Landscape series: 6

Inconveniences in the home neighborhood in Aruba

"Typical wildered open cacti-scrub landscape
Overgrown by grasses: former agricultural Cunucu"

Photo: Ruud Derix, 2003

The Aruban landscape has undergone many changes in history. This paper is part of the landscape series:

"Spatial Developments in the Aruban Landscape: A multidisciplinary GIS-based approach derived from geologic, historic, economic and housing information"

2016

Table of contents

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This paper is part of a series on the developments that relate to the Aruban landscape. To bring into perspective the current environmental threats and developments, we review aspects of inconveniences that Aruban household members experience within the direct neighborhood of their living quarter. We call the circumstances that surround these inconveniences conflict situations. Insight in conflict situations that relate to the local environment is vital to understand the effect of for instance urbanization and other socioeconomic developments on wellbeing and the developments in land-based and marine ecosystems.

At the basis of tourism in Aruba lies the natural beauty of coastal waters and ecosystems. Few people, however, understand that the quality of the coastal land arises not just from geological inheritance, but that it is dependent on present-day processes on land and at sea, and, that the crystal clear waters and fauna-rich marine ecosystems depend on a very delicate environmental balance between land and sea. It is a cynical truth that the success and economic developments on land undermine the quality of these ecosystems, posing a threat to nature and, therefore, also to tourism exploitation itself.

Economic developments come with human interference, habitat destruction, pollution and waste. In the limited availability of space on a small island like Aruba, sustainability is built on the delicate relationship between occurrences on land and at sea, i.e. changes in the landscape and environment are influenced by changes in the socio-economy and vice versa. Sustainable management requires anticipation and fine-tuning of current general knowledge. What makes "*calibrating*" actions a challenge is that the effects of human impacts partially remain hidden and accumulate until the threshold level is surpassed at which the effects become apparent. For instance, chemical pollution of groundwater and soils poses a risk to the environment and to public health with possibly long-term and costly consequences, but until it is significant the processes of chemical pollution are easily overlooked.

In this paper we will focus on the interface between the economy, society and the environment, where the results from human economic action start to bounce back on the wellbeing. First, we will focus on the apparent inconveniences at *home* in respect to the *local neighborhood.* Home is considered the place in which we experience most of our quality of life and where we are meant to experience the security of a shelter. Next, we will investigate some of the more 'hidden' processes in the environment that accompany economic development and that may not yet be in tune with our efforts to attain sustainable living.

Inconveniences in the home neighborhood

The spatial analysis of inconveniences that are experienced in the neighborhood of households can provide insight in the distribution of potential risks to environmental and public health. A higher spatial resolution of the mapping of residential concern pinpoints areas of conflict that otherwise may remain unnoticed (Leonard, Caughy, Mays, & Murdoch, 2011). This is what we intend in this study. The Census in 2010 included questions about how household members valuated the surroundings of their living quarter. The primary question was: "*Do you or more members of the household, experience any inconvenience in your immediate environment from…*..example 1, example2, etc."

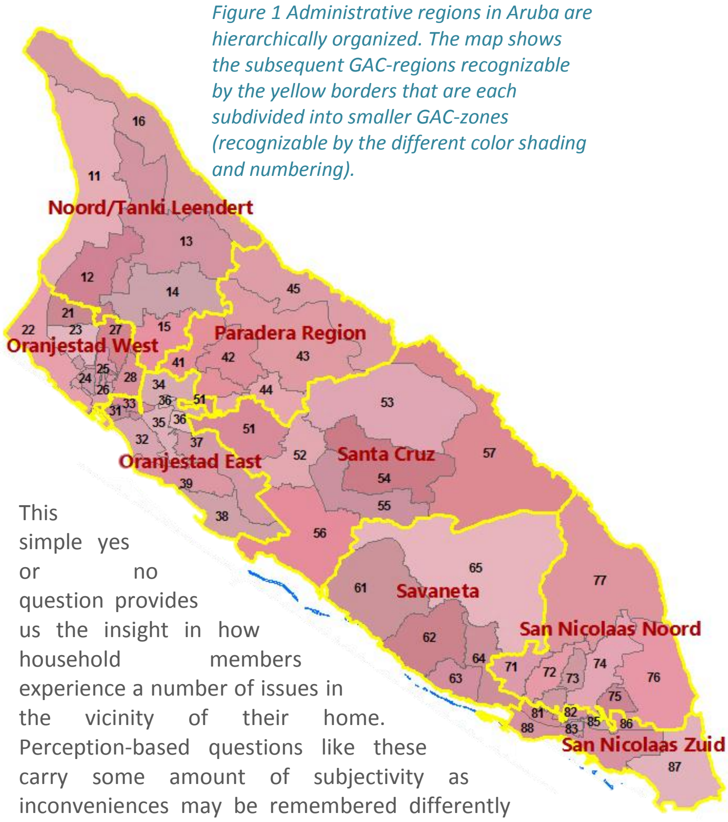


Figure 1 Administrative regions in Aruba are hierarchically organized. The map shows the subsequent GAC-regions recognizable by the yellow borders that are each subdivided into smaller GAC-zones (recognizable by the different color shading and numbering).

This simple yes or no question provides us the insight in how household members experience a number of issues in the vicinity of their home. Perception-based questions like these carry some amount of subjectivity as inconveniences may be remembered differently dependent on circumstances and timing. It is a strong argument, however, that something may be out of the ordinary when several households in the same neighborhood share a similar perception. Similar questions were asked in earlier Censuses, thus we can compare the spatial distribution of inconveniences over several decennia. Methodologically, however, a comparison between years, is only possible at the level of GAC-zones[1], i.e. at less spatial detail (Figure 1) since the GAC-zone is the highest level of detail that both the Census in 2000 and 2010 have in common. Moreover, due to the large surface extent of some zones it is difficult to link findings to local spatial characteristics at a finer spatial detail.

[1] The Geographical Address Classification system (GAC, 2012) is an administrative system of classification that was developed in Aruba for the purpose of information analyses. Its hierarchical structure enables users to present information at three different administrative levels. The GAC-system divides Aruba into 8 regions (see figure 1). Each of these regions is divided into a number of zones. Each zone consists of a number of streets or neighborhoods that however cannot easily be displayed as a surface area since the addresses do not fall exclusively in a specific area but overlap in space. A few zones (in particular along the Northeast coast) still remain largely unpopulated.

Therefore, in 2010, in preparation of the Census, we anticipated that we should be able to perform data analysis preferably at a higher spatial resolution. To overcome the lack of spatial detail we were able to aggregate and disseminate, in compliance with the rules of privacy protection, the point-based Census information at the level of GAC-zones, as well as at the level of a range of grid-tessellations with smaller square areas.

Environment issues that cause inconveniences at home

We reviewed if households experience inconveniences from 'dust', 'air pollution', 'noise', 'traffic', 'flooding after heavy rains', 'litter and accompanying stench', 'car wrecks' and 'stray dogs'. Some households refrained from participation in response to these types of questions (between 0.5% and 0.7%).

Dust is caused by the dry climate and constant (Northeast Trade) winds and is a common problem in Aruba, particularly in the more open areas. Households were asked specifically about whether they experienced some inconvenience due to an excess of dust, caused for instance, from *excavations*, *dirt roads* or *new construction* nearby. In similar fashion we asked about air pollution[2], exemplified as inconvenience for instance from *stench, exhaust fumes, soot, etc*., about noise, exemplified as sound hindrance from *airplane traffic or neighborhood nuisance*, about traffic, exemplified as inconvenience from *unsafety or other traffic related activity*, and about litter, exemplified as inconveniences from *dumped litter* or *such activities* in the direct neighborhood of the living quarter.

Inconvenience from	Dust	Noise	Air Pollution	Flooding
N zones with a decrease in inconveniences	49	30	15	9
N zones with an increase in inconvenience	0	19	34	40
Total GAC-zones	49	49	49	49
% of zones with a decrease	100%	61%	31%	18%
% of zones with an increase	0%	39%	69%	82%

Table 1 Number of GAC-zones where there was an increase (worsening situation) or decrease (improvement) in the percentage of households that experienced the specific inconvenience in their household neighboorhood in 2010 in comparison to the situation in 2000.

Comparison between the data of 2000 and 2010

In table 1 we summarize at the level of zones, changes between the 2000 and 2010 with regard to inconvenience from *dust, noise, air pollution* and *flooding.* A distinction is made per GAC-Zone whether there has been an increase or a decrease in the proportion of households that expressed their respective inconveniences in 2010 as compared to 2000.

[2] The US Environmental Protection Agency distinguished six major sources of Air Pollutants: Carbon Monoxide (CO), Lead (Pb), Nitrogen Dioxide (NO_2), Ozone (O_3), Sulfur Dioxide (SO_2), and Particulate Matter (PM_{10} or smaller).

The results show that the proportion of households that indicated to experience inconvenience from *dust* dropped within *all* GAC-*zones*. This does not imply that households do not experience inconveniences from dust anymore in 2010, but suggests that there has been a positive change towards improvement in how household members experience the direct surroundings of their home with regard to nuisance from dust. In regard to *noise* the situation appears to have improved in 61% of all zones.
In contrast, with regard to inconvenience from *air pollution*, that was exemplified by stench, exhaust fumes, or soot in the direct environment of the home, the situation worsened in 69% of all zones.
Similarly, inconvenience from *flooding after heavy rainfall* worsened in 82% of all zones in 2010 compared to 2000.

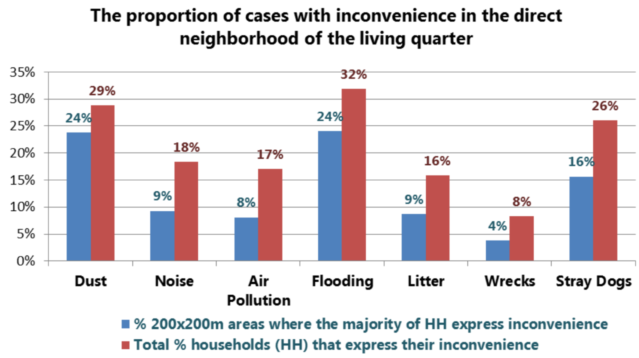


Figure 2 Relative level of inconveniences in 2010 per type of inconvenience and distribution over the 200x200m residential areas.

Prevalency in 2010 across 200x200 meter grid

We researched the occurrence of inconveniences from dust, flooding, litter, air pollution, noise, car wrecks, and stray dogs in more spatial detail at the level of 200x200 square areas to be better able to discern whether the inconvenience is concentrated in a specific area or whether the phenomenon is more common and occurs in all corners of the island. As the visualization by grids is a new and more recent method, only the data from the Census in 2010 could be used for this analysis. The local concentration of prevalent grid cell areas, i.e. 200x200m area in which more than 50% of households experiences inconvenience, reveals additional emblematic information on visual inspection of the map representation.

First, we analyze the spread of inconveniences, expressed as the proportion of inhabited 200x200m square areas where we observe prevalence (figure 2).
We noticed that the proportion of households that expressed some level of inconvenience was relatively high. For instance, inconvenience from *flooding* was expressed by 31.8% of all households and represents almost a quarter (24%) of all inhabited 200x200m areas.

Inconvenience from *dust* and *from stray dogs* was similarly reported, i.e. in respectively nearly one out of four (24% of inhabited space) and one out of six (16%) 200x200m square areas. Other kinds of inconveniences were much less widespread, such as inconvenience from *noise*, *litter, car wrecks* or *air pollution* (in respectively 9%, 9%, 4% and 8% of the inhabited square areas). Yet, prevalence in inconvenience in one out of every ten 200x200 m areas is still considerable.

Following, the areas where the majority of households (categorized as 50-75% and 75-100% of all households in the area) expressed their inconvenience is spatially visualized in the maps in figure 3c-g. We will discuss each of the conflict situations in more detail, next. The occurrence of inconvenience from *flooding after heavy rainfall* is discussed in a separate section in this paper.

Dust

Dust originates from solid particles (particulate matter) that primarily come from the soil, carried by the wind by human activities such as from construction and land clearance, traffic on unpaved residential roads, or, from the use of off-road vehicles on nature trails. Dust may also come from sea salt, pollen, spores, and tire particles as well. Small airborne dust particles are inhalable and can be carried long distances by the wind. Large particles from fugitive dust easily settle on the ground or rest on the vegetation where it cloaks and suffocates the foliage. Smaller particles (PM_{10} or smaller[3]) usually remain airborne for a while and when inhaled can cause diseases in the lower respiratory tract or in the lungs (Brunekreef & Forsberg, 2005).

Dirt and gravel roads are capable of producing large amounts of dust that can affect not only the vegetation and health, but even the chemistry of adjacent soils (Brown, 2009). Therefore, it is very relevant to evaluate the type of gravel and sand that is used on dirt roads (Kupiainen, Tervahattu, & Räisänen, 2003). Although the chemical composition of the dust particles play a role, its small particle size and the ability to be inhaled deeply into the respiratory tract defines the presence of small dust particles as a serious health risk factor, particularly in circumstances of prolonged exposure. Monitoring the concentration of PM_{10} and smaller particles (PM_5 and $PM_{2.5}$) is an important aspect in health programs. The ambient airborne PM concentration thresholds are commonly regulated under national health and safety codes (Pope, 2000) while internationally the UN/EU have set more general regulations to safeguard public health (unece, 2012).

The definition of dust may not be 100% robust to misinterpretation (EPA, 2015). Technically, we defined dust during the Census as *fugitive dust that* originates from soil. If dust incorporates small particles from combustion such as car exhaust with high carbon content, even if it can cause soiling, this is technically referred to as *air pollution*.

We explained the definitions that we used during the Census in 2010 by examples, however, we cannot be 100% sure that there has not been some confusion[4] between *dust* or *air pollution*. The data show the presence of inconvenience from *air pollution* along some of the main roads as well. This may correctly be considered attributable to the perception of small *particulate matter* from car exhaust, but it may also come from small *particulate matter* caused by the vehicles that swirl up dirt or particles from abrasion of the surface of roads and tires.

Our study shows (Figure 3d) that nearly a quarter (24%) of all households experience inconvenience from dust in the surroundings of the living quarter. In general, inconvenience from dust appears widespread in Aruba and is absent only in or near the dense populated centers of Oranjestad and San Nicolaas. The spatial pattern of households that experience inconvenience from *dust* reveals some small areas and a single larger area of particular concern, i.e. in the north in Aruba.

We lack adequate information about what exactly causes the dust (excavation sites, dirt roads, construction sites, etc.). In particular the northern region has been under construction during the recent decade and many residential roads remained unpaved. It is likely that in this region nuisance from the windblown sand and dust may be caused by the fine-grained gravel of sandy dirt roads and the combination of Northeastern Trade winds.

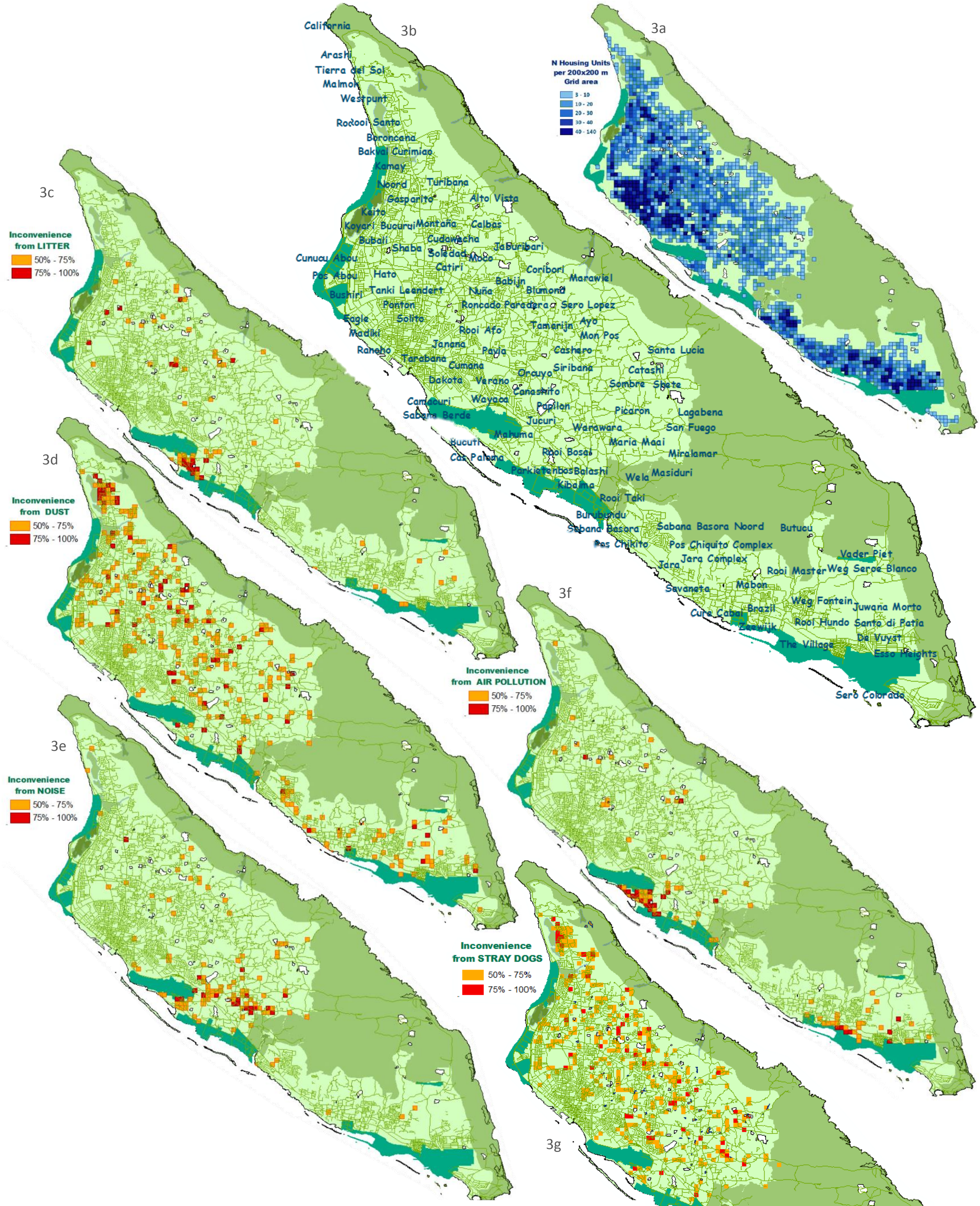
Noise

Inconvenience from noise occurs near the Reina Beatrix Airport (Figure 3e). It goes without saying that the departing and arriving planes may cause hinder from noise for those who live near the airport. Some concentration of areas with prevalence for inconvenience from noise occurs along the main road network. Worth mentioning is also the intense traffic in these locations, which may be the main cause of noise inconveniences. Inside residential neighborhoods inconvenience from noise may arise as well, for instance when the residential road serves as shortcut between different localities. A comparison between the maps of *inconvenience from noise and inconvenience from traffic* (Derix, 2013) indeed shows some concurrence along a few small roads within residence neighborhoods and suggests the existence of a road shortcut at these locations.

Inconvenience from noise does not only include inconvenience from the sound of airplanes or traffic, but may come from other sources of nuisance within the neighborhood as well. Inside residential areas we recognize ‘hotspots’ where households express their inconvenience from noise that is unlikely caused by traffic. In such cases there may be a local different source of hindrance, such as for instance ‘loud’ neighbors or business activity.

[3] PM_{10} is particulate matter with an average diameter size of 10 microns. This type of particulate matter is considered likely to be able to be inhaled and reach into the respiratory tract. PM_5 and $PM_{2.5}$ are considered likely to be able to be inhaled and reach into the respiratory tract as well as deeper in the lungs.

[4] Generally speaking, small particulate matter is a type of air pollution but commonly and also so during the Census in 2010 one specific type of small particulates, fugitive dust is considered as a separate category; in our case to be able to label inconveniences from dust from traffic on unpaved roads. The EPA defined Fugitive emission as particulate matter that is generated or emitted from open air operations in contrast to emissions that passes through a stack or a vent)



Figures 3 c-g show map representations of the spatial distribution of 200x200m square areas that show an above average level of inconveniences in the household for a number of activities in the direct surroundings of the living quarter. The respective square area is highlighted in orange or red color when respectively 50% to 75% percent and over 75 % of the households in that area reported to experience a specific inconvenience.

The maps also depict the main road network, as well as economic space (colored in greenish blue) and space reserved for nature (colored in green) (DIP, 2009). The map on top (3b) presents information about the names of local neighborhoods. The small map on the top right (3a) shows the density distribution of housing units in Aruba as a grid tesselation of 200x200m square areas with each cell catagorically representing the total number of housing units in that specific square area.

Air pollution and Litter

'Simeon Antonio', 'Bucuti', 'Cas Paloma' 'Parkietenbos', and to some degree also 'Mahuma' are adjoining localities that are situated just south of the Reina Beatrix Airport, near the public dumpsite and near businesses that use heavy road equipment. These neighborhoods are of particular concern as a majority of households express their inconvenience from noise (Figure 3e) and more so air pollution (Figure 3f) and litter (Figure 3c).

A large open waste dumpsite situated at Parkietenbos is likely to be one of the causes of the inconveniences experienced by neighboring households. More recently, a waste *separation* plant[5] was constructed at 'Parkietenbos', but the open public dumpsite is still operational.

Air pollution is an issue in households situated south of the airport but also near the oil refinery in San Nicolas (Figure 3f).

Abandoned excavation sites may serve as legal *(*RWZI-dumpsite in Wayaca) or illegal dumpsites (dumpsite at Sero Lopez). Both are frequently used as a source for litter, waste and other types of local disturbance in the surrounding areas*.* Similar in size as the excavation site in 'Mahuma' (currently closed) is a site at Alto Vista, in the northeast, and in the area of 'Weg Fontein', north of San Nicolaas. In both areas we observe heightened levels of inconvenience by households from litter and stench.

Stray Dogs

The main map in figure 3 shows the locations where hinder exists caused by stray dogs. Examples are found all over the island, but more so in the more rural regions and less in the city centers of Oranjestad and San Nicolas. In the region of 'Westpunt', east of the saliñas[6] in the north, and in 'Sabana Basora' and in a number of small locations, we observe a concentration of inconvenience from stray dogs. In 1989 (Sprang & Quant, 1989) an inventory survey of dogs and cats was conducted in Aruba. The study was repeated in 2003 (Rossen, 2003). In 1989, the researchers found that one in three dogs had regular access to roam free outside the compounds, compared to about one in four dogs in 2003. In 2003, one in every twenty dogs had full access to the street at any time of day. Almost two thirds of households owned more than one dog. The relatively high density of residential dogs is in line with the level of hindrance in 2010 that is spatially represented in figure 3g.

In 2015 new legislation was implemented to assure that households keep their dogs inside their own premises. The effort was to prevent hinder from free roaming residential dogs that disturb/attack pedestrians and cyclists.

Stray dogs are still a common sight, however. Mostly, these are abandoned dogs.

[5] Waste to Energy Plant

[6] The saliñas are the coastal wetland areas that still exist in the Northwest, but that have been blocked from the sea by tidal barriers and road infrastructures. At current, the brackish floodplain areas still show the characteristics from vegetation's adaptation to salinity and the presence of typical (migratory) bird species.

Soil enrichment, land-based pollution and rainwater runoff into the marine waters

Hidden disruptive processes in the environment

Little is known by the public about the Caribbean Sea which is under continuous stress from eutrophication and pollution. On the scale of regional polluters the position of Aruba has changed drastically in recent years, but the small island setting allows very little margin for error.

After the closure of the oil refinery in 2012, the direct environmental impact from pollution from the refinery activities ceased, but the consequences of earlier pollutive actions are still present[7]. Locally, in San Nicolas, and in the near region, problems still reside in the soils (Ridderstaat, 2007).

Today, pollution confines to small-scale industrial activities such as from the processing of salt water at the local water desalinization plant, from the leakage of the open dump site south of the Airport, from the traditional household cesspits, in particular in the coastal regions (that leak wastewater into the groundwater), and from the seasonal rainwater runoff into the sea. Many local cesspools near the coast situate on permeable Limestone Terraces and are traditionally made from bricks and not sealed at the bottom.

Hydrogeological/chemical studies (Finkel & Finkel, 1975) (Borst & de Haas, 2005) have emphasized the importance of freshwater retention sites to limit erosion and improve the formation of soils for agriculture and vegetation. Long-term monitoring studies of pollution and nutrient-enrichment in the neighboring islands Bonaire and Curaçao stress the impacts of daily pollution and eutrophication on the near shore coastal ecosystems and the lack of adequate sewage treatment plants that may prevent the sewage water to reach the sea (Lapointe & Mallin, 2011) (Goreau & Thacker, 1994). A proper water management on land is relevant for the maintenance of a healthy living environment on land as well as at sea.

Studies show that marine and terrestrial ecosystems in the Caribbean have difficulty with high levels of nutrient enrichment and thrive best in a nutrient-poor balance of state (Siung-Chang, 1997). In the worst case scenario, a nutrient rich coastal water stimulates microalgae growth (Lapointe e. a., 1998) and may create oxygen deprived zones. Under such circumstances, water becomes turbid (Goreau & Thacker, 1994) and coral communities, mangroves, and sea grass beds will suffer severe damage (UNEP, 2015). Other markers of a disrupted marine ecosystem are the lessened presence of predator fish that may trigger a population explosion of, for instance, jellyfish. It is without saying that even a small change in this direction may have a negative impact on the tourism industry.

The unforgiving disruptive enrichment by nitrogen and persistent/bioaccumulative substances of the nutrient-poor (oligotrophic) highly sensitive local marine ecosystems happens in an encroaching slow but devastating rate (Greenpeace.org, 2015), (Worldwatch, 2000) (Goreau & Thacker, 1994).

[7] http://www.oceanhealthindex.org/Countries/Aruba/

The contamination and enrichment of soils from household liquid waste and sewage may by itself be mild at any given moment but constituents accumulate in the soil and groundwater on a continual basis (Sharpley A.N., 1996). For instance, an alteration of the soil chemistry and acidification of the topsoil[8] is described from the local disposal of household waste, such as paints, detergents, oils and leaking batteries (Pimentel, 2005).
What happens next is that when soil constituents lose their binding capacity, nutrients such as nitrates, phosphates and urea find their way more easily from the groundwater into marine waters. Similarly, bio-persistent contaminants such as pesticides, heavy metals and household chemicals accumulate and seep into the deeper soil layers and groundwater and cause harm in the food chain at a large distance from their actual disposal site.

Next, we reveal some insight in the 'hidden' underlying process of infiltration of contaminants and nutrients into the natural surroundings and describe the role of typical geological and societal local circumstances.

The disposal of "eye-catching" municipal solid waste is recently well-organized, but the disposal of liquid waste still needs more attention. We have to gain information and grow awareness that helps to overcome and remove the solved substances of pollution and nutrient-enrichment before these can cause harm at sea.
In short, at the regional level, the processes that are less eye-catching but create accruing stress to the local marine environment are:

- *Acidification of marine waters, for instance due* to rising atmospheric concentrations of carbon dioxide (CO_2) and the consequential absorption of the gas by the oceans.
- *Sea water temperature rise*
- *Contamination and nutrient-enrichment of groundwater, in particular on the limestone, and their effluence into the marine waters*

Acidification may come from (polluted) stormwater runoff from land-based (industrial) activities. Unfortunately, we lack information about seawater acidification from land-based activities. Its impact even at a regional scale, however, may remain low since there is little industrial activity in Aruba. Thermal pollution at sea may come from 'coolant water'. Sea water temperature rise is expected to have a detrimental effect on marine life, although the phenomenon is at present insufficiently understood (Sewlal, 2010).

The effluent of land-based sources on the coastal marine environment has not been studied thoroughly in Aruba. Effluence can occur via:

- *Groundwater*
- *Rainwater runoff*[9]
- *Direct discharge* along the coast
- *Landfill leakage*
- *Fall-out* at sea as pollutants are carried by the wind

Better insight in these processes is relevant and significant to be able to manage the quality of near-coastal waters (Goreau & Thacker, 1994). We give an example of the dimension of pollution that can occur via waste water.

The effluence of pollutants from liquid waste

The constant drain of nutrients (and bio-persistent toxic substances) from residential living and economic activities filtrates in part into the soils and feeds into the groundwater. These land-based constituents eventually disperse into the coastal marine waters and overload the nutrient-poor (oligotrophic) marine ecosystems.
It is obvious that the high population density and impact from new building and road construction puts the small scale natural island setting under increasing stress. New insights learn that the question of when and where to act has long passed. Several studies in the Caribbean (Lapointe & Mallin, 2011) (Peters, 1997) have documented the effect from land-based runoff, the leaking of landfills, and, the warm water effluence on coral reef growth, or, the harm it brings to mangrove ecosystems along littoral coasts. Comparative studies in Aruba are lacking, however, but similar situations do exist.

A troublesome local situation with limestone terraces along the coast

The total balance of nutrients and contaminants (fertilizers, oils, salts, pesticides and detergents) that reaches the coastal waters will show considerable seasonal variation due to the seasonality of heavy rains and rate of evaporation.
As noted before, the *geology of the coastal zone* in Aruba may play an important role in the dynamics of exchange between land and sea. Most of the inhabited land along the coast is from karstic and highly permeable limestone rock (Derix, 2016c). Rainwater from the land interior reaches the porous limestone terraces from where most of it seeps into the sea, subterranean, via the ground water, via the faults and fracture lines or more directly at the surface via the dry-river systems. During most of the year, however, evaporation is so high as to prevent the effluence from leaking cesspools on the Batholith to reach the coastal waters. This may even be the case for many cesspools that are situated on the limestone terraces. In opposite direction, when evaporation is very high during the dry-season, coastal groundwater saline levels may even increase due to infiltration from sea water (Finkel & Finkel, 1975).
In contrast to the presence of limestone geological substrate, the compaction of soils and the cementation of the urban landscape will prevent rainwater to soak into the

[8] Nitrogen from wastewater sewage (detergents and urea) is thought to influence the biochemical processes in the soil. While there is an acidifying effect (biochemical release of free hydrogen (H+) acidic ions against less hydroxyl (OH-) basic ions) from ammonium nitrogen (urea) in soils, the highly soluble nitrates percolate into the groundwater. Acid surface soil can also increase dissolution of limestone layers and can cause dangerous sinkholes in Limestone layers on land.

[9] For a general discussion of urban wastewater runoff we refer to www.environment.nsw.gov.au/stormwater/

soil and therewith increase the amount of urban pollution that is washed out with surface water.

So, the magnitude of the nutrients and contaminants that reach the sea may be constrained in time and place but also altered dependent on local circumstances.

Studies conducted in limestone areas in Italy show that in fact limestone is quite effective in the neutralization of wastewater nutrients, often already within a single km distance from the infiltration point (Masciopinto & Carrieri, 2002). Unfortunately in Aruba, the limestone rocks are only up to 2.5 km wide and situated directly at the coast. The chance that polluted groundwater will leak from the limestone into the marine environment is still likely.
Groundwater studies in Aruba (Finkel & Finkel, 1975) have focused on the potential reserves of drinking water for agriculture purposes. A baseline study exists, however, that focuses on anthropogenic influences on groundwater quality (Sambeek, Eggenkamp, & Vissers, 2000). The study reveals elevated concentration of nitrates in a number of wells on the island and suggests that this may relate to the presence of nearby cesspools. In particular, in areas where there is easy penetrable limestone, a*quifers* and *wells* will be more susceptible to infiltration by persistent organic compounds and bacteria or viruses from nearby cesspools and contaminated soils, than in other parts (Wolf, Nick, & Cronin, 2015).
Their findings stress that cesspools need to be able to withstand a period of flooding, in particular in the flood-prone areas, but more preferable, avoid any risk on leaking into the ground water from modern septic systems. Currently, in Aruba, there is a policy to allow only completely enclosed septic tanks for new construction, but the rule is not yet fully legally embedded.

Monitoring the discharge of nutrients and contaminants

To keep track of the amount of contamination and enrichment from liquid waste[10] that reaches the marine environment via ground- and wastewater runoff is a challenging task. In Aruba, coastal water samples are collected and analyzed with the purpose of regularly monitoring the quality standards of safe swim water. Studies from abroad show that the contamination and nutrients thresholds for safe swim water are actually insufficient to safeguard the quality of coral ecosystems (Goreau & Thacker, 1994). Besides, while the measurements occur along the shallow coastline, discharge into the sea may occur via groundwater springs that seep off the coast into deeper waters.

In the ideal scenario, we would like to monitor the spatial pattern and intensity of subterranean groundwater effluence in combination with the concentrations and geochemical interactions between local soil constituents and contaminants in Aruba. Such studies, when feasible at all, are very costly and may, therefore, never be performed.

An alternative objective, therefore, might be to combine information already gathered from elsewhere and distillate the ‘probably’ that similar situations may occur locally as well. For instance, a study in 2011 (Lapointe & Mallin, 2011) in Curacao and in Bonaire shows that in relation to maintaining a healthy deep and shallow reef ecosystem a number of contamination indicators have already exceeded threshold values. No such studies exist in Aruba, but given the relatively similar pressures from population and housing, and a well-comparable climate and geological condition, one may carefully consider whether in Aruba, similar contamination of marine waters may occur.
Furthermore, the monitoring of net imports and net exports already provide insight in the level of local usage of for instance fertilizers, pesticides, or, cleaning products, and, therewith, the detrimental impact from disposed chemicals and nutrients via water, land or air. Knowledge about the chemo-physical characteristics and interactions of contaminants with local soil constituents, in combination with local hydrological and geomorphological conditions, may be useful to model impacts.

To get an impression of the amount of chemicals that is disposed in the local environment, yearly, we show the *total yearly import* of *soaps*, *detergents, cleansers* and *fertilizers* (the respective export figures are generally low and have not been shown in the representation in figure 4).

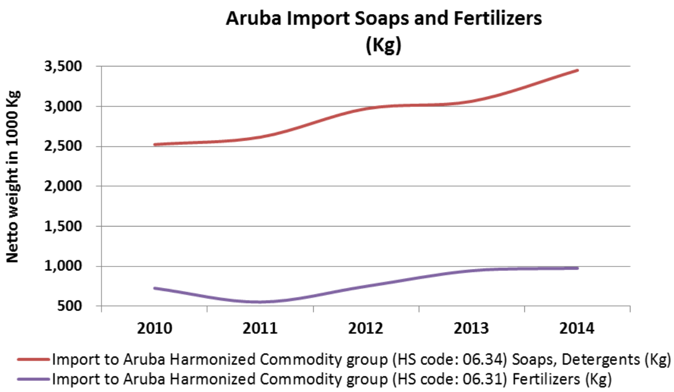


Figure 4 presents the weight import figures of respectively soaps, detergents and cleansers and of fertilizers, categorized by Aruba Customs Authority according to the Harmonized coding System[11] under category code 06.34 and 06.31, respectively.

In Aruba, in the absence of e central sewer system in most areas, soaps, fertilizers and pesticides are likely to end up in the garden soils and cesspools. The utilized substances will disintegrate and interact with soil constituents to become harmless substances, but part will accumulate in in the cycle of contaminated soil, ground- and effluent waters. On occasion, when disposed with the public waste stream the chemicals may be incinerated at the new local waste incineration plant, but we do not expect this to be

[10] We define household liquid waste as wastewater with contaminants of oils or fats, paints, detergents, cooking oils or hazardous household liquids, etc.

[11] CBS uses the International General Trade System for the processing and publication of all import and export data by commodities and by country. Total Imports and total export include all goods entering and respectively leaving the economic territory of Aruba. The economic territory of Aruba comprises of Aruba (the free circulation area) and the Free Zone Aruba. This is consistent with the General Trade System.

the case for most of the cleaners, pesticides and fertilizers. There is no separate waste collection stream for liquid waste products (except for some oils, fats and oil residues by restaurants and local car repairs, etc.).

Figure 4 shows a substantial rise (40%) in the import of *cleaning products* over the last five years (from 2.5 mio. kg up to 3.5 mio. kg per year). As most of these products will end into the soil we assume that there is a steady accumulation of phosphates and nitrogen in the soils that will eventually overload the binding capacity of soil constituents and wash away. Also, figure 4 reveals a rise in the import of fertilizers, be it in smaller quantities, up to 1 mio kg in 2014. We lack detailed local information about the effect of nutrients and (chemical) constituents on the oligotrophic local marine environment.

Uncontrolled effluence of nutrients and contaminants into the sea is influenced as well by local flooding after heavy rainfall and run-off into the sea.

Next, we will provide information about the level of incidental flooding after heavy rainfall, based on information gathered during the Census in 2010.

Incidental flooding

Local flooding carries a cost of damage to private and public property and infrastructure, causes accidents and inconveniences, and also poses a risk to public health.
Mostly, rain falls without causing extreme harm, but every few years, incidents occur when areas are flooded after heavy rainfall. To catch the incidental rainfall, rainwater dams (locally called 'Tanki') are built with the ability to overflow, but on one such occasion, unexpected damage to private property downstream occurred, when the rising mounts of water caused a breach in the Tanki outer wall.

In some areas, neighborhoods regularly suffer from the temporary inundation after heavy rains and inhabitants feel frustrated by the recurring events. New construction constantly changes the face of the landscape and changes the natural course of the rainwater. Sometimes small or even large dry-river waterways appear to be blocked completely. Later, when extreme rainfall occurs, the new homeowners in these neighborhoods get confronted with problems they were previously unaware of.

We analyzed the percentage of households that experience inconvenience from *flooding after heavy rainfall* in each of a 200x200 meter area. In *figure 5* we show the 200x200m square areas where over 50% of households experience inconvenience from flooding after heavy rains and refer to these as the *flood prone* areas. The data are from the Census in 2010. The maps also show the location of dry-rivers and the location of different watershed areas (*figure 5A*), the height topology (*figure 5B*) and the extent of the limestone layer near the coast. The location of the household draining systems is exemplified in more detail *in figure 5C and 5D* (CBS, 2010).
Coincidentally, the Census activities in 2010 took place during a period of intense rainfall.

Characterization of the flood prone areas

We mentioned already, that a relatively high percentage of households (32% in 2010) express experiencing inconvenience from *flooding after heavy rains* (figure 2). These households expressed inconvenience from flooding in nearly a quarter (24%) of all residential 200x200m areas. In 82% of the GAC zones, the inconvenience from *flooding after heavy rains* was expressed to be higher in 2010 than in 2000 (Table 1). This is an indication that the situation in the neighborhoods had worsened over the last decennium. The reason seems straightforward as the density of construction there increased over the years.

However, many of the flood prone areas are located on the Lower and Middle Terraces (Busonjé, 1974) along the coast. We typically would not expect flooding areas on a high permeable limestone substrate. The limestone is on average between 15 and 45 meters thick and rests on crystalline rock or on a bed of layered clays and sand. Furthermore, that close to the sea, the groundwater is only a few decimeters deep and not only the natural water runoff is slow in these low-lying areas, also the transmission speed[12] in the limestone is too slow to allow a rapid drain of rainwater. At a groundwater gradient of approximately 0.001 near the coast the transmissibility is calculated at about 1.1 mm/sec and 2.0 mm/sec at some distance more near the border with the crystalline Batholith (Finkel & Finkel, 1975). Transmissibility is known to become worse with soil compaction and subsurface obstruction as occurs, for instance from infrastructures and from the construction of hotels such as along the coast.

An exceptional high density of households that expressed inconvenience from flooding is located in the Northwest, south of Bubali Plas and in San Miguel (*Figure 5C*) and also in the Southwest, in Pos Chiquito and in Zeewijk (*Figure 5D*). Three other areas are worth mentioning, i.e. east of 'Kamerlingh Onne Straat' up to the 'De La Salle Straat' (in Oranjestad), in the area of Tanki Flip and in the area of Bucurui/Sabana Liber. Needless to say, there are other smaller spots where residents experience hindrance from *flooding after heavy rains*.

[12] Transmission is the passage of water through the substrate

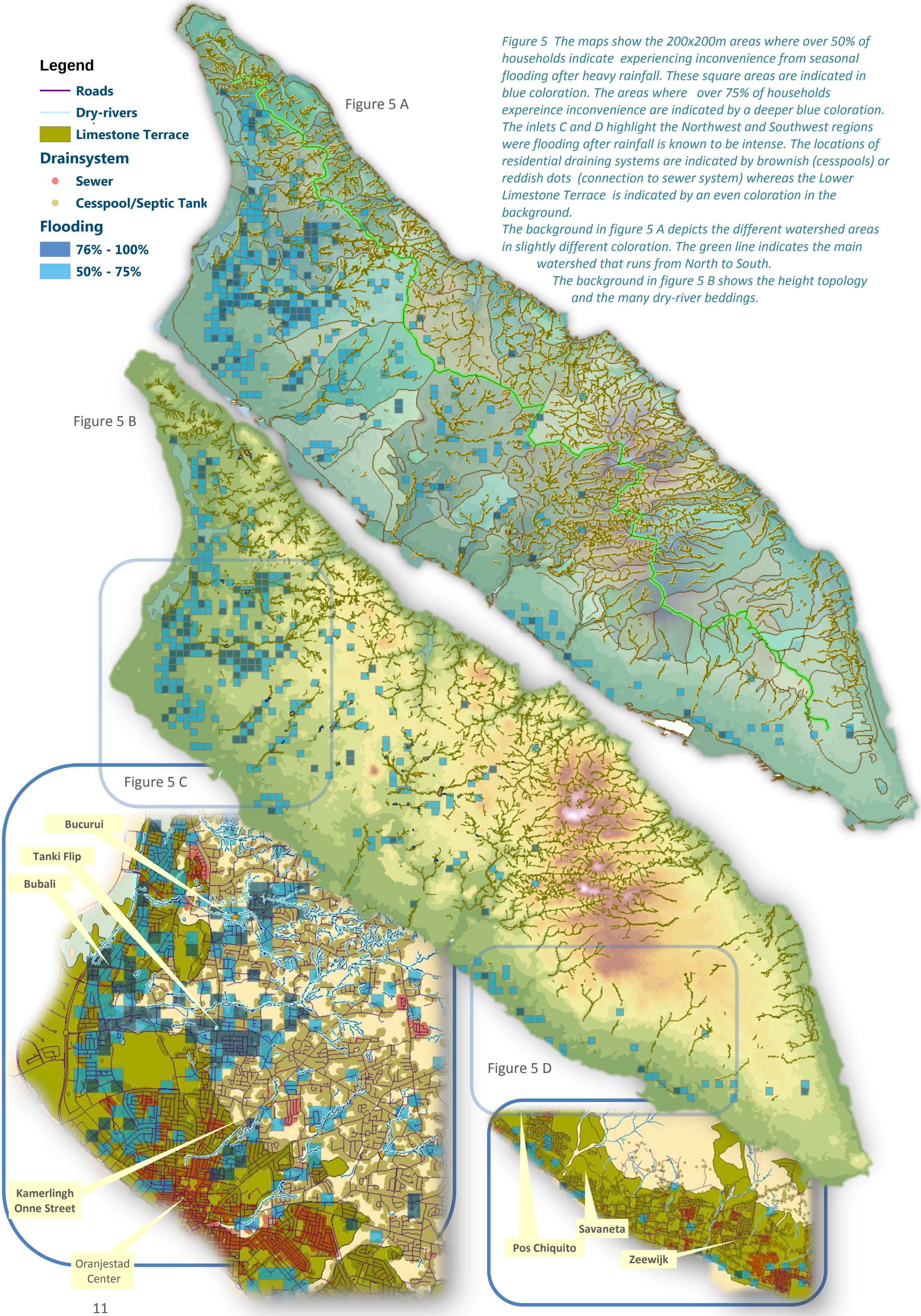


Figure 5 The maps show the 200x200m areas where over 50% of households indicate experiencing inconvenience from seasonal flooding after heavy rainfall. These square areas are indicated in blue coloration. The areas where over 75% of households expereince inconvenience are indicated by a deeper blue coloration. The inlets C and D highlight the Northwest and Southwest regions were flooding after rainfall is known to be intense. The locations of residential draining systems are indicated by brownish (cesspools) or reddish dots (connection to sewer system) whereas the Lower Limestone Terrace is indicated by an even coloration in the background.
The background in figure 5 A depicts the different watershed areas in slightly different coloration. The green line indicates the main watershed that runs from North to South.
The background in figure 5 B shows the height topology and the many dry-river beddings.

In an earlier paper on the geology of the landscape (Derix, 2016c) information from the Werbata map was discussed that outlines in fine detail the hydrological situation around the turn of the 19th into the 20th century. In 1911, Werbata already marked the strip along the coast north of Oranjestad and north of Savaneta as “flooded after rain”. Obviously, in absence of any housing, the area was considered unsuitable for inhabitation or for Aloe cultivation.

At the border between limestone terrace and batholith in the region of Bubali and Eagle, a number of (wind milled) wells pumped brackish and fresh groundwater to comply with the demand from the local population and their agricultural activities inland. Today, a local water sewage treatment plant (RWZI) is located next the small freshwater reservoir *Bubali Plas*. The saliñas that were present already a century ago also still exist, but as a result of land reclamation, drainage works, and weed invasion these wetland areas[13] are under continuous threat.

Drain problems for local housing projects seem to be solved with the construction of canals that improved the drainage and discharge of accumulated water to lower regions, such as in the area Madiki/Rancho (in Oranjestad) and in Pos Chiquito. In other areas such as in Bucurui/Sabana Liber the solution was more comprehensive and could not easily be solved by canalization since the area formed a local basin surrounded by infrastructure barriers.

A combination of size of the rainwater catchment area (background in Figure 5A), height topology (background in Figure 5B) as well as the type of geological substrate, type of plant cover or type of obstructions in the landscape define the likelihood of flood prone areas. Today the influence from man-made alterations to the natural course of the water adds to the topology of obstructions and causes some areas to suffer more than others.

For instance, the representation of watershed and height topology (Figure 5A and 5B) suggests a natural bottleneck in the low-lying area of Tanki Flip. In the same area, a large traffic junction with residential construction at all sides blocks the natural course of the water almost completely. The problem was largely solved with the construction of an artificial drain alongside the roads and traffic junctions (*see figure 5C*).

Similar low-lying areas exist *elsewhere* near the coast and more inland. A minimal difference in height may already suffice to slow down the natural drain of the rainwater, in particular when obstruction from housing development and infrastructure block the rainwater runoff.

Flooding of cesspools[14] and septic water infiltration

The inlets C and D of figure 5 show a detailed view of the spatial distribution of private and public sewer systems (red colored dots) and cesspools (beige-colored dots) in Aruba in 2010 (CBS, 2010). The inlets demonstrate that in the majority of the areas that are prone to flooding, households possess cesspools/septic tanks (see *Table 2*).

In 2010, in total 31.8% of households expressed inconvenience from flooding after heavy rains and 36.8% of these households (18% of all households) are located in the 200x200m areas that we defined as *flood prone areas* (i.e. while over 50% of households expressed inconvenience from flooding).

N	%	Type of draining system
76	*1*	have NO private toilet
543	*9*	have a Sewer
5.393	*88*	have a Cesspool/Septic tank
68	*1*	have a Combination Sewer - Cesspool/Septic
11	*0*	have other type of drain such as a chemical toilet
45	*1*	Not reported
6.136	*100*	Is 18% from total number of Households

Table 2 Households that locate in a flood prone area[15]

From all the households in the flood prone areas, 9% had a sewer connection and 88% had a cesspool/septic tank (Table 2). Across the total population of households, about 19% is connected to a sewer and 76% have a cesspool/septic tank. Some households may have a combination of cesspool and sewer system or use a chemical toilet (this happens for instance when the living quarter is a trailer without a separate drain), although these are small in numbers.

Cesspools in Aruba are traditionally built of stone and are semi-open to allow sewage to leak into the ground. An additional chamber enables filtration of the sewage such that it can be used for irrigation in the home garden. This ‘grey’ water is unsuitable for watering vegetables and herbs that are meant for human consumption as the water may still contain parasites and bacteria. As *seasonal flooding* occurs in areas where there are many cesspools, there is a certain risk to public health when there are cesspools that leak to the surface waters when submerged. Phosphates, nitrates and contaminants easily dissolve into the surface waters and flow into the sea with the rain-water runoff, whereas the discharge and scruff that may carry parasites float and settle to other populated areas and attract disease vectors.

[13] Both locations, the *saliñas* and the *Bubali Plas,* are recognized as important bird sanctuaries that play a role as important feeding and resting place for many migratory birds.

[14] A cesspool in Aruba is commonly a cemented underground chamber from blocks but semi-open to let the sewer water leak into the ground. Bacteria are important to decompose the solids, but quite often and unwittingly cleaners and detergents are disposed as well into the cesspool and this will kill the local bacteria. When decomposition of the discharges is incomplete and washed into the open there may be a threat to public health.

[15] A flood prone area is an area where over 50% of households in 2010 have indicated to experience hinder from flooding after heavy rains.

Geological unit *cf.* Busonjé	Sewer %	Cesspool/ Septic Tank %	Total %	N
Quartz-Diorite	***3***	***41***	***45***	**15,623**
Total Limestone	***16***	***36***	***54***	**18,937**
Deposit LT	*2*	*8*	*11*	3,675
Deposit MT	*11*	*24*	*37*	12,863
Erosion MT	*2*	*5*	*7*	2,399
Sub Total	*18*	*77*	*99*	34,560

Table 3 Percentage of households per type of drain system and type of geological unit in the most populated areas.
Source: Census, 2010 (CBS, 2010); map form Busonjé (1974).

We researched the proportion of cesspools on the limestone and on the Aruban Batholith. Differences in the composition of the substrate on the limestone and on the Aruban Batholith will have a different effect on the drainage and infiltration of sewage water (Sambeek, Eggenkamp, & Vissers, 2000).
Table 3 lists the proportion of household drainage system over the type of geological unit (see also *Figure 5C* and *5D*). The data shows that nearly half of all households with cesspools/septic tanks (36% from 77%) are situated on the permeable limestone terrace and just over half (41%) are situated on dioritic soils. From all sewer connections 16% of households are situated on the Limestone Terraces against only 3% on dioritic substrate. The low water table during part of the year will have made a sewer system essential to inhabitation on the more populated areas near the coast, albeit that many of these areas are not yet connected.

A study by Finkel and Finkel (1975) stresses the limited capacity of crystalline rock (Aruba Batholith) to absorb sewage from cesspools, although, on the limestone rock similar to in the detritus valleys of dry-rivers or more deep along the geological fault lines, sewage is expected to percolate even more easily into the groundwater. Groundwater underneath the hard crystalline rocks of the batholith is believed to follow a pattern of fracture lines and weak spots where differential weathering took place. At the border between Batholith and porous Limestone Terraces, dry-rivers often seem to end, but actually follow a path underneath the eroded limestone rock towards the sea or cut through the layer completely.

So, during flooding not only contaminants from the topsoil, but the contents of cesspools may also pollute surface waters and flow into the sea. The constant leaking of cesspools poses a serious risk to the groundwater quality and more directly to the water quality of nearby wells and aquifers (Finkel & Finkel, 1975). The vulnerability in flood prone regions along the limestone coast poses a risk in particular.

Septic water infiltration, however, also has a desalination effect on the groundwater that is particularly relevant during the dry-season along the coast, when, due to the water hydraulics and the high evaporation on land, salt water infiltration tends to be strongest. More inland, residential water discharge dilutes the salinity of the groundwater that has become brackish under the influence of the salt-spray winds (Sambeek, Eggenkamp, & Vissers, 2000).

Aside from the *hydrological mechanisms*, *chemical interactions and binding* with subsoil constituents will determine the speed at which contaminants and nutrients from human action on land are released into the fragile marine ecosystem. For instance, percolated *phosphorous* compounds of waste water bind easily with, and may even dissolve limestone (be it that this is a slow process over many years). In excess availability however, the not fixated compounds diffuse into the sea. *Nitrates* may rinse even more directly through the porous limestone and reach the ground- and coastal waters. Hydrogeological insight in the subterranean interconnection of groundwater systems and the interaction with surface water, the groundwater upwelling at sea and the hydraulics and transmissibility of the different rock compositions are highly relevant to better understand the detrimental effects of seawater contamination and nutrient enrichments.

Another process worth to consider is that consequential to the leaking of cesspools and watering of plants, in particular inside the enclosed residential plots, the suburban habitat is likely to change towards a more nutrient-rich, humid and less saline ecosystem.

Changes in the micro-climate[16] conditions

Besides contamination and nutrient-enrichment, soil humidity is likely to locally increase by the fencing and construction density that break the effect from the northeast trade winds and water runoff patterns. Even though Aruba has no large city-like urban area, the change in suburban climate conditions may still occur and create a situation comparable to what is called the '*urban heat effect*', more cautiously called '*suburban heat effect*' to mimic the situation in Aruba.

The *urban heat effect* (EPA, 2014) is a condition first described in larger cities when dense built-up areas retain the daily heat from the sun more so than the surrounding (rural) areas. Urban construction materials compared to rural land cover create a climate condition that differs by evaporation and thermal capacity (Bharat, 2009). The urban heat effect influences the climate in and above modern cities and causes serious problems such as *higher energy demands, water expenditures,* and the *accumulation of air pollution*. (Golden, 2004).

We expect that the factors that underlie the 'urban heat effect' are to some degree locally present in 'suburban' Aruba as well, because under the hot sub-tropical conditions the effect in micro-climate will be more pronounced. In Aruba, more hot air will remain in between buildings, in particular at lower heights, due to the increase in radiation from the cemented surface structures, decrease in evaporation from the absence of vegetation, and the absence of the natural cooling effect from the northeast trade winds.

[16] A microclimate is defined as local atmospheric conditions in a confined area that are different from its surroundings (see: wikipedia.org/wiki/Microclimate). The main parameters to define a microclimate within a certain area are temperature and humidity.

In addition, the changed suburban environment may also provide more competitive opportunities for species, such as insects, insect feeding birds, reptiles, weeds and grasses[17] that thrive well in disturbed, nutrient-rich and more humid environments. In contrast, in these suburban settings, we may expect conflict with nature as there is an increase in the use of pesticides[18], herbicides, fungicides and repellents to fight off intruding pests[19]. What is more, in the areas where there is dense housing and infrastructures, micro-climatic circumstances may change, as wind and water flow patterns become obstructed or funneled by buildings, walls and infrastructures. There may be an increase of erosion and turbid winds in one place and a standstill of waters or almost no wind at other locations.

Concluding remarks

In summary, today's major global environmental concerns can be categorized into:

- Chemical pollution and greenhouse gasses
- Nutrient enrichment
- Landscape fragmentation and loss
- Biodiversity loss
- Invasion by locally alien species

In the present series on the landscape we made a start to provide information about the status of these issues in Aruba. Roughly stated, at the interface between the economy, the environment and the society in Aruba we described the following conflicting situations:

- *Suburban expansion and land use*
  (Derix, Landscape series No.4: The Suburbanization of the Aruban Landscape, 2016d)
- *Living conditions and consumption patterns*
  (Derix, Landscape series No.5: Housing and accommodation in recent decades in Aruba, 2016e)
- *Waste, pollution, eutrophication, flooding and noise*

The latter aspect is detailed in the current paper. The information we provide may help to understand how the challenges we face in our own home environment and the actions we take translate into the challenges for the landscape and for the coastal marine environment.
For instance:

- ❖ *We may cause a suboptimal fertilization of local soils due to an unbalanced match between chemical substances in the specific substrate and the fertilizer compounds with the net result that much of the nutrients actually remain unbound and be wasted into the groundwater and into the sea.*
- ❖ *We may cause pollutive discharge in the home garden from the continuous leaking of cesspools, the disposal of chemicals with the wastewater from for instance paint jobs, batteries and oil remains, as well as with the disposal of phosphates and nitrates from soaps and detergents that come with dishwashing or cloth washing.*
- ❖ *The landscaping of our garden often comes with the introduction of exotic plant species that may require larger amounts of water. These 'richer' environments may provide better opportunities for some of the more adaptable local species, but may provide opportunities for competitive invasive species as well.*
- ❖ *Changes in near surface micro-climate conditions and richer topsoil may help the survival of alien weeds and insects that require costly pest control measures.*
- ❖ *The use of fungicides, herbicides, insecticides, etc., adds much harm to the local environment. We use toxic or bio-persistent chemicals because in large we lack information about suitable alternatives to pesticides.*
- ❖ *Unrestrained urban planning and house construction have an impact on the natural course of the rainwater, which comes with unpredictable costs during period of heavy rainfall.*
- ❖ *There is likely a heat buildup from predominantly asphalted and concrete surface area in the suburban environment that has negative consequences for water and electricity consumption. The use of local trees may bring less evaporative cooling (as they consume and evaporate little water), but will bring much shade and a more pleasant outdoor environment.*
- ❖ *The single-stoned outer walls of our houses often lack shade and allow the heat from the sun to radiate inside. As the buildup of heat during the day is longer retained at night in the heated suburban environment there will be an additional energy demand for air cooling.*
- ❖ *Soil compaction causes less water retention and an increase in urban stormwater runoff and erosion.*

The challenges above illustrate some of the factors relevant to establishing an environmentally sustainable home neighborhood. With more relevant information, alternative approaches can be thought of that not only serve the sustainable effort, but also save household expenditures.

[17] Unfortunately more invasive non-endemic species also adapt easily to the new environments.

[18] Some pesticides are known to inhibit nitrogen fixation in soils because they kill the respective bacteria and fungi that do so.

[19] We refer to http://en.wikipedia.org/wiki/Pesticide for a general description of the typology and chemo-physical characteristics of the different categories. Here we included all the goods within the category 38.08 of the Harmonic System

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