Cost-benefit analysis of adaptation Investments for Flood Risk Management for Industrial Estates in Mumbai

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Cost-benefit analysis of adaptation Investments for Flood Risk Management for Industrial Estates in Mumbai

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1. Introduction

The UNEP DTU partnership (UDP) is as part of the ADMIRE project (Adaptation Mitigation Readiness project) implementing a project on private sector engagement in flood risk management for small and medium sized enterprises in Mumbai with a team in Mumbai in India. The Climate Change and Sustainable Development group (CCSD) at DTU is as part of this project supporting the local team in the analysis of the costs and benefits of adaptation measures and prioritisation based on these findings. The adaptation analysis supports one of the key objectives of the project, namely: "Developing a sustainable framework for community-based private sector financed flood resilience efforts in Mumbai". The project implementation started in May 2016 and is implemented by MP Ensystems Advisory Private Limited (MPEnsystems) in Mumbai, headed by Dr. Archana Patankar.

This report is focussing on the cost benefit analysis (CBA) of SMEs' adaptation options and the assessment is based on data collected by MPEnsystems in a questionnaire survey of industrial SMEs and retail shops in Mumbai (MP Ensystems, 2016a). UDP and CCSD have during a visit to Mumbai in September 2016 worked jointly with MPEnsystems on the data and structure of the CBA, and CCSD has developed a simple open source spreadsheet tool for conducting the CBA.

Mumbai has experienced recurrent flood disasters[1], and the questionnaire reveals that most SMEs in industrial enterprises experience losses from flooding events every year, and this provides a good case for assessing potential costs and benefits of adaptation measures. Small and medium enterprises and retail businesses have faced increasing risks and multiple vulnerabilities with recurrent floods year after year, and future climate change is expected to worsen these risks further by changing the intensity, frequency and duration of rainfall over the city (Field et al., 2012). Some industrial estates and SMEs within these are trying to protect themselves e.g. by increasing entrance levels or by constructing temporary drainage channels, however such measures are not providing significant protection and can, when implemented individually by single or only a few SMEs, potentially increase indirect flooding risks in other areas. We are in this study assessing how a more comprehensive framework for planning adaptation measures, which are implemented in a cooperative manner by industrial enterprises hosting SMEs can help to reduce the flooding risks in Mumbai.

Focussing on the Ansa Industrial Estate Buildings J & K, which are hosting 171 SMEs in the L Ward of Mumbai, we are conducting a CBA of four structural adaptation measures and four non-structural adaptation measures (Table 2). The CBA assesses costs and benefits of the options and is used as a basis for drawing conclusions about how the industrial estates can be engaged in climate change adaptation. This discussion is further developed in a separate forthcoming report on financial options, which is going to be authored by MPEnsystems. The CBA model and the analysis in this way is expected to help local businesses build resilience against recurrent and extreme floods in the future, in the context of climate change.

[1] In July 2005, Mumbai city experienced extreme precipitation of 944mm over a 24-hour period. There was unprecedented flooding in the city that resulted in the direct losses of USD 1.24 billion, out of which USD 770 million were insured losses (infrastructure and big private businesses) and USD 149 million were uninsured losses of small private sector businesses including retail and small-scale industrial units. Households, too, suffered damage to structure and household assets and equipment worth USD 267 million, almost all of which was uninsured.

2. Summary of the flooding case and the suggested adaptation options

We are in our CBA analysis of adaptation options focussing on the Ansa Industrial Estate in the L Ward area of Mumbai in the floodplain of the Mithi River. According to *MP Ensystems 2016a* this area experiences severe floods during monsoon every year. Many SMEs and retail businesses are located in the areas around these flood spots. The most severe impacts of the extreme precipitation event in July 2005, with 944 mm precipitation within 24 hours, were experienced in the L ward due to Mithi river overflowing. The total area of the L ward is 15.56 sq. km., out of which 38.69% is used for residential, 3.74% for commercial and 12.76% for industrial establishments (MCGM, 2014).

Some initiatives have been taken to avoid flooding by the local government, but despite this many areas within the L ward continue to be flooded. Flooding is exacerbated by encroachments on the river, blocking of natural and manmade drains due to poor solid waste management and changing local topography with new constructions. It is recommended by *MP EnSystems 2016a* that upgrading of storm water infrastructure is accompanied by other efforts including solid waste management, construction of superior quality roads and removal of encroachments on waterways, which both need to be managed by the local government and to be supported by people's cooperation and private sector initiatives.

The extent and costs of flooding events in the L ward have been assessed by *MP EnSystems 2016a* in a questionnaire including in total 100 SME's and 100 retail units. The units have been selected randomly; however, 99 out of the SME's covered by the questionnaire are located on the ground floor of the industrial estate buildings, which is particularly exposed to flooding risks. All of these responded that floods occur every year during the monsoon, and out of these 54 pct. report that the floods occur 3-4 times per year. The flood damage cost information requested in the questionnaire was average cost experienced over the last 10 years, and there was no indication of the relationship between specific flooding events in terms of intensity, duration and water levels at the ground and the associated damages. We are therefore not able to derive a specific damage cost curve related to events based on such data.

Ansa industrial estate was constructed in 1984 and is currently comprised of 11 separate buildings, which all host a large number of SMEs (Figure 1). A total of 171 SME's are located within the two buildings J & K, and common types of businesses include heavy metal works, paper printing, textile designing, transport services, plastics manufacturing and warehouses. Out of the more than 1000 individual SMEs that are located within Ansa Estate, 21 completed the questionnaire survey, and it is on the basis of the answers of these respondents that the CBA is conducted. From the reported flood damage costs from Ansa Industrial estate we find an average annual flood damage cost of USD 352 for individual SMEs (Table 1). A major share of the total cost is associated with suspension of production and damages to physical infrastructure and to equipment and products. It should be noted here that all of the 21 SME's report that they have had regular damage costs related to flash floods during the past 5-10 years.

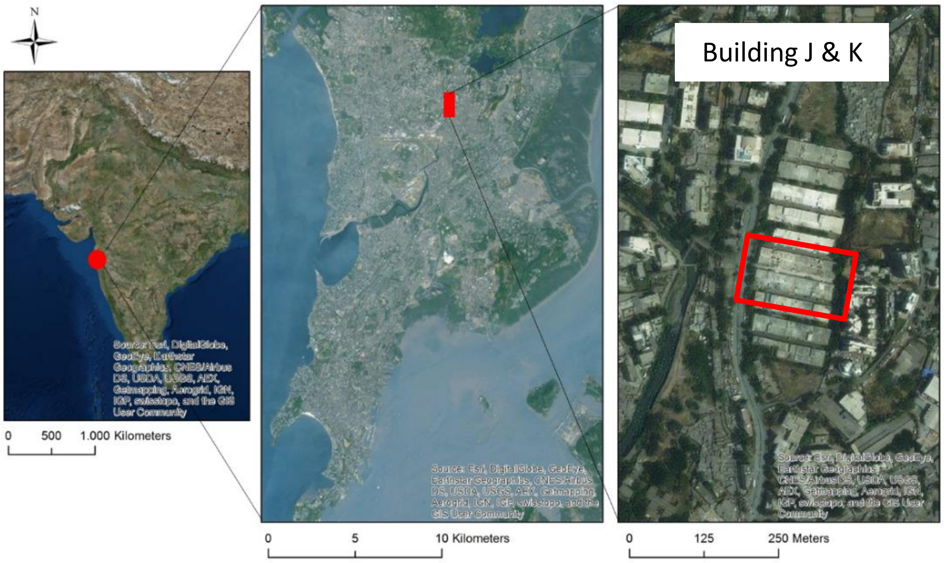


Figure 1. Location of Ansa Estate building J & K within Mumbai

Damage category	Damage cost/SME/year (USD)
Physical Infrastructure	91
Equipment and products	66
Immediate expenses due to flooding	7
Absence of employees	27
Suspension of production	161

Table 1. Reported flood damage for SME's located at Ansa industrial estate, average based on 21 respondents.

Based on field visits by the MPEnsystems, UDP, and CCSD project team and local storm water experts in September 2016, technical descriptions and designs of five structural and five non-structural adaptation measures suitable for Ansa and Sidhpura industrial estates were completed. The following eight adaptation measures (four structural and four non-structural) are considered suitable for our case study of Ansa industrial estate Building J & K and are thus included in the CBA (Table 2). See the ADMIRE document *"report on current and potential Adaptation measures for private businesses in Mumbai to reduce impacts of recurrent floods"* (MP Ensystems, 2016b) for technical details on the different adaptation measures.

Structural measures	Non-structural measures
Cut off channels at estate entrance	Awareness raising
Surface drainage and SWD drains on premises	Early warning system
Sump tank	Emergency planning
Dewatering ring wells and dewatering pumps	Solid waste management

Table 2. Structural and non-structural adaptation measures included in the CBA for Ansa industrial estate Buildings J & K

3. Methodological framework of the Cost Benefit Analysis

The purpose of doing a CBA for investments in climate change adaptation measures for flooding risks in Mumbai is to compare adaptation costs with the benefits of avoided damages. Risks are defined as the consequence of flooding events multiplied by the probability of the events. An assessment of flooding risks in this way requires a complicated and very data intensive analysis, where climate projections, impact modelling, damage cost assessment, and economic valuations are combined. These analytical elements are illustrated in Figure 2.

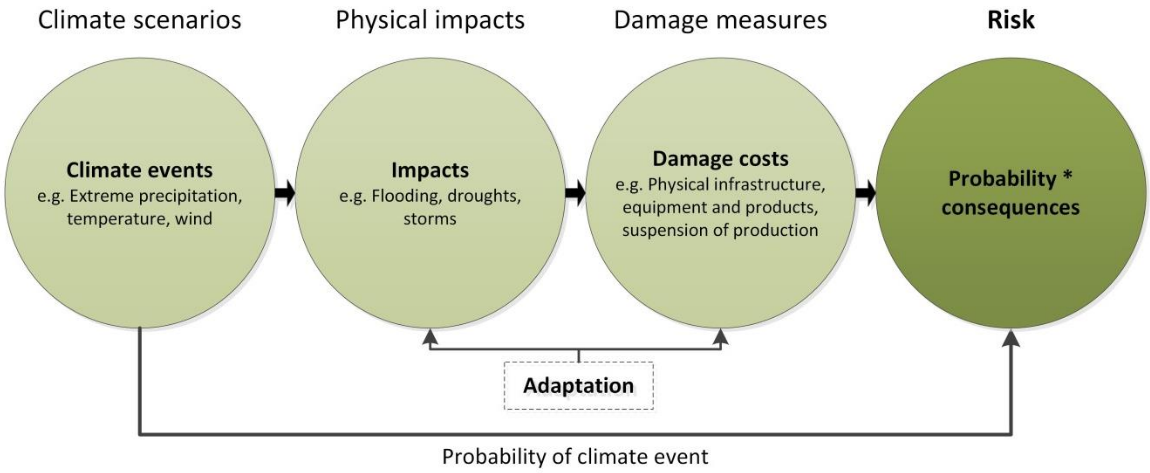


Figure 2. Structural elements included in climate impact and adaptation analysis

The first element in climate change and adaptation analysis, as illustrated in Figure 2, is to get data for the likelihood of specific climate events over the time frame of the assessment, which in the case of the Mumbai flooding study is data for precipitation events with different intensities over the time frame of the lifetime of the adaptation options considered (25 years for most of the measures - Table 3). This is followed by a physical impact assessment (e.g. based on hydrological modelling) for the industrial estate and includes estimates of physical damages and economic losses. Multiplying the damages and the probability of extreme flooding events enables the quantification of a risk estimate in monetary units, which can be compared with the cost of implementing adaptation measures.

The CBA will then compare the marginal costs of adaptation measures with the marginal risk reduction achieved by implementing the adaptation measures. It is beneficial from an economic point of view to implement adaptation measures as long as their marginal costs are less or equal to their risk reduction potential. This also implies, that there in many cases will be some residual damages left after the implementation of an adaptation strategy, because the adaptation costs for covering these are high and/or that very intensive precipitation events can be very rare (Halsnæs et al, 2015).

We are in the CBA of the adaptation measures using a number of cost concepts, which are defined in the following. The perspective of the current assessment is that the private sector in terms of an industrial estate is going to invest in adaptation measures to protect their enterprises. We are therefore taking the starting point in the assessment of private costs of flooding risks and adaptation measures.

Private costs are measured based on market prices including taxes and with a discount rate reflecting the costs of financing adaptation measures. All costs of implementing measures such as capital costs, maintenance, transaction costs, variable costs as e.g. energy are to be included. Private costs are different from financial costs, which are the costs of financing investments as e.g. reflected in the interest rate of borrowing money, and all costs of private investors are not reflected in this concept.

The CBA aims at optimizing the costs and benefits of investing in adaptation measures, and marginal costs are therefore a main measure. Marginal costs are the costs of adding one additional measure or of removing an additional unit of flooding risk. Costs or benefits of other measures, which are assumed to be implemented upfront (because they are cheaper according to cost effectiveness criteria), are not included in the marginal cost.

The total costs and risk reduction can then be calculated by adding up all costs. Based on this average costs and risk reduction can easily be calculated by dividing the totals with the number of units as e.g. SMEs involved or by the number of flooding events.

It is important to keep in mind that average costs are not the relevant measure to use in decisions on investments in climate change adaptation, because average costs are not indicating how far it is economically optimal to go with given adaptation measures and in relation to specific precipitation and flooding events. Marginal costs and benefits are here the relevant measure.

The assessment of risks and adaptation costs involves the comparison of economic flows which occur over a given time horizon. We are in the CBA measuring the costs on an annual basis and are transforming the costs to net present values (NPV's). The NPV determines the present value of net costs *C* by discounting the stream of costs back to the beginning of the base year (*t*=0) with an interest rate *i*.

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+i)^t}$$

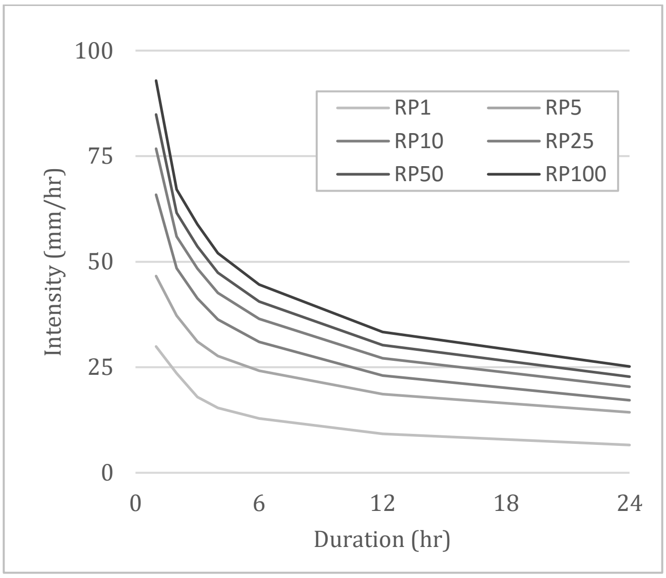
The specific CBA of the Mumbai case has been constrained due to data limitations, and a number of simplifying elements and assumptions have therefore been applied. These are introduced in the following, and the importance hereof is also discussed throughout this report.

4. Extreme precipitation in Mumbai today and under climate change

4.1. Present day extreme precipitation

Mumbai is characterized by multi-annual occurrences of heavy precipitation and related surface flooding during the seasonal passing of the South Asian Monsoon from June to October, with the majority of the annual rainfall of approximately 2000-2500mm falling within the period. Within the Mumbai metropolitan area extensive human and economic activities and associated high shares of impervious surfaces and limited natural infiltration, cause a large share of the precipitation to run-off. Consequently, local drainage systems and waterways overflow and large areas over the entire city suffer from surface flooding.

Detailed statistics on precipitation intensities and their expected return periods are important when designing suitable adaptation options as it provides key knowledge for deciding on the optimal level of protection from an economic point of view. Figure 3 shows intensity-duration-frequency curves and total daily precipitation for Mumbai based on available precipitation measurements from rain-gauges at different location within the Mumbai area. The present day precipitation intensities above 25mm-hr and 150mm-24hr are having a frequency of being at least annual events (RP1) in their reoccurrence period (Figure 3) (GOM, 2006), whereas precipitation intensities increase to 65mm-hr/412-24hr and 95mm-hr/604mm-24hr for return periods of 10 and 100 years respectively.



Events	Precipitation intensity (mm/24 hr.)
RP1	158
RP5	344
RP10	412
RP25	489
RP50	546
RP100	604

Figure 3. Intensity-duration-frequency curves (left) and total daily precipitation (right) for extreme precipitation in Mumbai for different return periods, RP10 = 10 year return period, based on GOM 2006.

4.2. Climate change projections of extreme precipitation

Projections of the impacts of future climate change on the intensity and frequency of extreme precipitation have not been analyzed comprehensively for Mumbai in the literature (e.g. using multiple combinations of climate models and climate scenarios followed by extreme value analyses and delta change methods), and the projections used in the CBA are therefore based on results over the entire South Asia region (Kharin et al., 2007). Using an ensemble of global climate models under three different climate scenarios (SRES: B1, A1B and A2 scenarios) Kharin et al., 2007 projects a 5-86 %[2] increase in the intensity of daily precipitation extremes with a 20 year return period for years 2081-2100 relative to 1981-2000 over the South Asian region. Also, a median value of +22 % is observed for the A1B mid-range climate change scenario. In our cost-benefit analysis on adaptation measures for the Ansa Estate we apply these findings to quantify future impacts of flooding during extreme precipitation. To quantify the impacts of climate change in a shorter term perspective corresponding to the lifetime of the suggested adaptation measures (e.g. a 25-year perspective) we assume that the intensity of precipitation increases linearly between 1981-2000 and 2081-2100, meaning that a median ≈ +10 % increase is realized in 2040 (25 years from today). Also, for use in the damage cost assessment of future flooding events we assume that an increase in precipitation intensities is

[2] Range across all models and scenarios

linearly related to the damage costs, meaning that a 22% increase in the intensity will cause a similar rise in the unit damage costs. The limitations in the availability of precipitation forecasts for Mumbai imposes uncertainty on, how often flooding events could happen in the future, and on also on the intensity of precipitation and the related flooding level. In the CBA, these data are important in determining the future benefits of reducing flooding risks by adaptation.

5. Estimating flood damage costs and risks from extreme precipitation

We are in our estimation of damage costs and risks taking the starting point in the questionnaire survey of 100 SME's in Mumbai, from where a total number of 21 SME's are located in the Ansa Estate. We are only using the damage cost data reported from the 21 SME's of the ANSA Estate in the CBA since, geographical location and other contexts specific aspects are key parameters in determining flood exposure and damages. We have modified the reported damage costs for the 21 reporting units in our upscaling to all 171 SME's located in our case study area in order to reflect that locations at different floors in the building matters. Finally, we have adjusted the value of the SME assets to reflect economic development over time.

More specifically, the following assumptions have been applied to the enable upscaling of the total damage cost from the 21 respondents to the total number of 171 SME's located in building J & K:

- The reported damages in the questionnaire include damages to physical infrastructure, products and equipment, immediate expenses due to flooding and production losses caused by absence of employees and suspension of production. We have assumed that the damages on physical infrastructure, equipment and products and immediate expenses due to flooding are only relevant for the 42 SME's located on the ground floor out of the total 171 SME's. The costs related to absence of employees and suspension of production are assumed relevant for all of the 171 SME's, as these costs are more connected to the accessibility of the premises rather than the location within the buildings (ground floor, 1st floor etc.).
- We assume that all damage cost categories will increase with an annual rate of 4 % per year for the time frame considered for the adaptation measures, and this reflects the assumption that the value of physical assets and of production losses will increase over time in line with general economic growth.

The projections of future annual damage costs of flooding are transformed into Net Present Values (NPV) using a discount rate to reflect the financial costs of industrial estates of investing in adaptation options. The interest rate applied in this calculation is 10.5% as this is the value recommended by the State Bank of India (Reserve bank of India, 2016).

The assessment of climate risks and adaptation costs in the current case study suffer from limited context specific data on damages associated with present and future precipitation events. Future return periods for the precipitation events are very uncertain, and we do not have information on how the damages develop with increasing precipitation intensities and duration. Furthermore, the damage cost data available are average costs over several years rather than marginal damage costs to be compared with marginal benefits of risk reduction. Another important limitation includes the lack of information related to the effectiveness of adaptation options. Despite detailed technical information available for the different structural options highlighting the ability of the measures to remove water from the premises, it is difficult to accurately determine their effectiveness in terms of reducing the annual risk since we have not established a relationship between the reoccurrence period and damage costs of individual events. Instead, we use previous findings from Europe to overcome this issue of data availability, which may not be representative for the conditions in Mumbai (see section 6.2 for additional information on how the risk reduction potentials of the structural measures were estimated). The development of a high resolution flood model for Mumbai would enable the quantification of this relationship on a local scale; however, the development of such a model has not been possible due to the resources available in this project.

6. Structural and non-structural adaptation measures for Ansa Estate

6.1. Description of measures

A number of structural and non-structural (soft) adaptation measures to increase overall flood resilience have been identified and recommended by local technical storm water experts. The structural measures have been designed specifically as long term solutions for industrial estates where no (or only limited) local surface drainage and storage capacities are currently available, while the soft measures are relevant for all flood-prone locations. Specific technical designs for the structural measures have been developed for the Ansa Estate building J & K, and this estate is considered to be highly representative for many similar industrial estates across the city and for other major urban areas in India.

In conclusion, similar adaptation measures are also relevant for multiple locations across the country, and if implementation of these measure are successful for Ansa Estate building J & K, it may serve as a case example for other industrial estates to follow. For detailed information on the different adaptation measures, see the ADMIRE document *"report on current and potential Adaptation measures for private businesses in Mumbai to reduce impacts of recurrent floods"* (MP Ensystems, 2016b).

Short descriptions and key information on the costs and lifetimes of the different structural and non-structural adaptation measures for Ansa Estate buildings J & K are presented in Table 3. Technical drawings, which were created by local storm water experts, of the structural measures can be found in the Annex of this report. The four selected structural adaptation measures are functionally interlinked and it is therefore required that they are implemented simultaneously in order to harvest the full risk reduction potential. The estimated risk reduction is thus based on the combined effect of all four measures and not on a disaggregated approach where we estimate the efficiency of each measure individually.

	Costs		Lifetime
	Investment (USD)	Maintenance[3] (USD/year)	Re-investment period
Structural			
1. Surface and storm water drainage (Figure 4):			
a. Cut-off channels at threshold (entrance of premises)	5.000	75 (5 person-days)	25 years
b. Surface drainage and SWD drains within premises	135.000	300 (20 person-days)	25 years
c. Sump tank	24.000	75 (5 person-days)	25 years
d. Dewatering ring wells and dewatering pumps	19.500	75 (5 person-days)	25 years
Total Structural	**183.500**	**525**	
Non-structural			
1. Awareness raising Increased common knowledge among industrial estate operators, SME owners and employees about disaster risk and actions to be taken individually and collectively to reduce overall and specific exposure and vulnerability towards the impacts of flooding. Awareness building includes information brochures and regular (annual) capacity building workshops with SME owners and the employees immediately before the onset of the Monsoon.	225	75	10 years
2. Early warning system Includes state of the art tools to forecast the occurrence of local heavy precipitation and flooding for Ansa estate. The system can be co-shared by a number of industrial estates located within the same geographical area. This measure includes training of industrial estate officers to be regularly updated on weather forecast, and potentially investments in up to date hardware and software technologies. If properly designed, updated and used, the early warning system can potentially reduce the damage from disasters by improving the response.	600	75	10 years
3. Emergency planning Development of emergency plan on the industrial estate level to deal with floods, highlighting the role of different stakeholders in the case of an emergency. The plan should be designed to include action to reduce the impacts to humans and losses to buildings, assets and economic activities. The development of an emergency plan is a one-time action; however, it needs to be complimented with regular (annual) information meetings, so that every stakeholder is updated on their specific role in case of an emergency.	375	75	10 years
4. Solid waste management During visits to several industrial estates it was observed that solid waste was not getting disposed of effectively causing internal drains to be clogged and further increasing the problem of flooding. This measure comprises improved disposal of solid waste through the municipal solid waste department or private companies.	1.700	1.125	No re-investment
Total non-structural	**2.900**	**1.350**	
Total – Structural and non-structural measures	**186.400**	**1.875**	

Table 3. Descriptions and costs of adaptation options assessed for the Case Study of Ansa estate buildings J & K

[3] Maintenance for structural measures includes annual cleaning of channels and drains and overhauling of the pumps (structural measure 1d) to prepare for the Monsoon season. USD 75 corresponds to approximately 5 days of work at an average daily salary of INR 500 + INR 500/day for other expenses (equipment etc.).

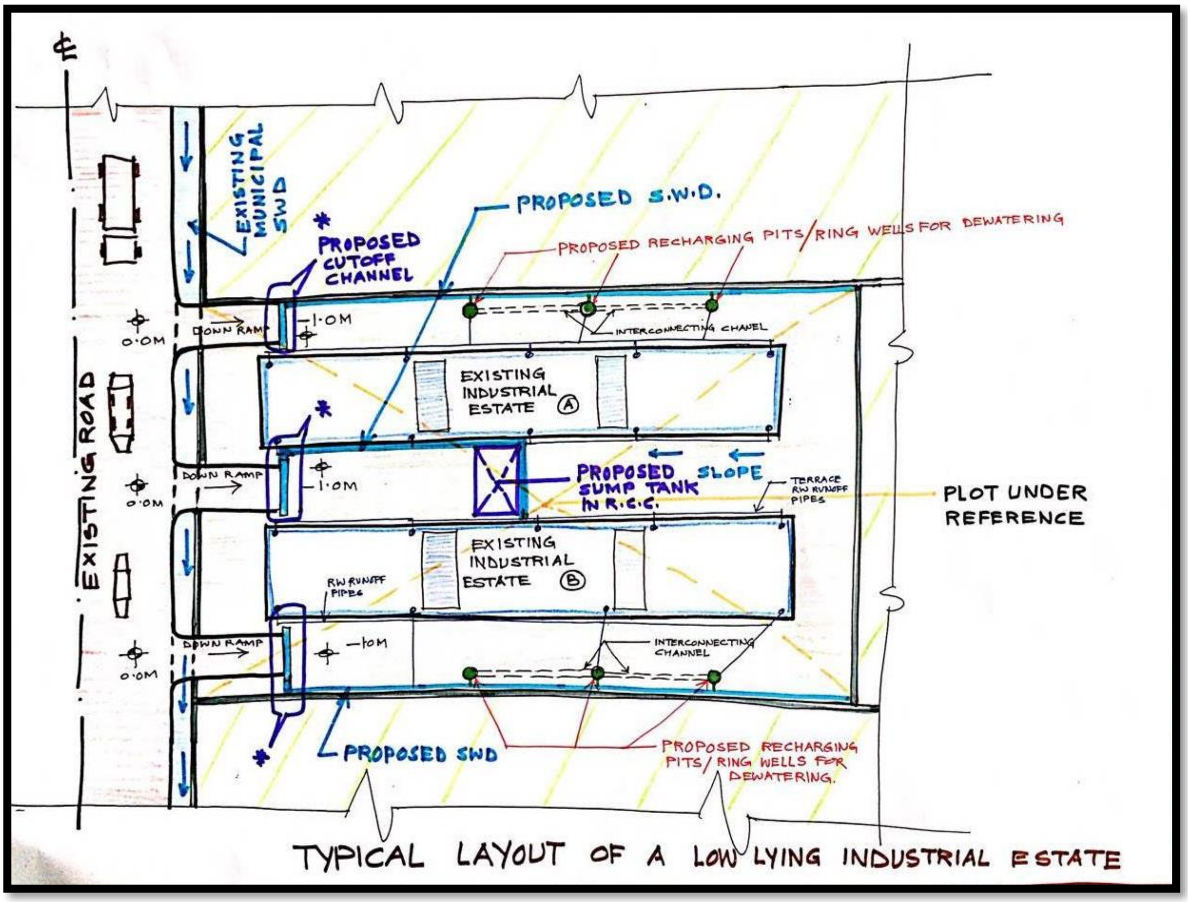


Figure 4. Planned surface and storm water drainage inside industrial estate

6.2.Risk reduction potential of structural adaptation measures

The effectiveness of the structural adaptation measures is known in terms of the combined water removal capacity of the measures. We estimate that they are expected to deliver a protection level of removing a maximum of approximately 40 mm water per hour. This corresponds roughly to precipitation events with a 2 year return period (RP2) under present day climatic condition (Figure 3).

Knowledge on the water removal capacity of the structural measures is used to calculate the share of water which is removed for the individual events, and more importantly the remaining share, which could potentially cause damages (Figure 5). Figure 5 shows the amount of precipitation potentially causing damage for events with different return period for the baseline with no adaptation (red dashed line) and after implementation of the structural adaptation measures (black dashed line). The difference between the red and the black lines is the amount of precipitation removed by the suggested structural adaptation measures. It should be noted here that these assumptions result in no flood damage on an annual basis, and only very limited damage every second year (corresponding to RP1 and RP2 respectively). The effect of adaptation measures with alternate water removal capacities are highlighted for illustrative purposes, with a maximum protection level corresponding to the capacity of the municipal drainage system (50mm/hr.) to where the excess water is pumped to in case of flooding on the Ansa industrial estate premises.

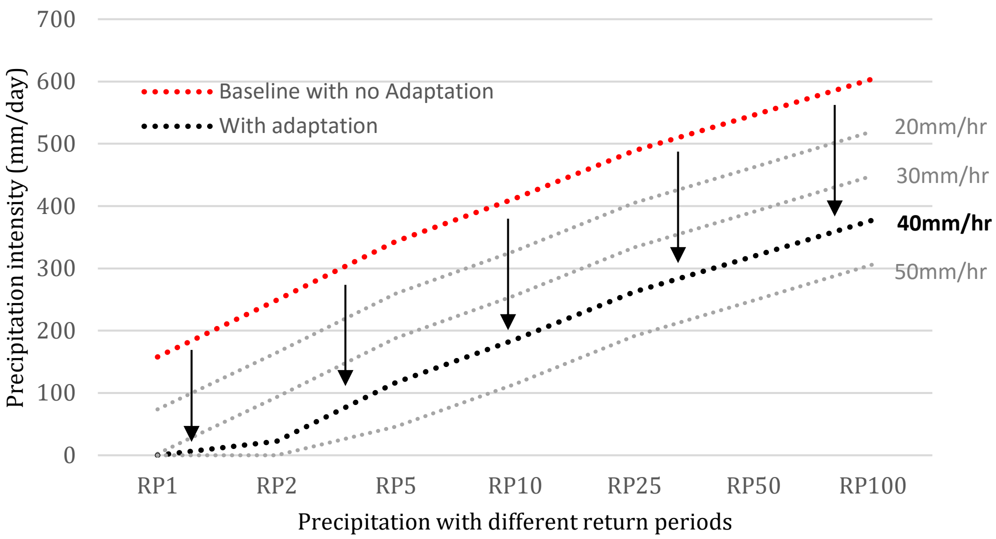


Figure 5. Precipitation potentially causing surface flooding and damages during extreme precipitation with different return periods (RP10 = 10 year return period) before and after implementation of structural adaptation measures with total protection levels of 20-50mm/hr. 20mm, 30mm, 40mm (included in the CBA) and 50mm are alternative water removal capacities related to the adaptation measures.

As we do not have any information on the damage costs related to the different precipitation events for Mumbai we use the findings of previous studies for Europe to quantify the relationship between precipitation intensity and damages and thereby the risk reduction potential of the adaptation measures (Jongman et al., 2012; Halsnæs et al, 2015). The damage reduction associated with the structural adaptation measures depends on how damages develop with increasing surface floods levels. Results from Europe suggest that damages caused by the least severe/most frequent precipitation events are the most important when estimating annual flood damage cost (dashed red line in Figure 6). Figure 6 shows that with no adaptation the most frequent events (RP1) are responsible for the largest share of annual damage cost. Implementing structural adaptation reduces damages the most for the most frequent events and the least for the less frequent (RP50-RP100) events. This implies that the importance of the individual events for annual damage costs shift towards the less frequent events. The decreasing importance when moving towards most extreme events is a result of the outcome of the "race" between the increase in damages and decrease in frequencies when going from low- to high-intensity extreme precipitation. After implementation of the suggested structural adaptation measures the importance shift towards less frequent events (dashed black line in Figure 6) as the damage related to the most frequent events is reduced considerably by implementing the adaptation measures. It should be noted that absolute damages are also reduced for larger events and that it is only the share of the total annual damage that increases after implementation of the structural measures, i.e. as the adaptation reduces damages completely for the most frequent events (RP1).

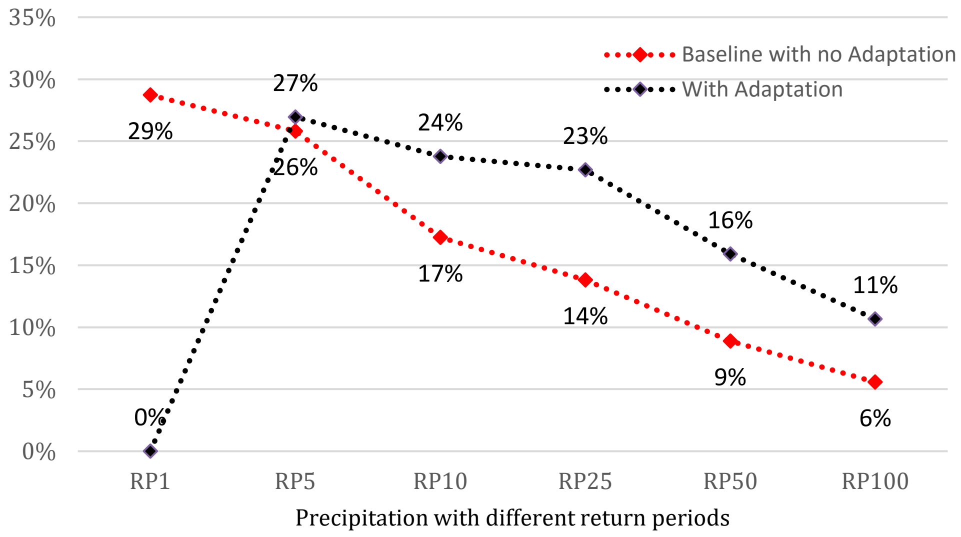


Figure 6. Share of annual flood damage of extreme precipitation with different return periods (RP10 = 10 year return period) before and after implementation of structural adaptation measures with a total protection level of 40mm/hr. water removed.

Based on the previous information on the relationship between the water removal capacity of the adaptation measures and the precipitation intensities of different events (Figure 5) and the share of annual damage related to different events (Figure 6), we are now able to estimate risk reduction potentials (reduction in annual flood damage) of the different structural adaptation measures for Ansa Estate (Figure 7). From this analysis we find a total risk reduction of 73 %, with the largest risk reductions for the smallest events and vice versa, following the implementation of the structural adaptation measures. The effect of adaptation measures with alternate water removal capacities is shown for illustrative purposes, and to highlight the importance of uncertainties in this respect. The estimated risk reduction potential of the selected structural measures for Ansa Estate aligns very well with previous findings of Hallegatte et al. 2010, who estimates that 70 % of flood damages related to a 1-in-100 year event today could be reduced by improving the drainage system in Mumbai (Hallegatte et al. 2010).

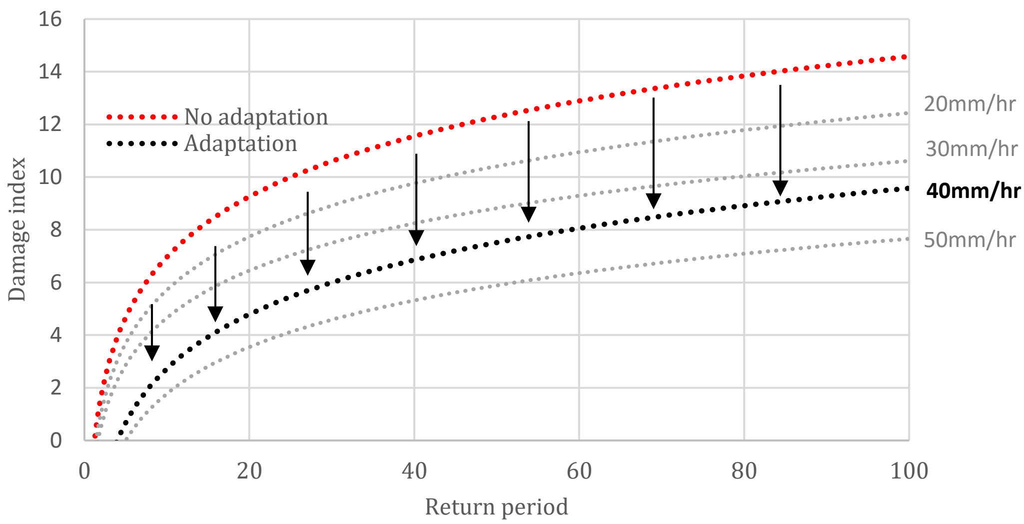


Figure 7. Damage cost index for flooding during extreme precipitation with different return periods (RP10 = 10 year return period) before and after implementation of structural adaptation measures with total protection levels of 20-50mm/hr.

6.3.Risk reduction potential of non-structural adaptation measures

Adding to the risk reduction of the structural adaptation measures, a number of non-structural (soft) initiatives (Table 3) will further bring down the damage costs related to flooding for Ansa industrial estate. The soft measures include increased awareness raising, early warning system, emergency planning and solid waste management. It is very difficult to estimate the exact impact of implementing non-structural measures on local or even regional scales. In practice the actual risk reduction will vary considerably between locations as a result of local conditions, including the degree to which such measures are regularly maintained (annual information activities prior to the monsoon), updated and adapted efficiently. As a consequence, there is substantial uncertainty related to the chosen level of risk reduction related to these measures. For Ansa Industrial estate we estimate the total risk reduction potential of the four non-structural measures to be 10 % of the total annual damage, which corresponds to and additional risk reduction of 40-50 % of the remaining risk (e.g. after the effect of the structural measures have been removed). This gives a total risk reduction of approximately 83 % of the structural and non-structural measures together (Figure 8).

7. Results

7.1. Cost-benefit analysis

Figure 8 shows the costs of flooding damages for our case study with and without the structural and non-structural adaptation measures considered. The major damage cost component is the cost of suspended production, and it can be seen that implementation of the adaptation measures is estimated to offer a damage cost reduction of as much as 87%.

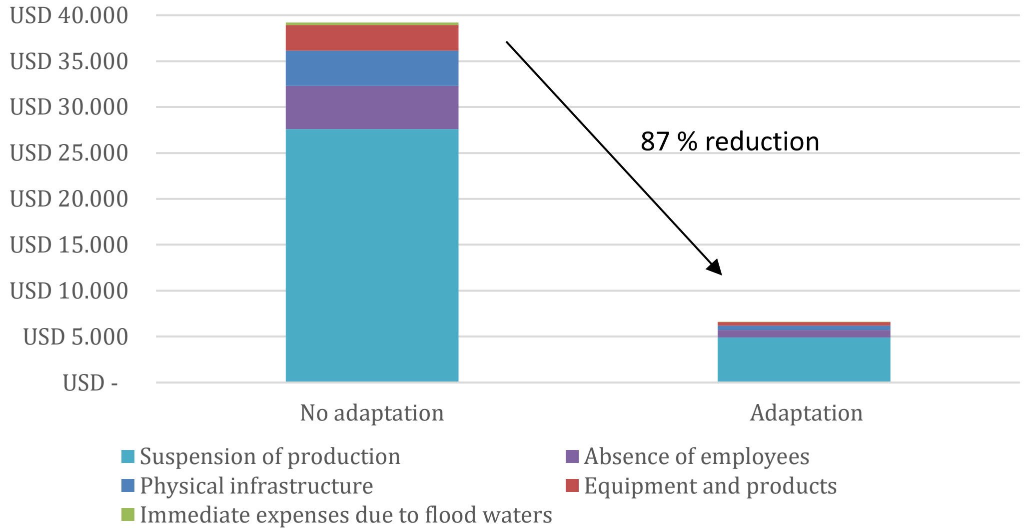


Figure 8. Present day annual damage costs related to flooding during extreme precipitation for Ansa Estate building J & K with and without implementation of structural and non-structural adaptation measures.

The CBA is comparing the costs and benefits of reduced flooding by implementing adaptation measures, and the following Figure 9 shows how the expected annual damage will develop over time given our assumptions. Expected annual damages are calculated as the damage costs multiplied by the probability of precipitation events causing flooding. The red color curves show the damages in annual monetary values without applying discounting. The expected value of damages is here increasing over time because future climate change will increase the probability of more intensive precipitation events and because of general economic growth, which is expected for this region. The black color curves are showing the expected damages, where the values of the future economic flows are discounted to NPV's and they are accordingly comparable with present day investments. The expected values are here decreasing over time, due to the high discount rate (12%) applied in the case study reflecting financial costs of investments in adaptation

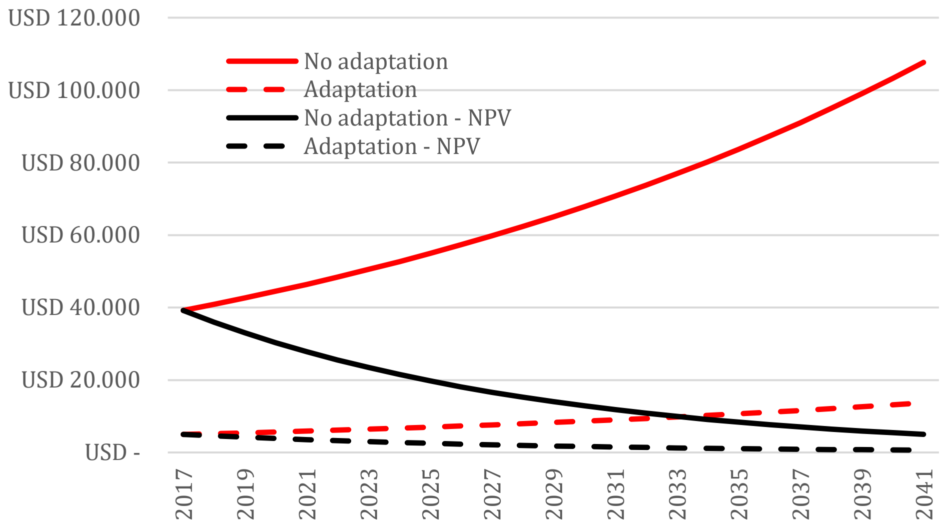


Figure 9. Expected annual damage (EAD) costs related to flooding during extreme precipitation for Ansa Estate building J & K with and without implementation of structural and non-structural adaptation measures.

The avoided damages by adaptation and the adaptation costs will accumulate over time as illustrated in Figure 10. It can be seen, that the expected value of the benefits of adaptation will exceed the costs after about 8 years, and net benefits will increase over the lifetime of the investment.

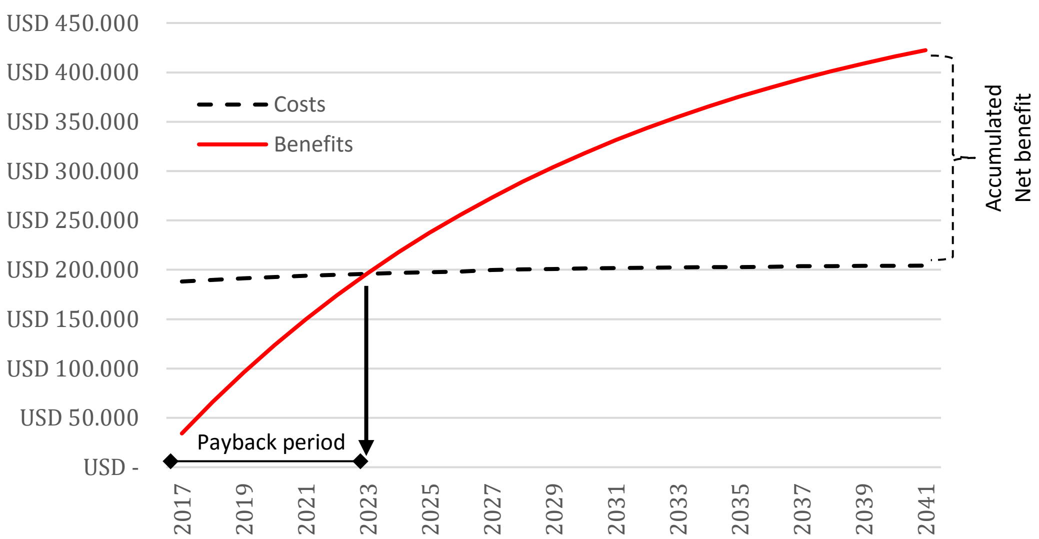


Figure 10. Net present value of accumulated adaptation costs and benefits for implementation of new structural and non-structural adaptation measures. Adaptation investment period and time is highlighted.

The key results of the CBA are summarized in Table 3. Investing in the suggested structural and non-structural measures is expected to generate a net benefit of 218,820 USD for the total number of 171 SMES's located in buildings J & K measured over the timeframe 2017-2041. The benefit cost ratio is found to be 2.07 (3.2 and 1.7 for ground floor and 1st floor SMEs respectively), so the investments are highly recommendable from an economic perspective. The payback period is 7 years, and the adaptation costs per SME is 1191 USD, of which 1100 USD is to paid at the time of implementation. Each SME can expect a total net benefit of USD 1279 (USD 2612 and USD 846 for ground floor and 1st floor SMEs respectively) in NPV over a 25-year time horizon if all eight measures are implemented.

Ansa Estate building J & K	**2017-2041**
Adaptation cost	203,668
Benefit	422,489
Net benefit	218,820
Benefit-Cost ratio	2.07
Adaptation cost/year	8,147
Benefit/year	16,900
Net benefit/year	8,753
Net benefit /SME	1,279
Adaptation costs/SME	1,191 (1100)*
Payback period	7 years
Payback time	2023

Table 4. Cost benefit summary of structural and non-structural adaptation measures for Ansa Estate building J & K over a period of 25 years (2017-2041) from implementation of adaptation measures. All values are calculated as net present values in USD. * 1st year investment payment in brackets.

7.2. Tool for cost-benefit analysis of climate adaptation measures

A spreadsheet-based tool for CBA of adaptation measures under present day and future climatic conditions have been developed by the CCSD team as part of project. The tool has been used to complete the analysis for Ansa Industrial estate as presented previously. The tool is developed as a generic framework, and is thus not limited to any specific geographical location, adaptation measure of climate event (e.g. flash floods). The strengths of such a framework is that it enables detailed and location-specific analysis, allowing the user to decide on any of the factors (discount rate, degree of climate change, cost and lifetime of adaptation measure, economic growth rates, damage cost categories etc.) which are relevant in the specific adaptation analysis. Conversely, the weakness of this approach is that is requires the user to specify all relevant input data. The development of the tool is currently ongoing, and for now no official user guide exists, and the tool is thus not streamlined for use without any contact to its developers. For now, the tool (in its most updated state) can be acquired by contacting Per Skougaard Kaspersen from the CCSD research group at the Technical University of Denmark (DTU).

8. Conclusion

Flooding from extreme precipitation in Mumbai has been very frequent over the last 10 years and industrial estates have suffered from large annual or sometimes multi-annual damages. The damage costs associated with the events have been assessed in a questionnaire survey, and based on this data a specific case study for the Ansa Industrial Estate of Mumbai reveals that it could be highly beneficial to invest in a number of structural and non-structural adaptation measures. The investments are expected to generate net economic benefits after a 7-year payback period, with increasing benefits over time. We find a benefit-cost ratio of 2.07 (3.2 and 1.7 for ground floor and 1st floor SMEs respectively) and a total net benefit for the entire estate of USD 218,820, corresponding to a net benefit of USD 1279 (USD 2612 and USD 846 for ground floor and 1st floor SMEs respectively) for each of the 171 SME's that are located in the case study premises of buildings J & K.

The results are surrounded by some uncertainties due to data limitations, which are particularly pertinent in relation to climate change projections and to context specific damage cost curves for specific precipitation and flooding events. However, flooding has been so frequent in the areas under investigation during the past recent decades, and the adaptation options suggested are associated with relatively low costs, so the recognized uncertainties do not seem to be a very important barrier for recommending investments in adaptation options for flooding control in the Mumbai industrial estates.

9. Annex

Drawings of structural adaptation measures for Ansa Estate building J & K

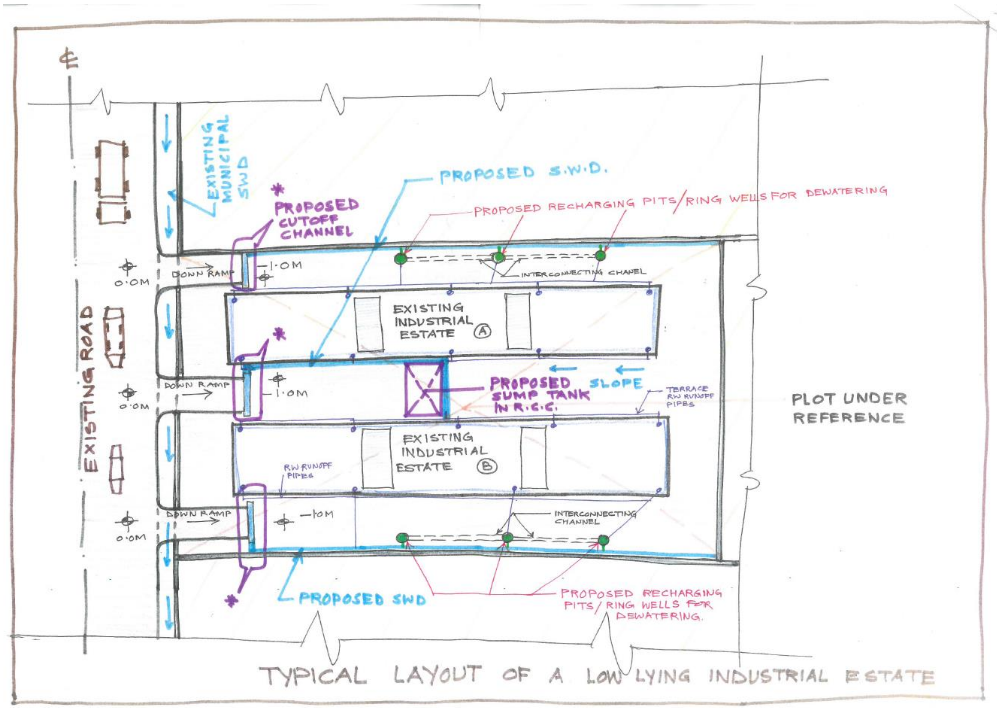


Figure A1: overview of structural adaptation measures proposed for Ansa Estate building J & K. (see Table 3 and EnSystems, 2016b for information on the different measures).

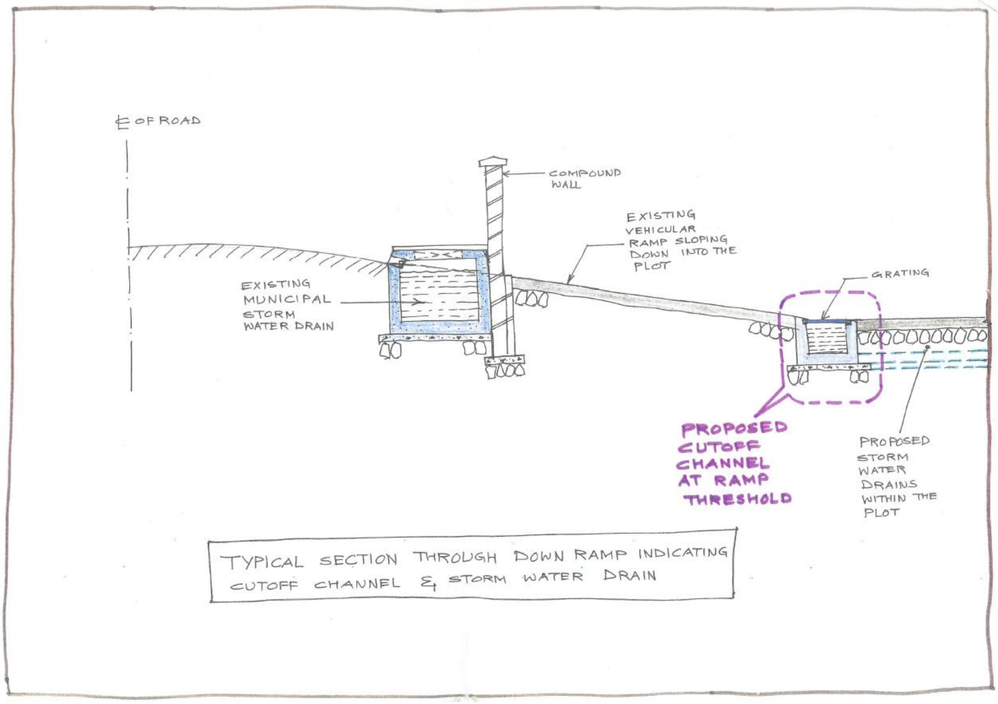


Figure A2: Structural adaptation measure - Cut off channel.

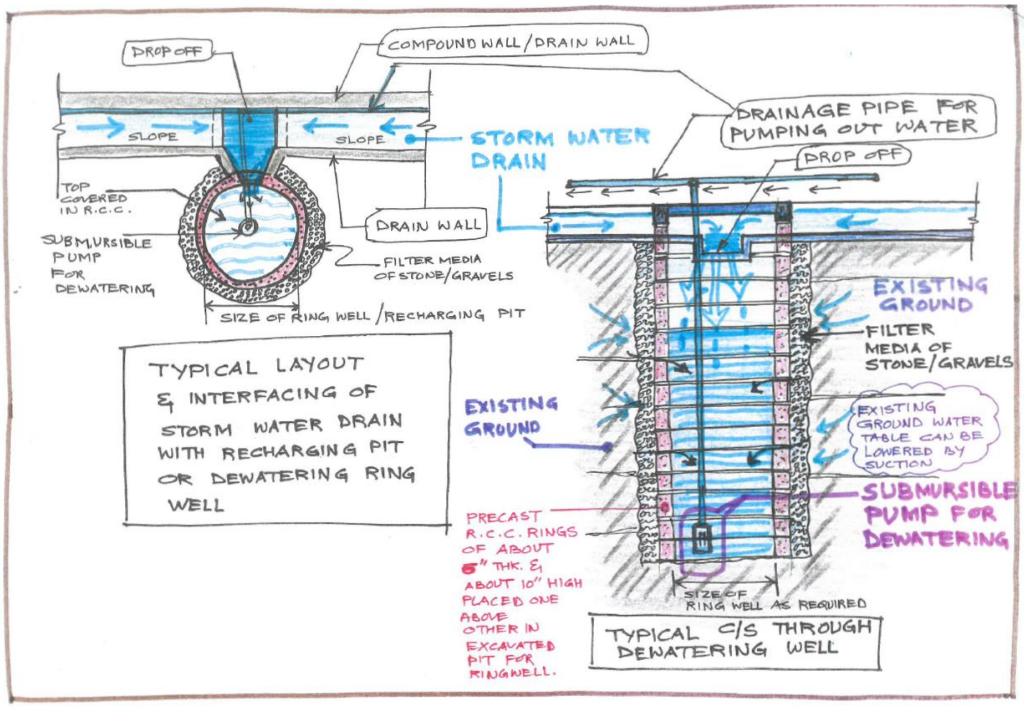


Figure A3: Structural adaptation measure – Surface storm water drainage and dewatering ring wells.

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