Methodology for assessing vulnerability and climate risk of villages in Citarum River Basin, West Java, Indonesia

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Abstract. River basins provide homes and livelihoods to millions of people and play important roles in providing water for agriculture, drinking, industry and sewage as well as for hydropower energy production. The threat of climate change on water resources is serious and has to be taken into account in developing short, medium, and long-term development and management plans of river basins. The competition for water resources is projected to increase significantly, not only because of growing global population but also due to increasing demands from industry and agriculture. The impacts of climate change will put further stresses on water resources with projected changes in precipitation patterns. Potentially, more extreme rainfall events will occur, which will cause increased runoff and leave less water available to recharge the groundwater. The study assessed the overall vulnerability profile of the villages over the 2005 to 2011 period. The vulnerability assessment showed that villages classified as ‘very vulnerable’ are characterised by seven key areas: limited access to clean water particularly during the dry season, many households and buildings being located near the river banks, main economic activities being dependent on agriculture, limited access to electricity, lack of education, and health facilities. There were 17 very vulnerable villages in 2011 in the CRB. The current level of climate risk in these villages is still medium, but in the future the risk will increase significantly. Immediate adaptation actions (within 1 to 5 years) are recommended for 25 villages. Short term adaptation actions (within 5 to 10 years) are recommended for over 100 villages.

1. Introduction

Vulnerability is defined as the degree to which a system is susceptible to and unable to cope with the adverse effects of climate change, including climate variability and extremes [1]. The understanding of village vulnerability is a critical step in climate change resilience planning and helps to ensure that strategies and interventions will be effective and address the greatest risks to villages and populations affected. Specifically for the Citarum River Basin (CRB), the availability of vulnerability and climate risk assessments will assist the community and other stakeholders to inform strategies, programmes and actions to reduce the impact of climate change.

Many methods are available for assessing the vulnerability to climate change at different scales and across sectors [2]. However, there is no consensus on the best approach to vulnerability assessment and it is not easy to determine which approach is the best [3]. In general, approaches entail considering at least one factor related to exposure to climate risks, susceptibility to damage, and capacity to recover. Therefore, whatever the definitions used and approach taken, each vulnerability study should
clarify its definitions and methods used in its assessment [3, 4]. This will ensure the appropriate use of the assessment for developing adaptation strategies and actions.

There is a range of vulnerability definitions, which may be framed based on the discipline of their origin (for example, from risk, hazard or biophysical assessment, political economy and the concept of ecological resilience). There is a need to understand what exactly is meant when 'vulnerability' is spoken or written about [5]. Definitions may be influenced by such factors as the scale of the decision (local, regional, global, landscapes, ecological regions, multiple scales) and exposure unit (individuals, households, social groups, places, sectors, activities, landscapes, regions, ecosystems, coupled human-environmental systems). Brooks [6] synthesises a variety of approaches of vulnerability, adaptive capacity and risk. The vulnerability can be assessed on different spatial scales, such as regional, district and village level.

Globally, few studies so far have assessed the vulnerability at a micro-level, i.e. at the level of villages. However, micro-level assessments have been conducted in parts of Bangladesh and Vietnam for example [7, 8, 9]. Village levels assessments have been completed and proved to provide the required detail vulnerability assessment to guide effective planning and climate resilient development. Effective planning for climate change adaptation requires a fine scale assessment of local vulnerabilities to enable decision makers to respond appropriately to the bottom-up, pro-poor perspective, integrated across sectors and reflective of local stakeholders’ experiences and values. This study provides an approach to analyse the vulnerability of villages in the CRB to the potential impact of climate change, to assess the level of climate risk of the villages in the CRB, and to identify priority locations for adaptation based on the results of vulnerability and climate risk assessments.

2. Data and Methods

2.1. Overview of the region

The CRB territory is located in the western parts of Java Island, Indonesia, and covers a total area of about 13,000 km$^2$ through three inter-connected river basins. The cluster of river basins consists of the 6,600 km$^2$ Citarum River Basin (CRB), which spans central parts of the territory and flows from south to north into the Java Sea, secondly, the 4,400 km$^2$ cluster of small basins whose drainage areas are connected to the Citarum River system through the East Tarum Canal, and thirdly the Cikarang and Bekasi Rivers with a combined drainage area of 2,000 km$^2$, which are connected with the Citarum River through the West Tarum Canal.

![Figure 1. Map of CRB location.](image)
remaining forests cover only about 10.2% in the territory. Deforestation of the upper catchments have caused increased sediment loads, flash floods, landslides, and other water-related disasters. The numerous environmental issues in the CRB result predominantly but not exclusively from the same urbanisation and industrialisation that is the cause of water supply shortages.

2.2. Key risks in the region
The CRB is facing pollution, sanitation, and environmental problems, such as deforestation, siltation, drought and flood. A number of studies suggest that deforestation will continue to the future [10, 11], turning natural land (forests, farmyards, empty lands) into build up areas (housing, industrial areas, transportation infrastructure). This will worsen depleting water supply (decrease of infiltration, causing water catchments volume deficit) and drought conditions during the dry season and intensity flooding during the wet season (increase of direct surface water runoff). Climate change will make the situation worse [12]. A recent study suggests a flood return period of 14 years under land use conditions of 2000, increasing to more frequent return periods of 13 and 10 years for land use conditions in 2010 and 2025. With climate change, the once in 13 year flood would occur on average once every 5 years assuming a land use of 2010, increasing the frequency of flood risk even more [13].

2.3. Assessment Methodology
2.3.1. Vulnerability Assessment. The assessment of the vulnerability is a critical step in developing climate change resilience planning. It helps to ensure that resilience strategies and interventions will target the most vulnerable populations, and address the greatest risks to sectors and systems. The results can inform existing adaptation capacities, potential impacts of climate change, identify the most vulnerable groups, sectors and systems, and factors that make them vulnerable and how they may be affected. It can also inform which adaptation strategies and interventions could enhance their resilience. The resilience of a system to the impact of climate change will depend on its vulnerability level. The more vulnerable the system, the less resilient the system is to the climate change impact.

2.3.2. Vulnerability Indicators and Underlying Data. The vulnerability profile of villages in the CRB was assessed by deriving a vulnerability index using the 2005 and 2011 data from Statistics Indonesia. There are about 1,179 villages in the CRB. Indicators describing their levels of sensitivity, exposure and adaptive capacity are described in the following sections.

Vulnerability is measured using three factors, namely level of exposure, level of sensitivity and adaptive capacity. It is derived from biophysical and socio-economic indicators, representing attributes of villages and their inhabitants. The indicators are integrated into a vulnerability index by assigning weighting values depending on their importance in shaping vulnerability. The selection of the weight values is subjective, based on the understanding and knowledge of experts on the relative importance of the indicators. Details of the weight values and methodology are described in Boer et al. [14].

The vulnerability index can be used as a tool by local governments to monitor measure and evaluate the impact of development programmes. Implementation of adaptation actions will change underlying indicators and increase the resilience of villages to climate change impacts. Indicators representing sensitivity and exposure both contribute to the increase of vulnerability and are combined into a Sensitivity and Exposure Index (SEI). A higher vulnerability results from higher levels of sensitivity and exposure. On the other hand, indicators representing adaptive capacity contribute to a decrease in vulnerability and are combined into an Adaptive Capacity Index (ACI). A lower vulnerability results from a higher adaptive capacity.
The vulnerability profile can be defined using the quadrant as shown in Figure 3 where villages can be grouped into five types (Table 1). The two extreme types are Type 5 (very vulnerable with high sensitivity and exposure level and low adaptive capacity) and Type 1 (not vulnerable with low SEI and high adaptive capacity).
Table 1. Categorisation of villages according to their vulnerability profile.

| Village Types According to Vulnerability Level | Sensitivity and Exposure Index (SEI) | Adaptive Capacity Index (ACI) |
|-----------------------------------------------|-------------------------------------|-------------------------------|
| Type 1: Not Vulnerable                        | Low                                 | High                          |
| Type 2: Quite Vulnerable                      | High                                | High                          |
| Type 3: Medium                                | Medium                              | Medium                        |
| Type 4: Vulnerable                            | Low                                 | Low                           |
| Type 5: Very Vulnerable                       | High                                | Low                           |

a. Sensitivity and Exposure Index (SEI)

The level of sensitivity is derived from socio-economic and biophysical data, reflecting the internal conditions of the system. For example, villages with fewer poor people and better access to drinking water will be less sensitive to climate variability, but when a village relies heavily on rainwater or access to clean river water during a drought it is more sensitive. Similarly, a village that has an irrigation system will be relatively less sensitive to the impact of drought compared to one without.

Indicators representing the level of sensitivity of villages

- **Source of drinking water (SAM)** Indicates the access of households to drinking water such as piping system (provided by drinking water company PDAM), electric pump, well, spring, rainfall and others. Households that are connected through a piping system will be less sensitive than those without. During periods of drought, they can still access drinking water.

- **Poverty index (KPs)** Indicates the ratio between poor households and the population size of the village. Villages with a higher poverty index are more sensitive.

- **Main Source of Income (SMP)** Indicates the sensitivity of household income to climate hazards. Villages where the main source of the income is very climate-dependent, such as agriculture, are more sensitive.

- **Agricultural land use (LLp)** Indicates the area of land in villages which are sensitive to climate variability and climate change.

- **Low land rice area (LSw)**

The level of exposure is derived from biophysical data, representing the extent in which the system is in contact with, or subject to climate variability. For example, houses which are close to the river bank will have higher level of exposure to flood than those far from the river bank.

Indicators representing the level of exposure of villages

- **Number/Percentage of Household living in River Bank (KBs)** Indicates the distance of settlements and properties to the hazard. For example, villages where many households live near the river bank will have a higher level of exposure to flood.

- **Number/Percentage of Building in River Bank (BGs)**

- **Population density (KPdk)** Indicates the number of people who can potentially be affected by a hazard. This will be higher in villages with higher population density and describes the level of exposure.
b. The Adaptive Capacity Index (ACI)

Adaptation can be related to actions or measures that may reduce the level of exposure or the level of sensitivity of the system, and to conditions that enable the system to improve the adaptive capacity. The adaptive capacity is derived from socio-economic and biophysical data. For example, villages with higher level of community education would have better adaptive capacity.

Indicators representing the adaptive capacity of villages

| Indicator                           | Description                                                                 |
|-------------------------------------|-----------------------------------------------------------------------------|
| Electricity (FLt)                    | Household access to electricity indicates the level of wealth. Wealthier families are assumed to have a higher adaptive capacity. |
| Education facilities (FPk)          | Indicates the ability and capacity of a community to manage the risk. The higher the education level of a village, the better is their adaptive capacity. |
| Health facilities (FKs)             | Indicates the access of communities to health facilities. The better the health facilities in a village, the better the adaptive capacity as this ensures community members have good access to immediate treatments whenever a hazard strikes. |
| Road infrastructure (IJ)            | Indicates the main road surface type, which affects the condition of the transportation system and ensures safe and timely distribution of aid, evacuation etc. Villages with asphalt roads have higher adaptive capacity compared to villages with gravel or soil road infrastructure. |

2.3.3. Climate Risk Assessment. Climate risk can be described as a function of the probability of a climate hazard occurring and the vulnerability (Figure 4). The level of climate risk of the villages is derived by overlaying the probability of the climate extreme (decrease, no change or increase compared to current probability) and the vulnerability maps of 2011. This information informs the change of climate risk of villages in the future assuming no change in the vulnerability. To reduce the risk, the vulnerability should be lowered and the priority locations for the implementation of adaptation actions should be given to villages who presently already display a high and future very high climate risk. Least priority is given to villages that have very low climate risk at present and lower climate risk in the future.

![Figure 4. Definition of Climate Risk.](image-url)
Using the above definition, the level of climate risk can be defined using the risk matrix as suggested by Beer and Ziolkowski [15] in Table 2. This matrix suggests, for example, that if the probability of a climate hazard increased in the future due to climate change while the vulnerability remains the same, the level of climate risk will increase.

**Table 2. Matrix of climate risk as a function of probability of climate hazard and the vulnerability.**

| Vulnerability               | Very likely (increase) | Likely (No change) | Unlikely (Decrease) |
|----------------------------|------------------------|--------------------|---------------------|
| Very Vulnerable            | VH                     | H                  | M-H                 |
| Vulnerable                 | M-H                    | M                  | M-H                 |
| Medium                     | M-H                    | M                  | M                   |
| Quite Vulnerable           | M                      | L-M                | M                   |
| Less or not Vulnerable     | L-M                    | L                  | L                   |

The future climate risk of villages in the CRB is defined using the climate risk matrix above. The vulnerability level of villages in the future is assumed to be the same as the present one (based on the 2011 analysis in the previous section). Climate extremes considered are flood and drought occurrences. To assess the change of the probability, the rainfall threshold causing flood and drought is considered. These are based on historical flood and drought data from agriculture, at district level from 1989-2010 and obtained from the Directorate of Plant Protection.

Climate change scenarios being used in this analysis are the new IPCC scenarios, RCP-2.6, RCP-4.5, RCP-6.0, and RCP-8.5 [16], see box. The change in the future probability of flood and drought is defined by comparing the probability of the climate hazards under current and future climates (RCP scenarios). Thus, the future probability of climate extreme would increase, remain the same or decrease. This analysis is described in detail in Faqih et al. [17] and shown in Figure 5 and Figure 6.

Figure 5 suggests that the probability of rainfall causing floods is expected to increase mostly over the upper area of the CRB. Significant increases are found in the western part of Bandung, mostly for the RCP4.5 and RCP8.5 scenarios. More frequent rainfall causing floods in the upper part of the CRB could potentially increase the risks not only in the region but also in the middle and lower part of CRB. Figure 6 shows that the occurrence of drought in the upper area of the CRB will be more frequent in the future. The probabilities of the rainfall causing droughts are also found to increase in the lower part of CRB, especially in Bogor, Karawang and Bekasi.
Figure 5. Probability of rainfall causing floods for the baseline (1989-2010) and RCP8.5 (2071-2100).

Figure 6. Probability of rainfall causing droughts for the baseline (1989-2010) and RCP8.5 (2071-2100).

3. Result
3.1. Study results A: Sensitivity, Exposure and Adaptive Capacity of Villages in the CRB
3.1.1. Sensitivity. The following section highlights the findings and spatial distribution of factors influencing the sensitivity and ultimately the vulnerability of villages, such as source of drinking water, poverty index, main source of income, agricultural land use and low land rice area.

a. Source of Drinking Water
The majority of households still rely on wells for water, mostly with manual but increasingly with electrical pumps. In 2005, more than 71% of the households accessed clean water from wells, but in 2011 this has decreased to 65% (Figure 7). Interviews revealed that many of the wells, particularly those in the upper and middle parts of the CRB, have no water during dry season. About 67 villages
changed the main source of drinking water from wells to spring water, particularly in the middle (sukalaksana, gunungsari, margaluyu, mekarjaya, campakawarna) and upper (sukawening, cibodas, cimaung, sirnajaya, pasirwangi) parts of CRB. There were also some villages in the lower part whom changed the main source of water from well to spring water such as in sukawangi, cibadak, bunder, cipurwasari, kuralanggeng.

Figure 7. Percentage of village based on source of drinking water in 2005 and 2011.

b. Poverty Index.
The poverty index of villages is based on the condition of households in term of their ability to meet their basic needs (food, health services, education, cloth and housing). Poor households (defined as ‘pra-sejahtera’) have four characteristics (inability to meet basic food needs (food), access to health services, low education, and houses with soil-floor). The number of poor households in villages of the CRB is high. In almost half the villages, the ratio between poor households and the population size is higher than 40%. About 60 villages (5%), mostly located in the lower part of CRB, have a ratio exceeding 80%. Most of the poor households are found in villages where agriculture is the main source of the income, such as in the lower CRB, where most households are involved in rice farming and in the upper part of CRB, where farmers are mostly engaged in horticulture [18]. Rice farmers on the north coast of West Java are mostly subsistence farmers with farmlands of less than 0.25 hectares and some with no lands. This results in monthly average incomes of only about IDR 300,000 (about 1 USD per day; [19]). Horticulture farmers with the same land size are able to get much higher income than rice farmers, so diversifying rice crop with horticulture may increase rice farmer’s income. A study in low land rice farming at Indramayu in West Java suggests that introducing various vegetables (horticulture) to rice farming as second or third crops could increase farmer’s income up to 7 times, especially for red pepper and onion [18].

c. Main Source of Income
In 2005, there were no villages with mining as their main source of economic activity. However, in 2011 it was recorded that many households in five villages have shifted their main economic activities from agriculture to mining, such as lime mining and other ‘galian C’. These villages include BuahBatu (upper), Sukamatri, Sinargalih and Naggerang (middle), Mulangsari and Cimahi (lower).

d. Dry Land Agriculture
Most villages rely on agriculture as their main source of income. Rice farming is the dominant agriculture activity in the lower part of the CRB, whilst horticulture such as potato, tomatoes, chilli and other vegetables are widespread farming activities in the middle and upper part. This has shifted slightly towards non-agricultural activities between 2005 and 2011, when about 8% of villages shifted
their main source of income. Main economic activities shifted to industry, trade and services in districts and cities with rapid industrial development, such as Kerawang, Bandung and Garut. For example, villages in the upper CRB that shifted their main economic activities to industry and trade were Margamulya, Cipaku, Nagrog, Rancakole, Kopo (middle: Laksanamekar, Cipeundeuy, Mandalawangi, Ganjarsari, Sarimukti; lower: Skaroya, Parakanmulya, Duren, Bendungan, Pasirranji, Karangmekar). Villages in the upper CRB that changed their main economic activities to services include Cisurupan, Cibural, Bandasari, Bojongsari, Cilengkrang (middle: Sindangasih, Sukamaju, Cihideung, Pakujahi, Selacau; lower: Pawenang, Parakansalam, PasawahanKidul, Ciherang, Mulyasari).

In 2005, most villages (66%) use less than 14% of their land for dry land agriculture (i.e. non-rice). However, the percentage of villages where a large proportion (over 40%) of the land is used for dry land agriculture increased significantly from around 11% in 2005 to 34% in 2011, indicating expanded dry land agricultural activities particularly in the middle and the upper part of CRB. 50 villages (4%) increased their dryland agriculture areas rapidly, from less than 14% to about 60% of the total area within the period of 2005-2011. These villages include Sukaresmi, Sirmajaya, Bongas, Kertawangi, Cimenyang in the upper CRB, Gunungsari, Girimukti, Cidadap, Ciputri and Majalaya in the middle CRB and Parungbanteng, Bojongtimur, Cijagang, Tugu Utara and Cibadak in the lower CRB. Limited alternative income sources pushed households to expand their agriculture land.

The expansion of dry land agriculture took place in the previously forested land causing deforestation, which may increase the vulnerability of villages. Forests play important roles in buffering extreme climate events. For example, villages with less forest cover will be more sensitive to extreme rainfall compared to ones with larger forest cover. Rainfall will more directly flow as surface runoff and can expose downstream areas to flooding. Similarly, during dry condition the region can be exposed to drought risk as the water retaining capacity of soil is low.

e. Area of Rice Paddy

Most of the villages located in the downstream areas of the CRB conduct rice agriculture on more than 70% of their land. There are some villages in the middle and upper CRB with active rice agriculture areas of about 70%. From 2005 to 2011, many villages in the CRB shrunk their rice agriculture areas due to the conversion to non-agriculture land uses such as settlements [11]. Villages in which their rice agriculture area decreased rapidly from about 50-70% of their total land area to less than 40% occurred not only in the upper, but also in the middle and lower CRB. This rapid conversion occurred in 14 villages, namely Cibodas, Jagabaya, Mekarpawitan, Bojong and Cilampeni in the upper CRB, Girimulya and Bojongsalam in the middle CRB and Bojongmangu, Kalihurip, Cintalaksana, Pusuerjaya, Tanjungoakis, Mekarbuana and Sukaharja in the lower CRB. Low land rice agriculture requires a lot of water. Any decrease in rainfall will have a serious impact on the yield, thus villages with large proportions of their land cultivated by low land rice would be more sensitive than those with low proportions.

3.1.2. Exposure. The following section highlights the findings and spatial distribution of factors influencing the exposure and ultimately the vulnerability of villages, such as number of households and buildings on the river bank, and the population density.

a. Number of households living on the river bank.

Less than 30% of villages have households living near the river bank. In villages with river side settlements, this generally amounts to less than 3.7% of households. This slightly increased from 2005 to 2011, suggesting that new households settled near the river banks. In 2011, there were 7 villages where more than 20% of households lived near the river bank. These are Wongunjaya in Cianjur District (57%), Andir (38%), Ciparay (35%), Arjuna (24%) and Majalaya (21%) in Bandung District, Pantai Mekar (27%) in Bekasi District and Tamelang (21%) in Karawang District. The village with the
highest percentage of households living near the river bank (about 57%) is Wangunjaya in the middle area of CRB.

b. Number of buildings on the river bank
Less than 30% of villages have buildings established near the river bank, as previously mentioned. In villages with riverside buildings, the percentage of buildings near the river bank is generally less than 4.5%. This slightly increased from 2005 to 2011 with additional 72 new villages with riverside buildings. There are 8 villages with more than 20% of the buildings located near the river bank. In the upper CRB, these villages include Andir, KebonWaru and SindangPanon and in the lower CRB, they include MekarMulya, Kutanegara, ParungMulya, Galumpit and Kuta Mekar. The increasing number of households living near the river bank will also increase the level of exposure of households to flooding. Andir is the village with the highest proportion of households near the riverside building (37%).

c. Population density
The total number of people living in the villages in the CRB reached 9.73 million in 2005 and increased to 11.45 million in 2011. The population density varied amongst the villages. Most villages (around 60%) have a population density of less than 2,500 people/km2. The highest density was found in the villages of the upper CRB, particularly in the cities of Cimahi and Bandung, and some settlements in the Bandung District. A significant increase in population density occurred between 2005 and 2011 in 38 of villages (from 2,500 to more than 7,600 people/km2), for example in Padasuka, Citeureup, Margasuka, Cirangrang, Cibaduyut Kidul, Batununggal (upper CRB), Cipaisan, Ciseureuh, Duren, and Karawang Kulon (lower CRB). Villages with the lowest population density in the upper, middle and lower CRB are Mekarwangi, Sukalaksana and Ciramahilir respectively. The villages with the highest population density are Babakan Asih(63,300 people/km2) in Bandung City (upper CRB) and Solokpandan (Middle CRB). The village with the lowest population density of 5.552 people/per km2 is Tenjolaya (upper CRB).

3.1.3. Adaptive Capacity. The following section highlights the findings and spatial distribution of factors influencing the adaptive capacity and ultimately the vulnerability of villages, such as number of households who have access to electricity and health facilities, the level of education and road infrastructure.

a. Households with electricity
Villages where most households (80% to 100%) use electricity increased from 55% in 2005 to 91% in 2011, with main increases in cities such as Bandung and Cimahi. However, there are still villages where the percentage of households with electricity is below 50% in 2011, indicating poor economic conditions of the community and a lower adaptive capacity. These villages are Cigondewah Kaler, Cihawuk, KebonPisang, and PasirBiru in Bandung District; Cipangeran, Cibitung, and Kertajaya in Bandung Barat District; Cipayung, and Sukakarya in Bekasi District; Buanajaya, and Tanjung Rasa in Bogor District; and Cibanggala, Situhiang, Sukasirna, and CiramaGirang in Cianjur District. On the other hand, there were some villages in which the percentage of household with access to electricity decreased such as in Situhiang (middle CRB) and Sidangpanon (lower CRB). This indicated that the increase in the number of households in these villages was not followed by the development of electricity facilities.

b. Education facilities
The number of villages with lower education facilities (more than 10,000 people per unit school) increased from 22% in 2005 to 35% in 2011, while the number of villages with higher education facilities (less than 4,000 people per unit school) decreased. This suggests that the number of education facilities did not increase with the rate of population growth, particularly in the upstream (e.g. BalongGede, Cikondang) and downstream (Cadassari) area of the CRB. However, there are six villages where education facilities have increased significantly between 2005 and 2011, namely
Cilengkrang, Warudoyong, Numgur Jaya and Pasawahan Anyar (upper CRB), Wargasaluyu (Middle CRB) and Cijerang (lower CRB). In these villages, education facilities increased from more than 10,000 people per unit school to less than 5,000 people per unit school. The village with the poorest education facilities is Ancol (upper CRB; more than 85 thousand people per unit school) while the best one is Citarum village (upper CRB; less than 2,000 people per unit school).

Ideally, this indicator would describe the education level of communities and not just the number of schools. However, this information is not available for all districts and therefore the number of schools was used instead of the education level. Villages with lower education facilities will have a lower adaptive capacity compared to those with good education facilities.

Health facilities. The availability of health facilities has improved from 2005 to 2011, mostly in the upper and middle areas of the CRB. The ease of access and condition of health facilities and services reflect the adaptive capacity, especially during extreme climate events. There were four villages, two in the upper and two in lower CRB in which the number of health facilities increased significantly (from more than 3704 to less than 1724 people per unit facilities). These villages are Taman Sari, Mekarsari, Karanganyar and Telukjaya. The villages in the upper, middle and lower CRB with the highest health facilities, i.e. 1 unit health facility serving less than 1724 people, are Tanggulun, Kadumekar and Cipeudey and those with the lowest health facilities are Padasuka, Ciranjang and Cicadas.

c. Road infrastructure
The condition of the transport infrastructure in villages has also improved. In 2011, almost 85% of villages have asphalt roads, less than 15% have roads with gravel and very few villages have roads with soil. The improvement of the road infrastructure occurred in most of the cities and districts. Very rapid improvement in road infrastructure (from soil to gravel-asphalt) occurred during 2005 to 2011 in 23 villages, such as Bandasari, Cipanjalu in the upper CRB, Sukabungah, Kertamukti Sukaresmi in the middle CRB, and Sukamukti, Ciririp in the lower CRB. There were few villages in which the road infrastructure has deteriorated between 2005 and 2011, for example Baros and Cibokor. Villages with better road infrastructure have higher adaptive capacities, making evacuation and distribution of aid more efficient.

3.2. Study results B: Vulnerability Profile of Villages in the CRB
A vulnerability profile is assigned to a village, based on the SEI and ACI indicators and approach previously described (Figure 3). The vulnerability of villages in the CRB region as shown in Figure 8 and Table 3 shows the overall improvement in vulnerability from 2005 to 2011.

![Figure 8. Vulnerability map of CRB.](image)
Table 3. Percentage of village based on criteria of vulnerability in 2005 and 2011.

| Vulnerability Profile                        | Percentage of village (%) |
|---------------------------------------------|---------------------------|
| Type 1: low SEI – high ACI (Not Vulnerable) | 23 17                     |
| Type 2: high SEI – high ACI (Quite vulnerable) | 24 51                  |
| Type 3: medium SEI – medium ACI (Medium)    | 44 30                     |
| Type 4: low SEI – low ACI (Vulnerable)      | 5 1                       |
| Type 5: high SEI – low ACI (Very Vulnerable)| 4 1                       |

Forty four percent of villages were assessed with a medium vulnerability in 2005, which improved to quite vulnerable for 51% of villages in 2011 (Table 3). This was due to difficulties in accessing clean water hence increasing the villages’ sensitivity, but improvements in electricity access also improved their adaptive capacity. This was highlighted in (Figure 9), indicating that the access to clean drinking water (SAM), and electricity access (Flt) has increased over the time period. There was also a significant decrease in the number of villages with a very vulnerable level from 4% in 2005 to 1% in 2011 (Table 3). As many as 45 villages have changed the level of vulnerability from very vulnerable (VV) to better conditions.

In 2011, 17 very vulnerable villages existed (Table 4), of which a few were not vulnerable in 2005, such as Margasuka and Babakan Ciparay (upper CRB), Hergamanah, Cinangsi and Gudang (middle CRB), Cibalongsari, Cipayung (lower CRB). The vulnerability of the two villages (Margasuka and Babakan Ciparay) did not improve and went from less vulnerable to very vulnerable. The number of households with limited access to clean water increased significantly in these two villages. Additionally, more households relied on agriculture activities, while health and electricity facilities dropped and very high population growth occurred. The population density changed from 4,828 to 8,573 per km$^2$ in Margasuka and from 13,857 to 24,345 per km$^2$ in Babakan Ciparay between 2005 and 2011.

Figure 9 represents the spider graph of all indicators used to define vulnerability. The average conditions of vulnerability indicators for villages which were very vulnerable in 2011 and the changes of the indicators relative to the 2005 are presented. The increase in sensitivity and exposure (SEI) and decrease in adaptive capacity (ACI) indicates the increase in vulnerability. The figure shows that the increase in vulnerability of the villages in the upper CRB was mainly due to the increase in the number of river bank households (K Bs), river bank building (BGs), population density (KPdk) and difficulties in accessing clean water (SAM), as well as the decrease in education (FPk) and health facilities (FKs). For villages in the middle and lower CRB, other indicators contributed to the increase of vulnerability levels such as the expansion of agriculture lands (LLp) and low land rice (LSw). The spider graphs show vulnerability profiles of villages with different level of vulnerability allowing us to determine the main contributing factors to their vulnerability. This assessment and analysis would help to identify appropriate types of adaptation actions.

The result of the analysis suggests that the main contributing factors to the village’s vulnerability are:

- Main source of income (SMP)
- Households living near river bank (K Bs)
- Buildings near river bank (BGs)
- Source of drinking water (SAM)
- High dependence to agriculture activities (LLp and LSw)
- Lack of education (FPk)
- Lack of health facility (FKs)

Adaptation actions for the villages should be directed to the above 7 key areas. Adaptation actions should be directed to increase access to water, to generate more income alternatives and to improve access to health, and education facilities. It should be noted that even villages with low SEI, still faced
the problem in accessing clean water and getting other alternative livelihood activities outside agriculture.

Figure 9. Spider graph of SEI and ACI indicators in 2005 (line) and 2011 (dash) for very vulnerable villages.
Table 4. Villages that increase in the level of vulnerability to very vulnerable in 2011.

| DAS  | No. DIS | DISTRICT  | No. SUB DIS | SUB DISTRICT | NO. VIL | VILLAGE  | 2005 | 2011 |
|------|---------|-----------|-------------|--------------|---------|----------|------|------|
| UPPER | 73      | BANDUNG   | 020         | BABAKAN CIPARAY | 001     | MARGASUKA | LV   | VV   |
| UPPER | 73      | BANDUNG   | 020         | BABAKAN CIPARAY | 002     | CIRANGRANG | M    | VV   |
| UPPER | 73      | BANDUNG   | 020         | BABAKAN CIPARAY | 003     | MARGAHAYU UTARA | V   | VV   |
| UPPER | 73      | BANDUNG   | 020         | BABAKAN CIPARAY | 004     | BABAKAN CIPARAY | LV   | VV   |
| UPPER | 73      | BANDUNG   | 030         | BOJONGLOA KALER | 003     | BABAKAN ASIH | M    | VV   |
| UPPER | 73      | BANDUNG   | 160         | BATUNUNGGAL CIBEUNYING KALER | 002     | BINONG | M    | VV   |
| UPPER | 73      | BANDUNG   | 220         | BOJONGPICUNG CIKALONGKULON | 013     | HEGARMANAH | M    | VV   |
| MIDDLE | 03    | CIANJUR   | 160         | CIKALONGKULON | 002     | CINANGSI | M    | VV   |
| MIDDLE | 03    | CIANJUR   | 240         | CIKALONGKULON | 004     | GUDANG | M    | VV   |
| LOWER  | 03     | CIANJUR   | 230         | SUKARESMI | 004     | CIWALEN | M    | VV   |
| LOWER  | 14     | PURWAKARTA | 050        | SUKATANI | 004     | CIBODAS | VV   | VV   |
| LOWER  | 15     | KARAWANG  | 040         | KLARI   | 012     | CIBALONGSARI | M   | VV   |
| LOWER  | 16     | BEKASI    | 041         | CIKARANG TIMUR KEDUNGWARING | 003     | CIPAYUNG | M    | VV   |
| LOWER  | 16     | BEKASI    | 050         | KEDUNGWARING | 002     | BOJONGSARI | VV   | VV   |
| LOWER  | 16     | BEKASI    | 130         | PEBAYURAN | 002     | BANTARJAYA | M   | VV   |
| LOWER  | 16     | BEKASI    | 130         | PEBAYURAN | 012     | KARANGSEMAR | M   | VV   |

3.3. Study results C: Climate Risk Profile of Villages in the CRB
3.3.1. Flood risk in the CRB. The level of flood risk varied considerably across the CRB and most villages fall under the risk categories of low to medium under the current climate conditions (Figure 10). The future level of flood risk of most villages would increase irrespective of the emission scenarios from low-medium to medium-high, if there is no change in vulnerability. The level of flood risk continues to increase until the end of the century. The change is significant, particularly for scenarios RCP4.5 and RCP8.5.

RCP4.5 is the most likely scenario out of the four. Parties to the United Nations Framework Convention on Climate Change (UNFCCC) have already committed to limit emissions following this scenario, even though not legally binding. Under this scenario, the flood risk of most of villages in the upper and lower part of CRB will increase. However, the level of the risk of some villages in the middle part of CRB might decrease in the period 2011-2040, but it would increase again in the period 2041-2100 (Figure 10).

3.3.2. Drought risk in the CRB. The level of drought risk for most villages in the CRB is categorised between low and medium under the current climate conditions (Figure 11). Drought risk will also increase in the future, mostly from medium to medium-high for all emission scenarios. It will continue to increase until the end of the century.
Figure 10. Level of flood risk for villages in the CRB under current and future climate conditions.
Figure 11. Level of drought risk for villages in the CRB under current and future climate conditions.
3.4. Priority Villages for the Implementation of Climate Change Adaptation

Currently, most villages in the CRB are already exposed to climate risk. If the implementation of development does not consider the villages’ vulnerability to potential climate change impacts, there would be increases of climate risk level and the vulnerability of the villages. Adaptation plans and actions should consider the current and future levels of climate risk, be targeted to reduce the vulnerability, and prioritise villages for implementation.

Table 5 shows the number of villages that have been classified as requiring adaptation action over different time spans, which has been assessed by evaluating the current and future climate risks. Immediate adaptation action (within 1 to 5 years) is recommended for villages that already display a medium-high to very high level of climate risk. For example, 21 villages fall into this category for either flood or drought, resulting in 25 villages classified as requiring immediate action due to flood and/or drought risk. Short-term adaptation actions (within 5 to 10 years) are recommended for over 100 villages which currently display a medium climate risk, which is projected to increase to medium-high and high.

![Table 5: Villages classified by urgency of adaptation action.](image)

Table 5 shows the number of villages classified as requiring adaptation action over different time spans, with the level of climate risk being assessed by evaluating the current and future climate risks. Immediate action (within 1 to 5 years) is recommended for villages already displaying medium-high to very high levels of climate risk. For example, 21 villages fall into this category for either flood or drought, resulting in 25 villages classified as requiring immediate action due to flood and/or drought risk. Short-term action (5 to 10 years) is recommended for over 100 villages showing medium climate risk, which is projected to increase to medium-high and high.

Figure 12 shows the current and projected climate risk for the villages and how the classification is made by the urgency of the required adaptation action.

![Figure 12: Prioritization of climate change adaptation actions based on the level of current and future climate risk.](image)
Table 6 provide the list of 25 villages which need immediate (1-5 years) adaptation programmes and actions to reduce their vulnerabilities, *i.e.* villages with a medium-high to very high level of climate risk. Most of these villages are already exposed to flood and drought risk, except for Hegarmanah, Cinangsi, Gudang, and Karangsegar (high drought risk only) and Cirangrang, Cigondewah Kaler, Gempol Sari and Jamika (high flood risk only).

Table 6. Twenty five villages which need immediate adaptation programmes and actions.

| District        | Sub District | Villages       | Flood Current | Future | Drought Current | Future |
|-----------------|--------------|----------------|---------------|--------|-----------------|--------|
| Cianjur         | Bojongpicung | Hegarmanah     | -             | -      | H               | H      |
|                 | Cikalongkulon | Cinangsi       | -             | -      | M-H             | H      |
|                 | Gudang       | -              | -             | -      | M-H             | H      |
| Sukaresmi       | Cibodas      | M-H            | H             | -      | M-H             | H      |
| Purwakarta      | Ciwalen      | M-H            | H             | -      | M-H             | H      |
| Karawang        | Kutamekar    | H              | H             | -      | H               | H      |
|                 | Parungmulya  | H              | H             | M-H    | H               | H      |
| Bekasi          | Cibalongsari | VH             | VH            | VH     | VH              | VH     |
| CikarangTimur   | Cipayung     | H              | VH            | H      | H               | H      |
| Kedungwaringin  | Bojongsari   | H              | H             | M-H    | H               | H      |
| Pebayuran       | Bantarjaya   | M-H            | H             | M-H    | H               | H      |
|                 | Karangsegar  | -              | -             | M-H    | -               | H      |
| Bandung City    | BabakanCiparay | BabakanCiparay | VH           | VH     | H               | H      |
|                 | Cirangrang   | M-H            | H             | -      | -               | -      |
|                 | Margahayu Utara | VH         | VH            | H      | H               | H      |
|                 | Margasuka    | VH             | VH            | H      | H               | H      |
| Bandung Kulon   | CigondewahKaler | H          | H             | -      | -               | -      |
|                 | Gempol Sari  | H              | H             | -      | -               | -      |
| Batununggal     | Binong       | VH             | VH            | VH     | VH              | VH     |
|                 | Cibangkong   | H              | H             | M-H    | H               | H      |
|                 | KebonWaru    | H              | H             | H      | H               | H      |
| BojongloaKaler  | BabakanAsih  | VH             | VH            | H      | VH              | VH     |
|                 | Jamika       | H              | H             | -      | -               | -      |
| CibeunyingKaler | Cigadung     | H              | VH            | H      | H               | H      |
| Cicendo         | Sukaraja     | M-H            | H             | H      | H               | H      |
4. Discussions

Vulnerability can be assessed at different spatial scales, such as regional, district and village levels. The assessment of the vulnerability at the appropriate scale is important to make effective decisions. In the CRB, prior to this study, a village level vulnerability assessment was not available and findings from this study are new. The study has shown significant variations in vulnerability and has highlighted the need for this detailed level of assessment.

This study has demonstrated the effectiveness of this micro-level assessment approach. In this study, vulnerability was measured by three factors, namely the exposure, level of sensitivity and adaptive capacity, which have significant variations if assessed at different spatial scales. The assessment of these micro-level exposure and sensitivity factors could provide an accurate village level vulnerability assessment that could effectively guide village level planning and policy for resilient development.

It should be noted, that indicators selected for defining the exposure, sensitivity and adaptive capacity depend on data availability, the understanding of the connection between the data and the indicator as well as their connection with climate variability and climate change. Consequently, the indicators could be expanded as data becomes available. Also, indicators might be influenced by other factors not been taken into account. For example, waste may be dumped into a river or drainage canal. If the waste production was much higher than the capacity to manage it, a slight increase in rainfall might cause flooding in a village, making the village more sensitive to a change in rainfall intensity. The availability of alternative livelihoods might reduce the sensitivity of a community, particularly in the case of rainfall dependent employment opportunities.

A number of critical indicators contributing to vulnerability were not taken into account. Some important indicators could be used to refine the SEI, and many were related to water resource management:

- Level of exposure to flood considering the position of villages in the river stream (upstream to the downstream). Villages located in the downstream areas will have a higher level of exposure to the flood than those located in the upstream areas.
- Elevation and rainfall pattern of the villages. For example, the water supply from wells, rivers and springs is affected by the elevation of the village. A village located at higher altitude will have a lower water table resulting in a higher sensitivity to water scarcity. Similarly, water supply from rainfall is affected by rainfall patterns and season characteristics of the region. These indicators could be used to correct the level of sensitivity for drinking water availability and climate.
- Capacity of the drainage system.
- Percentage of the area with irrigation facilities.
- Ratio between waste production and waste management relating to the percentage of waste that could be managed.
- Poverty.
- Dependence ratio.

Some important indicators that could be used to refine the ACI include human and social capitals, the percentage of the population by level of education, the presence of community organisations, the presence of extension services, the availability of an emergency fund etc.

The use of vulnerability and climate risk assessments in developing climate change adaptation policies, programmes and actions by local governments is still very limited. The identification of particularly vulnerable regions or regions that are least well equipped to cope with the impacts of climate change can act as an entry point for understanding and addressing the processes that cause and exacerbate vulnerability [20, 21, 22]. Therefore, the results of the assessments can be used to assist local governments in identifying targeted areas (i.e. where) for the implementation of adaptation actions as well as the types of actions (i.e. what) should be prioritised to address the factors causing the vulnerability. They are also useful for evaluating whether existing development programmes could address the factors causing the vulnerability effectively, in term of the suitability or level of intervention given the scale of the problem. In many cases, the level of intervention may not match the
scale of the problem (e.g. intervention programmes that are implemented only in parts of vulnerable
villages) due to limited government budget. This information may facilitate government officials to
identify other partners (i.e. who) that can be invited to expand the level of intervention.

Results of vulnerability assessments contained some limitations for the use of defining types of
actions (i.e. what), as comprehensive data is often not available for defining the vulnerability of a
region. Therefore, identifying actions for addressing the vulnerability by looking directly at factors
(indicators) used in vulnerability assessments could be misleading as indicators may not fully reflect
the vulnerability of the regions. Boer et al. [23] suggests that indicators should be grouped based on
their closeness in representing development problems in the regions. Development problems are often
reflected by the condition of the indicators used in the assessment. For example, the condition of
infrastructure in the regions is one of the development problems that should be addressed since the
state of infrastructure will be reflected in the vulnerability. Poverty is another aspect, since regions
with non-functioning infrastructure and a high poverty rate may have limited capacity to address the
impact of climate change and hence are very vulnerable. Therefore, programmes that address concrete
development problems can directly contribute to decreasing vulnerability.

Looking directly at vulnerability indicators to define adaptation actions may limit the type of action
to only the one that addresses the sanitation issue (e.g. increasing fraction of household with improved
sanitation system). Adaptation actions should be prioritised and evaluated by looking at their
contribution in addressing the overall development problem and their impact in improving
vulnerability indicators [23]. For example, a sectoral programme/action in the agriculture sector may
aim to develop the capacity of farmers to use a cropping calendar to manage droughts. This
programme may directly improve a defined vulnerability indicator. However, the successful
implementation of this programme may overall reduce crop failure due to drought, resulting in an
increase of the farmer’s income and leading to reduce the number of poor farmers (reducing the
poverty index). Defining an adaptation action which would directly look at reducing the vulnerability
indicators may have led to reducing the land used for agriculture, but this policy may undermine the
food security of the region.

5. Conclusion

This approach, the first village level vulnerability assessment for the CRB has demonstrated the
effectiveness of this micro-level assessment approach and is applicable to other countries and river
basins. As demonstrated in other countries such as Bangladesh and Vietnam, village level
vulnerability assessments are essential to guide climate resilient development and planning. This has
been further highlighted in this study for the CRB. This study assessed the vulnerability and climate
risk of around 1,179 villages in the CRB, West Java, Indonesia. It is very important for local
governments to plan and implement development programmes that take into account the increasing
vulnerability and climate risks outlined in this study.

The overall vulnerability profile of the villages improved from 2005 to 2011. This is attributed to
improved access to electricity. On the other hand, most villages experienced difficulties in accessing
clean drinking water. Wells dried up, particularly in the upper and middle part of the CRB, and some
households sourced their water from springs instead during the dry season.

The vulnerability assessment identified 17 very vulnerable villages in 2011. These are
characterised by seven key areas: limited access to clean water particularly during the dry season,
many households and buildings being located near the river side, main economic activities being
dependent on agriculture, limited access to electricity, lack of education, and health facilities.
Adaptation actions should be directed to increase access to water, to generate more income
alternatives and to improve access to electricity, health, and education facilities. The 17 very
vulnerable villages are mostly located in the district of Bandung City (BabakanCiparay, Ciranrang,
Margahayu Utara, Margasuka, Binong, BabakanAsih and Cigadung) and in the districts of Purwakarta
(Cibodas), Karawang (Cibalongsari), Cianjur (Hegarmanah, Cinangsi, Gudang, Ciwalen) and Bekasi
(Cipayung, Bojongsari, Bantarjaya, Karangsegar). Currently, most villages in the CRB are already
exposed to climate risk. If the implementation of development does not consider the villages’
vulnerability to potential climate change impacts, the level of climate risk would definitely increase and villages would become more vulnerable.

Under a steady state of vulnerability, the future level of flood and drought risk of most villages will increase irrespective of the emission scenarios, and under the most likely emission scenarios, the flood risk of most of villages in the upper and lower part of CRB will increase. However, the level of risk of some villages in the middle part of CRB might decrease in the period 2011-2040, but it would increase again after 2040. The occurrence of drought in the upper area of the CRB will be more frequent in the future with increases also in the lower part of CRB, especially in Bogor, Karawang and Bekasi areas.

As many as 25 villages would require immediate adaptation actions to reduce their vulnerability to drought and/or flood. Most of these villages are already exposed to flood and drought risk, except for Hegarmanah, Cinangsi, Gudang, and Karangsegar (high drought risk only) and Cirangrang, CigondewahKaler, Gempol Sari and Jamika (high flood risk only). Short-term adaptation actions are recommended for over 100 villages, which exhibit a medium climate risk and are projected to increase to medium-high and high.

The indicators used were informative and provided good guidance, but they were limited and could be influence by other factors. The indicators used in the study dependent on data availability, the understanding of the connection between the data and the indicator as well as the influence of climate variability and climate change. The indicators could be expanded as data becomes available. A number of critical indicators contributing to vulnerability were not taken into account and could also be improved over time, specifically those relating to water resource management.

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