (Lden) and is expressed in A-weighted decibels (dB (A)). The measure Lden accounts for the fact that noise in the evening and the night are more annoying than during the day. The average noise levels during the day (7–19 hours), the evening (19–23 hours) and the night (23–7 hours) were calculated first and the levels of noise in the evening and the night are increased with 5 and 10 dB (A), respectively. Subsequently, the daily mean noise was calculated by dividing the noise levels during day, evening and night by 3. More details on the assessment of traffic noise raster data are available elsewhere.[47]

The noise level of a particular raster cell was linked to the point locations of all addresses that fall within that specific raster cell. The point locations of all addresses in the Netherlands were obtained from the Register of Addresses and Buildings (BAG-register, June 2015) of the Netherlands' Cadastre, Land Registry and Mapping Agency, and the linkage was performed by using GeoDMS software (Object Vision BV, Amsterdam, the Netherlands). In GECCO, the address-level traffic noise data were aggregated to mean values of 6-digit postal code areas. This aggregation of data facilitated the linkage of these data to individual-level data of the various cohort studies.

Liveability

The Netherlands Ministry of the Interior and Kingdom Relations has measured liveability, that is the extent to which the living environment is in line with the conditions and needs of residents, in each 4-digit postal code area in the Netherlands using the liveability score (table 2).[48–50] The liveability score is based on six dimension scores, which are derived from 49 indicators. The dimensions are: (1) population, (2) social cohesion, (3) public space, (4) safety, (5) level of resources and (6) housing stock. The liveability score ranges from 1 (extremely negative) to 7 (extremely positive).[48 49]

Neighbourhood environment

Statistics Netherlands shares rich data on neighbourhood environments for specific years in the Netherlands (table 2).[20 21 51–63] These data are related to several domains, including: (1) population demographics (eg, sex, age, marital status and ethnicity), (2) housing stock (eg, average home value), (3) energy consumption (eg,

average electricity/gas consumption), (4) income (eg, proportions of residents/households with a low/high income), (5) social security (eg, proportions of social security beneficiaries), (6) companies (eg, number of industrial companies), (7) motor vehicles (eg, average number of cars per household), (8) area (eg, total area size of land and/or water) and (9) proximity and density of specific resources in the neighbourhood (eg, general practices, supermarkets, educational facilities, public transport facilities and cultural facilities). These data on the neighbourhood environment are extensively described elsewhere.[20 21 51–63]

Geographic Information Systems (GIS) software, ArcGIS V.10.1 (ESRI, Redlands, California, USA), was used to allocate the centroid of 6-digit postal code areas to a neighbourhood, as delineated by Statistics Netherlands and the Netherlands' Cadastre, Land Registry and Mapping Agency. The GIS technique of spatial joining was used to link the neighbourhood data of Statistics Netherlands to 6-digit postal codes.

Urbanisation grade

Urbanisation grade is the mean number of addresses per square kilometre within a circle with a radius of one kilometre.[64] Data on the level of urbanisation of neighbourhoods are provided by Statistics Netherlands and are defined in five categories.[20 21 51–63] These five categories are: (1) extremely urbanised (≥2500 addresses/km^2), (2) strongly urbanised (1500–2500 addresses/km^2), (3) moderately urbanised (1000–1500 addresses/km^2), (4) hardly urbanised (500–1000 addresses/km^2) and (5) not urbanised (<500 addresses/km^2). For the purpose of this paper, urbanisation grade was dichotomised. The first three categories are defined as 'urban area' and the latter two categories are defined as 'rural area'.

FINDINGS TO DATE

Using the postal code information for our respondents in 2006, we linked geo-data to 44 657 individuals (including 202 Generations^2-participants in 2009). The mean age of all GECCO-participants was 43.8 (SD=12.0) years with an age range of 18–100 years. The study sample included 26 528 (59.4%) women and 10 048 (22.5%) participants had a high educational level (table 3).

GECCO includes respondents from national cohort studies which recruit participants from the entire country as well as respondents from regionally oriented cohort studies. To illustrate, the GECCO-participants of the NHS lived in 3 (0.7%) of the 458 Dutch municipalities in 2006, whereas GECCO-participants of the NTR covered all municipalities (table 4).

Table 4 presents the distribution of the geo-data in each individual cohort study, GECCO and the Netherlands. In general, there is variability in geo-data within and across GECCO-cohorts. The environmental exposure measures of participants in GECCO generally appear to be similar to those of residents in the entire country. For example, if we compare the point estimate of road-traffic, rail-traffic and air-traffic noise of GECCO-participants with that of all inhabitants in the Netherlands, the absolute difference is only 0.4 dB (A) (table 4).

Data on urbanisation grade were available for 43 678 participants (97.8%). The majority of these participants (58.8%) lived in urban neighbourhoods (table 4). As expected, the urban and rural neighbourhoods, in which the GECCO-participants were living, differed significantly in terms of population and household characteristics, SES, air pollution, road-traffic, rail-traffic and air-traffic noise, liveability and a range of neighbourhood characteristics (table 5). For example, the levels of road-traffic, rail-traffic and air-traffic noise and air pollution were higher in urban neighbourhoods than in rural neighbourhoods (table 5).

Recent findings in GECCO

So far, one study has been conducted in GECCO.[65] Generaal *et al*[65] conducted a cross-sectional study, including data from 2980 NESDA-participants, to examine whether urbanisation grade and objectively obtained socioeconomic (ie, SES, home value, number of social security beneficiaries per 1000 households and proportion of immigrants), physical (ie, air pollution, traffic noise and availability of green space and water) and social aspects (ie, social cohesion and safety) of the neighbourhood in which persons live are associated with the presence and severity of depressive and anxiety disorders. The findings showed that not urbanisation grade, but rather neighbourhood socioeconomic factors (ie, low SES, more immigrants and more social security benefits), physical factors (ie, high levels of air pollution and high levels of traffic noise) and social factors (ie, lower social cohesion and less safety) were associated with the presence of depressive and anxiety disorders. Furthermore, it was found that most of these neighbourhood characteristics were also associated with increased depressive and anxiety symptoms severity.[65] The study by Generaal *et al*[65] shows that several environmental characteristics are related to mental health of residents and suggest that policymakers should target a wide range of environmental aspects in order to promote mental health.

Currently, a nation-wide meta-analysis is conducted to examine the associations of neighbourhood characteristics with the prevalence and severity of depression, using data from 32 487 individuals from eight Dutch cohort studies (including all six GECCO cohort studies and two additional cohort studies). Furthermore, analyses are conducted in GECCO to examine the associations between the food environment and health outcomes, including obesity and type 2 diabetes mellitus. Currently, efforts are made by the GECCO research team to expand the consortium with other Dutch cohort studies.

Strengths and limitations

Following the recognition that lifestyle behaviours and health outcomes are related to our environment, there

Table 3 Characteristics of the participants within GECCO in 2006*†

	GECCO (all cohort studies)	Generations^2-study	Longitudinal Aging Study Amsterdam	Netherlands Longitudinal Study on Hearing	Netherlands Study of Depression and Anxiety	Netherlands Twin Register	New Hoorn Study
Sample characteristics							
Number of respondents	44 657	202	2123	995	2974	35 556	2807
Age in years (Mean (SD)) (range)	438 (12.0) (18.0–100.0)	30.3 (4.1) (18.3-41.0)	72.0 (95) (57.7–98.6)	46.6 (12.2) (18.0–70.0)	41.9 (13.1) (18.0–65.0)	41.5 (9.5) (18.0–100.0)	53.4 (6.7) (40.0–66.0)
Sex (female) (n (%))	26 528 (59.4)	202 (100.0)	1206 (56.8)	625 (62.8)	1974 (66.4)	21 020 (59.1)	1501 (53.5)
Educational level (n (%))‡							
Low	9535 (21.4)	0 (0.0)	1078 (50.8)	63 (6.3)	199 (6.7)	7473 (21.0)	722 (25.7)
Intermediate	12 985 (29.1)	56 (27.7)	687 (32.3)	457 (45.9)	1733 (58.3)	9026 (25.4)	1026 (36.6)
High	10 048 (22.5)	143 (70.8)	358 (16.9)	475 (47.8)	1042 (35.0)	7043 (19.8)	987 (35.2)
Other/Unknown	12 089 (27.0)	3 (1.5)	0 (0.0)	0 (0.0)	0 (0.0)	12 014 (33.8)	72 (2.5)

*Table 3 presents 2006-data for all cohort studies, except for the Generations^2-study. For the Generations^2-study 2009-data are shown.
†Means and SD are presented for normally distributed continuous variables. Frequencies and proportions are presented for categorical variables.
‡Highest completed level of education was categorised as: Low (elementary not completed, elementary education or lower vocational education), Intermediate (general intermediate education, intermediate vocational education or secondary education) and High (higher vocational education, college education or university education).
GECCO, Geoscience and Health Cohort Consortium; n, number of observations.

Table 4 A selection of geo-data within GECCO and within each individual cohort study*†‡

	Spatial scale	The Netherlands	GECCO (all cohort studies)	Generations[2]-study	Longitudinal Aging Study Amsterdam	Netherlands Longitudinal Study on Hearing	Netherlands Study of Depression and Anxiety	Netherlands Twin Register	New Hoorn Study
Spatial distribution of cohort study									
Local versus nationwide cohort study	–	–	Nationwide	Nationwide	Nationwide	Nationwide	Nationwide	Nationwide	Local
Municipalities inhabited by participants (n (%))‡	Municipality	458	458 (100.0)	53 (12.9)	90 (19.7)	288 (62.9)	205 (44.8)	458 (100.0)	3 (0.7)
Population and households									
Number of men and women (Median (IQR))	PC4	2595.0 (680.0–6696.3)	7980.0 (4805–11 190.0)	9045.0 (5355.0–12 342.5)	8950.0 (5775.0–11 940.0)	8345.0 (5500.0–11 045.0)	9355.0 (6340–12 470.0)	7540.0 (4595.0–10 625.0)	9540.0 (5095.0–11 450.0)
Percentage of residents (≥65 years) (Median (IQR))	Neighbourhood	13.0 (9.0–18.0)	13.0 (8.0–17.0)	12.0 (8.0–16.0)	14.0 (10.0–20.0)	13.0 (8.0–17.0)	12.0 (7.0–17.0)	13.0 (9.0–17.0)	11.0 (7.0–18.0)
Percentage of Western immigrants (Median (IQR))	Neighbourhood	8.0 (6.0–11.0)	8.0 (5.0–10.0)	9.0 (7.0–14.0)	7.0 (4.0–10.0)	9.0 (7.0–11.0)	10.0 (7.0–14.0)	8.0 (5.0–10.0)	8.0 (6.0–9.0)
Percentage of non-Western immigrants (Median (IQR))	Neighbourhood	5.0 (2.0–13.0)	4.0 (2.0–11.0)	10.0 (4.0–18.0)	5.0 (2.0–14.5)	6.0 (3.0–12.0)	7.0 (4.0–17.0)	4.0 (2.0–9.0)	9.0 (4.0–14.0)
Average household size (Mean (SD))	PC4	2.3 (0.3)	2.4 (0.3)	2.2 (0.4)	2.3 (0.4)	2.3 (0.4)	2.1 (0.4)	2.4 (0.3)	2.3 (0.2)
Housing stock (Median (IQR))	Neighbourhood	1370.0 (710.0–2440.0)	1195.0 (610.0–2210.0)	1725.0 (905.0–3390.0)	1175.0 (500.0–2130.0)	1390.0 (762.5–2605.0)	1817.5 (785.0–3610.0)	1260.0 (635.0–2215.0)	730.0 (430.0–920.0)
Socioeconomic status									
Socioeconomic status score (Median (IQR))	PC4	0.21 (–0.46 to 0.65)	0.27 (–0.22 to 0.67)	0.68 (–0.15 to 1.13)	0.32 (–0.20 to 0.50)	0.28 (–0.39 to 0.72)	0.09 (–0.96 to 0.63)	0.32 (–0.17 to 0.71)	–0.04 (–0.15 to 0.16)
Home value (in €1000,-) (Median (IQR))	Neighbourhood	197.0 (155.0–242.0)	205.0 (165.0–248.0)	244.0 (198.0–296.0)	193.0 (164.0–244.0)	200.0 (162.0–247.0)	207.0 (151.3–253.0)	208.0 (168.0–248.0)	175.0 (152.0–220.0)
Social security									
Number of social security beneficiaries per 1000 households (Mean (SD))	Neighbourhood	46.0 (48.2)	38.1 (40.8)	34.0 (36.9)	42.2 (41.4)	41.5 (40.6)	54.4 (53.4)	36.5 (39.6)	37.0 (36.2)
Number of incapacity benefits per 1000 residents (15–64 years old) (Mean (SD))	Neighbourhood	78.5 (35.3)	77.1 (30.3)	65.5 (24.6)	88.4 (37.1)	74.6 (25.4)	73.1 (38.3)	75.0 (28.2)	101.1 (30.3)
Noise									
Road-traffic, rail-traffic and air-traffic noise (in dB (A)) (Mean (SD))	PC6	53.5 (5.8)	53.1 (5.7)	55.8 (4.8)	53.9 (5.7)	53.9 (5.5)	54.8 (3.3)	52.9 (5.9)	53.8 (4.1)
Air pollution									
Mass concentration of NO_x (in $\mu g/m^3$) (Mean (SD))	PC6	35.2 (11.5)	34.0 (10.6)	38.2 (14.0)	35.6 (12.4)	36.2 (11.6)	40.0 (12.2)	33.4 (10.5)	32.5 (4.6)
Reflectance of PM2.5 filters (in 10^{-5}/m) (Mean (SD))	PC6	1.3 (0.2)	1.2 (0.2)	1.3 (0.3)	1.2 (0.3)	1.3 (0.3)	1.4 (0.3)	1.2 (0.2)	1.1 (0.1)

Continued

Table 4 Continued

	Spatial scale	The Netherlands	GECCO (all cohort studies)	Generations^2-study	Longitudinal Aging Study Amsterdam	Netherlands Longitudinal Study on Hearing	Netherlands Study of Depression and Anxiety	Netherlands Twin Register	New Hoorn Study
Mass concentration of PM2.5 (in µg/m^3) (Mean (SD))	PC6	16.6 (0.7)	16.5 (0.7)	16.3 (0.6)	16.4 (0.8)	16.6 (0.7)	16.4 (0.6)	16.5 (0.7)	15.9 (0.2)
Mass concentration of PM_{coarse} (in µg/m^3) (Mean (SD))	PC6	8.4 (0.8)	8.3 (0.8)	8.7 (1.1)	8.5 (1.0)	8.5 (0.9)	8.8 (1.1)	8.2 (0.7)	8.2 (0.3)
Mass concentration of NO_2 (in µg/m^3) (Mean (SD))	PC6	24.4 (6.8)	23.7 (6.3)	26.0 (7.7)	23.7 (7.0)	25.2 (6.9)	27.9 (7.5)	23.3 (6.2)	22.7 (2.3)
Liveability									
Liveability (n (%))	PC4								
Extremely negative		27 635 (0.2)	37 (0.1)	0 (0.0)	2 (0.1)	0 (0.0)	6 (0.2)	29 (0.1)	0 (0.0)
Very negative		195 255 (1.2)	207 (0.5)	0.0 (0.0)	12 (0.6)	7 (0.7)	9 (0.3)	179 (0.5)	0 (0.0)
Moderate		766 535 (4.7)	1349 (3.0)	12 (6.0)	159 (7.5)	30 (3.0)	265 (8.9)	883 (2.5)	0 (0.0)
Moderate positive		2 219 065 (13.7)	4921 (11.1)	20 (10.0)	241 (11.4)	126 (12.7)	603 (20.3)	3418 (9.6)	513 (18.3)
Positive		5 827 290 (35.8)	16 844 (37.8)	70 (34.8)	580 (27.3)	438 (44.2)	1298 (43.7)	12 165 (34.3)	2293 (81.7)
Very positive		7 047 355 (43.3)	20 661 (46.4)	94 (46.8)	1110 (52.3)	378 (38.1)	772 (26.0)	18 307 (51.7)	0 (0.0)
Extremely positive		183 105 (1.1)	493 (1.1)	5 (2.4)	17 (0.8)	12 (1.3)	17 (0.6)	442 (1.3)	0 (0.0)
Urbanisation grade									
Urbanised area (yes (n (%))	Neighbourhood	10 099 420 (61.8)	25 702 (58.8)	142 (71.4)	1194 (58.7)	685 (70.1)	2278 (76.7)	18 947 (54.5)	2456 (88.9)

*Table 4 presents data for all cohort studies in 2006, except for the Generations^2-study. For the Generations^2-study geo-data from 2009 are shown.
†The sample size may vary for some variables, because of missing values. Means and SD are presented for normally distributed continuous variables. Medians and IQR are presented for skewed continuous variables. Frequencies and proportions are presented for categorical variables.
‡In 2006 and 2009, there were 458 and 411 municipalities in the Netherlands, respectively.
dB(A), A-weighted decibels; GECCO, Geoscience and Health Cohort Consortium; n, number of observations; NO_2, nitrogen dioxide; NO_x,nitrogen oxides; PC4, 4-digit postal code; PC6, 6-digit postal code; PM_{coarse}, particulate matter with diameter 2.5–10 µm; PM2.5, particulate matter with diameter ≤2.5 µm.

Table 5 Differences in geo-data between urban and rural areas within GECCO*

	Spatial scale	Respondents in urban areas (n=25 702)	Respondents in rural areas (n=17 976)	P value
Population and households				
Number of men and women (Median (IQR))	PC4	9540.0 (6915.0–12 350.0)	5265.0 (2570.0–8390.0)	<0.001
Percentage of residents (≥65 years) (Median (IQR))	Neighbourhood	12.0 (7.0–18.0)	13.0 (10.0–16.0)	<0.001
Percentage of Western immigrants (Median (IQR))	Neighbourhood	9.0 (7.0–11.0)	5.0 (4.0–8.0)	<0.001
Percentage of non-Western immigrants (Median (IQR))	Neighbourhood	8.0 (4.0–16.0)	2.0 (1.0–3.0)	<0.001
Average household size (Mean (SD))	PC4	2.2 (0.3)	2.5 (0.2)	<0.001
Housing stock (Median (IQR))	Neighbourhood	1530.0 (875.0–2827.5)	790.0 (325.0–1525.0)	<0.001
Socioeconomic status				
Socioeconomic status score (Median (IQR))	PC4	0.16 (−0.53–0.63)	0.40 (0.08–0.71)	<0.001
Home value (in €1000,-) (Median (IQR))	Neighbourhood	189.0 (153.0–229.0)	230.0 (190.0–276.0)	<0.001
Social security				
Number of social security beneficiaries per 1000 households (Mean (SD))	Neighbourhood	50.3 (46.8)	20.3 (18.9)	<0.001
Number of incapacity benefits per 1000 residents (15–64 years old) (Mean (SD))	Neighbourhood	79.3 (28.3)	73.8 (32.7)	<0.001
Noise				
Road-traffic, rail-traffic and air-traffic noise (in dB (A)) (Mean (SD))	PC6	54.2 (4.7)	51.7 (6.6)	<0.001
Air pollution				
Mass concentration of NO_x (in µg/m^3) (Mean (SD))	PC6	38.1 (10.7)	28.3 (7.3)	<0.001
Reflectance of PM2.5 filters (in 10^{-5}/m) (Mean (SD))	PC6	1.3 (0.2)	1.1 (0.2)	<0.001
Mass concentration of PM2.5 (in µg/m^3) (Mean (SD))	PC6	16.6 (0.6)	16.4 (0.7)	<0.001
Mass concentration of PM_{coarse} (in µg/m^3) (Mean (SD))	PC6	8.6 (0.8)	7.9 (0.3)	<0.001
Mass concentration of NO_2 (in µg/m^3) (Mean (SD))	PC6	26.8 (5.7)	19.3 (4.1)	<0.001
Liveability				
Liveability (n (%))	PC4			<0.001
Extremely negative		35 (0.1)	0 (0.0)	
Very negative		201 (0.8)	0 (0.0)	
Moderate		1310 (5.1)	6 (0.1)	
Moderate positive		4475 (17.4)	363 (2.0)	
Positive		13 552 (52.8)	3012 (16.8)	
Very positive		5998 (23.4)	14 116 (78.9)	
Extremely positive		96 (0.4)	384 (2.2)	

*The sample size may vary for some variables, because of missing values. Means and SD are presented for normally distributed continuous variables. Medians and IQR are presented for skewed continuous variables. Frequencies and proportions are presented for categorical variables. Differences in mean were tested using Independent-Samples T-test for normally distributed continuous variables, differences in median were tested using Mann-Whitney U test for skewed continuous variables and differences in frequencies were tested using Pearson χ^2 test.

dB(A), A-weighted decibels; GECCO, Geoscience and Health Cohort Consortium; n, number of observations; NO_2, nitrogen dioxide; NO_x, nitrogen oxides; PC4, 4-digit postal code; PC6, 6-digit postal code; PM_{coarse}, particulate matter with diameter 2.5–10 µm; PM2.5, particulate matter with diameter ≤2.5 µm.

is a need for resources and improved tools to quantify environmental contributions to health and disease. Currently, the knowledge of individual-level physiology and disease manifestation as well as the tools to study these relationships are far ahead of those for the more upstream environmental characteristics that may influence behaviours and health. The main strengths of GECCO are the centralisation of a variety of objectively measured geo-data on the address-level, postal code-level and neighbourhood-level and the linkage of these environmental-level data to individual-level data from six longitudinal cohort studies in the Netherlands. GECCO facilitates and enables researchers from various disciplines to address research questions on the relationships between the environment and health outcomes. The collaboration between the cohort studies in GECCO

increases the power of analyses and ensures sufficient geographical variation in environmental determinants. Although the collaboration between the cohort studies in GECCO increases power of analyses and enables nuanced analyses on specific subgroups, procedures are required to harmonise variables between cohort studies.

Some geo-data (eg, traffic noise) have been suggested to vary more over time than other geo-data (eg, air pollution).[44–46 66] A strength of GECCO is that a variety of geo-data have been collected for different years. This makes it possible to link most geo-data to the exact assessment period of the cohort studies. For this cohort profile, geo-data were linked over periods as closely matched to the assessment period of the various cohort studies, resulting in a temporal mismatch of a maximum of 5 years for some of the participants. This particular mismatch is related to the linkage of 2009-data on air pollution to data from NESDA in 2004 and can still be considered as an accurate match.[44–46]

For this cohort profile, the linkage of geo-data with individual-level cohort data was done locally without confidential information (eg, residential addresses) leaving the research premises, so that the privacy of respondents is safeguarded at all times. Although some geo-data were collected on the address-level, it should be acknowledged that most collected geo-data in GECCO are related to administrative residential areas and are not related to specific contexts (eg, work environment or exact geographic life environment) that might also impact health and well-being of individuals.[67]

A consortium with such a high number of individuals using the same geo-data offers unique opportunities for (longitudinal) studies on the complex relationships between the environment and health outcomes. For example, future studies could focus on the associations of environmental exposure measures with physical functioning, psychosocial functioning, biomarkers and lifestyle behaviours.

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