GeoJournal
https://doi.org/10.1007/s10708-018-9914-z

Vulnerability reduction and adaptation to climate change through watershed management in St. Vincent and the Grenadines

Álvaro Enríquez-de-Salamanca

Abstract St. Vincent and the Grenadines is an archipelagic state of the Caribbean that regularly suffers natural disasters; climate change is increasing the frequency of intense hurricanes and storms. The southernmost watersheds of St. Vincent have a rugged topography that favours flash-flooding in rainy events, with great damage because the area concentrates most of the country's population and infrastructure. To deal with this problem the Government has developed studies, engineering works and a watershed management plan. Land use management is an effective way of controlling hydrological impacts; the plan divides the watersheds in three uses, nature conservation (46%), agriculture and agroforestry (24%), and urban (30%), with categories, establishing permitted, prohibited and restricted activities. The area is close to the limit of urban development; if further expansion were essential it should be done by increasing density in lower and flatter areas. Many houses, usually low-income settlements, are in flooding or landslide risk areas, which should be decolonized, changing land use. It is also necessary to avoid hillside arable crops. Adaptation to climate change through land use management is essential, although unfortunately less socially and politically appreciated than engineering works.

Keywords Climate change adaptation · St. Vincent and the Grenadines · Caribbean · Watershed management

Introduction

St. Vincent and the Grenadines is an archipelagic State in the Eastern Caribbean, in the Windward Islands (Fig. 1), comprised of a main island, St. Vincent, and a chain of 32 islands and cays, the Grenadines, only seven of them inhabited (Fig. 2). The country area is 389 km^2 in total with the main island being 344 km^2.

Due to its geographical location and conditions, the country regularly suffers natural disasters such as hurricanes, tropical storms, sea surges, earthquakes, landslides or volcanic activity (Robertson 2005; Ferdinand 2006; Boruff and Cutter 2007; Le Friant et al. 2009; GFDRR 2010; Simpson et al. 2012; GSVG et al. 2018; Table 1). In addition, a significant proportion of the population lives in areas vulnerable to floods, landslides or coastal risks. In the 2013 storm 16,885 people were affected, with damages of more than 86 million US dollars and losses of 22 million (GSVG 2014a).

Á. Enríquez-de-Salamanca (✉)
DRABA ICM/Universidad Nacional de Educación a Distancia (UNED), Cañada Nueva 13, 28200 San Lorenzo de El Escorial, Madrid, Spain
e-mail: aenriquez@draba.org

Fig. 1 Map of the Caribbean Region

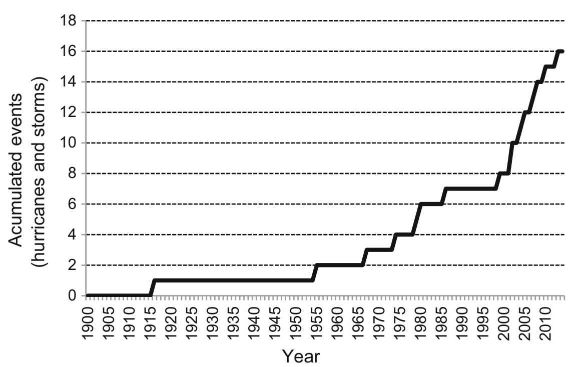


Fig. 2 Accumulated hurricanes and storms (1900–2014)

The frequency of natural disasters appears to be increasing. Predictions in the Caribbean region suggest a future warming manifested both on average and extreme temperatures (Angeles et al. 2007; Cashman et al. 2010; Biasutti et al. 2012). These changes will be greater in the northwest Caribbean in comparison to the eastern (Rhiney 2015). It is expected that there will be an increase in the number of very warm days and nights and a decrease of cool days and nights (Peterson et al. 2001), a lengthening of seasonal dry periods, and increased frequency of drought conditions (Cashman et al. 2010). Changes in precipitation are highly uncertain. Although the Caribbean is projected to become drier (Biasutti et al. 2012), particularly the Eastern region (Jones et al. 2015), some authors suggest an increase in the rain during the wet season (Angeles et al. 2007) while others predict a decrease, at least at the end of the twenty-first century (Karmalkar et al. 2013). According to Christensen (2010), rainfall shows mostly an upward trend St. Vincent and the Grenadines. It is highly probable an increase in tropical storms or heavy rains frequency (Peterson et al. 2001; Angeles et al. 2007; Christensen 2010; Biasutti et al. 2012). The analysis of the accumulated frequency of hurricanes and storms between 1900 and 2014 in St. Vincent and the Grenadines shows a growing recurrence, especially in the twenty-first century (Fig. 2). Intense hurricanes probably will become more frequent, but it is not clear if the total number of hurricanes will change: Lugo (2000) notes that there are models predicting increases while others predict decreases; Christensen (2010)

Table 1 Major events affecting St. Vincent and the Grenadines (1900–2014) *Sources*: Boruff and Cutter (2007), ECLAC (2011), Rhiney (2015), GSVG et al. (2018) and personal data

Hazard	Year	Events	Return period
Drought	1958, 1970–1975, 2002, 2009–2010	4	28.5 year
Earthquake	1928, 1939, 1946, 1953, 1997[a]	5–7[a]	16.3–22.8 year[a]
Fire		Annual	< 1 year
Flood	1977, 1986, 1987, 1992, 2011, 2013, 2014	7	16.3 year
Hurricane, storm	1916, 1955, 1967, 1974, 1979, 1980, 1986, 1987, 1999, 2002, 2004, 2005, 2007, 2008, 2010, 2012, 2013	18	6.3 year
Landslide		Frequent	< 1 year
Tsunami		1	> 100 year
Volcanic eruption	1902, 1971, 1979	3	38 year

[a]Results according to different authors

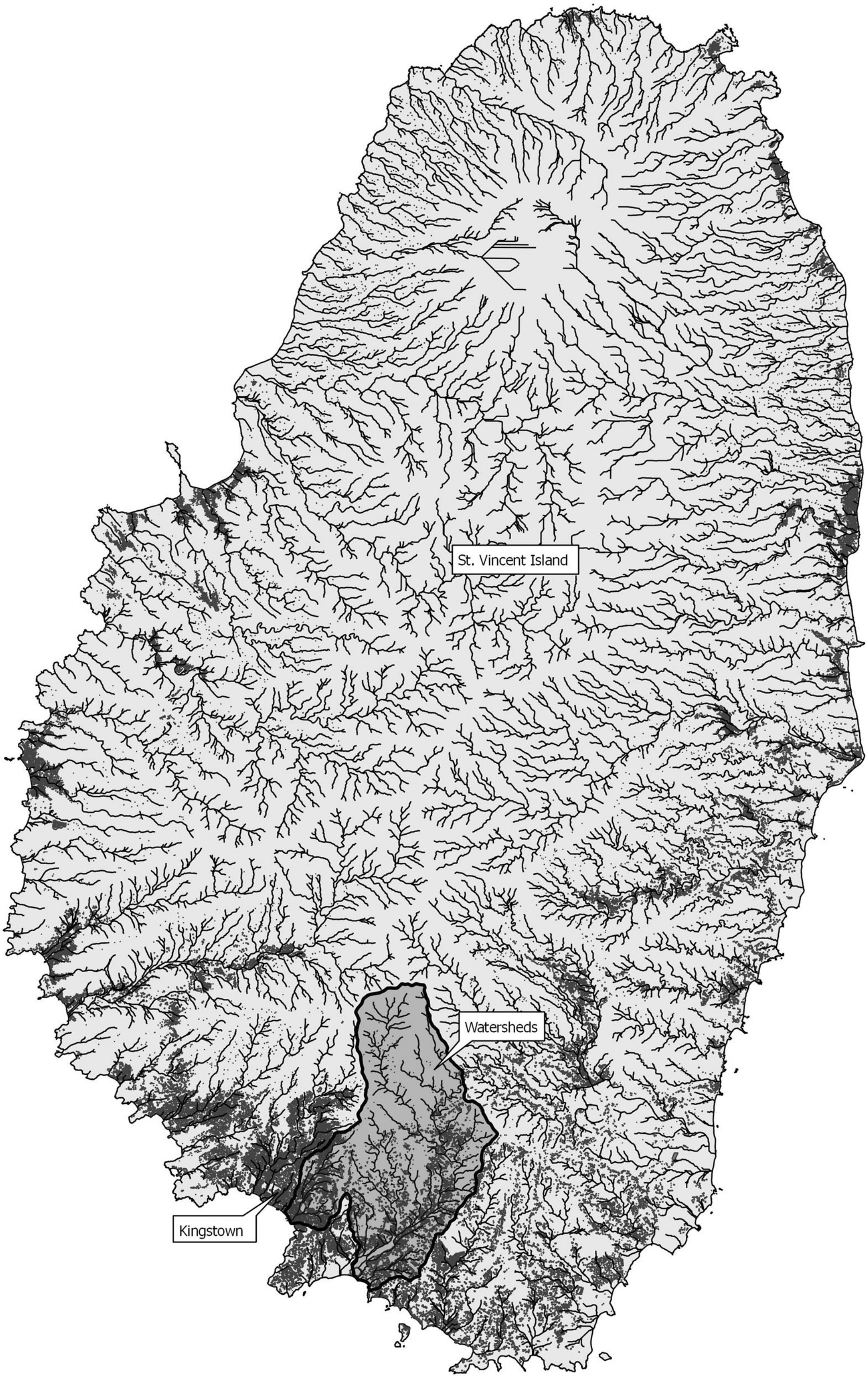
indicates that it is not clear if there will be more hurricanes; Biasutti et al. (2012) predict that hurricanes become less frequent, although more intense; and Jones et al. (2016) project small increases to small decreases in tropical cyclones count per year by the end of the century.

Problems associated with climate change have different manifestations across the country. St. Vincent is a rugged island with perennial water courses, while the Grenadines are flat and ephemeral flows, so hazards and impacts are very different; in this paper we focus on problems on the main island. The lengthening of the dry season, possible reductions in receiving rainfall and higher rates of evapotranspiration due to increased temperatures may produce stress in the vegetation and reduction in available water resources. St. Vincent is relatively water abundant, having both surface water and groundwater resources (Rossing 2010), but Cashman et al. (2010) point out that the country demand exceeds supply during the dry months, and ECLAC (2011) indicates that although it is generally believed that the supply on St. Vincent is more than enough to meet developmental needs, climatic and socioeconomic trends call this assumption into question. In coastal areas storm surges during hurricanes and wave energy produce erosion, affecting road sections and settlements.

Hurricanes produce different effects in ecosystems such as sudden and massive tree mortality or changes in forest regeneration, species, age classes or biomass and nutrient turnover (Lugo 2000), although the long run impacts of human land use greatly exceed the effects of catastrophic natural disturbance (McDowell 2001). In St. Vincent the biggest problem is flash flooding, associated with intense rain episodes. The rugged topography reduces the concentration time, producing, when precipitation is high, a rapid accumulation of water in the lower parts of the watersheds. The flash-flood response is highly dependent on land uses, especially urbanization (Pratomo et al. 2010; Korah and Cobbinah 2017), which increases impervious surface area (Showqi et al. 2014; Zhou et al. 2014) and volume of runoff and implies a loss of other uses (Dewan et al. 2012). Ramos-Scharrón and LaFevor (2016) highlight the unquestionable influence of unpaved roads on runoff in the Northeastern Caribbean. In St. Vincent is also important the presence of arable crops on steep slopes.

The southernmost watersheds of St. Vincent, especially South and Warrawarrow rivers, concentrate most of the country's population. This territory is greatly covered of scattered houses, and includes the main country's infrastructures, such as roads, port, former airport (decommissioned since 2017) or the main country's power station. Consequently, flash flooding in this area causes great damage, affecting not only the local population, but also communications or electricity supply throughout the country.

St. Vincent and the Grenadines, as most Small Island Developing States (SIDS), is highly vulnerable to climate change (Robinson 2017), and required to adapt to its impacts, especially to heavy rainfall, hurricanes and tropical storms. To deal with these events the Government had received funding from the


St. Vincent Island
Watersheds
Kingstown

◀**Fig. 3** Location of the studied watersheds in St. Vincent Island

International Bank for Reconstruction and Development to implement the Disaster Vulnerability Reduction Project (DVRP). The objective of this umbrella project was to make an assessment of the hydrological and hydraulic problems facing the country, and develop a programme of remedial works to ensure long-term protection from flooding and coastal erosion. Firstly, it was elaborated a hydrological study, updated and with greater detail than those already existing. The most urgent problems (e.g. bridge foundation scouring, riverbank erosion, recurrent floods) have been addressed through independent projects, each one with an Environmental Management Plan (EMP). Finally, a Watershed Management Plan (WMP) was prepared for Warrawarrow and South rivers, focused on reducing the damages caused by extreme hydrometeorological phenomena through an increase in resilience, based on better management of land use. The aim of this paper is to explain the methodological basis and criteria followed to conduct this WMP.

Methods

Study area

The studied watersheds are located in the southern part of St. Vincent (Fig. 3). The South River watershed is small, 2.5 km long and 1 km wide, with an area of 1.77 km^2; the South River runs with North East–South West direction, flowing into the sea in Kingstown, the capital. The Warrawarrow watershed has an area of 12.88 km^2, with an elongated shape, 6.5 km long and 2.6 km wide; the Warrawarrow River runs with North–South direction, flowing into the sea in Arnos Vale, close to the old ET Joshua airport.

The area has a tropical marine climate characterized by a marked dry season, from mid December to mid May, and a rainy season from mid May to mid December. Hurricanes are a perennial hazard in the wet season. The intense storm of 2013 took place in December, outside the hurricane season.

The watersheds have mainly slopes of 30 degrees or more, greater in the highest areas. Only the urban areas close to the sea are flat, with slopes lower than 2%. Dominant land uses are forests in the upper parts (changing from deciduous below 100 m to cloud forest above 300 m), mixed with crops (usually woody and eddoe crops), grassland and urban areas in the middle and lower parts. The north area is included in the proposed Kingstown Forest Reserve (GSVG 2018) and in an Important Bird Area (Culzac-Wilson 2008).

The population of St. Vincent and the Grenadines in 2016 was 109,643 inhabitants. The watersheds are located in St. George, the country's third largest parish and the most populated with 44% of the country's inhabitants. The parish includes Kingstown, the capital and largest settlement of the country, and Arnos Vale, both high-density urban areas surrounded by a wider area of medium and low-density housing. The area concentrates important transport infrastructure such as the old ET Joshua airport (decommissioned since 2017), the port of Kingstown and some main roads. However, the northern half of Warrawarrow watershed is mountainous, with poor communications.

Management principles

There are many definitions for integrated watershed management, for example: the process of organizing land, water, and other natural resource use on a watershed to provide goods and services to people without affecting adversely soil and water resources (Brooks et al. 2013); any human action aimed at ensuring the sustainable use of watershed resources (FAO 2017); or a continuous and adaptive process of managing human activities in an ecosystem, within a defined watershed (CCME 2016). Van der Zaag (2005) considers integrated water resources management a "relevant, yet elusive and fuzzy concept". Consequently, water management should include environmental, social and economic criteria. According to Biswas (1990), watershed management requires tasks such as strict control of land-use practices, afforestation and forest management, and implementation of soil and water conservation practices.

A WMP is the tool to guide the watershed management, and it should combine measures to improve or conserve the ecosystem services and functions, increase land productivity and resource efficiency and improve or diversify people's livelihoods and income (FAO 2017). The WMP was based on a series of principles (Pretty and Shah 1997;

Heathcote 2009; Brooks et al. 2013; CCME 2016): (1) the geographic unit is the watershed (in this case, two contiguous); (2) it should be applied an integrated approach, assessing natural resources (quality, impacts and conservation), land uses and social demands; (3) management would make compatible environmental protection and social demands, combining the expectations of the different stakeholders; (4) management should follow the precautionary principle, avoiding degradation instead of restoring damages, and protecting if there is uncertainty about risks; (5) most environmental impacts affecting watersheds are cumulative; (6) management should be adaptive and flexible; (7) watershed management is a crosscutting activity, involving all the population and Government departments, with a shared responsibility; (8) local people should be a solution rather than a problem; (9) natural resources and social demands change locally, so it is necessary to establish use categories (zoning); (10) it is necessary monitoring to detect if the objectives have been fulfilled, and to adapt them.

Main problems of the watersheds

The main problems historically experienced in the studied watersheds are: (1) flash-flooding during intense rain episodes (hurricanes and storms), affecting the lower parts of the watersheds, where most of the population and infrastructure is located; (2) landslides in areas with steep slopes, usually associated with a loss of forest cover caused by agricultural use; (3) uncontrolled housing, occupying forests and areas with flood risk; (4) risk of siltation or obstruction of watercourses during rainy episodes, causing unforeseen erosion and flooding problems; (5) erosion of riverbanks bordering houses or critical infrastructures; (6) capacity problems with bridges and channeled river sections.

Objectives

Worte (2017) indicates for Canada that water management tends to receive public attention and funding only during times of crisis. Similarly, in St Vincent and the Grenadines the concern about disaster vulnerability reduction and climate change adaptation intensifies after Hurricane Tomas in 2010, and especially after the storm of December 2013, which leads to the development of the DVRP. The most urgent need was to correct the damage caused and avoid the repetition of the same problematic situations. That led to different projects, mainly engineering works, to solve problems that had already occurred, and that will predictably recur, such as the replacement of three bridges (due to capacity problems or foundation scour); the repair of a forest track as an alternative route to the main road during emergencies; the defence of margins in a section of Warrawarrow river adjoining with critical infrastructure (the country's main power station and a government company of infrastructure maintenance); and the increase of the capacity of the existing channel at the mouth of the Warrawarrow river to avoid flooding in the old ET Joshua airport and the Arnos Vale Stadium.

There are two groups of adaptation measures, and by extension, of management measures, anticipatory, to avoid problems, and responsive or reactive, to solve existing problems (Enríquez-de-Salamanca et al. 2017); both are important, but the first is more desirable, according to the precautionary principle.

The projects developed were reactive adaptation measures that do not solve the causes, but only the symptoms. Consequently, there were necessary also to develop anticipatory adaptation measures, directed mainly to reduce the intensity of and fluvial erosion, without generating a loss of productive uses for the population; this is the main objective of the plan. Consequently, the WMP aims to increase the resilience of the watersheds, both in natural and human systems, in the face of extreme hydrometeorological phenomena that are being exacerbated due to climate change. To achieve this, the plan proposes land use management focused on reducing (or at least avoid the increase) the runoff, the incidence of flash floods and river erosion.

Input data and design tools

We have made thematic maps, using GIS, about: vegetation and land use, based on updated orthophoto and field works; slopes, based on topography; urban areas, based on cartography and orthophoto; and protected areas, geology, soils and natural hazards using available data. The intersection of all these maps allowed a multicriteria vision of the watersheds, There was also a hydrological study (GSVG 2014b) that defined flood-prone areas. Other data sources were the

EMPs of the remedial works projects developed in the DVRP framework.

Watershed management

Intense rainfall and watershed characteristics determine runoff and water concentration speed, which are the cause of the main problems in these watersheds, as flooding, landslides, riverbanks erosion or capacity problems on water courses.

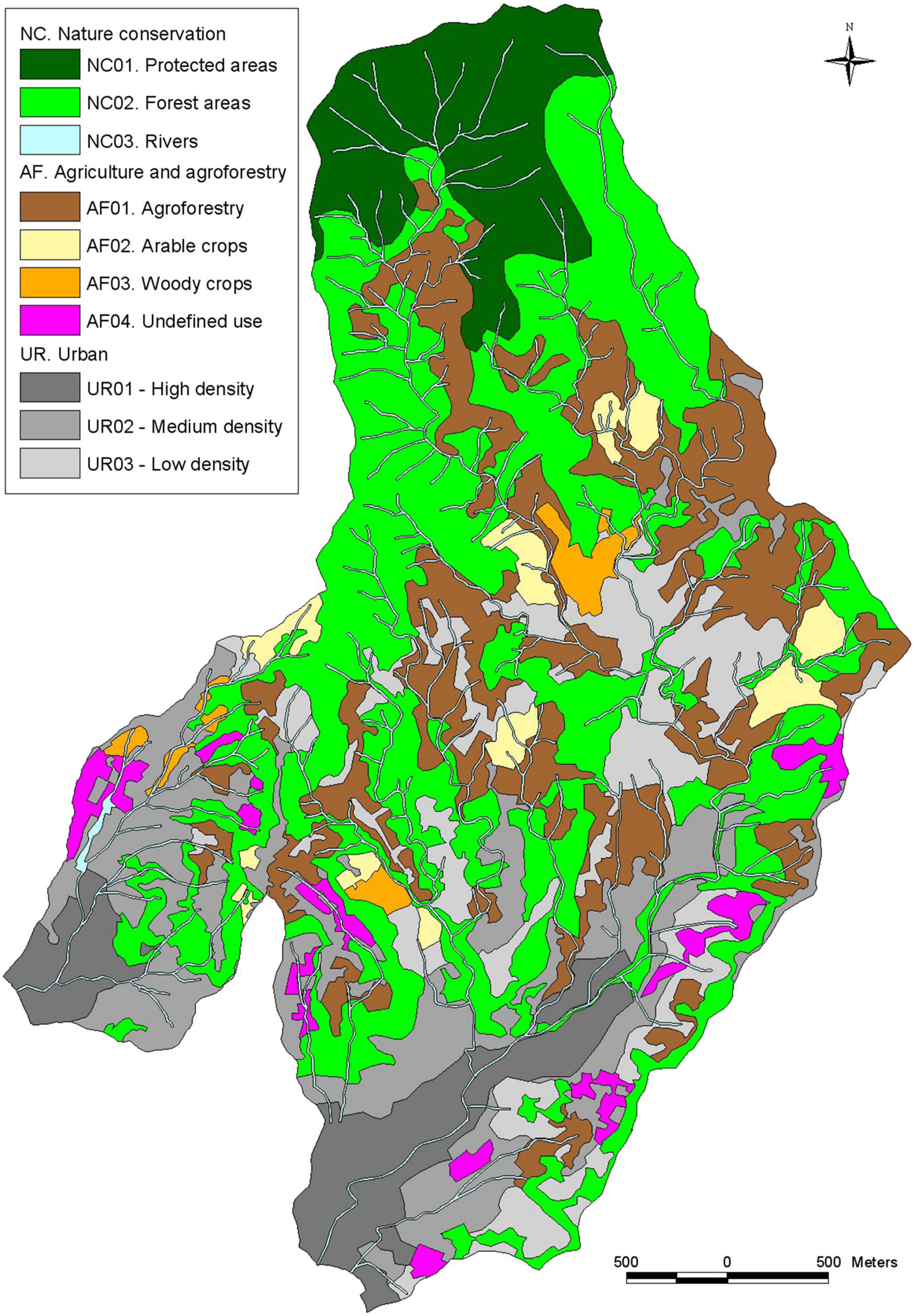
Intense rainfall is normal in the region, due to general climatic conditions, but its frequency is likely to increase as a result of climate change. Two main characteristics influence runoff, orographic and lithological conditions, and land use. The first cannot be modified (at least not extensively), while the second is highly dependent on human action. The relationship between land uses and the hydrological behaviour of a basin is evident. Hanson et al. (2004) calculated the percolation rates in soils of Honduras, which were greatest in forest and decreased successively in coffee plantations and grass-covered hillslopes. Kang and Park (2015) identify urbanization as the key variable in watershed management of their study basin in South Korea. Caballero et al. (2013) calculated that the watershed discharge is four times greater in cloud forest areas, highlighting the importance of protecting these forests for the sustained provision of clean, potable water in the populated areas of Central America. Narimani et al. (2017) compare current land uses for a watershed in Iran with two scenarios, alfalfa cultivation with suitable tillage and grassland development, detecting in these scenarios a reduction in annual average sediment load of 90–94% and in annual average surface runoff of 55–67%, respectively. Boongaling et al. (2018) detect that land use changes in a watershed in the Philippines (increase in built-up areas and reduction in vegetation) increase surface runoff (5%) and sediment yield (6%) and reduce baseflow (−11%), with significant differences in streamflow during the stormy months and baseflow in dry months between degraded sub-basins (+ 31% streamflow; − 26% baseflow) and improved sub-basins (− 4% streamflow; + 5 baseflow). Consequently, as these examples show, the influence of land use on runoff, baseflow and sediment yield is enormous, so its management is essential to prevent hydrometeorological hazards.

A basis for the WMP is to assign different uses to the territory, depending on the environment, land use, population, vulnerability and risks. The WMP proposes three uses, nature conservation, agriculture and agroforestry, and urban, each one with subcategories (Table 2). The uses and categories are assigned according to current land uses, topography, hydrography, slopes, protected areas, and different problems detected (Fig. 4).

For each of the categories, permitted, prohibited, and restricted uses have been established, the latter

Table 2 Uses and categories in the watershed management plan

Use	Category	Description
NC. Nature conservation	NC01. Protected areas	Kingstown Forest Reserve, Important Bird Area
	NC02. Forest areas	Forest areas of the upper parts of the watersheds
	NC03. Rivers	Rivers, streams and in general all watercourses
AF. Agriculture and agroforestry	AF01. Agroforestry	Mosaic of agricultural and forest areas
	AF02. Arable crops	Intensive agriculture by tilling and arable farming
	AF03. Woody crops	Extensive agricultural. Lower erosion problems than AF02 and fewer restrictions
	AF04. Undefined use	Deforested areas without use: grasslands, abandoned fields, degraded scrublands
UR. Urban	UR01. High density	Large urban areas as Kingstown and Arnos Vale
	UR02. Medium density	Suburbs of Kingstown an Arnos Vale
	UR03. Low density	Built up areas in the intermediate zones of the watersheds


NC. Nature conservation
NC01. Protected areas
NC02. Forest areas
NC03. Rivers
AF. Agriculture and agroforestry
AF01. Agroforestry
AF02. Arable crops
AF03. Woody crops
AF04. Undefined use
UR. Urban
UR01 - High density
UR02 - Medium density
UR03 - Low density
N
500
0
500 Meters

◀ **Fig. 4** Watershed zoning

requiring specific authorization on a case-by-case basis (Table 3).

The zoning of watersheds, and the regulation of uses associated with each category, aim to protect hydrologically more favourable uses (such as forests and rivers) and avoid harmful practices, such as urbanization in flood areas or hillside eddoe crops, which increase the runoff and reduce the time of water concentration in the lower area of the basin.

However, when establishing the categories and possible uses, it is necessary to bear in mind that this area concentrates most of the country's population, with a strong demand for housing, and that there is family farming on which a significant part of the population depends. As noted by Pretty and Shah (1997), farmers have been seen as "mismanagers of soil and water", and forced to adopt new conservation practices, frequently unsuccessful and expensive, when they should be considered a potential solution, rather than a problem. Consequently, the proposed management must allow a hydrological improvement of the watersheds, without this supposing a sacrifice for the population, residents and farmers, since if this is the case the plan would be doomed to failure. For example, family farming may be compatible with nature conservation (outside protected areas) if not extensive, and often requires the construction of isolated dwellings, a restricted use that can be authorized on a case-by-case basis.

The established zoning proposes 46% of land destined for nature conservation (mainly forests),

Table 3 Permitted, prohibited, and restricted uses by categories

Use	Category	Permitted uses	Prohibited uses	Restricted uses
NC. Nature conservation	NC01. Protected areas	Promotion and improvement of forests and wildlife	Agriculture, livestock, housing, infrastructure	Low-impact public use if not affect endangered wildlife species
	NC02. Forest areas	Sustainable forestry. Low-impact public use (hiking, biking)	Intensive agriculture or livestock, urban development	Family farming and isolated houses if do not imply forest destruction
	NC03. Rivers	Promotion and improvement of wildlife and water quality	Waste dumping, discharges, watercourse diversion, mining	River crossing, or diversion, water extraction, fishing, spilling
AF. Agriculture and agroforestry	AF01. Agroforestry	Forestry (40–100%), agriculture (0–60%). Hedgerow maintenance	Urban development. Agriculture in more than 60% of the area	Isolated houses associated with farming
	AF02. Arable crops	Agriculture, in areas with gentle slope and without erosion risk	Urban development. In areas with erosion risk AF-02 must be used	Isolated houses associated with farming
	AF03. Woody crops	Agriculture, in areas without high erosion risk	Urban development	Isolated houses associated with farming
	AF04. Undefined use	They could be used for any purpose depending on location		
UR. Urban	UR01. High density	Streets/buildings covering more than 80% of the area. Flat areas	Development in steep areas, and NC or AF areas. Forest destruction	Developments should have environmental assessment
	UR02. Medium density	Streets/buildings covering 50–80% of the area. Flat-moderate slope	Development in steep areas, and NC or AF areas. Forest destruction	Developments should have environmental assessment
	UR03. Low density	Streets/buildings covering less than 50% of the area. Any slope	Development in NC or AF areas	Isolated houses associated with farming in NC or AF areas

Table 4 Area and occupation percentage of uses and categories

Use	Category	Area and occupation percentage							
		Existing				Proposed			
NC. Nature conservation	NC01. Protected areas	1.25 km^2	8.52%	5.63 km^2	29.38%	1.25 km^2	8.52%	6.82 km^2	46.49%
	NC02. Forest areas	4.38 km^2	20.86%			4.75 km^2	32.38%		
	NC03. Rivers					0.82 km^2	5.59%		
AF. Agriculture and agroforestry	AF01. Agroforestry	1.51 km^2	10.31%	6.15 km^2	41.98%	2.52 km^2	17.18%	3.50 km^2	23.86%
	AF02. Arable crops	1.38 km^2	9.39%			0.43 km^2	2.93%		
	AF03. Woody crops	0.43 km^2	2.96%			0.19 km^2	1.30%		
	AF04. Undefined use	2.83 km^2	19.32%			0.36 km^2	2.45%		
UR. Urban	UR01. High density	0.39 km^2	2.65%	2.89 km^2	19.64%	0.99 km^2	6.75%	4.35 km^2	29.65%
	UR02. Medium density	2.49 km^2	16.99%			1.95 km^2	13.29%		
	UR03. Low density					1.41 km^2	9.61%		

24% for agricultural and agroforestry uses and 30% for urban use (Table 4).

The proposed zoning allows a moderate growth of urban use and maintenance of agriculture, at the expense of significant increase in forest area, especially based on the conversion of shrubs and grasslands. Arable crops are removed from the slopes and relocated to gently sloping land, leading to an unavoidable reduction in their area. This reduction may be compensated with more sustainable practices, such as agroforestry, and there are also areas with undefined use (AF04) that can be used for arable crops. Urban use grows moderately, especially due to an increase in density, occupying wastelands inside existing urban areas. Hydrological improvement is achieved by avoiding urban expansion in sensitive areas, eliminating hillside crops and though the revegetation of degraded areas to improve infiltration, and reduce erosion and runoff (Zimale et al. 2017).

Complementary outputs

As noted above, a first step in the DVRP was conducting a new hydrological study (GSVG 2014b) to replace those developed previously (GSVG 2006a, b), with updated meteorological data (including 2010 hurricane Tomas and 2013 tropical storm), and a more detailed runoff calculation. The WMP included detailed and updated information, so it was a basic tool for runoff calculation. Runoff coefficient has been calculated through the curve number method (Soil Conservation Service 1985), in three soil moisture situations, combining land use, soils and watershed and sub-watershed maps with GIS.

Discussion and conclusions

St. Vincent and the Grenadines is a SIDS in the Caribbean, which regularly suffers natural disasters such as hurricanes, tropical storms, sea surges, earthquakes, landslides or volcanic hazards. Climate change is increasing the frequency of intense storms and hurricanes, giving rise to frequent flash floods, with significant human and material damage. To adapt to the increased frequency of intense rain events, the country is developing adaptation actions within the DVRP, including hydrological studies, remediation works and a WMP for Warrawarrow and South rivers,

Fig. 5 Land use in the watersheds. At the left, housing on the outskirts of Kingstown. To the right, different land uses in the upper part of Warrawarrow watershed: forest, agroforestry, woody crops and hillside arable crops

in the south of St. Vincent, the most populated region in the country.

On the one hand, reactive adaptation works have been carried out, solving problems such as damage in bridges or roads, erosion on riverbanks or capacity problems in drains, bridges or channeled river sections. On the other hand, a management of land use in the watersheds has been proposed, a very effective way of controlling hydrological parameters such as runoff, baseflow or sediment yield. To achieve that, it has been carried out a watershed zoning based on current land uses, topography, hydrography, slopes, protected areas, population's expectations and problems detected, establishing three main uses, nature conservation, agriculture and agroforestry, and urban. Each use has different categories, with permitted, prohibited or restricted activities. In total it is proposed to allocate 46% of the land to nature conservation, 24% to agriculture and agroforestry and 30% to urban use. This distribution implies a moderate growing of urban areas, maintenance of agriculture and an important growth of forest areas; this is achieved thanks to the management of scrub and grassland, changing the use locally to arable crops, and mainly to forest areas through reforestation. The results are more conservative that those proposed by Zhang et al. (2014) in China to reduce peak flow in a watershed: 30% of forest land, less than 50% of urban land and no more than 55% of agriculture land.

There are two main factors causing hydrological problems in these watersheds. Firstly, the area is close to the limit of urban development potential; a further urban expansion would imply important hydrological problems. But at the same time it is the most populated area of the country, and the demand for housing is intense, so prohibiting expansion would be unreal. Urban expansion should be done by increasing density in unsaturated areas in the lower and flatter areas of the watersheds, and not colonizing new slopes. There is a close relationship between population's wealth and risk exposure. Low-income settlements tend to be in areas prone to flooding and landslides; many households on the outskirts of Kingston worry that their homes will collapse during the next storm due to their location on steep slopes (Rossing and Rubin 2010; Fig. 5). Further, in this area individuals are reluctant to leave their houses in high-risk areas for relocation, leaving some of their members in the risk-prone house to defend it; to prevent that, risk areas should be converted to alternative uses precluding habitation (Nielsen 2010). Consequently, the inclusion of risk-prone urbanized areas in non-urban uses (nature conservation or agriculture and agroforestry) should involve specific actions to make effective the land use change, such as demolition of buildings without protection possibilities, plantations or agricultural transformation. Risk reduction must be accompanied by programs to improve living conditions.

Secondly, another important problem are arable crops in steep slopes (especially eddoe), a traditional practice frequent in the upper parts of the watersheds (Fig. 5), which generate landslides, large soil losses, watercourses siltation and runoff increase; consequently, they should be avoided. In order to achieve this, it is necessary to provide to family farmers alternatives for the location of these crops, or less impactful cultivation methods, especially agroforestry. To reduce the need for new croplands, efforts must be made to increase agricultural production by maintaining soil fertility, as indicated by Mashi and Shuaibu (2018) for Nigeria; this is incompatible with hillside crops.

Vulnerable regions such as the one studied, where extreme hydrometerological processes are being exacerbated by climate change, require actions to reduce vulnerability, which in turn are also adaptations to climate change. These actions should combine reactive measures, to solve damages, with anticipatory measures, to minimize the occurrence of disasters. However, the adaptation to disasters is often reactive, mobilizing resources when a disaster occurs, to solve the damage produced. Anticipatory measures, applied before the occurrence of extreme events, need greater attention. Between them, the management of land use in watersheds is an essential measure, which should not be eclipsed by engineering works, which are much more attractive due to their greater social acceptance and political benefits.

Compliance with ethical standards

Conflict of interest The author declares that there is no conflict of interest.

References

Angeles, M. E., Gonzalez, J. E., Erickson, D. J., & Hernández, J. L. (2007). Predictions of future climate change in the caribbean region using global general circulation models. *International Journal of Climatology, 27*(5), 555–569.

Biasutti, M., Sobel, A. H., Camargo, S. J., & Creyts, T. T. (2012). Projected changes in the physical climate of the Gulf Coast and Caribbean. *Climatic Change, 112*(3–4), 819–845.

Biswas, A. K. (1990). Watershed management. *International Journal of Water Resources Development, 6*(4), 240–249.

Boongaling, C. G. K., Faustino-Eslava, D. V., & Lansigan, F. P. (2018). Modeling land use change impacts on hydrology and the use of landscape metrics as tools for watershed management: The case of an ungauged catchment in the Philippines. *Land Use Policy, 72*, 116–128.

Boruff, B. J., & Cutter, S. L. (2007). The environmental vulnerability of Caribbean island nations. *Geographical Review, 97*(1), 932–942.

Brooks, K. N., Ffolliot, P. F., & Manger, J. A. (2013). *Hydrology and the management of watershed* (4th ed.). Ames: Wiley–Blackwell.

Caballero, L. A., Easton, Z. M., Richards, B. K., & Steenhuis, T. S. (2013). Evaluating the bio-hydrological impact of a cloud forest in Central America using a semi-distributed water balance model. *Journal of Hydrology and Hydromechanics, 61*(1), 9–20.

Cashman, A., Nurse, L., & John, C. (2010). Climate change in the Caribbean: The water management implications. *The Journal of Environment & Development, 19*(1), 42–67.

CCME (2016). *Summary of integrated watershed management approaches across Canada*. Canadian Council of Ministers of the Environment.

Christensen, J. H. (2010). Summaries of likely climate change impacts, by country. In D. Verner (Ed.), *Reducing poverty, protecting livelihoods, and building assets in a changing climate. Social implications of climate change for Latin America and the Caribbean* (pp. 373–400). Washington, DC: The World Bank.

Culzac-Wilson, L. (2008). St Vincent & the Grenadines. In D. C. Wege & V. Anadon-Irizarry (Eds.), *Important Bird Areas in the Caribbean: Key sites for conservation* (pp. 295–308). Cambridge: Birdlife International.

Dewan, A. M., Yamaguchi, Y., & Rahman, M. Z. (2012). Dynamics of land use/cover changes and the analysis of landscape fragmentation in Dhaka Metropolitan, Bangladesh. *GeoJournal, 77*(3), 315–330.

ECLAC. (2011). *An assessment of the economic impact of climate change on the water sector in Saint Vincent and the Grenadines*. United Nations: Economic Commission for Latin America and the Caribbean.

Enríquez-de-Salamanca, A., Díaz-Sierra, R., Martín-Aranda, R. M., & Santos, M. J. (2017). Environmental impacts of climate change adaptation. *Environmental Impact Assessment Review, 64,* 87–96.

FAO. (2017). *Watershed management in action—Lessons learned from FAO field projects*. Rome: FAO.

Ferdinand, I. M. A. (2006). *Hurricane risk reduction strategies in the Windward Islands: Public and practitioner's perspectives.* Thesis. Coventry University.

GSVG. (2006a). *Kingstown and Arnos Vale drainage improvement study. Project No. SVGDMP-CON-ICB-F-B15/03.* Kingstown: Government of St. Vincent and the Grenadines-DLN Consultants.

GSVG. (2006b). *Island wide flood risk assessment study. Project No. SVGDMP-CON-ICB-F-B12/03.*Kingstown: Government of St. Vincent and the Grenadines-DLN Consultants.

GSVG. (2014a). *Rapid Damage and Loss Assessment (DaLA). December 24–25, 2013 Floods*. Report. Kingstown: Government of Saint Vincent and the Grenadines.

GSVG. (2014b). *Hydrology/hydraulic modeling and geotechnical site investigation of bridges, fords and rivers. Contract No. 783/2014*. Kingstown: Government of St. Vincent and the Grenadines-Euroconsult.

GSVG. (2018). *Protected areas. National parks, rivers and beaches authority*. Government of Saint Vincent and the Grenadines. http://nationalparks.gov.vc. Accessed May 20 2018.

GSVG, NEMO, UNISDR, & ECHO. (2018). *Disaster Risk Reduction Country Document. Saint Vincent and the Grenadines.* Government of Saint Vincent and the Grenadines-National Emergency Management Office (NEMO)-United Nations Office for Disaster Risk Reduction (UNISDR)-European Commission's Humanitarian

Aid and Civil Protection department (ECHO). http://dipecholactools.org/saintvincent. Accessed April 10 2018.

Hanson, D., Steenhuis, T. S., Walter, M. F., & Boll, J. (2004). Effects of soil degradation and management practices on the surface water dynamics in the Talgua River watershed in Honduras. *Land Degradation and Development, 15,* 367–381.

Heathcote, I. W. (2009). *Integrated watershed management: Principles and practice* (2nd ed.). NJ: Wiley.

Jones, P. D., Harpham, C., Harris, I., Goodess, C. M., Burton, A., Centella-Artola, A., et al. (2015). Long-term trends in precipitation and temperature across the Caribbean. *International Journal of Climatology, 36*(9), 3314–3333.

Jones, J. J., Stephenson, T. S., Taylor, M. A., & Campbell, J. D. (2016). Statistical downscaling of North Atlantic tropical cyclone frequency and the amplified role of the Caribbean low-level jet in a warmer climate. *Journal of Geophysical Research: Atmospheres, 121*(8), 3741–3758.

Kang, M. G., & Park, S. W. (2015). An adaptive watershed management assessment based on watershed investigation data. *Environmental Management, 55,* 1006–1021.

Karmalkar, A. V., Taylor, M. A., Campbell, J., Stephenson, T., New, M., Centella, A., et al. (2013). A review of observed and projected changes in climate for the islands in the Caribbean. *Atmósfera, 26*(2), 283–309.

Korah, P. I., & Cobbinah, P. B. (2017). Juggling through Ghanaian urbanisation: Flood hazard mapping of Kumasi. *GeoJournal, 82*(6), 1195–1212.

Le Friant, A., Boudon, G., Arnulf, A., & Robertson, R. E. A. (2009). Debris avalanche deposits offshore St. Vincent (West Indies): Impact of flank-collapse events on the morphological evolution of the island. *Journal of Volcanology and Geothermal Research, 179*(1–2), 1–10.

Lugo, A. E. (2000). Effects and outcomes of Caribbean hurricanes in a climate change scenario. *The Science of the Total Environment, 262*(3), 243–251.

Mashi, S. A., & Shuaibu, H. S. (2018). People and sustainable land management: Assessment of stakeholders knowledge of the nature of landuse/cover change in Abuja, Nigeria. *GeoJournal, 83*(3), 545–562.

McDowell, W. H. (2001). Hurricanes, people, and riparian zones: Controls on nutrient losses from forested Caribbean watersheds. *Forest Ecology and Management, 154*(3), 443–451.

Narimani, R., Erfanian, M., Nazarnejad, H., & Mahmodzadeh, A. (2017). Evaluating the impact of management scenarios and land use changes on annual surface runoff and sediment yield using the GeoWEPP: A case study from the Lighvanchai watershed, Iran. *Environmental Earth Sciences, 76,* 353.

Nielsen, S. T. (2010). Coastal livelihoods and climate change. In D. Verner (Ed.), *Reducing poverty, protecting livelihoods, and building assets in a changing climate. Social implications of climate change for Latin America and the Caribbean* (pp. 123–165). Washington, DC: The World Bank.

Peterson, T. C., Taylor, M. A., Demeritte, R., Duncombe, D. L., Burton, S., Thompson, F., et al. (2001). Recent changes in climate extremes in the Caribbean region. *Journal of Geophysical Research*, *107*(D21), 4601.

Pratomo, R. A., Jetten, V. D., & Alkema, D. (2010). A comparison of flash flood response at two different watersheds in Grenada, Caribbean Islands. *International Symposium on Geophysical Issues. IOP conference series: Earth and environmental science*, 29, 012004.

Pretty, J. N., & Shah, P. (1997). Making soil and water conservation sustainable: From coercion and control to partnerships and participation. *Land Degradation and Development, 8,* 39–58.

Ramos-Scharrón, C. E., & LaFevor, M. C. (2016). The role of unpaved roads as active source areas of precipitation excess in small watersheds drained by ephemeral streams in the Northeastern Caribbean. *Journal of Hydrology, 533,* 168–179.

Rhiney, K. (2015). Geographies of Caribbean vulnerability in a changing climate: Issues and trends. *Geography Compass, 9*(3), 97–114.

Robertson, R. E. A. (2005). St. Vincent and the Grenadines. In J. M. Lindsay, R. E. A. Robertson, J. B. Shepherd, & S. Ali (Eds.), *Volcanic hazard atlas of the Lesser Antilles* (pp. 241–261). Trinidad and Tobago: University of the West Indies.

Robinson, S. (2017). Climate change adaptation trends in small island developing states. *Mitigation and Adaptation Strategies for Global Change, 22*(4), 669–691.

Rossing, T. (2010). Water scarcity, climate change, and the poor. In D. Verner (Ed.), *Reducing poverty, protecting livelihoods, and building assets in a changing climate. Social implications of climate change for Latin America and the Caribbean* (pp. 21–62). Washington, DC: The World Bank.

Rossing, T., & Rubin, O. (2010). Climate change, disaster hot spots, and asset erosion. In D. Verner (Ed.), *Reducing poverty, protecting livelihoods, and building assets in a changing climate. Social implications of climate change for Latin America and the Caribbean* (pp. 63–91). Washington, DC: The World Bank.

Showqi, I., Rashid, I., & Romshoo, S. A. (2014). Land use land cover dynamics as a function of changing demography and hydrology. *GeoJournal, 79*(3), 297–307.

Simpson, M. C., Clarke, J. F., Scott, D. J., et al. (2012). *CARIBSAVE Climate Change Risk Atlas. St. Vincent and the Grenadines*. Barbados: DFID-AusAID-CARIBSAVE.

Soil Conservation Service. (1985). *National engineering handbook. Section 4-Hydrology*. Washington DC: USDA.

Van der Zaag, P. (2005). Integrated Water Resources Management: Relevant concept or irrelevant buzzword? A capacity building and research agenda for Southern Africa. *Physics and Chemistry of the Earth, 30,* 867–871.

Worte, C. (2017). Integrated watershed management and Ontario's conservation authorities. *International Journal of Water Resources Development, 33*(3), 360–374.

Zhang, G., Guhathakurta, S., Lee, S., Moore, A., & Yan, L. (2014). Grid-based land-use composition and configuration optimization for watershed stormwater management. *Water Resources Management, 28*(10), 2867–2883.

Zhou, Y., Wang, Y., Gold, A. J., August, P. V., & Boving, T. B. (2014). Assessing impact of urban impervious surface on watershed hydrology using distributed object-oriented simulation and spatial regression. *GeoJournal, 79*(2), 155–166.

Zimale, F. A., Tilahun, S. A., Tebebu, T. Y., Guzman, C. D., Hoang, L., Schneiderman, E. M., et al. (2017). Improving watershed management practices in humid regions. *Hydrological Processes, 31*(18), 3294–3301.