Storm Surges, Heavy Rain and Strong Wind: Impacts of Tropical Cyclone Winston in Fiji—Focus on Health

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Abstract On February 20th, 2016, tropical cyclone (TC) Winston, a category 5 cyclone, hit Fiji, affecting more than half the population of the country and leaving behind damages worth more than 30% of the GDP of the country. The health sector alone suffered damages and losses amounting to FJ$13.9 million, corresponding to the damage or destruction of 88 health facilities out of 214. One characteristic of this cyclone was the importance of damages caused by the storm surge associated with the cyclone in some areas. This is extremely worrying in a changing climate and more specifically the context of sea-level rise, and studies indicate that climate change has an influence on cyclones and storm surges although it is still difficult to precisely quantify it. TC Winston had important impacts on health and on the health system in Fiji. A total of 44 casualties were recorded, and more than 120 people were injured, including 45 who were hospitalized. Cases of diarrheal diseases, leptospirosis and typhoid were observed and monitored, but actions were taken and there was no large outbreak after the cyclone. This chapter provides general information about TC Winston, then presents the specific impacts of the storm surge associated with TC Winston and discusses the influence of climate change, and the last sections details and discusses the impacts of TC Winston on health in Fiji.

1 Introduction—Tropical Cyclone Winston in Fiji

The tropical disturbance TD09F, which would become tropical cyclone (TC) Winston, was first observed between Fiji and Vanuatu on February 7. The system evolved into a category 1 cyclone and was named Winston on February 11, 2016, by the Regional Specialised Meteorological Centre (RSMC) based in Nadi, Fiji. The category 1 cyclone was located west of Fiji and was moving southwards. On February 14th, TC Winston turned northeast and stayed north of Tonga on the 17th. At that stage, most of the forecasts indicated it would continue northeast, but it turned back

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and started to move westward and reached category 5 on both the Australian Tropical Cyclone and Saffir-Simpson intensity scales by February 19th. TC Winston made a landfall in Fiji on February 20th (Fig. 1), with maximum sustained 10-min wind speed estimated at 204 km/h (110 kt) near its center (Fiji Meteorological Services 2016a, b) but maximum gust wind speed was recorded at 303 km/h (Government of Fiji 2016). TC Winston also brought heavy rain to Fiji, with accumulated rainfall over February 20th and 21st reaching 479 mm at Nadarivatu, in the north of Viti Levu, close to the cyclone's path, compared to the long-term average rainfall for February based on the 1971–2000 period which stands below 300 mm. This heavy rain over a short time period generated flooding in several locations in Fiji although the main urban centers were not affected (Fiji Meteorological Services 2016b).

Not only was TC Winston a very intense cyclone but it made a direct landfall to Fiji, the eye passing just between the two main islands of Vanua Levu (north) and Viti Levu (south) where the capital city Suva is located. This led a large part of Fiji to sustain the maximum wind speed over 100 km/h and in some areas up to over 150 km/h (Fig. 2). This resulted in a significant part of the population, infrastructure and environment of Fiji exposed to these strong winds (Fig. 3).

The consequences of the direct landfall of a category 5 cyclone in Fiji were disastrous for the country. Forty-four people were killed, twenty-seven hospitalized, one hundred and seventeen injured, four hundred eighty-five thousand and thirty lost the livelihood of the family breadwinner, and a total of five hundred forty thousand four hundred and fourteen were affected. In May 2016, damages were estimated at more than FJ$1.5 million and the losses at more than FJ$1.3 billion. The total of over FJ$2.85 billion corresponded to one-fifth of Fiji's 2014 GDP (Government of

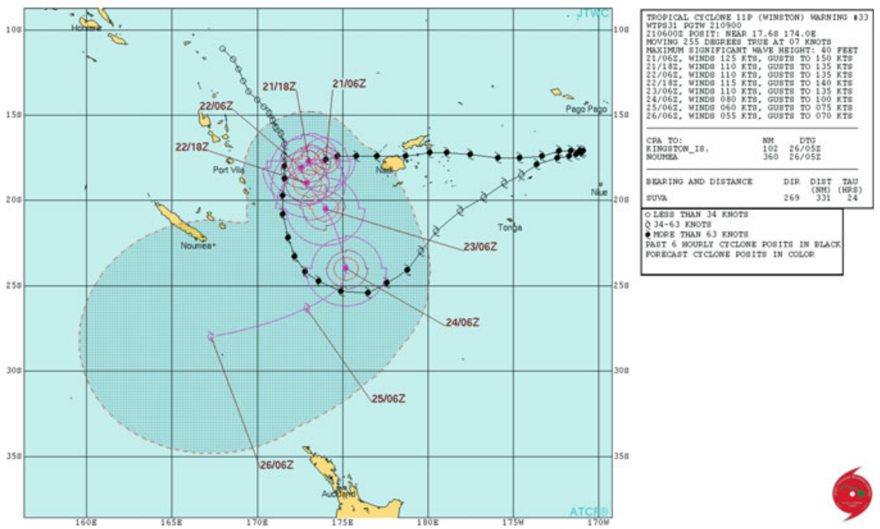

Fig. 1 Tropical cyclone Winston observed (black spirals) and projected (pink spirals) path. *Source* Joint Typhoon Warning Centre (2016)

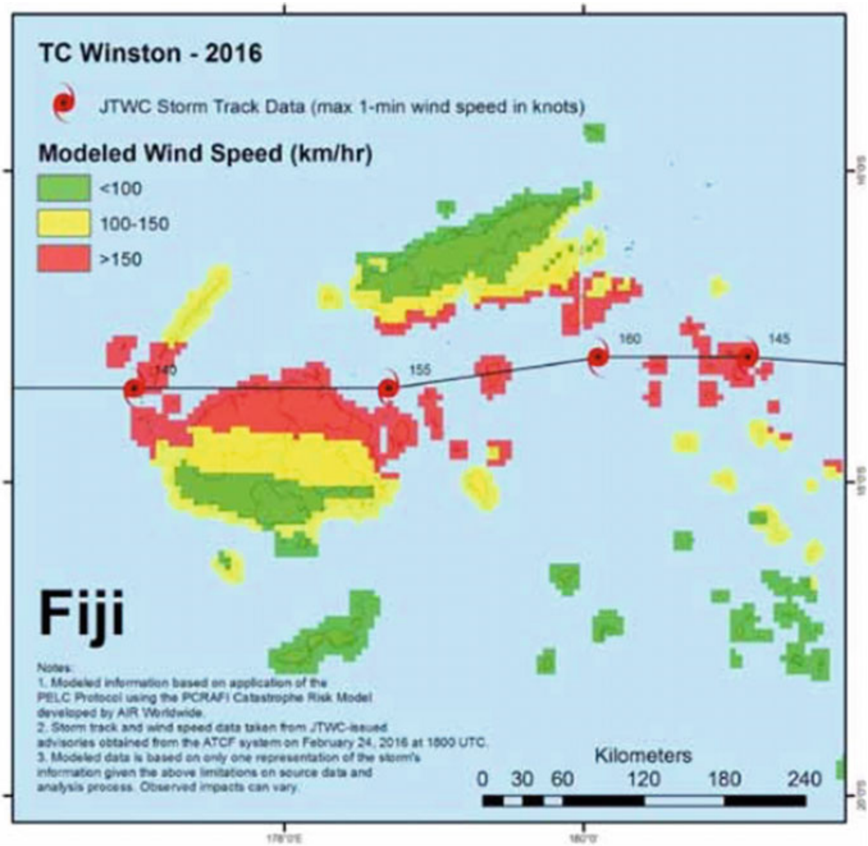

Fig. 2 Map of modeled wind speed during tropical cyclone Winston path through Fiji between February 19 and 22, 2016. *Source* Government of Fiji (2016)

Fiji 2016). All economic sectors were affected although the agriculture sector alone suffered damages and loss accounting for FJ$542 million, while damages and loss in the health sector amounted to FJ$13.9 million (Government of Fiji 2016).

The government declared the state of emergency for all four divisions on February 20th. The nine national humanitarian clusters coordinated the government in its response to the event and different national, regional and international organization and governments supported Fiji in the response and reconstruction phases (Government of Fiji 2016).

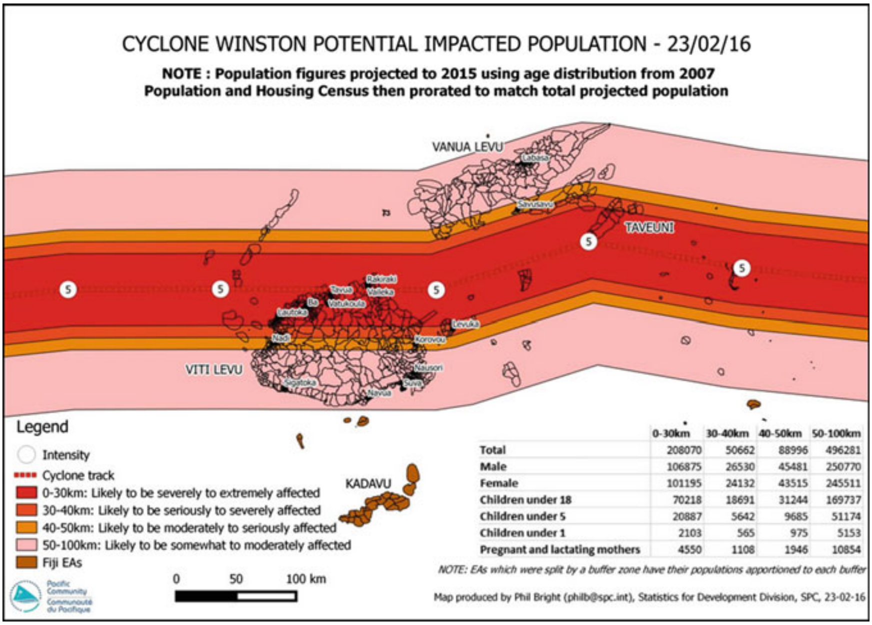

Fig. 3 Tropical cyclone Winston path through Fiji and potential affected population as of February 23rd, 2016. The cyclone on the Australian Tropical Cyclone Intensity Scale is indicated by the figure at the center of the spiral. *Source* Fiji Ministry of Health and Medical Services and WHO (2016)

2 TC Winston Storm Surge and Waves and Their Impacts

With an atmospheric pressure of 930 hPa measured at the center of the cyclone on February 19, a storm surge was expected to affect the coastal areas of Fiji during TC Winston (Fiji Meteorological Services 2016a). Contrarily to the Australian Tropical Cyclone intensity scale, the Saffir-Simpson Hurricane scale indicates a range of height for storm surges associated with tropical cyclones of different categories. For category 5, when winds are stronger than 249 km/h, the US National Weather Service from the National Oceanic and Atmospheric Administration indicates that the storm surge can be higher than 5.5 m (18 ft). However, the actual height of a storm surge is controlled by local parameters such as bathymetry and flow bottom friction (Bastidas et al. 2016). Another important parameter is the influence of storm size (in particular its radius) on the height of storm surges. When this parameter is included in the model to predict storm surges, there is a better correlation with the observed surges in the USA (Irish et al. 2008). There is no such study conducted in the Pacific so far but it could be useful for early warning systems to get a more precise prediction of storm surges.

Reports on the characteristics of TC Winston include precise information on the wind speed and amount of rainfall; however, there is no precise information on the height of the associated storm surge, although it has been recognized that the storm surge was responsible for a significant part of the damages observed in different locations around Fiji; in particular Koro and Vanua Balavu Islands and the southern coast of Vanua Levu where the seawater reached 200 m inland in some locations (Government of Fiji 2016). This significant storm surge generated damages on infrastructure and coastal vegetation and plantations (Fig. 4). Marine ecosystems such as coral reef which are known to protect the coast were also damaged by the storm surge (Government of Fiji 2016).

The intensity of TC Winston and its occurrence, one year after TC Pam, another category 5 cyclone which affected Vanuatu, Tuvalu and Kiribati in 2015 led to the question of the influence of climate change on the intensity and/or frequency of these "super cyclones" and the attribution of their characteristics (e.g. Emanuel 2005, 2017; Knutson et al. 2010; Terry and Lau 2018; Tukayabu et al. 2015). This question was very relevant in the case of TC Winston due to the regional context. Climate change has been recognized since the mid-1990s by all leaders of the Pacific Small Islands Developing States (PSIDS) as a very serious threat for their development and even, in the case of the low lying atoll countries like Tuvalu, Kiribati or the Republic of the Marshall Islands, as a threat to their mere existence, leading to the inclusion of climate change adaptation and mitigation in two major frameworks for the region: the Framework for Pacific Regionalism in 2014 and the Framework for Resilient Development in the Pacific in 2016 (Pacific Community et al. 2016; Pacific Islands Forum Secretariat 2014). There is thus an intense activity of observation and monitoring of climate change impacts in the region, with a special focus on the impact of sea-level rise. The question was also raised in response to the succession

Fig. 4 Picture of Vatulele Village, north-eastern extremity of Koro Islands after TC Winston. Koro was one of the most affected small islands in Fiji, where most of the damages were caused by strong wind (185 km/h) and the storm surge. *Source* Fiji National Disaster Risk Management Office (n.d.)

of intense tropical cyclones (categories 4–5) in the region before 2016, including (but not limited to): TC Pam (cat. 5 in 2015 in Vanuatu), TC Ian (cat. 4, in 2014 in Tonga), TC Evan (cat. 4 in 2012 in Samoa and Fiji) and TC Tomas (category 4 in 2010 in Fiji). In this context, the two questions on TC Winston and climate change were: Was the frequency of these intense cyclones the result of climate change? Was sea-level rise partly responsible for the height of the storm surge associated with TC Winston?

In response to the first question, although recent studies have shown that model results indicate and increase in the frequency of intense cyclone due to climate change (e.g., Sugi et al. 2016; Backmeister et al. 2018), globally by an average of 25–30% per °C of global warming (Holland and Bruyère 2013), there is a large regional variability and the frequency is expected to decrease in the South Pacific Basin (Sugi et al. 2016).

With regards to the second question, a recent study of super typhoon Haiyan in the Philippines, comparing the models of the storm surge associated with this cyclone in a changing climate with the storm surge associated with a similar cyclone in a pre-industrial environment, indicated that up to 20% of the height of the storm surge could be attributed to climate change (Takayabu et al. 2015). This supported the findings of a study conducted in Bangladesh which concluded that sea-level rise of 0.3 m and increased sea surface temperature by 2 °C would increase the area inundated by a storm surge by about 15% (Karim and Mimura 2008). However, a study on the strength of the waves associated with TC Winston based on the displacement of coral boulders on the coasts indicated that the waves for TC Winston reached up to 10 m high with an associated flow around 14 m/s but were not unprecedented and were, in fact, comparable to those generated by TC Tomas (cat. 4) in 2010 (Terry and Lau 2018). It seems thus likely that climate change, and in particular sea-level rise, will increase the height and the intensity of storm surges associated with tropical cyclones, widening the inundated areas and generating more damages. Even if comparable events were observed in the previous 400 years, the extent of coastal development since then, both in terms of population increase and infrastructure building, would significantly increase the risks in the coastal region of Fiji.

3 Impacts on Health

In terms of direct impacts, the number of casualties was 43 on March 10th, 2016 but increased to 44 on March 18th (Fiji Health and Nutrition Cluster 2016a, b). On March 10th, 126 people were reported injured, 45 were hospitalized as a direct consequence of TC Winston, probably due to trauma caused by collapsed structures, debris carried by strong winds or near drowning. These cases were treated in the different health structures, and tetanus shots were also provided to limit the risk of contracting the disease (Fiji Health and Nutrition Cluster 2016a). However, tetanus being part of the national childhood immunization program, coverage in 2013 was estimated to be above 95% and 74% for maternal tetanus toxoid; a part of the population, including elderlies who were not included in the childhood program, remains at risk though (Fiji Ministry of Health and Medical Services and WHO 2016). A total of 19,812 people were displaced (Fiji Health and Nutrition Cluster 2016a). This figure decreased to 4,299 on March 18th, and 361 on March 29th (Fiji Health and Nutrition Cluster 2016b, c).

The high number of displaced people, sheltered in 557 evacuation centers, caused worry on the higher risk of secondary impacts due to living in overcrowded conditions. In such situation, the risk of transmission of communicable diseases, such as acute respiratory infections, measles and rubella, diarrheal disease (bacterial and viral), hepatitis A, Leptospirosis, meningococcal disease and typhoid, increases (Fiji Ministry of Health and Medical Services and WHO 2016). Children under 5 are particularly at risk, especially from acute respiratory infection and diarrheal disease, as was observed after the floods in Honiara and Guadalcanal, Solomon Islands, in 2014 which were followed by a diarrheal epidemic affecting more widely children under 5 who had 20 more chances to contract the disease than older children (Fiji Ministry of Health and Medical Services and WHO 2016). One of the priorities of the Fijian authorities and of the Health and Nutrition Cluster was to limit the secondary impacts as much as possible. These secondary impacts are generally attributed to three main causes: lack of proper nutrition, in particular for children below 5, lack of access to clean water, and life in overcrowded conditions in shelters (Fiji Ministry of Health and Medical Services and WHO 2016). A few case suspicions of measles were recorded after TC Winston (Fiji Health and Nutrition Cluster 2016b) and several cases of conjunctivitis were recorded in Suva (Fiji Health and Nutrition Cluster 2016c).

The reduction in the public health risks associated with TC Winston comprised different actions which built on public health programs in place before the cyclone. A specific Early Warning Alert and Response System (EWARS) was put in place to monitor risks of transmission of communicable diseases with 33 stations participating on March 18(Fiji Health and Nutrition Cluster 2016b). Among the diseases monitored by the EWARS was acute or bloody diarrhea, expected to be caused by bacterial since the other potential cause, rotavirus, vaccination, has been part of the national childhood immunization program since October 2012, thus limiting the risks of a large outbreak (Fiji Ministry of Health and Medical Services and WHO 2016). Some clusters of diarrhea were observed in Keiyasi and other badly affected areas (Fiji Health and Nutrition Cluster 2016b; Fiji Ministry of Health and Medical Services and WHO 2016). Priorities identified to be addressed by the first appeal to international aid included: supporting the delivery of health services to all people, procurement and distribution of urgent and essential medical products such as treatment and vaccines and provide children and maternal care as well as address the risk of sexually transmissible diseases (Fiji Ministry of Health and Medical Services and WHO 2016).

In addition to diarrheal disease, leptospirosis and typhoid were monitored by EWARS. Leptospirosis had been observed after the floods in Fiji in 2012 when 576 cases were reported with 7% fatalities (Lau et al. 2016). Although there were some concerns for the Navua area on March 19th, no cases were observed after TC Winston (Fiji Health and Nutrition Cluster 2016b). A typhoid outbreak of 35 cases was observed after TC Winston in the villages of Qelekuro and Nabulini on the north-east part of Viti Levu, the main island of Fiji but no fatalities were observed. This outbreak was explained by a worsening of the environmental conditions due to the cyclone in an area of high seroprevalence of antibodies against *Salmonella enterica*, one of the bacteria responsible for typhoid fever (de Alwis et al. 2018). To address this outbreak, twenty thousand doses of typhoid vaccine have arrived in Fiji for outbreak prevention and control, if indicated in line with the typhoid fever vaccination strategy that has been finalized by the Public Health Intervention group (Fiji Health and Nutrition Cluster 2016d).

Vector-borne diseases such as dengue, zika and chikungunya were also monitored after TC Winston since several of these diseases are present in Fiji. On March 19th, 71 cases of dengue-like disease (fever, rash, edema of the hands and feet, joint and muscle pain) were reported from Lautoka, west of Viti Levu (Fiji Health and Nutrition Cluster 2016b) and on April 9th, 15 cases of Zika had been confirmed (Fiji Health and Nutrition Cluster 2016d). Prevention measures to limit the proliferation of mosquitoes were implemented to limit further spreading of these diseases.

Malnutrition was a serious problem in some areas after TC Winston, in particular for children under 5. On March 9th, a total of 15 malnutrition cases were recorded, 12 mild and 3 severe ones which were treated at divisional hospitals (Fiji Health and Nutrition Cluster 2016a). The number of cases increased to 26 on March 29th (Fiji Health and Nutrition Cluster 2016c). To address this issue, food ration contents were reviewed, micronutriment powder was distributed and a nutrition specialist joined the staff of the Fiji Ministry of Health and Medical Services for three months after TC Winston (Fiji Health and Nutrition Cluster 2016c, d). The cyclone had a significant impact on local fisheries which provide fish to schools, limiting the supply of proteins to the children (World Conservation Society 2016). Several cases of malnutrition were observed on Koro Island. Because of the damages caused by the cyclone on this island, the terrestrial food sources were damaged or destroyed by strong wind, heavy rain and storm surge which also led to a contamination of the soil by saltwater (Government of Fiji 2016). In addition, coastal fisheries in Koro were very badly affected by the cyclone, for example around 96% of the fishing boats in Koro were destroyed, affecting the food supply of the households, 92% of which depends on local fisheries for subsistence and leading to a decrease in the amount of fish delivered to the local school to 0% (World Conservation Society 2016). The cyclone also had a longer impact on livelihoods in Koro since 50% of their income came from Kava farming which was completely destroyed after the cyclone (World Conservation Society 2016). The situation regarding food supply was difficult and there was some evidence of young girls offering sexual services in exchange for food, thus increasing the risk of sexually transmitted diseases and of violence. A system of food vouchers was established by the government to facilitate food supply for all affected people (Government of Fiji 2016).

A total of 8,466 people received psychological first aid after TC Winston. Training of trainers workshops was organized by the Ministry of Health and Medical Services to support the deployment of staff in all areas of Fiji, and more than 300 nurses were trained to provide psychological help (Fiji Health and Nutrition Cluster 2016b, d).

Persons with disabilities were also affected by TC Winston. A survey was conducted by UNICEF and the Pacific Disability Forum on a sample of 963 people. The findings indicate that 13.6% of children with disabilities were in need of psychological aid, and that specific first aid kits and dignity kits were needed to ensure a level of hygiene preventing the development of diseases. It was also noted that a significant number of persons with disability did not go to the shelter during Winston, either because there were accessibility issues or because of the lack of security (Pacific Disability Forum and UNICEF 2016).

4 Impacts on the Health System

The damages and loss faced by the health sector in Fiji amounted to FJ$13.9 million and corresponded to the damage or destruction of 88 health facilities out of 214, including clinics (Table 1). The damages included damage to the infrastructure themselves, loss of medical supplies, interruption of telecommunications, road and sea transportation and disruption of water and energy supplies. For example, parts of the main hospital in Fiji were flooded (Canyon 2017). Priority requests to partners included the procurement of vaccine cold chains (Fiji Health and Nutrition Cluster 2016a). Despite these damages, the priorities were the establishment of medical care centers to treat the different medical emergencies and to ensure the continuous care for patients with chronic diseases or infections (Fiji Health and Nutrition Cluster 2016a). However, some of the main health facilities were able to reopen and function normally relatively rapidly after the cyclone (Canyon 2017).

To face the needs to treat the population after the cyclone, retired nurses were re-engaged to support the medical teams deployed in the country (Government of Fiji 2016). Despite the support for the extra personnel, it was sometimes difficult to send medical personnel in affected areas because of the lack of means of transportation and because the safety of the first responders and other personnel on the ground needed to be ensured (Fiji Health and Nutrition Cluster 2016a). However, one public health outreach program was organized with the support of the extra nurses and another one was carried in mid-March. While the Eastern Division of Fiji was fully covered, 85% of the villages and 84% of the settlements were visited in the Northern Division and 96% of the villages and 82% of the settlements were visited in the Western Division (Fiji Health and Nutrition Cluster 2016b).

The reconstruction of the health infrastructures was expected to cost around FJ$31 million to ensure that all health facilities are fully operational. The most important costs for the reconstruction covers the relocation of some facilities in less exposed areas, the reconstruction of damaged facilities and the provision of drug and supplies (Government of Fiji 2016). In addition to these costs, FJ$59 million are needed to make the sector more resilient to climate change and disasters in the long term. Costs planned for this building-back-better include the retrofitting of existing facilities, build back better the destroyed facilities and the costs associated with the relocation of facilities (Government of Fiji 2016).

Table 1 Number of facilities damaged or with some functionality lost by division

Type of facility	Number of facilities reported				Total	Facilities that lost some form of Functionality				Total	Facilities that were damaged				Total
	Central	West	East	North		Central	West	East	North		Central	West	East	North	
Hospitals	8	7	5	4	24	–	–	–	–	–	7	7	1	3	18
Health centers	20	27	15	18	80	–	2	1	–	3	9	21	2	3	35
Nursing stations	22	28	36	21	107	4	–	–	–	4	12	18	1	3	34
Old people's home	1	1		1	3	–	–	–	–	–	1	–	–	–	1
Total	51	56	63	44	214	4	2	1	0	7	29	46	4	9	88

Source Fiji Health and Nutrition Cluster (2016a)

5 Conclusions

TC Winston caused devastation in Fiji in February 2016, leading to an important loss of lives and catastrophic socio-economic consequences. The health sector faced important damages and losses and struggled to continue to care for the health of Fijians in the aftermath of the cyclone. In some places, such as Koro island, strong winds, heavy rain and high storm surges combined to destroy infrastructures and food sources for coastal villagers. This destruction had long-term impacts and affected food security and several malnutrition cases were recorded on the island. The magnitude of the cyclone and its associated impacts raised the question of the influence of climate change and sea-level rise in the frequency and intensity of these extreme events. Although new studies focus on the attribution of cyclones to climate change, it is still difficult to precisely quantify the influence anthropogenic climate change has on cyclones. The high number of people seeking shelter in the evacuation centers increased the risk of secondary outbreak of diarrheal, acute respiratory diseases and vector-borne diseases that were already present in Fiji such as typhoid, dengue or leptospirosis. Although some cases were observed in the most affected areas or in urban environment, the monitoring and treatment of these cases prevented the generation of large outbreaks of these diseases. Malnutrition was closely monitored as well as vector-borne disease and campaigns of reduction of mosquito populations were conducted in the months after the cyclone. A total of 88 health facilities were damaged or destroyed, out of the 214 located in Fiji, for a total of FJ$13.9 million. Infrastructures damages, issues with power and clean water supply were the biggest problems, and there was a need to procure system to ensure the continuity of cold chain for vaccines against the secondary diseases. However, these difficulties were addressed so the health of Fijian could be supported as best as possible under the circumstances. The reconstruction of the health infrastructure, including building back better for a more resilient health sector to climate change and extreme events, is expected to cost FJ$ 90 million, but it is considered an important investment due to the vulnerability of the country to these issues.

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