

JORDAN URBAN CLIMATE RISK ANALYSIS



City
Resilience
Program



GFDRR
Global Facility for Disaster Reduction and Recovery

About the City Resilience Program

Established in June 2017, the World Bank's City Resilience Program (CRP) empowers cities to invest in climate and disaster resilience. The CRP has assembled a diverse range of World Bank sectoral expertise as a global technical support system to assist cities in integrating climate change and disaster risk into their upstream capital investment planning and access the financing needed for climate-smart investments to succeed. Rather than trade off between competing sectoral needs, the CRP helps cities tackle their most pressing development challenges through integrated, cross-sectoral, spatially-based priorities that capture the interaction between the natural and built environments.

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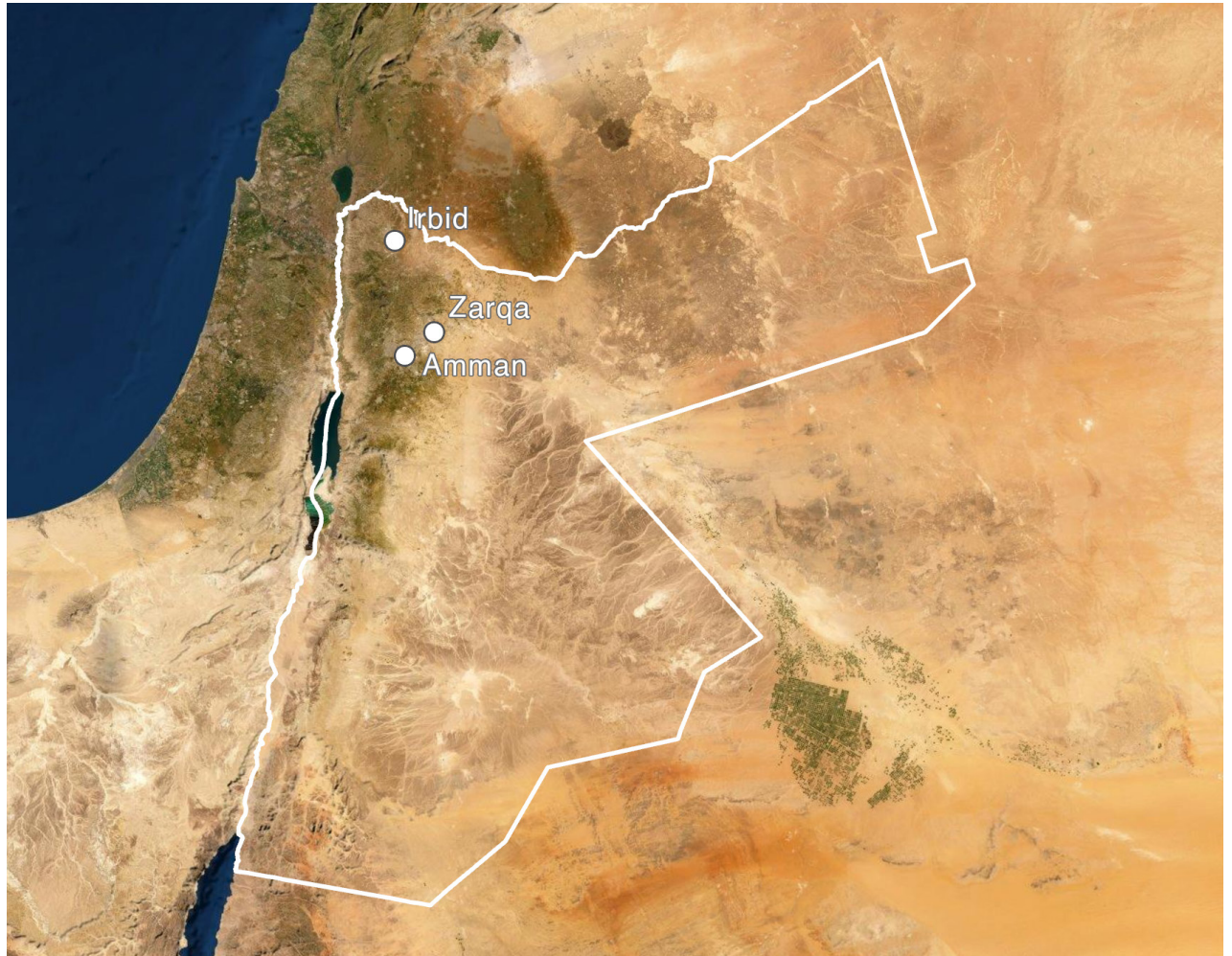
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The Urban Climate Risk Analysis represents a starting point for climate risk assessments. The global datasets used here do not necessarily take into account granular variations on the ground level, but rather serve as a rough approximation of local conditions. Moreover, climate change introduces deep uncertainty in evaluating future risks, which tend to be complex and nuanced. Therefore, the findings of this analysis are meant to be used in conjunction with local data and ground truths before they could be directly applied toward concrete actions.

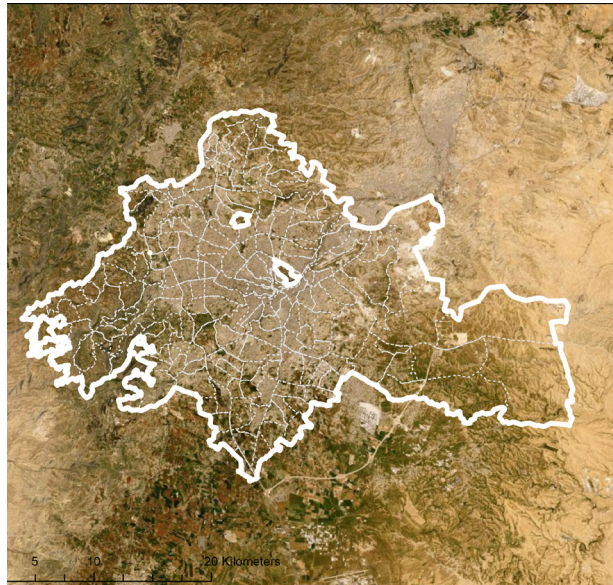
CHAPTER 1

OVERVIEW



Areas of Interest (AOIs)

This climate risk analysis is prepared for the Jordan Country Climate and Development Report (CCDR), with a focus on the urban sector. In most of Jordan, the local geography is marked by its arid or semi-arid landscape and relative lack of water bodies, which set the context for disaster and climate risks. The three largest Jordanian cities are covered in this analysis, including the capital Amman, as well as Irbid and Zarqa. All three cities are located in northern Jordan and have experienced continuous urban growth in recent decades. At the same time, ongoing changes in climate conditions and local populations pose a significant challenge to assessing the exposure and vulnerability to various risks.



*Top left: Amman
Top right: Irbid
Bottom left: Zarqa*

This analysis draws from the latest data on current and projected climate hazards and applies them to the urban environment in Jordan, presenting a birds-eye view on the extent and distribution of risks in the three cities. In particular, it delves into air pollution, flooding, urban heat, drought, and landslide hazards. Chapters 2-4 examine the different hazards on a city scale, while chapter 5 offers an inter-city comparison and delves deeper into climate projections. Together, these assessments help interpret risks through the lens of climate change and lay the foundation for adaptation strategies.

It is important to note, however, that this analysis represents merely a starting point for climate risk assessments. The global datasets used here do not necessarily take into account granular variations on the ground level, but rather serve as initial approximations of local conditions. Moreover, climate change introduces deep uncertainty in evaluating future risks, which tend to be more complex and nuanced than can be captured in a single headline. Therefore, the findings of this analysis are meant to be used in conjunction with local data and ground truths before they could be directly applied toward concrete actions.

Data and Methodology

This analysis evaluates the current risk levels and presents scenarios of future risk evolutions. For current risks, the data sources include the 2019 Global Burden of Disease Study (air pollution), 2020 Fathom-Global 2.0 Flood Data (pluvial and fluvial flooding), 2013-21 Landsat 8 satellite data (urban heat), 2021 Global Landslide Hazard Map (landslide), and European and Global Drought Observatories datasets (drought). For each city, depending on the spatial resolution, these data provide individual datapoints or data on intra-city variations, which are visualized and selectively benchmarked against regional peer cities.

Future projections are more complex. Climate models often share structural errors, and effective bias correction requires vast data that may not exist. The relatively lack of observational record also makes it difficult to directly assess model reliability, not to mention that part of the climate trajectory hinges on human choices, which cannot be estimated probabilistically.

Apart from existing deep uncertainties with climate models, applying projections to the urban scale comes with the

added uncertainty of dynamic factors of atmospheric circulation. Unlike thermodynamic components of climate studies (e.g., surface warming, moistening), the dynamic components are less robust in theory, observations, and models. This reduced degree of confidence compounds the already immense challenge of using climate models to come up with local adaptation policies.

To disentangle the uncertainties, the climate research community establishes scenarios to set baselines for climate models and offer internally consistent narratives for possible climate futures. One of the dimensions of these scenarios is socioeconomic developments. Different trajectories of demographic changes, urbanization, and economic development are summarized into five Shared Socioeconomic Pathways (SSPs), which are widely used in current climate research such as the Intergovernmental Panel on Climate Change (IPCC) assessment reports. As the SSPs are non-probabilistic, they facilitate an event-oriented approach to risk perception and overcome the shortfalls associated with human probabilistic thinking in a context of high uncertainty.

Data and Methodology (continued)

This analysis focuses on three of the five SSPs when presenting climate projections. These SSPs are chosen because they represent a wide variety of ways in which the world may evolve, which could help expand the exploration of potential policy responses for mitigation and adaptation. SSP1, named “sustainability – taking the green road”, depicts a path with low mitigation and adaptation challenges thanks to gradual, sustainable, and inclusive development. SSP2, the “middle of the road” scenario, faces medium mitigation and adaptation challenges due to business-as-usual practices and slow and uneven progress toward sustainable development. Finally, SSP5, the “fossil-fueled development”, confronts high mitigation challenges but low adaptation challenges. In this case, energy intensive development leads to rapid technological

progress, which is believed to be able to eventually carve out a path (e.g., geo-engineering) for sustainability.

Several projection datasets are incorporated in this analysis, including built-up area, temperature change due to urban land expansion, and flood-related indicators from the Coupled Model Intercomparison Project Phase 6 (CMIP6). The selection of SSPs lays out various internally consistent climate futures, illustrating the range of possible outcomes depending on socioeconomic developments and/or radiative forcing. Since the SSPs do not have assigned probabilities, they are not predictions. Instead, they support a non-probabilistic decision-making framework that allows policymakers to explore adaption strategies that are robust against deep uncertainties.

Key Findings

- Air pollution is a serious problem in all three cities, especially in Zarqa, where the PM2.5 concentration is 4.3 times the WHO standard of 10 $\mu\text{g}/\text{m}^3$. Even worse, the pollution has shown no sign of stopping, having increased by 22% in Zarqa since 1990. This is possibly due to the high density of industries in Zarqa, which houses over half of Jordan's factories.
- Although the urban areas enjoy lower summer surface temperatures than the surrounding desert, they still experience tremendous heat that could cause negative health effects. The average surface temperatures for the three cities all exceed 40 degrees Celsius, and more important, they have all witnessed intensifying summer heat to varying degrees in the past eight years. Such a noticeable increase within this short timespan implies that the urban heat issue is exacerbating. Meanwhile, there is a clear link between land cover and the degree of heat intensification, highlighting the role of urban land use planning in mitigating heat-related hazards.
- While fluvial flooding is minimal in urban areas, pluvial flooding currently affects 7-13% of urban settlements, and 4-10% of dense settlements. On a positive note, there is no universal pattern of risky settlement growth. In both Amman and Zarqa, settlements exposed to pluvial flooding grow at a slower rate than those that are protected. Flood projections indicate small increases in pluvial flood exposure under SSPs 1 and 5, but the rate of increase will have slowed significantly compared to the past few decades.
- The drought indicators convey mixed signals for drought conditions in Jordanian cities. In 2020, all three cities have received more precipitation than normal in terms of both short- and medium-term aggregations. Yet, the total water storage (TWS) level continued to decline throughout the year, pointing to potential existence of groundwater drought. The diverging indicators could be due to anomalies in the hydrological processes involved in the transformation of precipitation into TWS.

Key Findings (continued)

- On average, under SSPs 2 and 5, all three cities are projected to become drier in the future, as precipitation and water runoff are expected to decline by up to 10% and 40%, respectively. This could mean longer and more serious drought conditions, negatively impacting urban residents, industries, and agriculture. At the same time, while this may seem to offer some relief for flood risks, a closer scrutiny of the climate models demonstrates that extreme precipitation is actually predicted to increase, especially in the 2050s, by up to more than 10%. This could lead to worse pluvial flood hazards for Jordanian cities, because flash floods could intensify and the drier, degraded soil would be less capable of fending off the floodwater.
- Due to low levels of precipitation, the three cities have extremely low risks of rainfall-triggered landslide. The average return period tends to be very long, and only a small fraction of city areas is exposed. It is not clear whether or how the increasing frequency of extreme weather events resulting from climate change might change landslide hazards.
- Based on continuing urbanization and projected climate changes, a set of policy recommendations are made to enhance climate adaptation and urban resilience. These recommendations cover areas that include localization of climate adaptation, complementarity between urban adaptation and urban mitigation, green infrastructure development, urban water resources management, urban agriculture, localized resilience programs and investments, and integration of climate interactions into planning.

CHAPTER 2

AMMAN

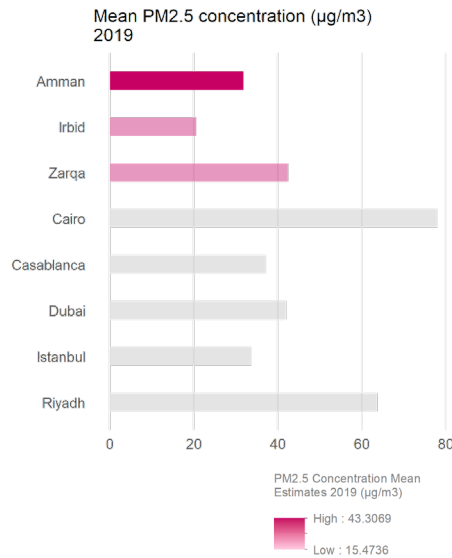
As the capital of Jordan, Amman is the largest city in the country. With a population of over four million and an area of **707** square kilometers (defined by the area of interest), it is also one of the major urban areas in the Middle East and North Africa (MENA) region. As a result, Amman has attracted migrants and experienced considerable growth. Since 1985, the settlement area in the city has more than doubled, from **144** to **290** square kilometers in 2015.



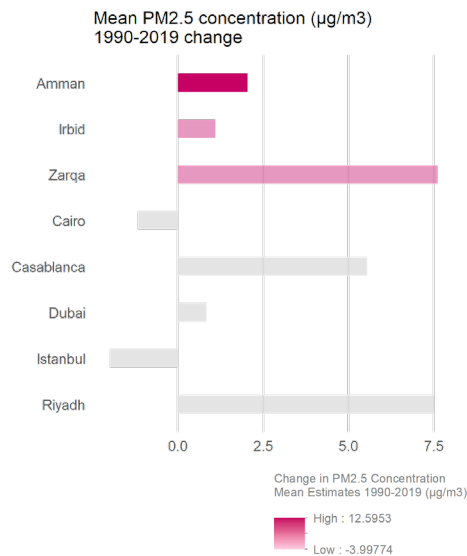
Air Pollution: PM2.5

In this analysis, air pollution is measured by fine particulate matter (PM2.5) concentration and ozone pollution. PM2.5 particles are of concern because their small size allows them to travel deep into the cardiopulmonary system.

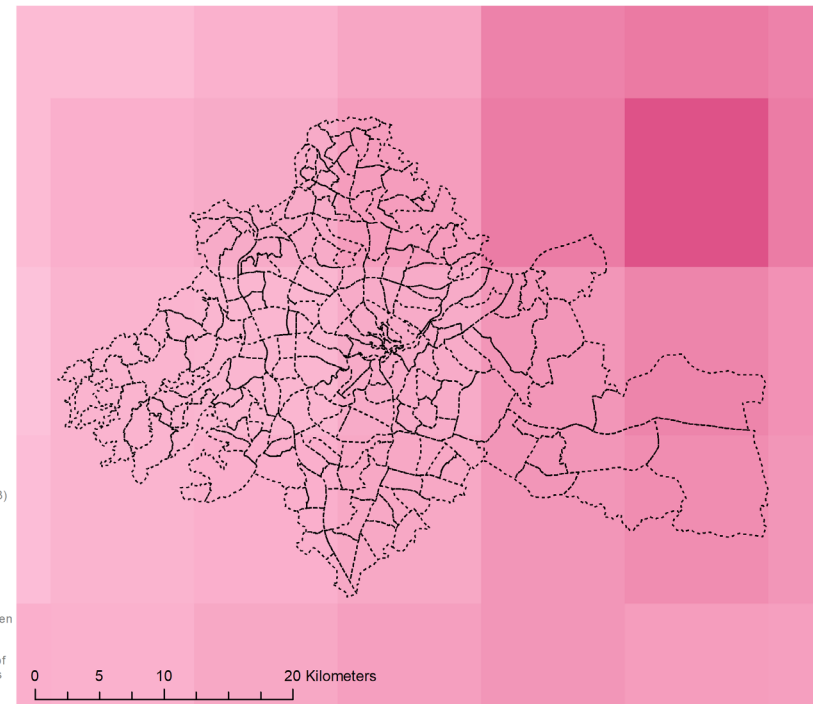
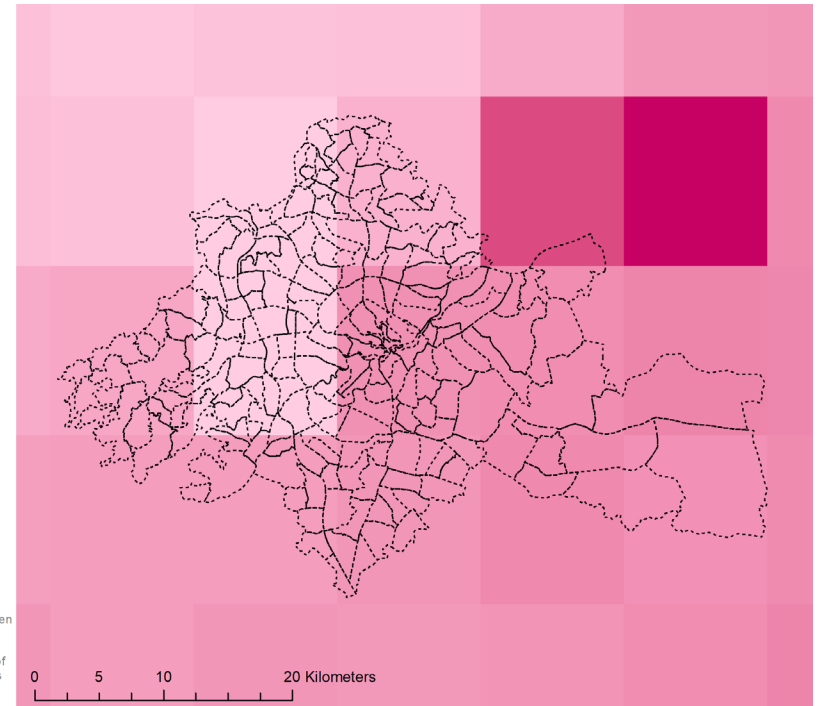
In Amman, PM2.5-related air pollution is a serious concern. The average PM2.5 concentration in 2019 is **32 $\mu\text{g}/\text{m}^3$** , more than three times the WHO guideline of 10 $\mu\text{g}/\text{m}^3$. According to the WHO, a PM2.5 concentration of 10 $\mu\text{g}/\text{m}^3$ is associated with an **8%** increase in long-term mortality. Therefore, the air quality in Amman constitutes a significant health risk for the residents, though the map shows some variations between neighborhoods. Nevertheless, Amman only has about half as much PM2.5 concentration as some regional cities such as Cairo and Riyadh, highlighting the regional significance of the air pollution problem. In the period from 1990 to 2019, pollution from PM2.5 concentration has exacerbated slightly, increasing by **2 $\mu\text{g}/\text{m}^3$** . As climate change potentially reduces rainfall, PM2.5 particles could linger in the air longer and worsen the pollution.



Source: Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Air Pollution Exposure Estimates 1990-2019. Seattle, United States of America: Institute for Health Metrics and Evaluation (IHME), 2021.



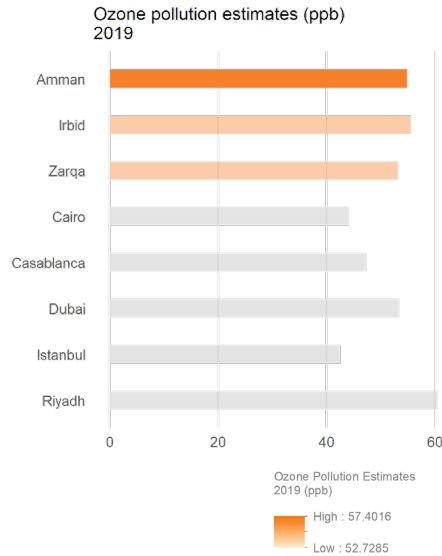
Source: Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Air Pollution Exposure Estimates 1990-2019. Seattle, United States of America: Institute for Health Metrics and Evaluation (IHME), 2021.



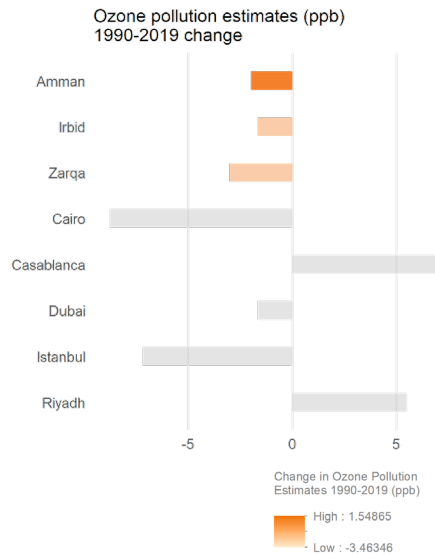
Air Pollution: Ozone

Ground-level ozone is linked to health issues such as aggravated lung diseases and asthma attacks, especially on hot sunny days when ozone can reach unhealthy levels. Even relatively low levels of ozone can cause health problems.

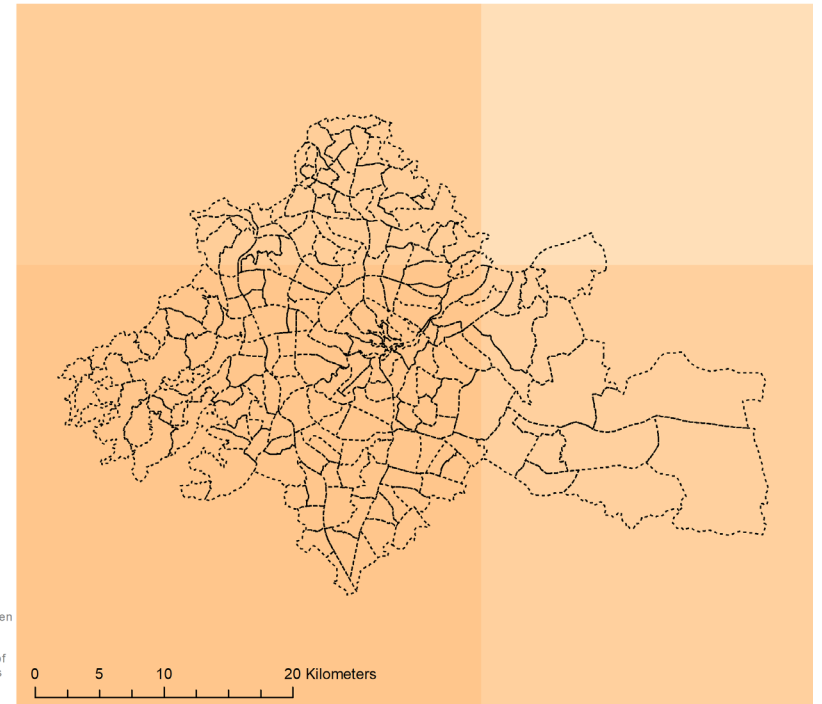
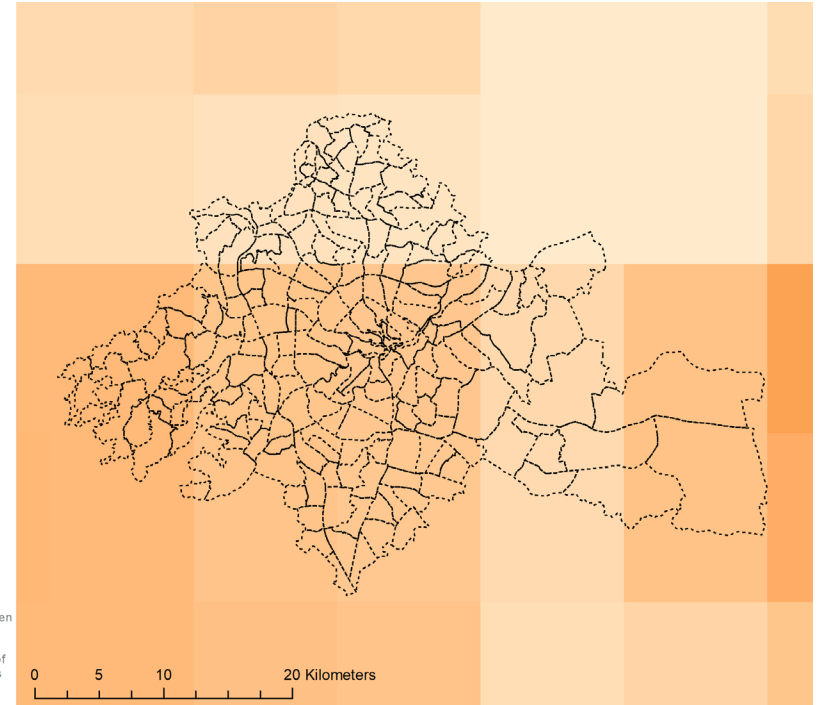
In terms of ozone pollution, the average ozone level in Amman is **55 parts per billion (ppb)**, similar to other regional cities, and below the US EPA standard of 70 ppb. Since 1990, the ozone pollution in Amman has in fact decreased by **2 ppb**.



Source: Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Air Pollution Exposure Estimates 1990-2019. Seattle, United States of America: Institute for Health Metrics and Evaluation (IHME), 2021.

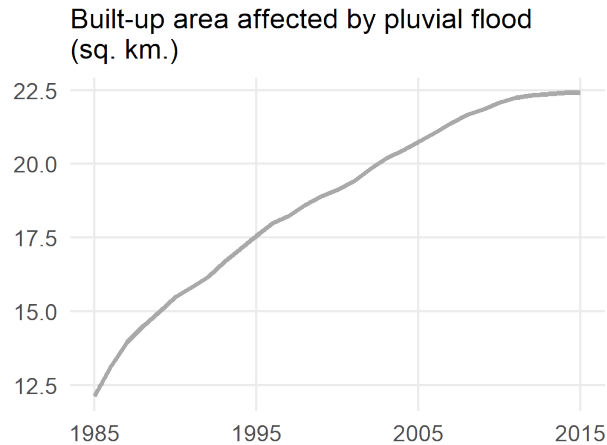


Source: Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Air Pollution Exposure Estimates 1990-2019. Seattle, United States of America: Institute for Health Metrics and Evaluation (IHME), 2021.



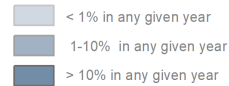
Pluvial Flooding with Built-up Area

In Amman, pluvial flooding caused by precipitation jeopardizes less than 10% of the settlement area as of 2015. Potential pluvial flood zones spread across different areas of the city and affect old and new settlements alike. From 1985 to 2015, the settlement areas exposed to pluvial flooding grew from **12.1** to **22.4** square kilometers, an average annual rate of **2.8%** and an **85%** increase in total, lower than the overall settlement growth rate.

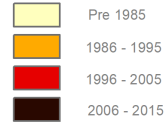


Built-up Area Affected in Rainwater Flood Risk Zone

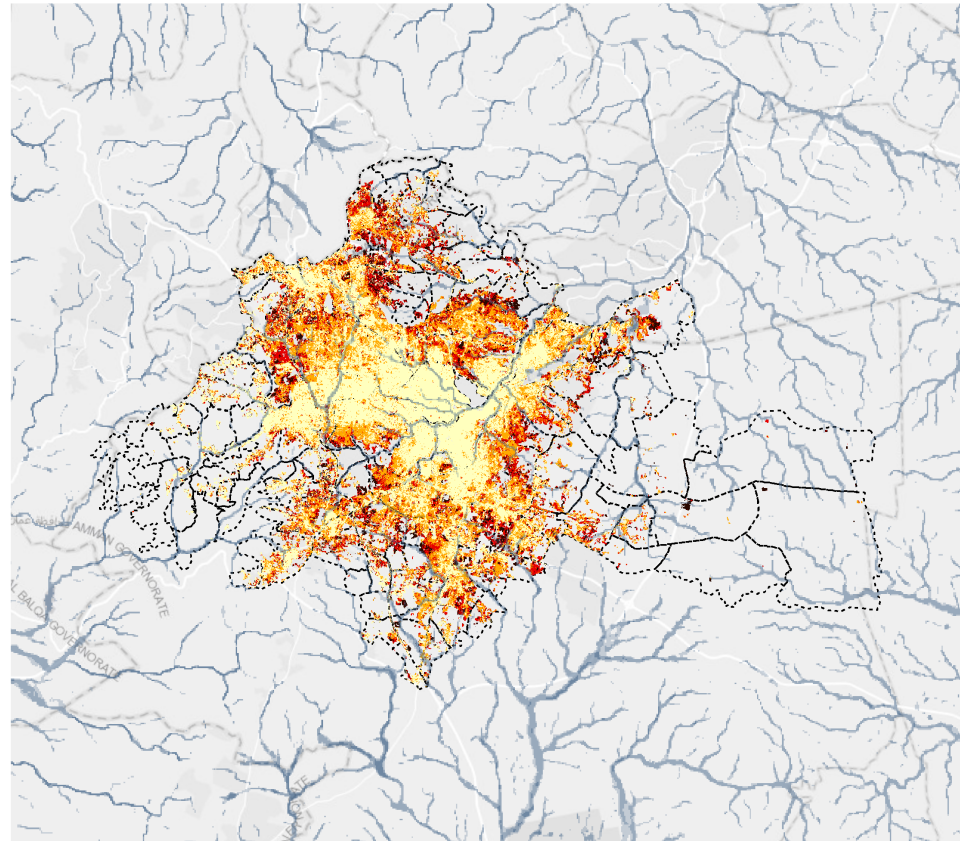
Rainwater Flood Probability



Date Built

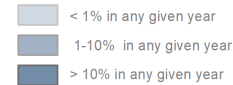


Source: World Settlement Footprint Landsat 5/7"; SSBN 3 arc second (90 m) Global Hazard Data (World Bank License)

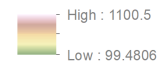


Rainwater Flood Risk Zone Overlay on Elevation

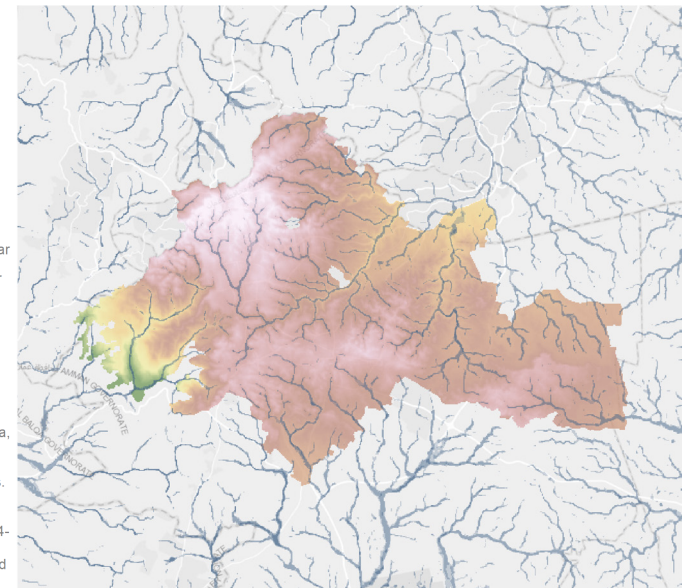
Rainwater Flood Probability



Elevation (m)

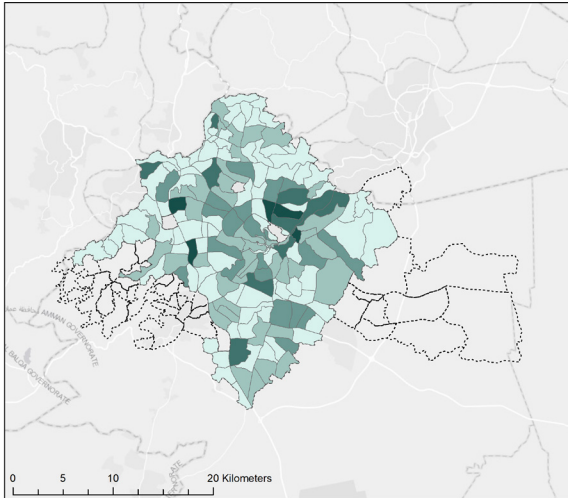
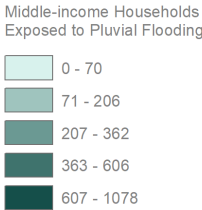
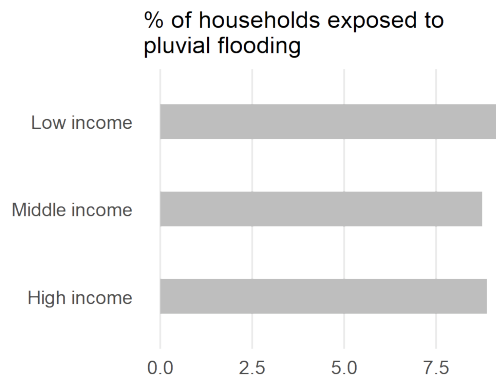
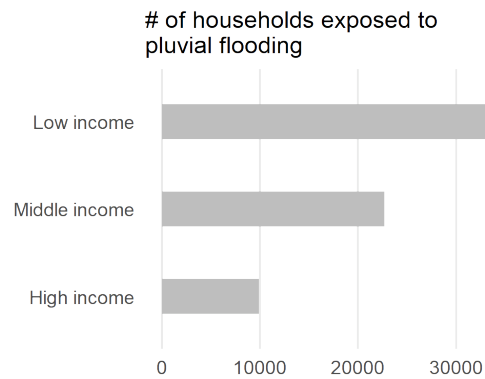
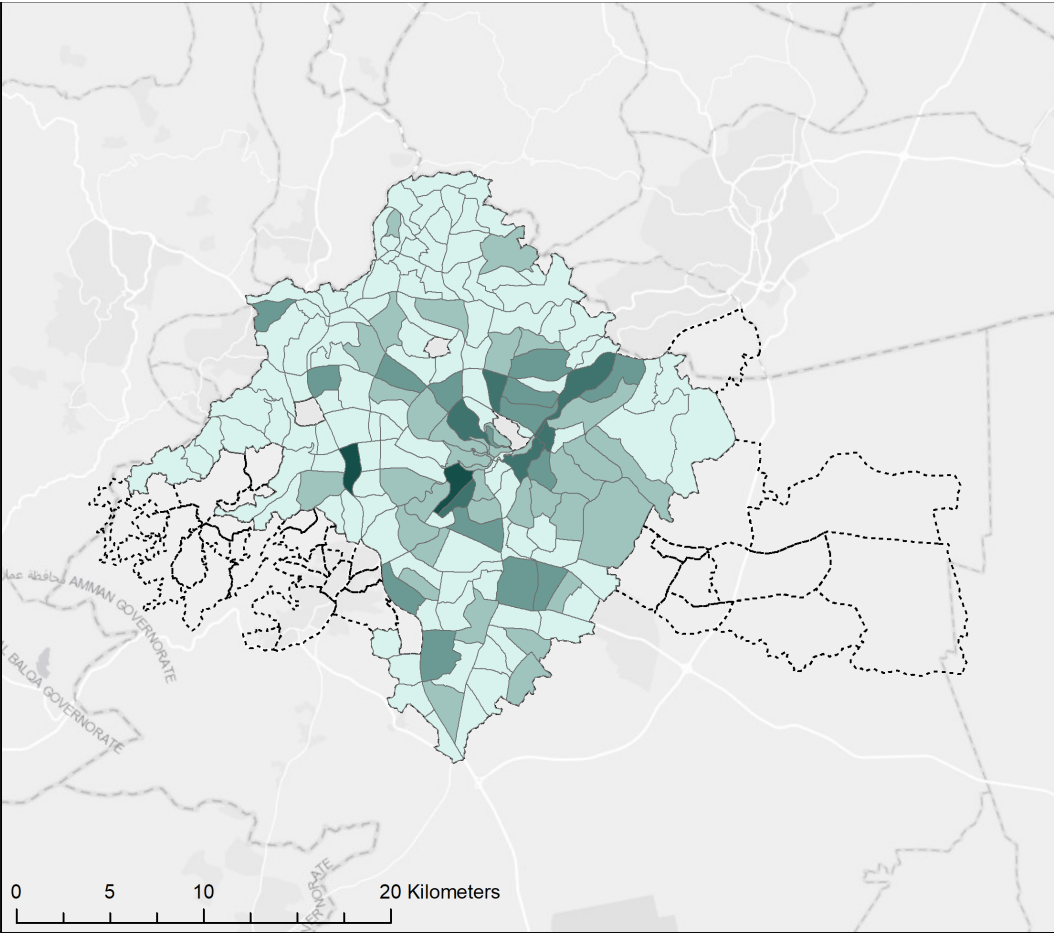
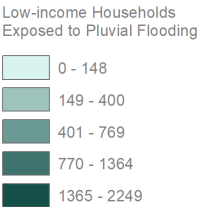


Source: Yamazaki D., D. Ikeshima, R. Tawatari, T. Yamaguchi, F. O'Loughlin, J.C. Neal, C.C. Sampson, S. Kanai & P.D. Bates. A high accuracy map of global terrain elevations. Geophysical Research Letters, vol.44, pp.5844-5853, 2017; SSBN 3 arc second (90 m) Global Hazard Data (World Bank License)



Pluvial Flooding and Vulnerable Households

According to census information, about **66,900** households are potentially exposed to pluvial flooding, including **34,300** low-income households. The risk faced by low-income households are not disproportional: about the same percentage of households from each income tier are subject to potential pluvial flooding. However, the exposure is spatially uneven. The city center, in particular, has a higher concentration of at-risk low-income households, who might be less equipped to deal with flood events than high-income families.



Pluvial Flooding with Population

In Amman, **10%** of the densest settlement areas (at least 86 persons per 100 square meters, or the two densest bins on the map) are exposed to pluvial flooding. People are particularly sensitive to flooding in cases where population density is high, zoning regulations are absent or not enforced, flood controls are weak, and emergency response infrastructure and early warning systems are lacking. One consequence of increased population density in cities is an increase in impermeable surfaces, which leads to an increase in stormwater runoff. When populations are exposed, vulnerable, dense, and ill-prepared, the effects of climate change on them are exacerbated along with the increased intensity and frequency of harmful flood events.

Population Affected
in Rainwater Flood
Risk Zone

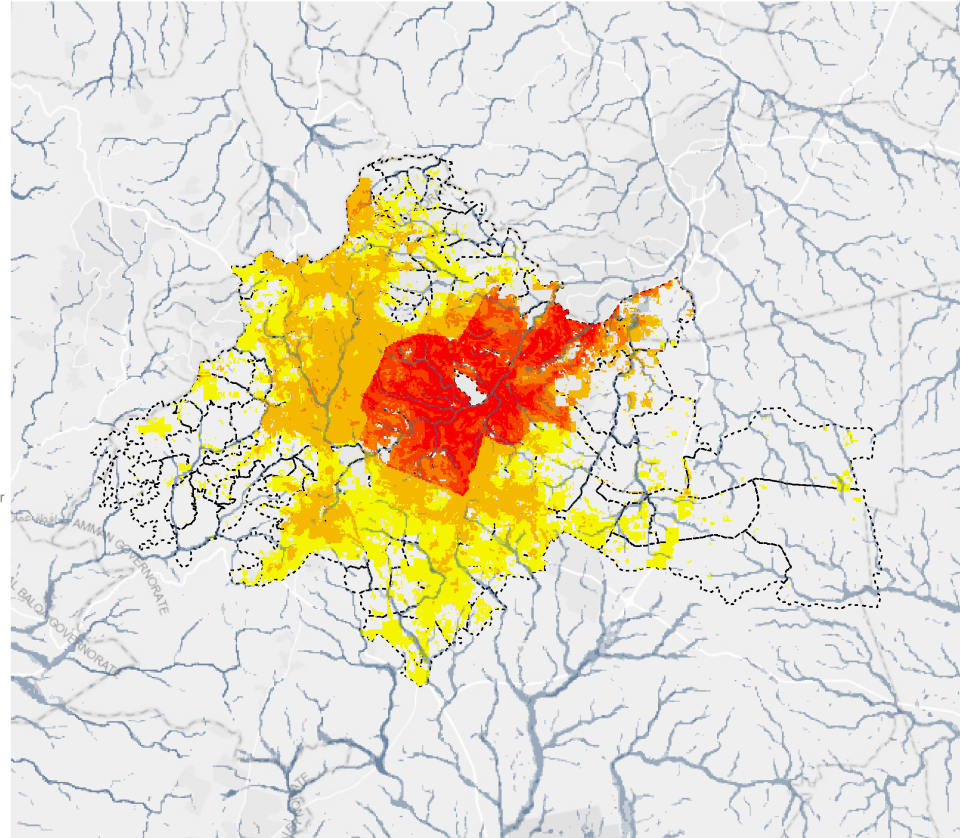
Rainwater
Flood Probability

< 1% in any given year
1-10% in any given year
> 10% in any given year

Number of persons
per 100 sq. m.

5 - 33
34 - 57
58 - 85
86 - 111
112 - 160

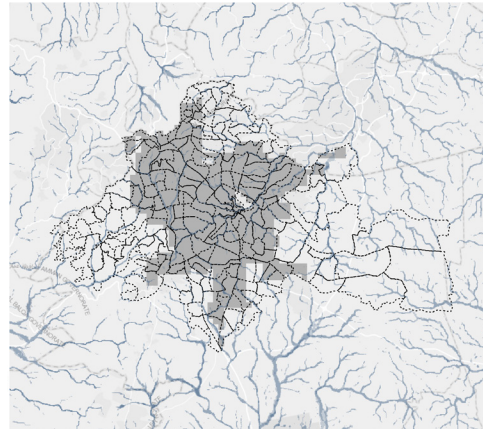
Source: WorldPop
<https://www.worldpop.org/>;
SSBN 3 arc second (90 m)
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Bank License)



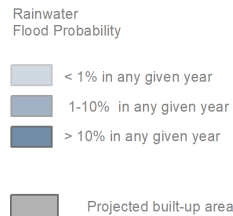
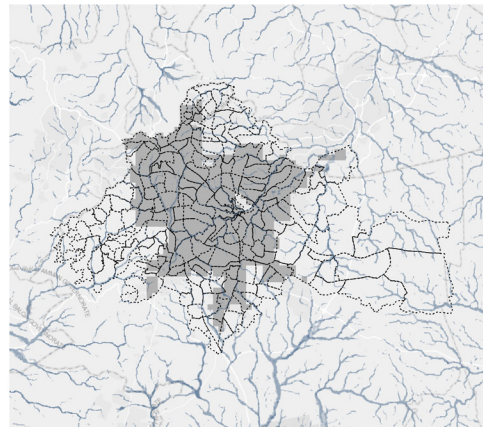
Pluvial Flooding with Built-up Projections

Amman's settlements are projected to further expand into places facing current flood risks. Under both SSP1 and SSP5, the area of at-risk settlements will reach **26 square kilometers by 2030** and **31 square kilometers by 2050**. Compared to the urban growth pattern in the 31-year period between 1985 and 2015, the projections predict slower expansion of built-up area into flood hazard zones in the future. However, this analysis assumes a flood hazard unchanged from the present one; climate change and urban development may increase the future exposure of land and built-up area to flooding further.

SSP1
2030 (bottom) and
2050 (right)



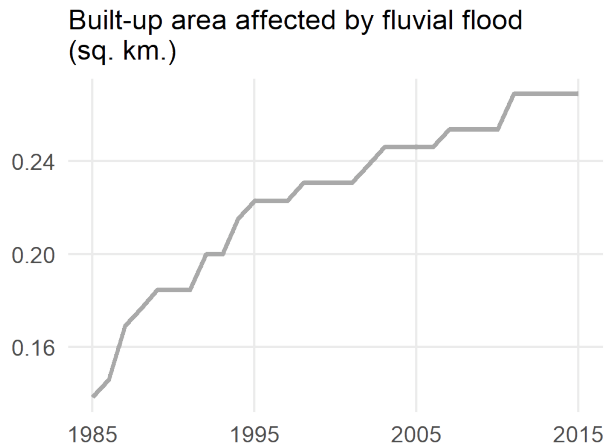
SSP5
2030 (bottom) and
2050 (right)



Source: SSBN 3 arc second (90 m) Global Hazard Data (World Bank License); Chen, G., Li, X., Liu, X. et al. "Global projections of future urban land expansion under shared socioeconomic pathways." *Nat Commun* 11, 537 (2020). <https://doi.org/10.1038/s41467-020-14386-x>

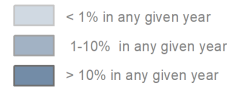
Fluvial Flooding with Built-up Area

Fluvial flooding is not a source of concern in Amman. The potential fluvial flood zone is very limited and only affects a small area (**0.27 square kilometer**) in the southern tip of the city. The change in this figure from 1985 to 2015 has been miniscule.

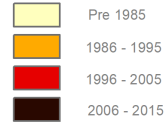


Built-up Area Affected in River Flood Risk Zone

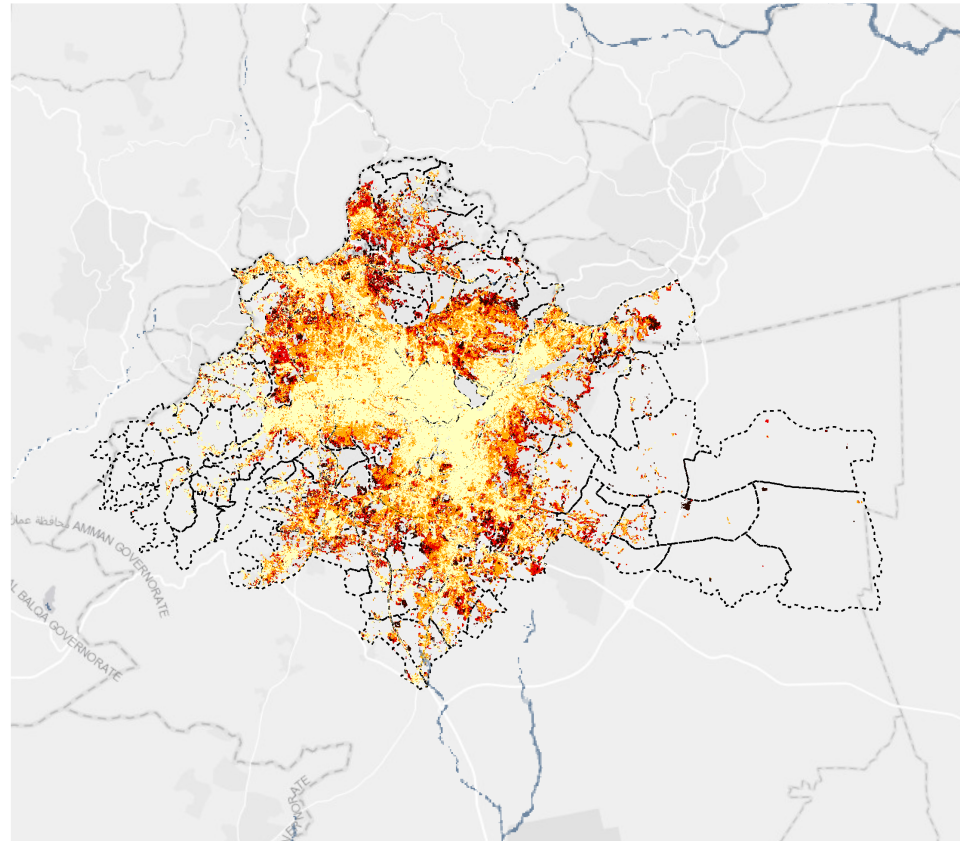
River Flood Probability



Date Built

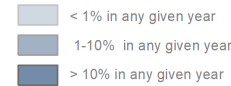


Source: World Settlement Footprint Landsat 5/7"; SSBN 3 arc second (90 m) Global Hazard Data (World Bank License)

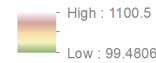


River Flood Risk Zone Overlay on Elevation

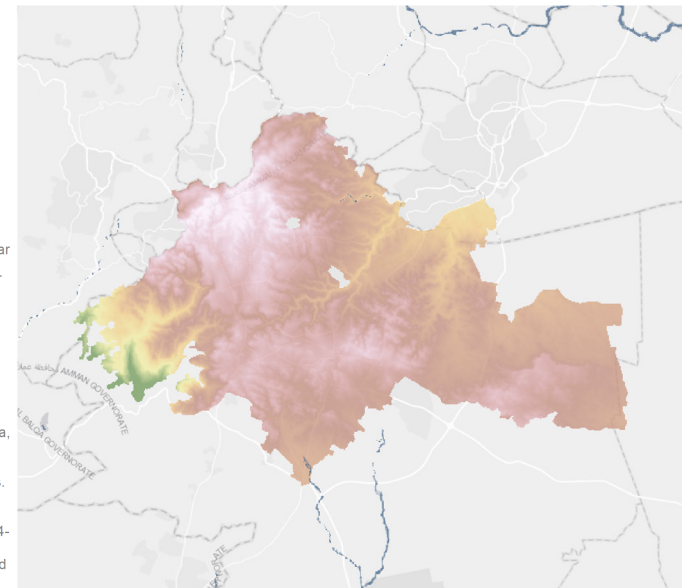
River Flood Probability



Elevation (m)

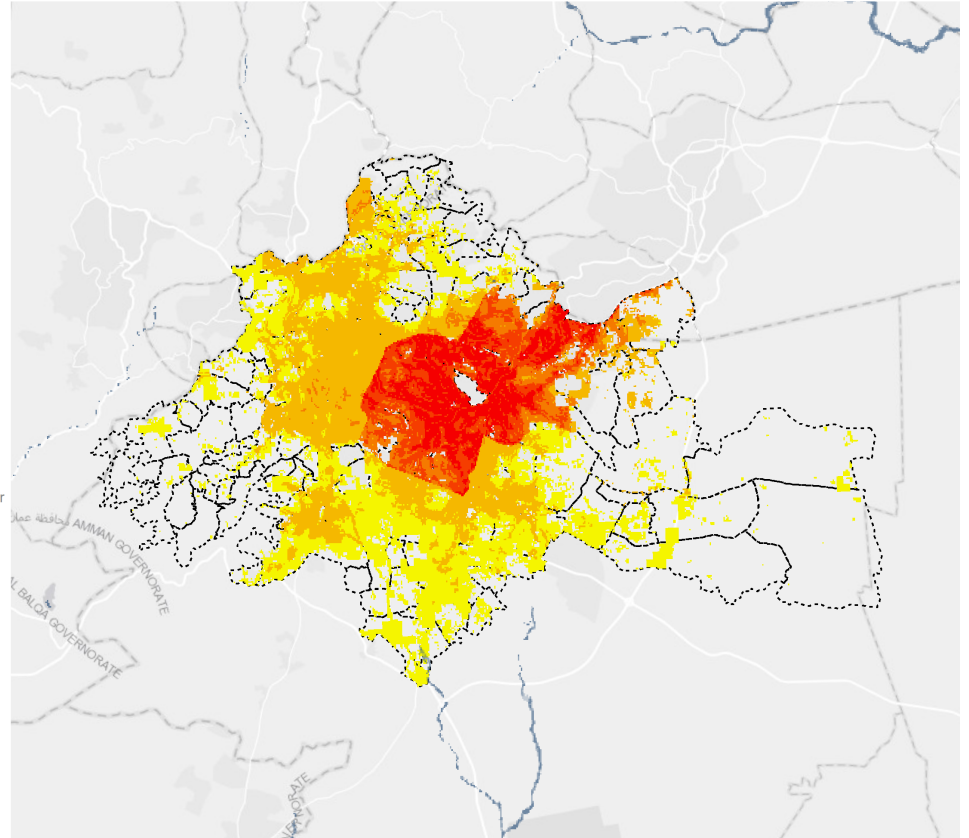
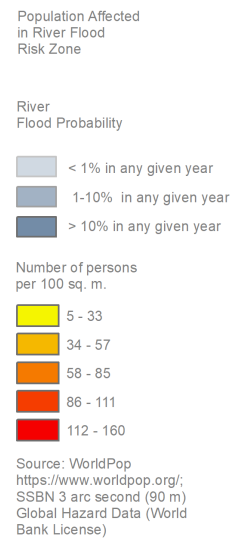


Source: Yamazaki D., D. Ikeshima, R. Tawatari, T. Yamaguchi, F. O'Loughlin, J.C. Neal, C.C. Sampson, S. Kanai & P.D. Bates. A high accuracy map of global terrain elevations. Geophysical Research Letters, vol.44, pp.5844-5853, 2017; SSBN 3 arc second (90 m) Global Hazard Data (World Bank License)



Fluvial Flooding with Population

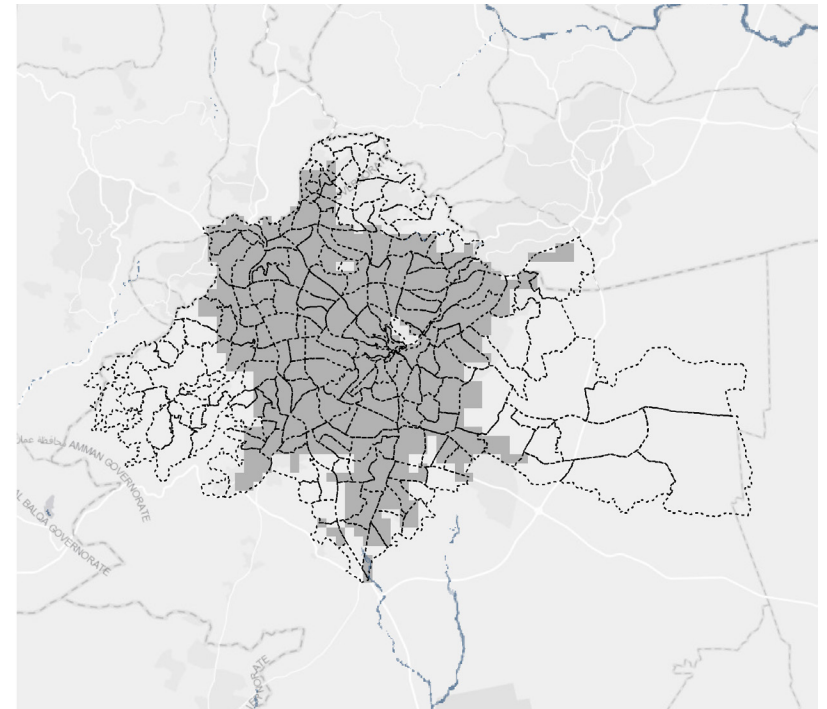
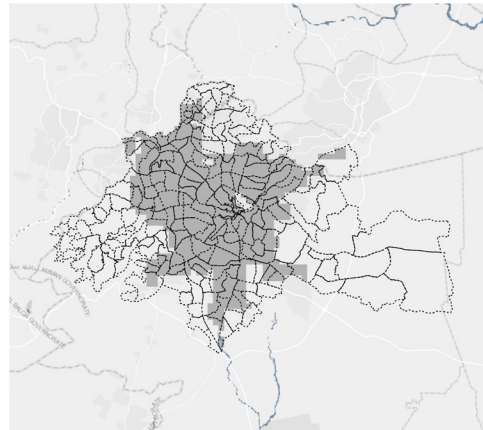
Similarly, none of the densest settlements in Amman are exposed to potential fluvial flooding.



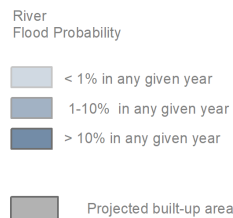
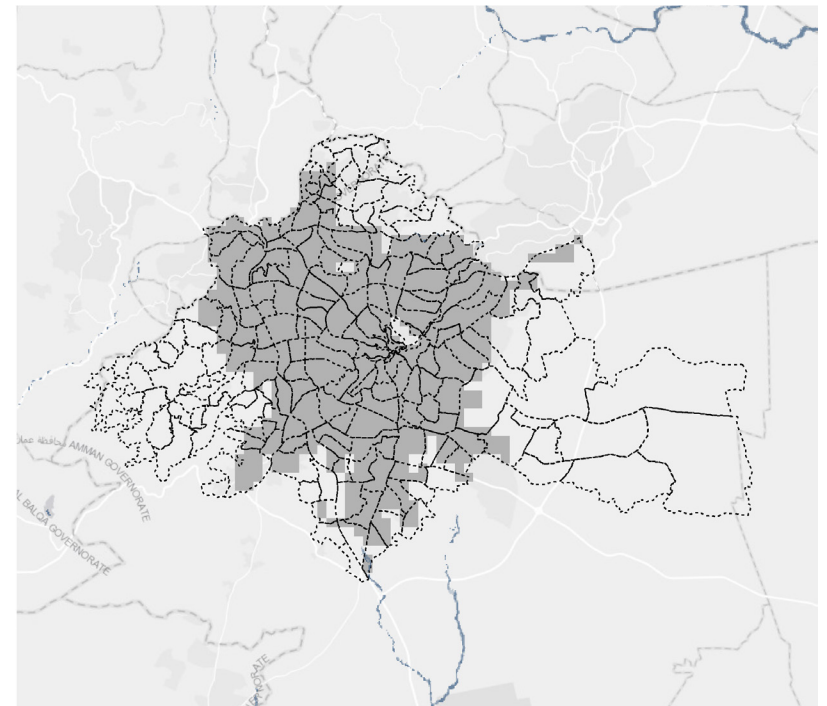
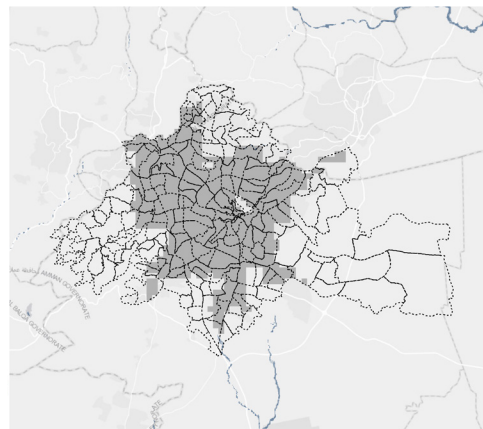
Fluvial Flooding with Built-up Projections

Even in future projections, the area of settlements at risk of fluvial flooding is expected to stay **below 1 square kilometer** by 2050, under both SSP1 and SSP5.

SSP1
2030 (bottom) and
2050 (right)



SSP5
2030 (bottom) and
2050 (right)



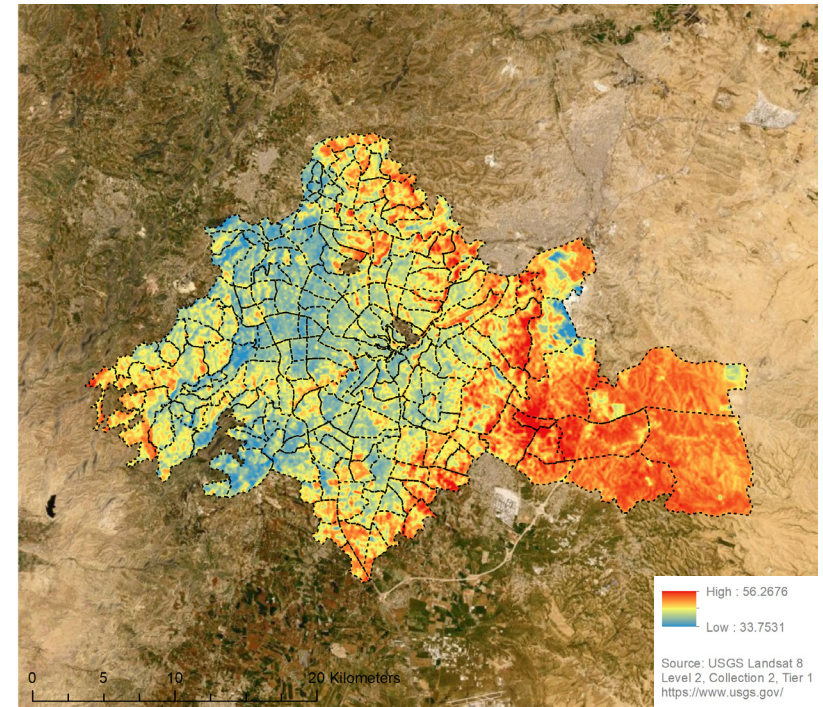
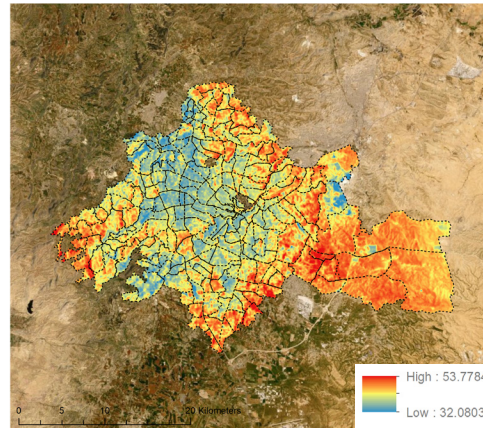
Source: SSBN 3 arc second (90 m) Global Hazard Data (World Bank License); Chen, G., Li, X., Liu, X. et al. "Global projections of future urban land expansion under shared socioeconomic pathways." Nat Commun 11, 537 (2020). <https://doi.org/10.1038/s41467-020-14386-x>

Urban Heat

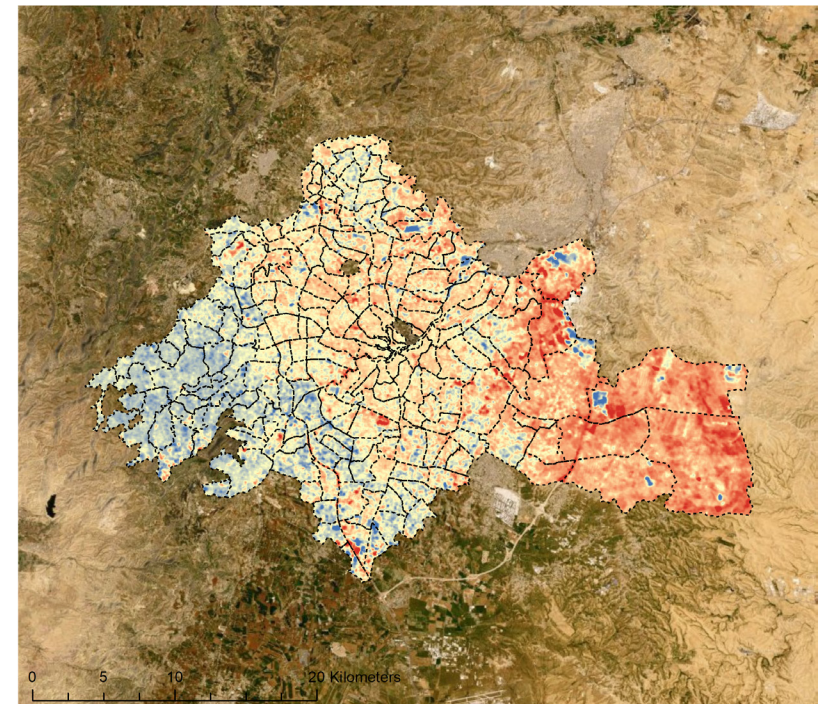
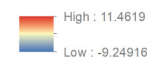
The urban heat maps measure the land surface temperature during July and August, the two hottest months in Jordan. Note that surface temperature refers to the temperature of the ground, as one would feel on one's feet, rather than on one's face.

In Amman, the settled areas tend to be cooler than the rural outskirts, likely due to the desert landscape surrounding the city. Nevertheless, the average surface temperature in the urban center is still high, exceeding 33 degrees Celsius. Moreover, within a short time span of eight years, the average summer temperature of the entire city has gone up from **45.0** degrees in 2013 to **46.8** degrees in 2021, a **1.8**-degree difference. To complicate the matter further, the heat intensification is highly uneven. Eastern Amman has seen the most dramatic temperature increases of over 11 degrees, whereas western Amman has gotten cooler by up to 9 degrees. Still, most of the settlements experienced noticeable temperature increases, which could heighten the risk of adverse health effects and productivity loss due to extreme heat.

*Average Summer Surface Temperature (°C)
2013 (bottom) and
2021 (right)*

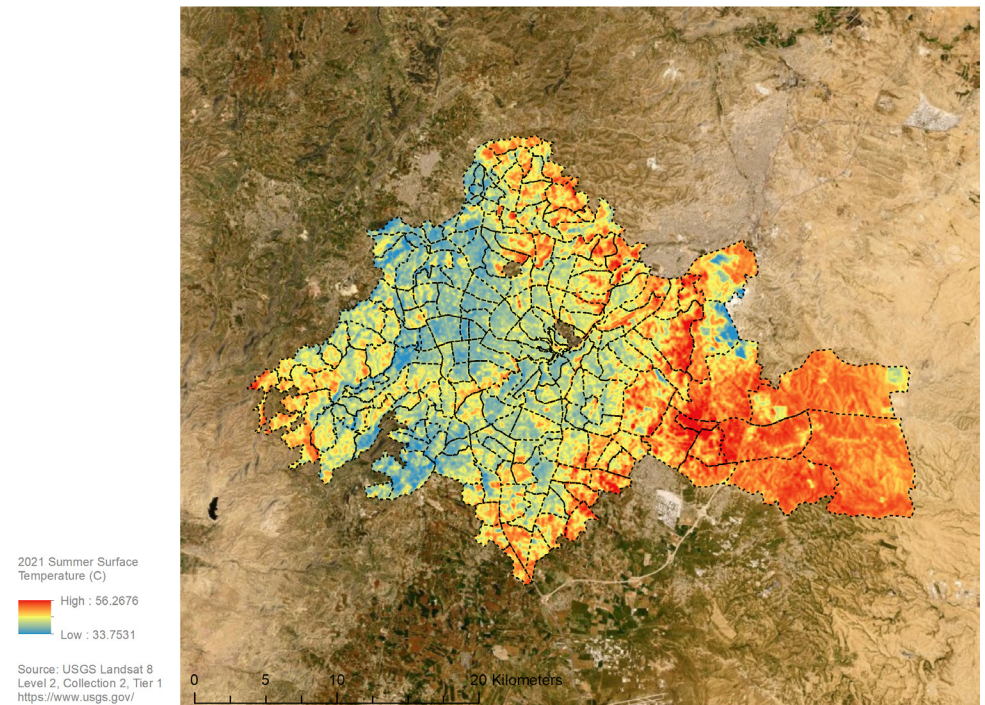
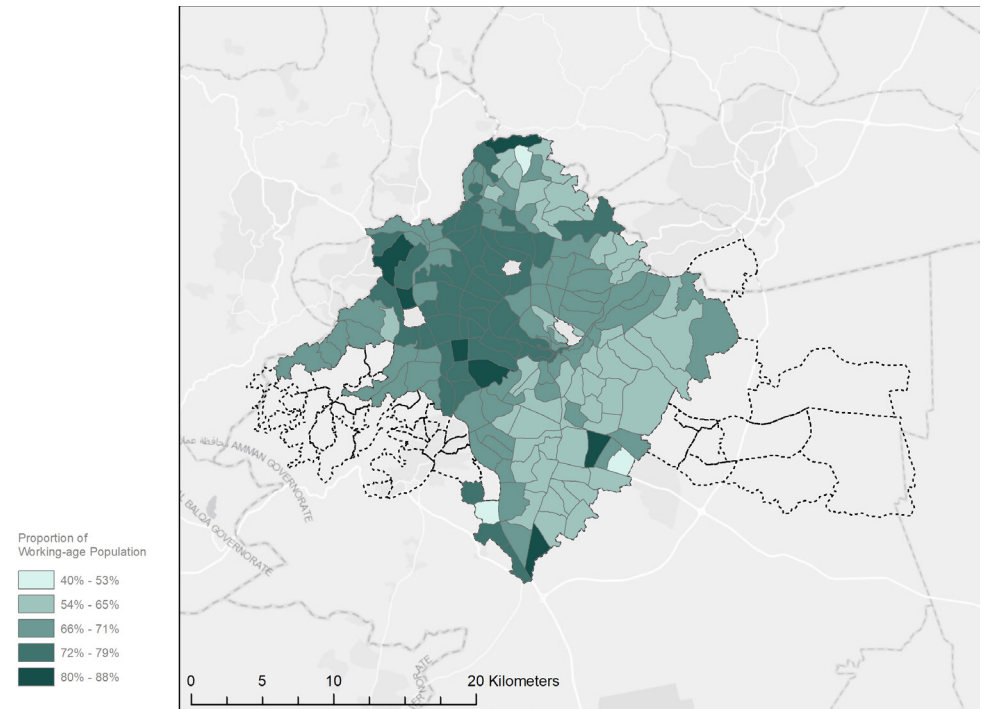


*2013-2021 Summer Surface
Temperature Change (°C)*



Urban Heat and Socioeconomic Equity

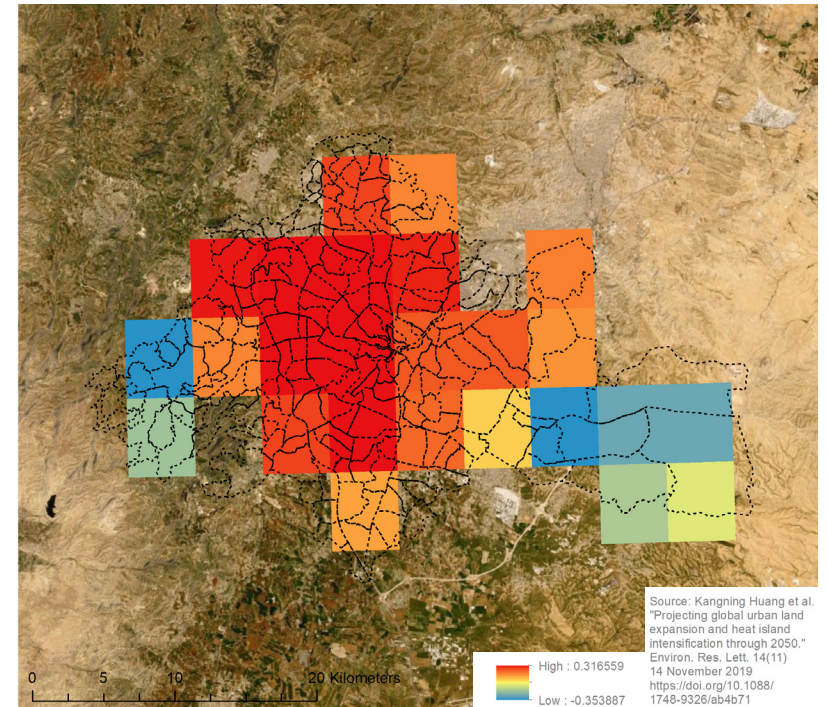
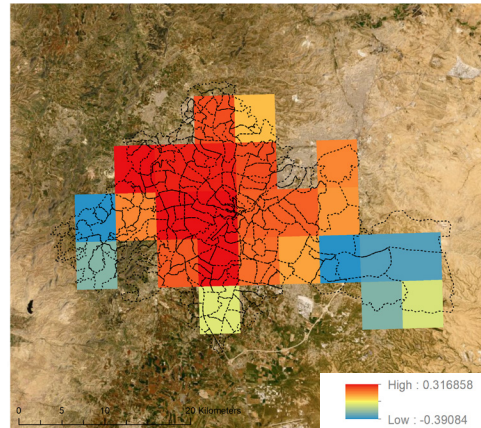
When it comes to the relationship between socioeconomic disparities and uneven spatial distribution of heat hazards, there seems to be a correlation between the fraction of working-age population in a neighborhood and the average summer temperature. A simple linear regression shows a coefficient of **-0.13** (highly statistically significant with $p < 0.001$), meaning that a 1% increase in working-age population is associated with a 0.13 degree decrease in average temperature. The adjusted R-squared value is **0.14**, which means that the variation in working-age population percentages explains 14% of the variation in average temperatures.



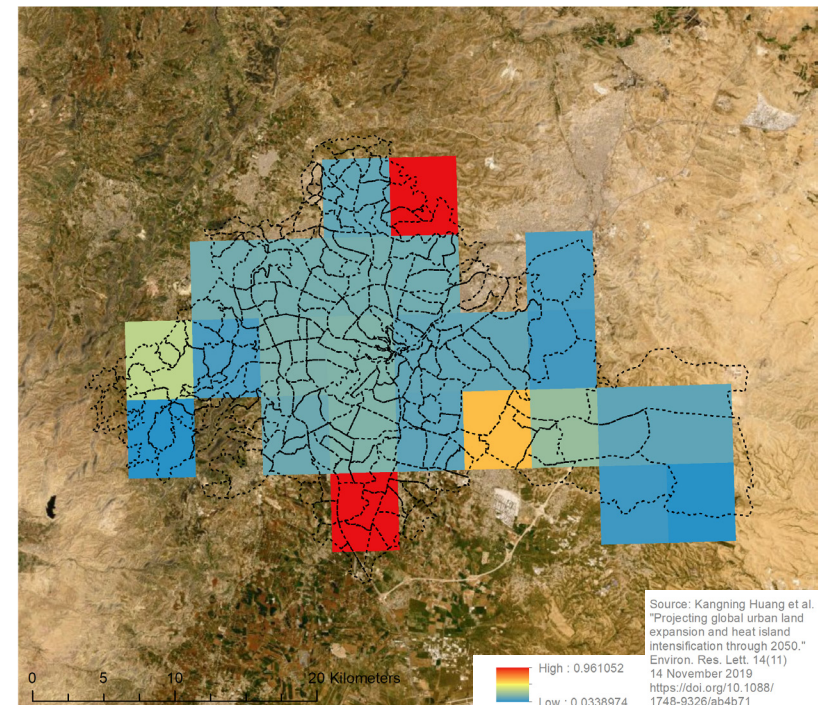
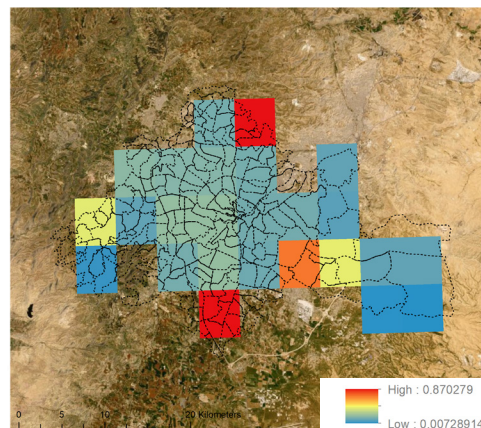
Urban Heat Projections

Given the close link between urban land cover and summer temperature, it is crucial to explore how continued urbanization will impact temperature in the future. Therefore, the projections here isolate the effects of urban land expansion on air temperature from other confounding factors. According to the projections, settled areas of Amman will see slight summer daytime temperature rises from urban land expansion of **up to 0.3 degrees** by 2050 under both SSP1 and SSP5, whereas the more rural areas could expect small drops in temperature. However, in the nighttime, the disparity between urban and rural areas disappears, if not reverses. All parts of Amman could experience higher nighttime temperatures due to urban land expansion, and there are sporadic spots in the outskirts where such effects could be felt more intensely.

Projected Change in Summer Daytime Air Temperatures Due to Urban Land Expansion under SSP1 (bottom) and SSP5 (right) (2050) (°C)



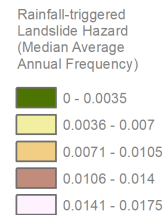
Projected Change in Summer Nighttime Air Temperatures Due to Urban Land Expansion under SSP1 (bottom) and SSP5 (right) (2050) (°C)



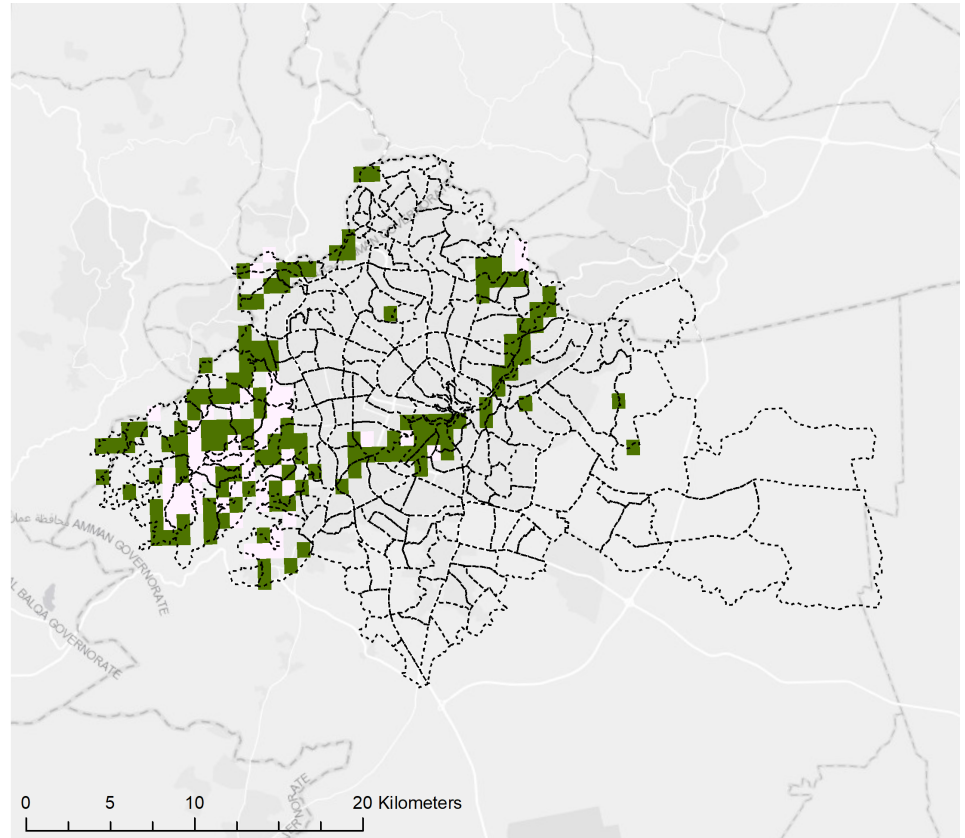
Landslide

Amman has the highest level of rainfall-triggered landslide hazard among the three cities. Even so, the risk level is still very low. Across the whole city, the average value of the median annual frequency is just **0.0014**, roughly corresponding to a **700-year** return period. The landslide hazard is present in about **19%** of the city, mostly concentrated in western and central Amman.

With this Report's focus on climate change, the landslide analysis here examines rainfall-triggered landslides. The rainfall-triggered landslide hazard is measured by the median average annual frequency in a gridded format.



Data Source: Global Landslide Hazard Map (1 km)
<https://datacatalog.worldbank.org/search/dataset/0037584/global-landslide-hazard-map>



CHAPTER 3

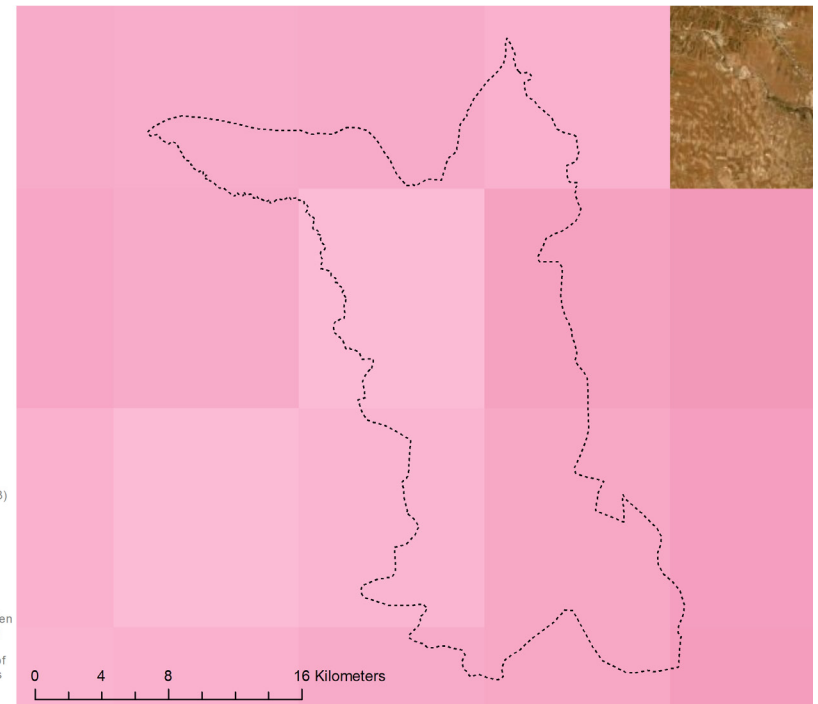
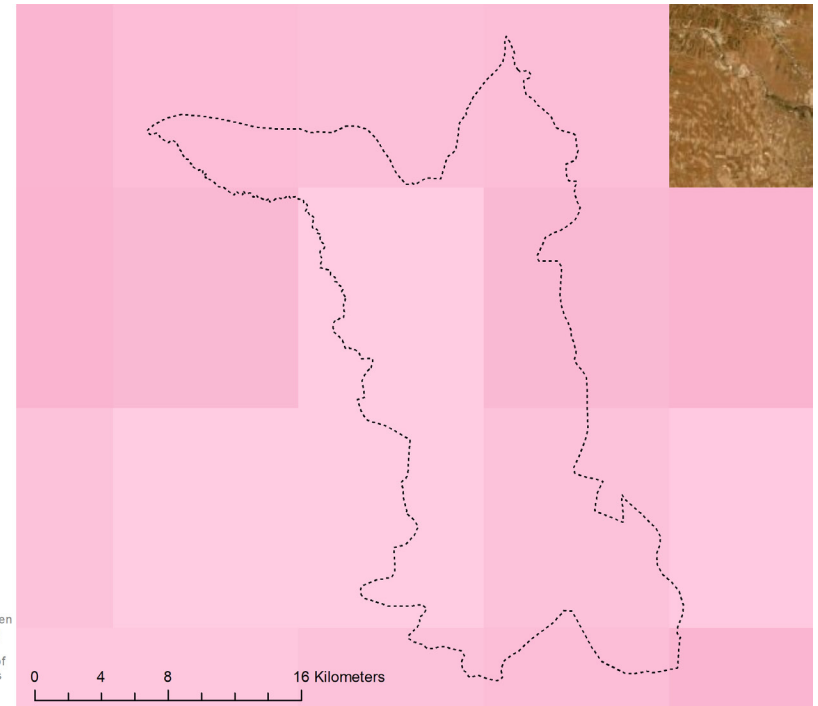
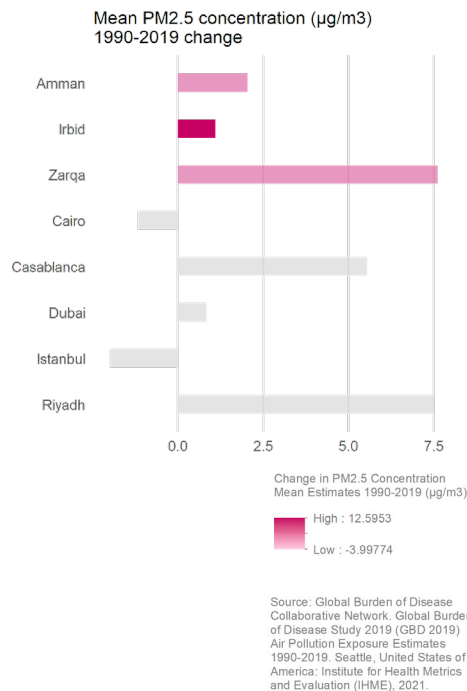
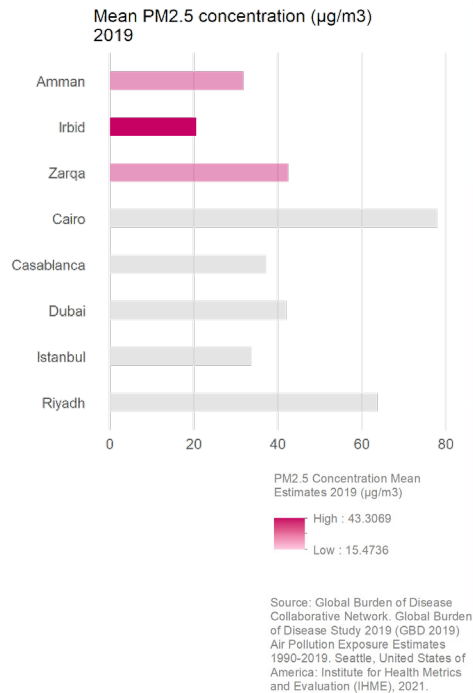
IRBID

Irbid, the largest city in the Irbid Governorate, is the third largest in Jordan, after Amman and Zarqa. It also has the second largest metropolitan population in Jordan after Amman, with around two million residents. Today, this historic city enjoys a total area of **341** square kilometers (defined by the AOI) and **91** square kilometers of settlements as of 2015, up from **53** in 1985.



Air Pollution: PM2.5

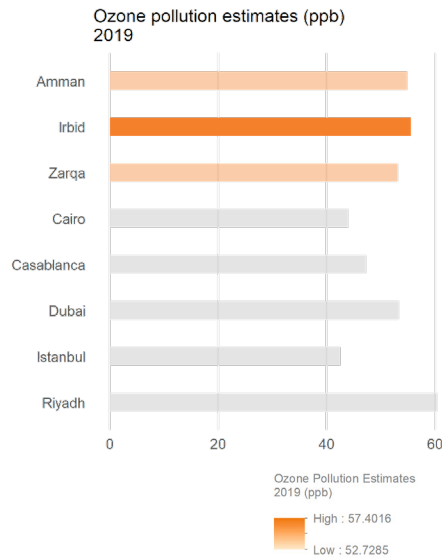
The air pollution level in Irbid is milder than in Amman and in other regional cities, but still exceeds the WHO standard. The average PM2.5 concentration in 2019 is about two-thirds of Amman's level, at **21 $\mu\text{g}/\text{m}^3$** , which is approximately twice the WHO guideline of 10 $\mu\text{g}/\text{m}^3$. According to the WHO, a PM2.5 concentration of 10 $\mu\text{g}/\text{m}^3$ is associated with an **8% increase in long-term mortality**. Therefore, the air quality in Irbid constitutes a significant health risk for the residents, though the map shows slight variations between neighborhoods. In the period from 1990 to 2019, pollution from PM2.5 concentration has exacerbated very slightly, increasing by **1-2 $\mu\text{g}/\text{m}^3$** . The average increase across the city is **1.1 $\mu\text{g}/\text{m}^3$** . As climate change potentially reduces rainfall, PM2.5 particles could linger in the air longer and worsen the pollution.



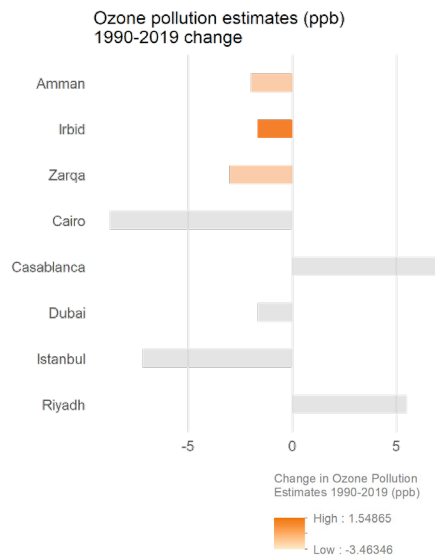
Air Pollution: Ozone

Ground-level ozone is linked to health issues such as aggravated lung diseases and asthma attacks, especially on hot sunny days when ozone can reach unhealthy levels. Even relatively low levels of ozone can cause health problems.

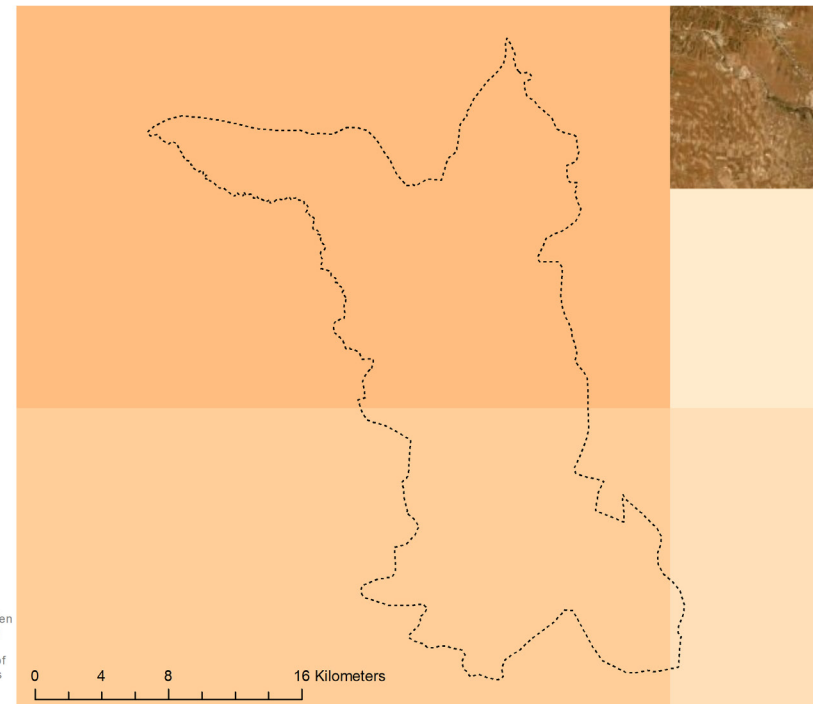
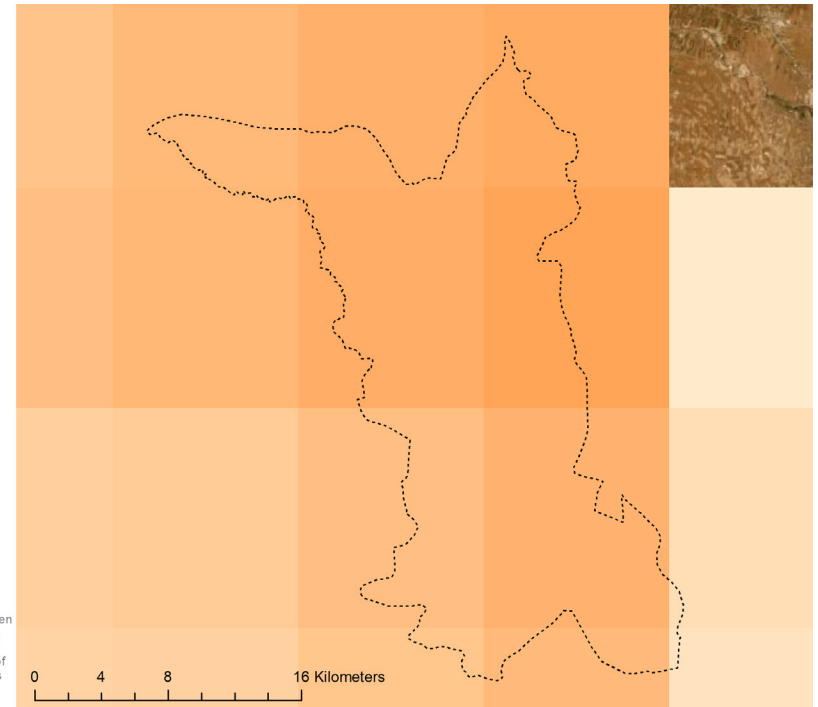
In terms of ozone pollution, the average ozone level in Irbid is **56 parts per billion (ppb)**, about the same as in Amman, and below the US EPA standard of 70 ppb. Since 1990, the ozone pollution in Irbid has decreased by **2 ppb**.



Source: Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Air Pollution Exposure Estimates 1990-2019. Seattle, United States of America: Institute for Health Metrics and Evaluation (IHME), 2021.

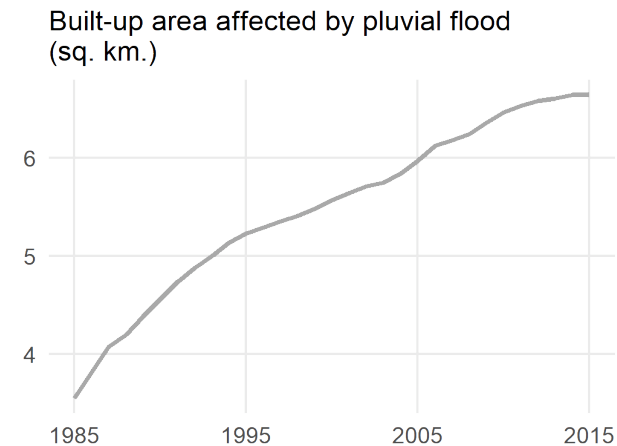


Source: Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Air Pollution Exposure Estimates 1990-2019. Seattle, United States of America: Institute for Health Metrics and Evaluation (IHME), 2021.



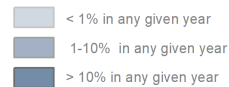
Pluvial Flooding with Built-up Area

In Irbid, pluvial flooding caused by precipitation jeopardizes around 7% of the settlement area as of 2015. Potential pluvial flood zones spread across different areas of the city and affect old and new settlements alike. From 1985 to 2015, the settlement areas exposed to pluvial flooding grew from **3.5** to **6.6** square kilometers, an average annual rate of **2.9%** and an **87%** increase in total, **17** percentage points higher than the overall settlement growth rate.

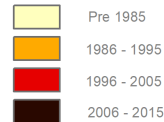


Built-up Area Affected in Rainwater Flood Risk Zone

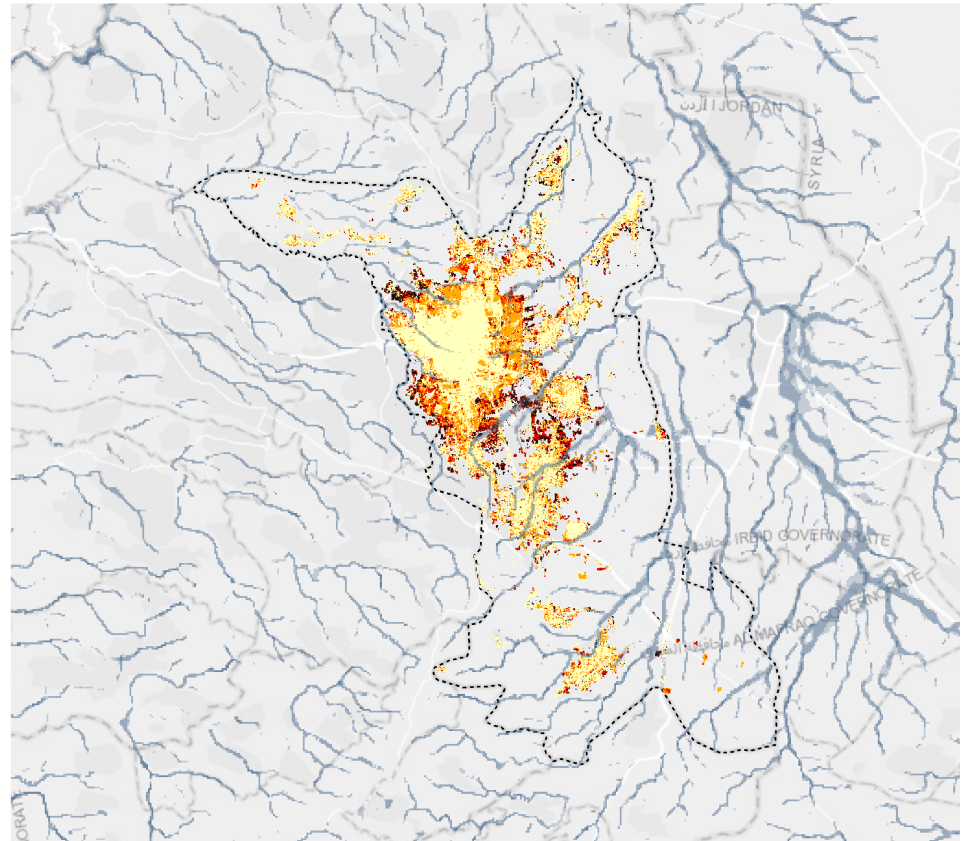
Rainwater Flood Probability



Date Built

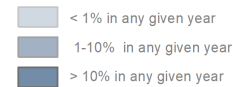


Source: World Settlement Footprint Landsat 5/7"; SSBN 3 arc second (90 m) Global Hazard Data (World Bank License)

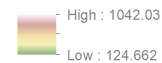


Rainwater Flood Risk Zone Overlay on Elevation

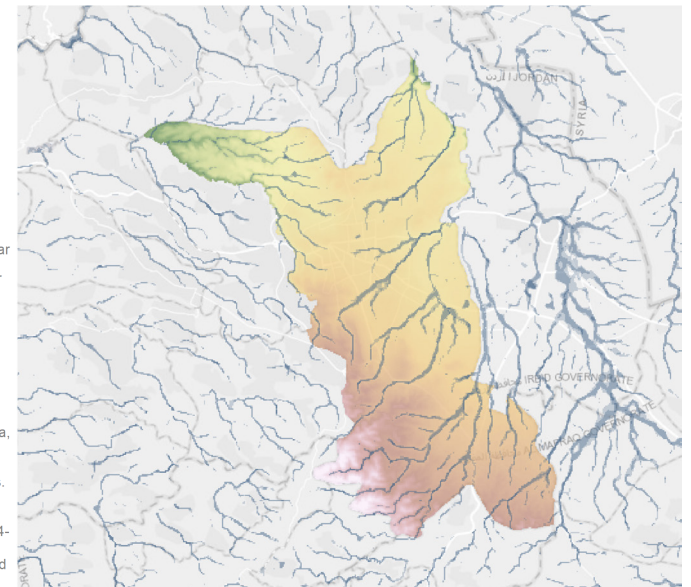
Rainwater Flood Probability



Elevation (m)



Source: Yamazaki D., D. Ikeshima, R. Tawatari, T. Yamaguchi, F. O'Loughlin, J.C. Neal, C.C. Sampson, S. Kanai & P.D. Bates. A high accuracy map of global terrain elevations. Geophysical Research Letters, vol.44, pp.5844-5853, 2017; SSBN 3 arc second (90 m) Global Hazard Data (World Bank License)



Pluvial Flooding with Population

In Irbid, **4%** of the densest settlement areas (at least 52 persons per 100 square meters, or the two densest bins on the map) are exposed to pluvial flooding. People are particularly sensitive to flooding in cases where population density is high, zoning regulations are absent or not enforced, flood controls are weak, and emergency response infrastructure and early warning systems are lacking. One consequence of increased population density in cities is an increase in impermeable surfaces, which leads to an increase in stormwater runoff. When populations are exposed, vulnerable, dense, and ill-prepared, the effects of climate change on them are exacerbated along with the increased intensity and frequency of harmful flood events.

Population Affected
in Rainwater Flood
Risk Zone

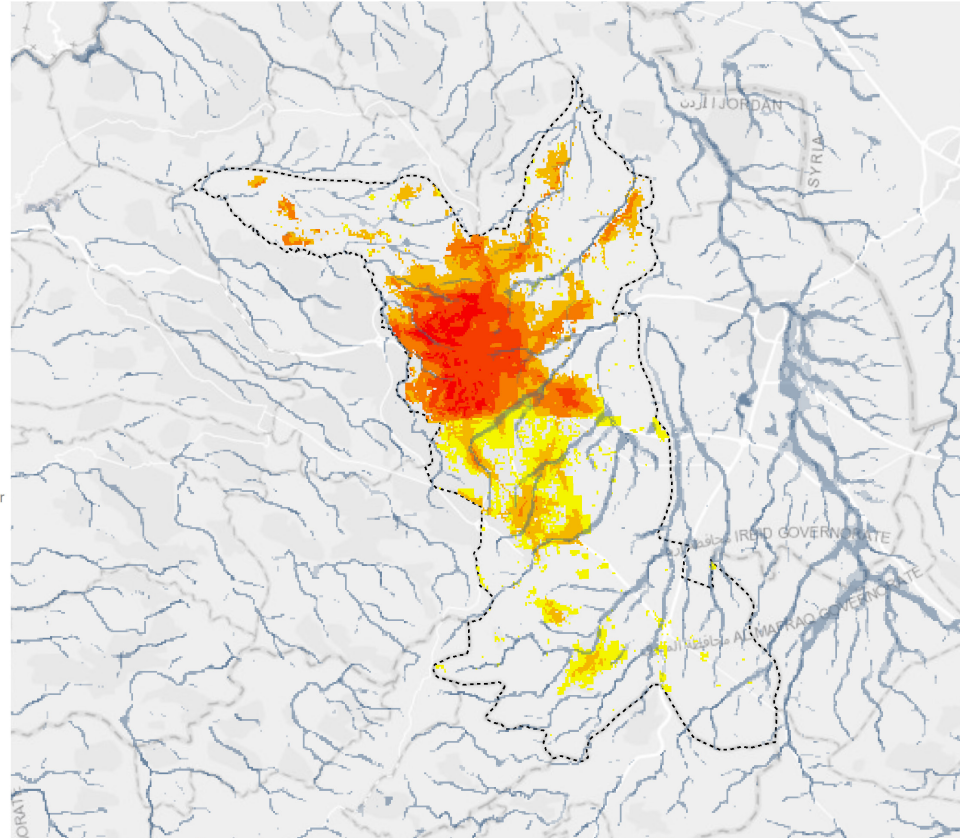
Rainwater
Flood Probability

< 1% in any given year
1-10% in any given year
> 10% in any given year

Number of persons
per 100 sq. m.

13 - 28
29 - 38
39 - 51
52 - 65
66 - 79

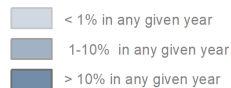
Source: WorldPop
<https://www.worldpop.org/>;
SSBN 3 arc second (90 m)
Global Hazard Data (World
Bank License)



Pluvial Flooding with Built-up Projections

Irbid's settlements are projected to further expand into places facing current flood risks by 2050. Under SSP1 and SSP5, the area of at-risk settlements will reach **7.9** and **8.7** square kilometers by 2050, respectively. Compared to the urban growth pattern in the 31-year period between 1985 and 2015, the projections predict slower expansion of built-up area into flood hazard zones in the future. However, this analysis assumes a flood hazard unchanged from the present one; climate change and urban development may increase the future exposure of land and built-up area to flooding further.

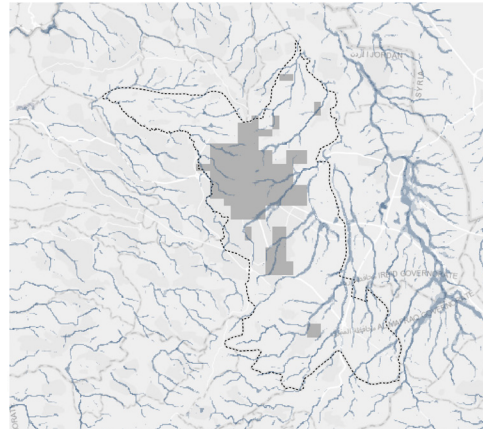
Rainwater
Flood Probability



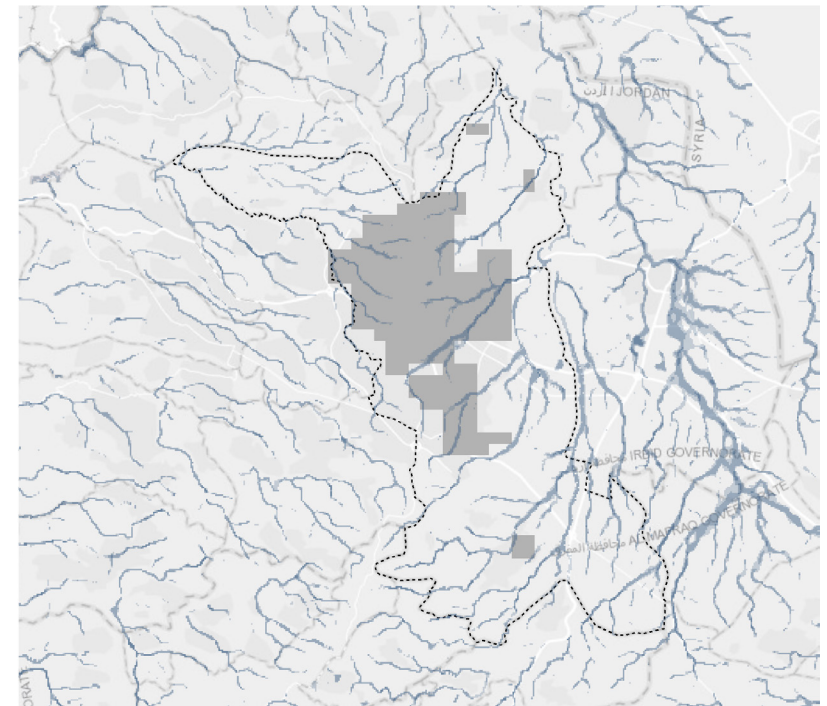
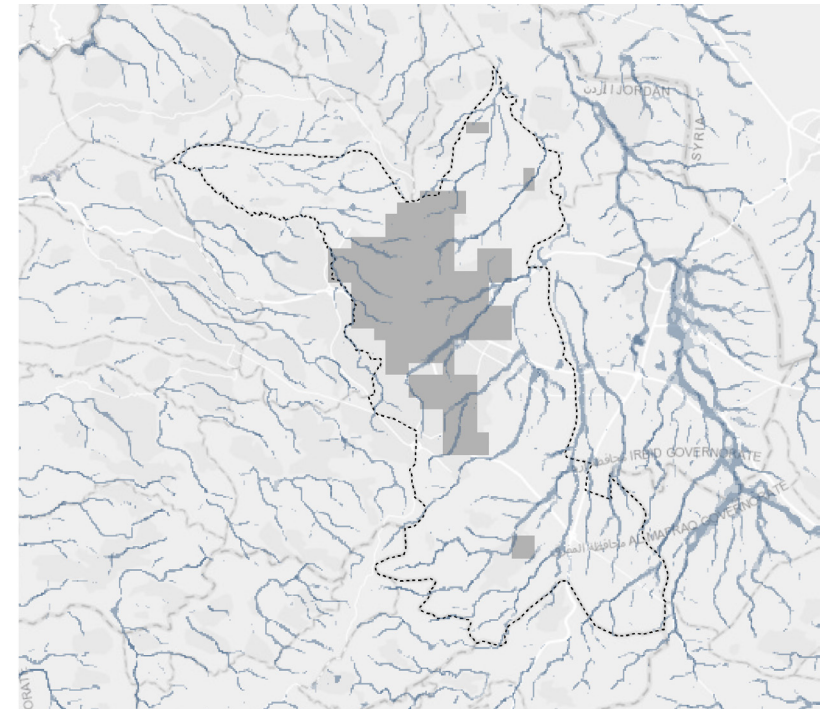
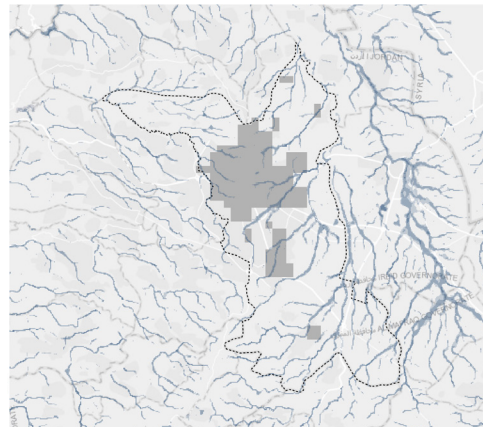
Projected built-up area

Source: SSBN 3 arc second (90 m) Global Hazard Data (World Bank License); Chen, G., Li, X., Liu, X. et al. "Global projections of future urban land expansion under shared socioeconomic pathways." Nat Commun 11, 537 (2020). <https://doi.org/10.1038/s41467-020-14386-x>

SSP1
2030 (bottom) and
2050 (right)

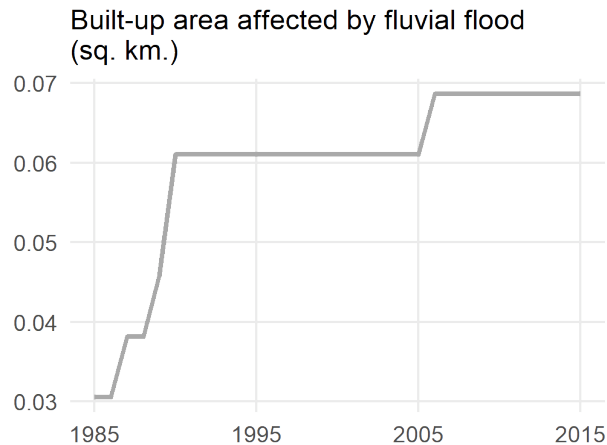


SSP5
2030 (bottom) and
2050 (right)



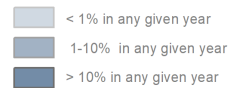
Fluvial Flooding with Built-up Area

Fluvial flooding is not a source of concern in Irbid. The potential fluvial flood zone is very limited and only affects a small area (**0.07 square kilometer**) in the eastern edge of the current settlements. The change in this figure from 1985 to 2015 has been miniscule.

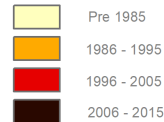


Built-up Area Affected in River Flood Risk Zone

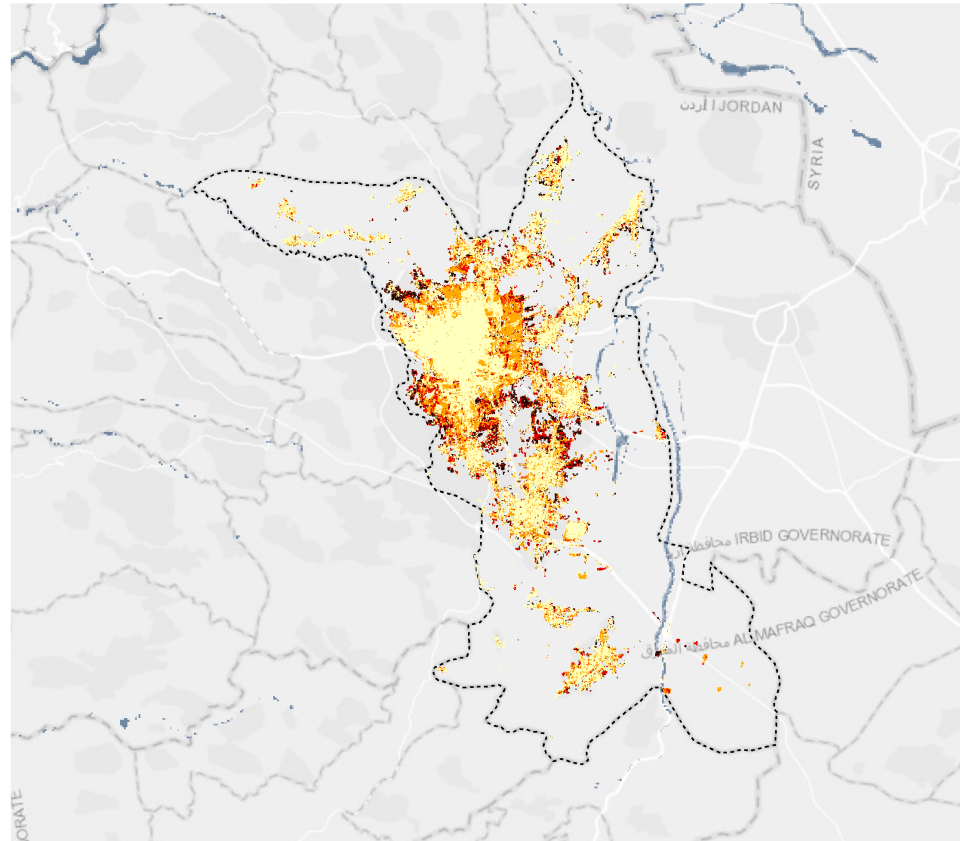
River Flood Probability



Date Built

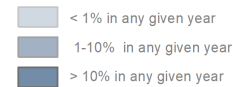


Source: World Settlement Footprint Landsat 5/7"; SSBN 3 arc second (90 m) Global Hazard Data (World Bank License)

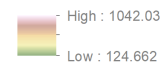


River Flood Risk Zone Overlay on Elevation

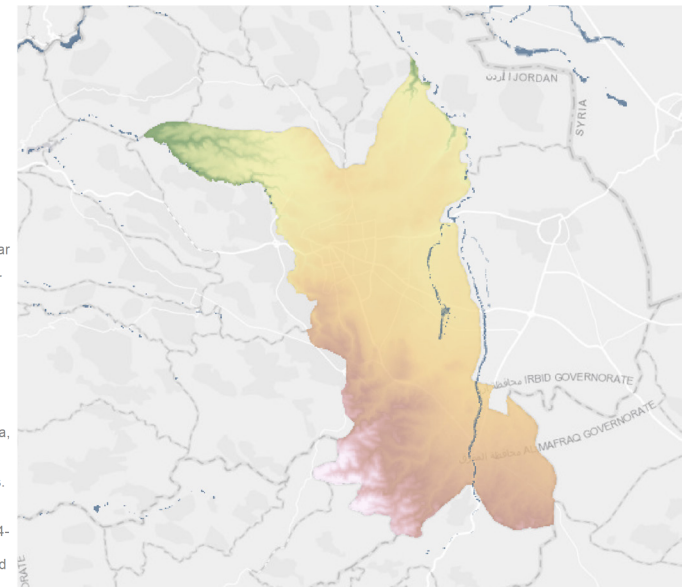
River Flood Probability



Elevation (m)



Source: Yamazaki D., D. Ikeshima, R. Tawatari, T. Yamaguchi, F. O'Loughlin, J.C. Neal, C.C. Sampson, S. Kanai & P.D. Bates. A high accuracy map of global terrain elevations. Geophysical Research Letters, vol.44, pp.5844-5853, 2017; SSBN 3 arc second (90 m) Global Hazard Data (World Bank License)



Fluvial Flooding with Population

Similarly, none of the densest settlements in Irbid are exposed to potential fluvial flooding.

Population Affected
in River Flood
Risk Zone

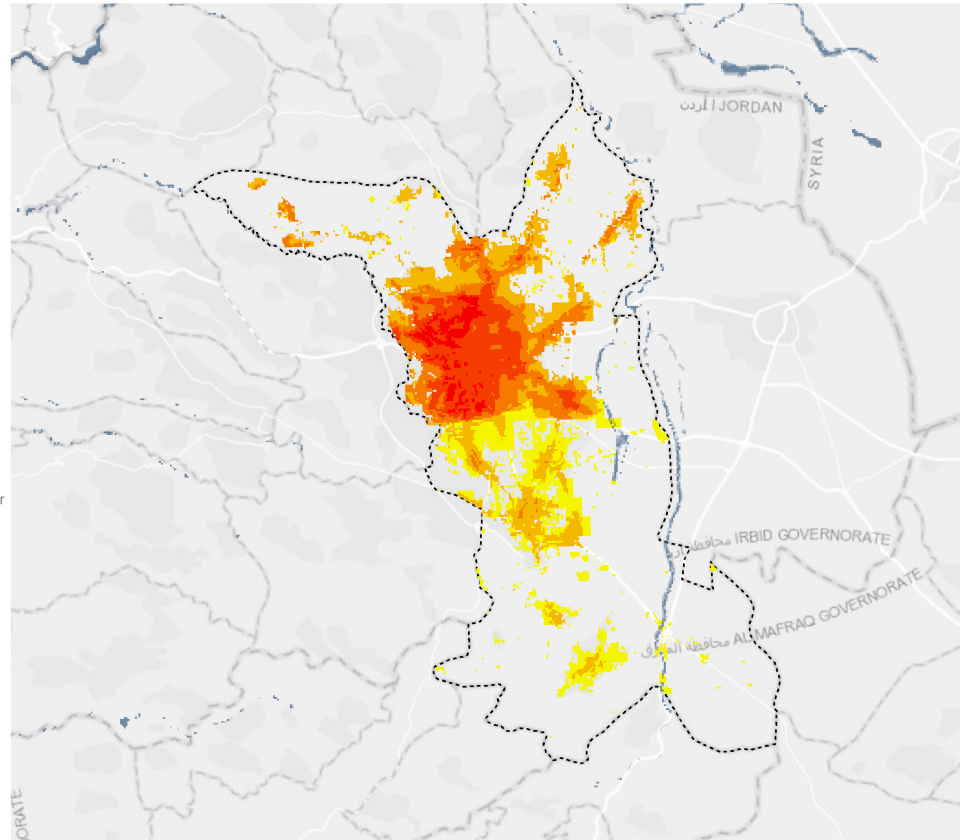
River
Flood Probability

< 1% in any given year
1-10% in any given year
> 10% in any given year

Number of persons
per 100 sq. m.

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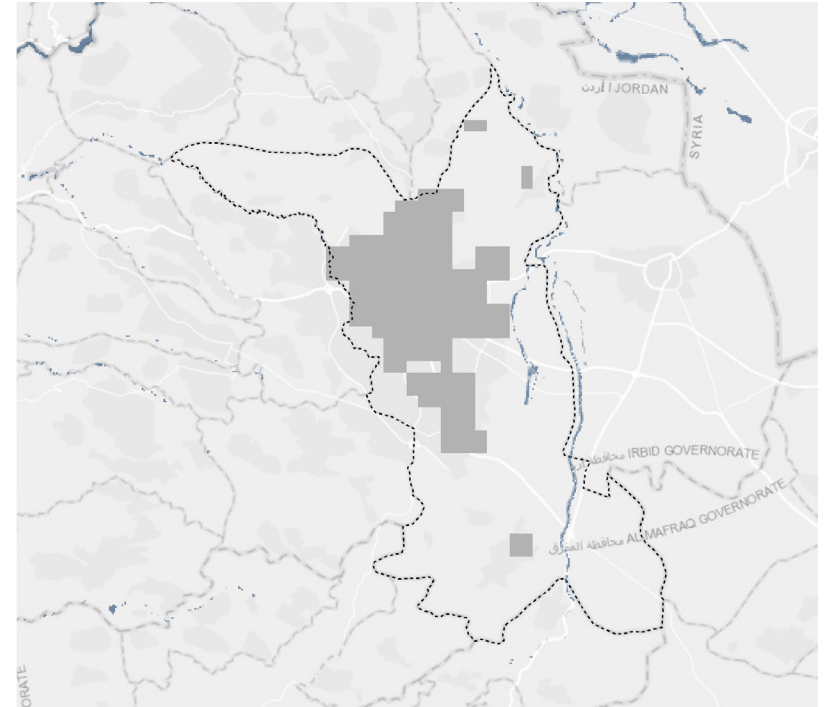
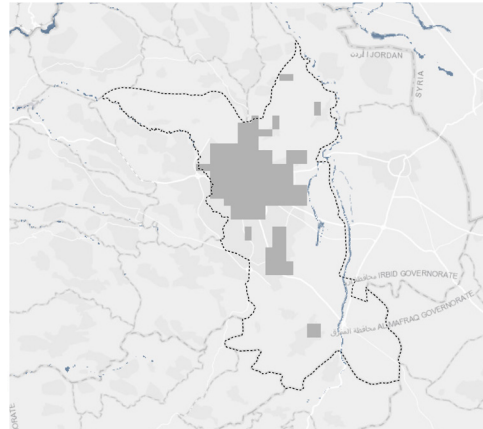
Source: WorldPop
<https://www.worldpop.org/>;
SSBN 3 arc second (90 m)
Global Hazard Data (World
Bank License)



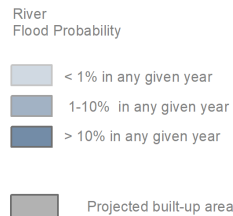
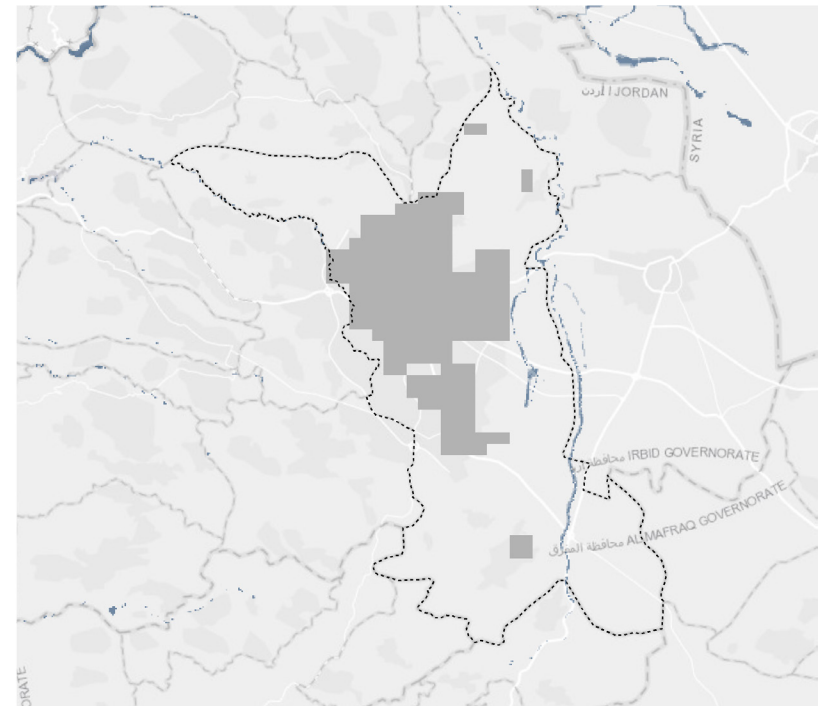
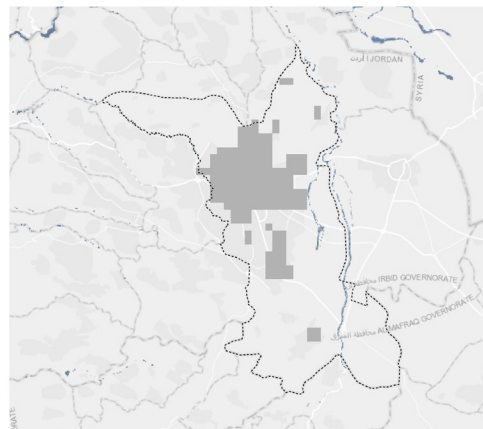
Fluvial Flooding with Built-up Projections

Even in future projections, the area of settlements at risk of fluvial flooding is expected to remain **close to 0** by 2050, under both SSP1 and SSP5.

SSP1
2030 (bottom) and
2050 (right)



SSP5
2030 (bottom) and
2050 (right)

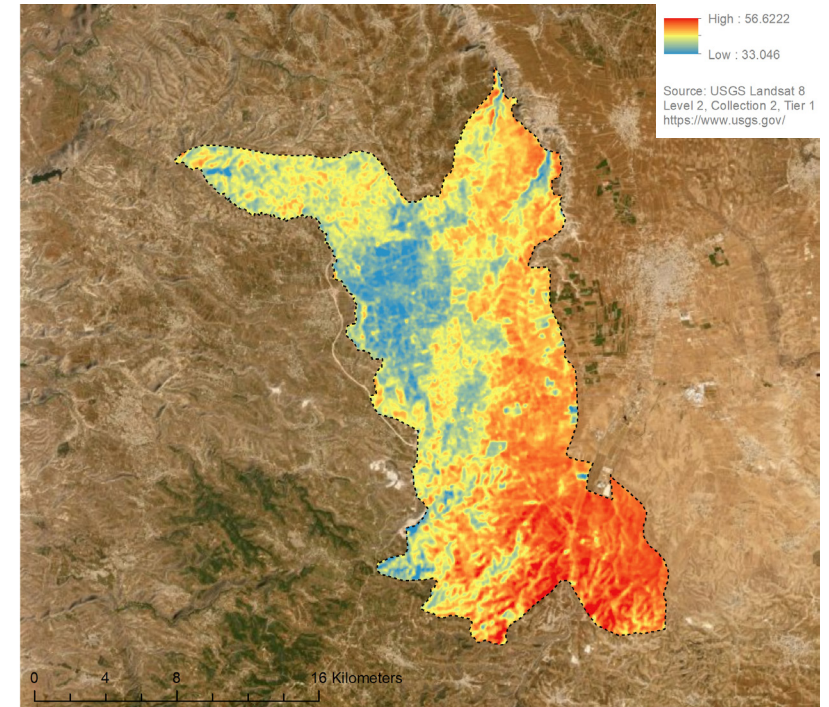
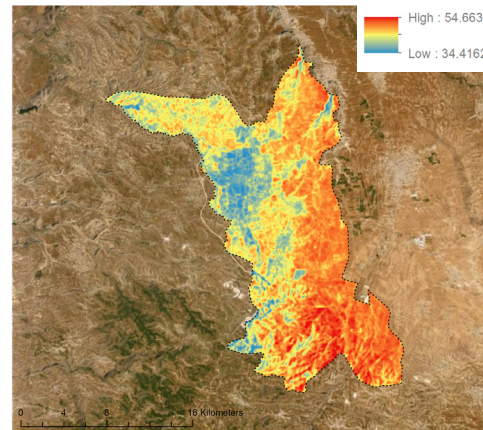


Source: SSBN 3 arc second (90 m) Global Hazard Data (World Bank License); Chen, G., Li, X., Liu, X. et al. "Global projections of future urban land expansion under shared socioeconomic pathways." Nat Commun 11, 537 (2020). <https://doi.org/10.1038/s41467-020-14386-x>

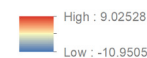
Urban Heat

In Irbid, the settled areas tend to be cooler than the rural outskirts, likely due to the desert landscape surrounding the city. Nevertheless, the average surface temperature in the urban center is still high, exceeding **33** degrees Celsius. Moreover, within a short time span of eight years, the average summer temperature of the entire city has gone up from **47.0** degrees in 2013 to **47.8** degrees in 2021, a **0.8**-degree difference. To complicate the matter further, the heat intensification is highly uneven. Southern Irbid has seen the most dramatic temperature increases of around **9** degrees, while the city center has either stayed roughly the same or become cooler. In eastern and central Irbid, there are even small pockets of drastic temperature decreases of up to **11** degrees, seemingly occurring in agricultural fields. This stark contrast clearly illustrates the close connection between land cover and surface temperature, offering an important lesson for land use planning and heat reduction.

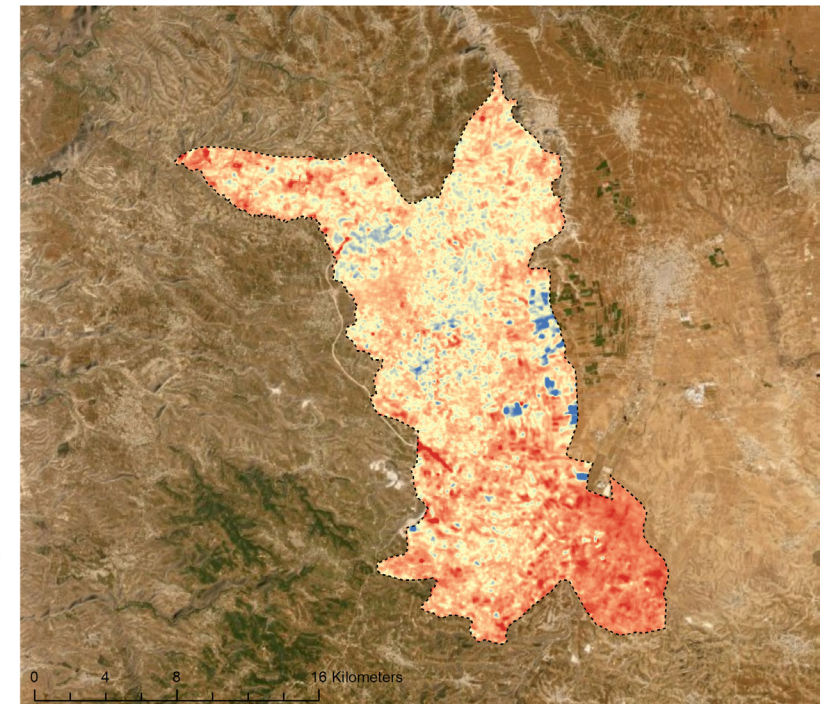
Average Summer Surface Temperature (°C)
2013 (bottom) and 2021 (right)



2013-2021 Summer Surface Temperature Change (°C)



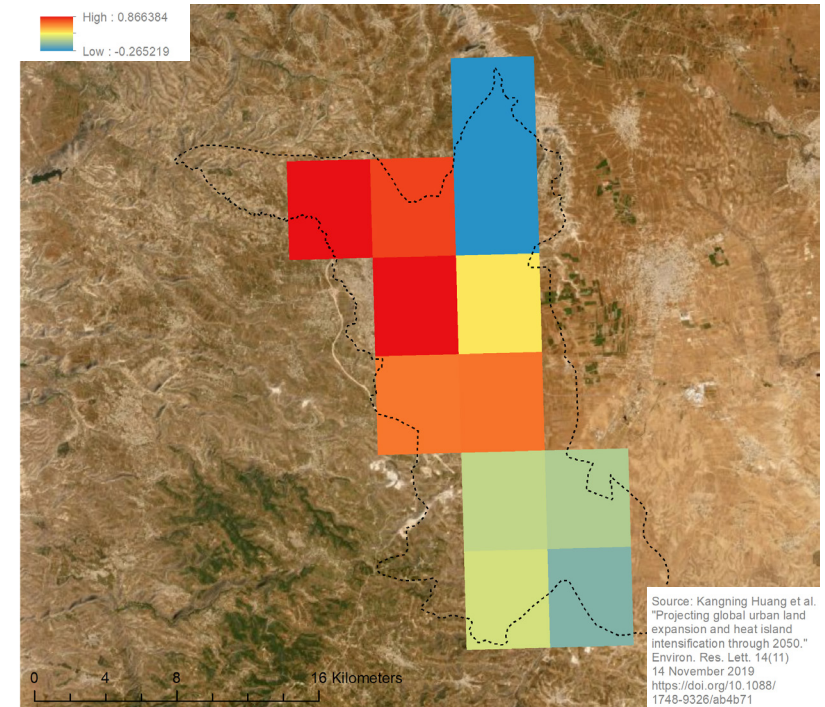
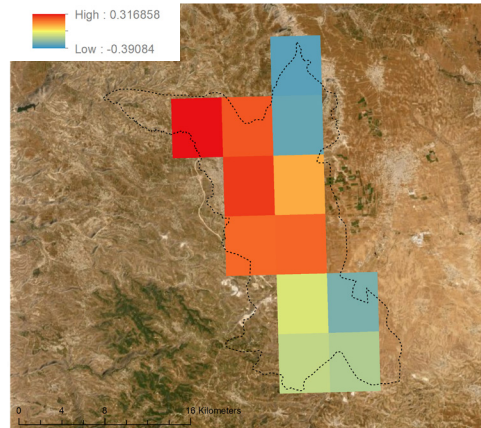
Source: USGS Landsat 8 Level 2, Collection 2, Tier 1
<https://www.usgs.gov/>



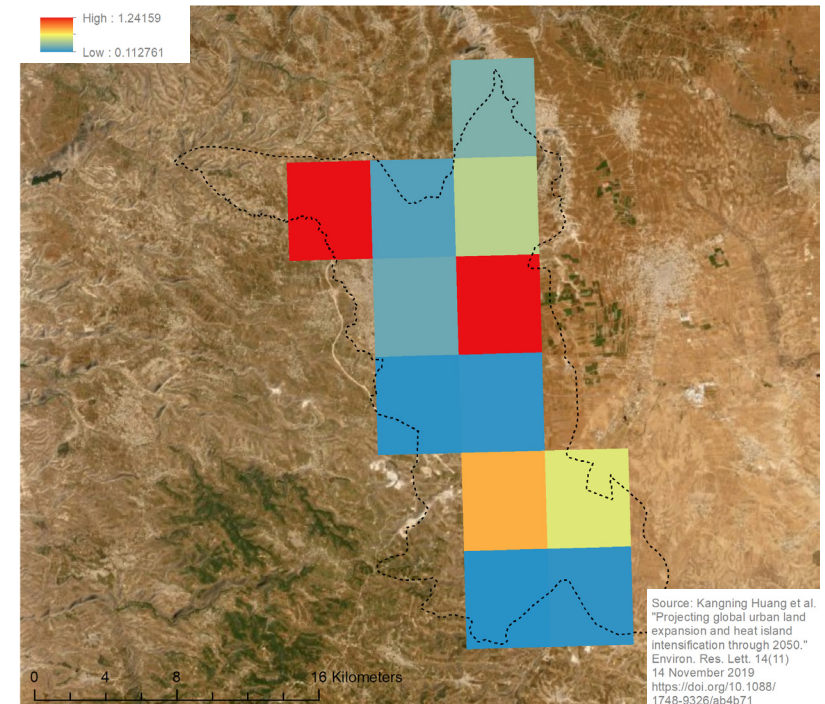
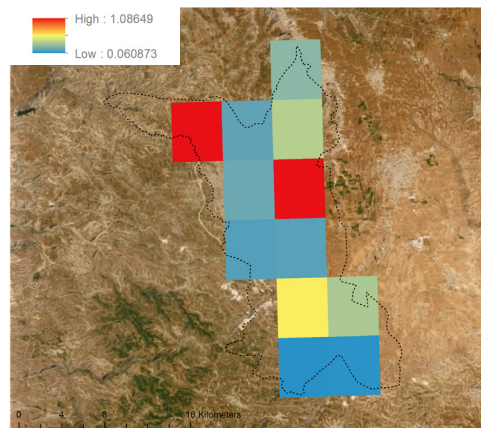
Urban Heat Projections

Given the close link between urban land cover and summer temperature, it is crucial to explore how continued urbanization will impact temperature in the future. Therefore, the projections here isolate the effects of urban land expansion on air temperature from other confounding factors. According to the projections, by 2050, settled areas of Irbid will see slight summer daytime temperature rises from urban land expansion of up to **0.3** degrees under SSP1 and up to **0.9** degrees under SSP5, whereas the more rural areas could expect small drops in temperature. Nighttime temperature change is more dramatic, though urban areas are not necessarily the most strongly affected. Places with **1-degree** nighttime temperature rise due to urban land expansion are located near the borders of Irbid, while the urban center is projected to experience mild warming.

Projected Change in Summer Daytime Air Temperatures Due to Urban Land Expansion under SSP1 (bottom) and SSP5 (right) (2050) (°C)



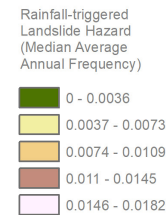
Projected Change in Summer Nighttime Air Temperatures Due to Urban Land Expansion under SSP1 (bottom) and SSP5 (right) (2050) (°C)



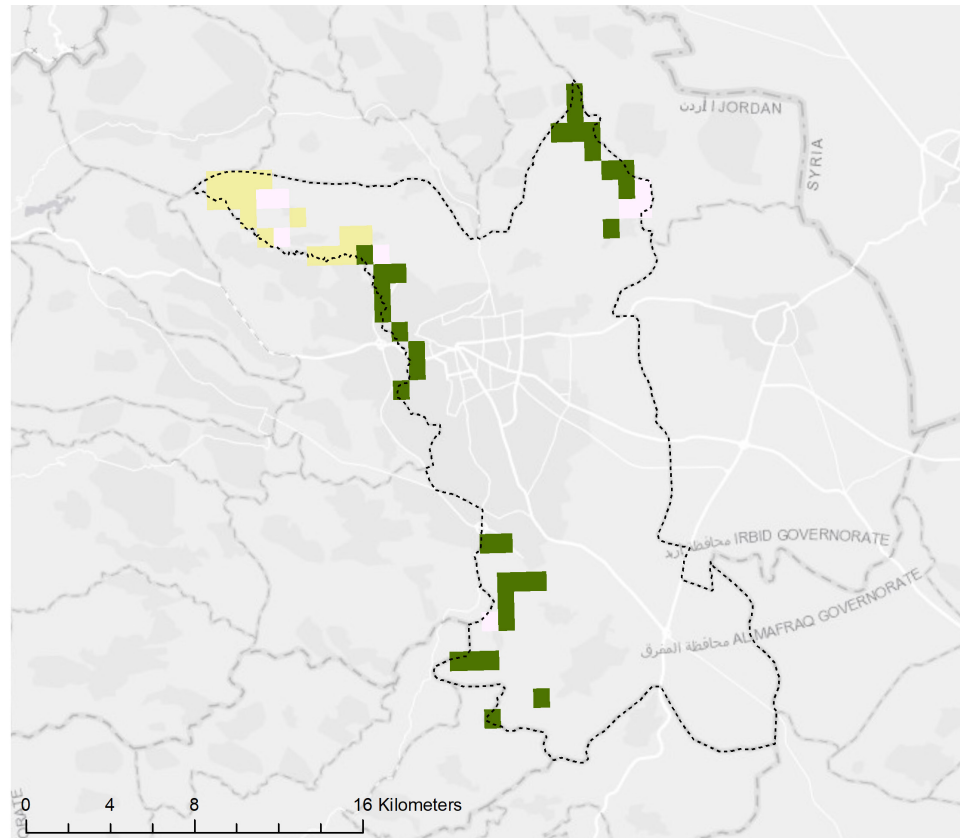
Landslide

Among the three cities, Irbid comes in second with regards to the level of rainfall-triggered landslide hazard. The risk level is very low. Across the whole city, the average value of the median annual frequency is just **0.0007**, roughly corresponding to a **1,500-year** return period. The landslide hazard is present in about **11%** of the city, mostly concentrated in the western and northeastern parts of Irbid.

With this Report's focus on climate change, the landslide analysis here examines rainfall-triggered landslides. The rainfall-triggered landslide hazard is measured by the median average annual frequency in a gridded format.



Data Source: Global Landslide
Hazard Map (1 km)
<https://datacatalog.worldbank.org/search/dataset/0037584/global-landslide-hazard-map>



CHAPTER 4

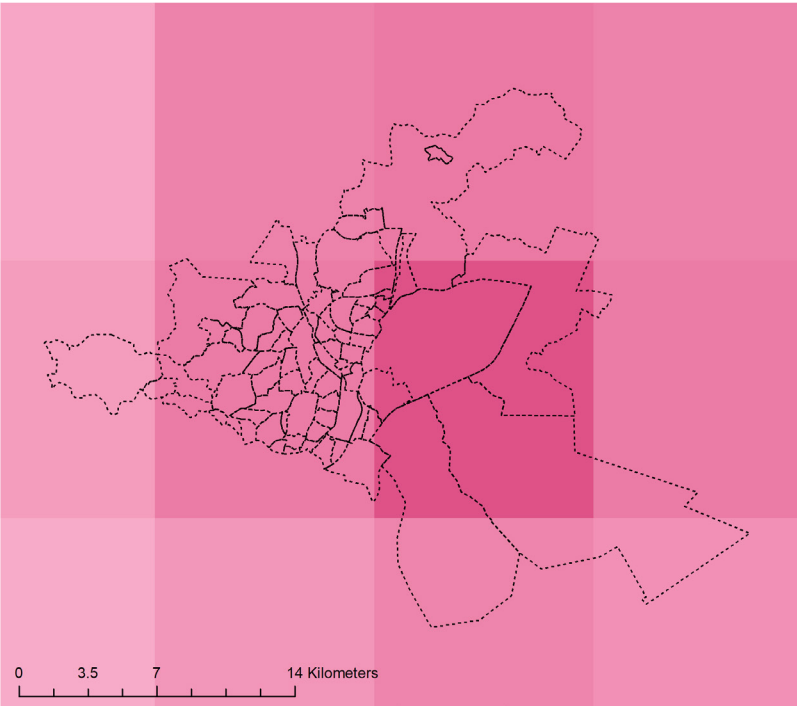
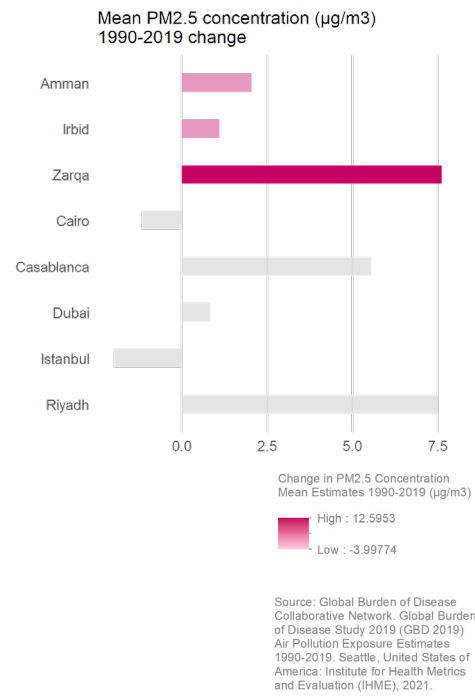
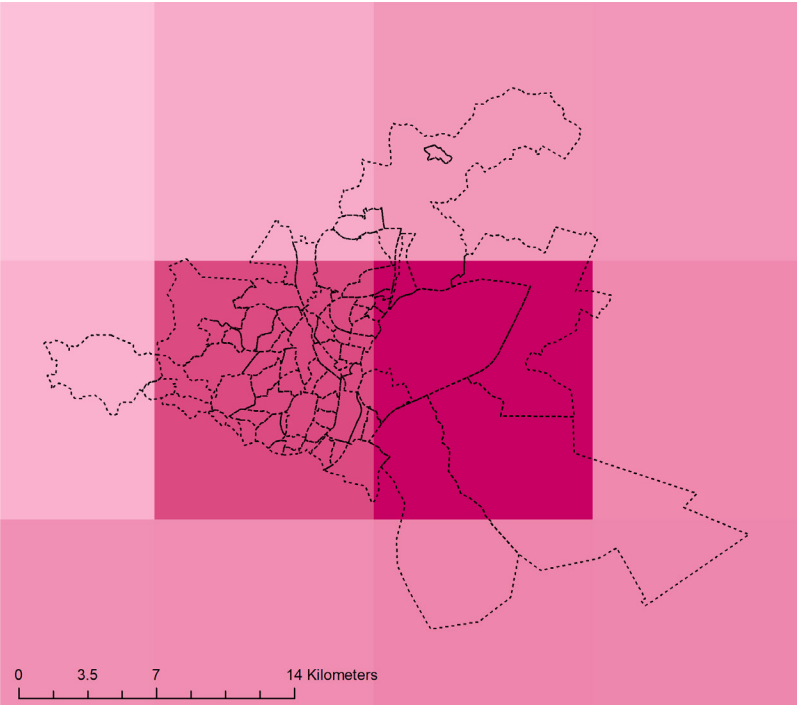
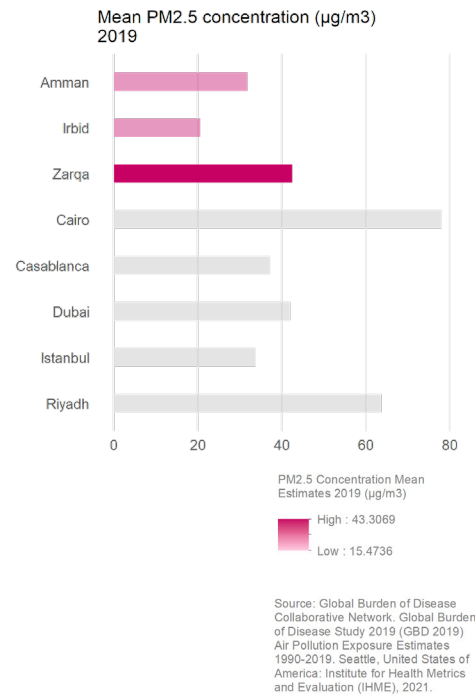
ZARQA

Zarqa, the capital of the Zarqa Governorate, shares its southwest border with Amman. With a population of 635,160 inhabitants in 2015, it is the most populous city in Jordan after Amman. Home to over 50% of Jordanian factories, it is also the country's industrial center, due to its low real estate costs and proximity to Amman. The Zarqa AOI has an area of **266** square kilometers, the smallest of the three. Settlements in Zarqa have nearly tripled in recent decades, growing from **19** square kilometers in 1985 to **54** in 2015.



Air Pollution: PM2.5

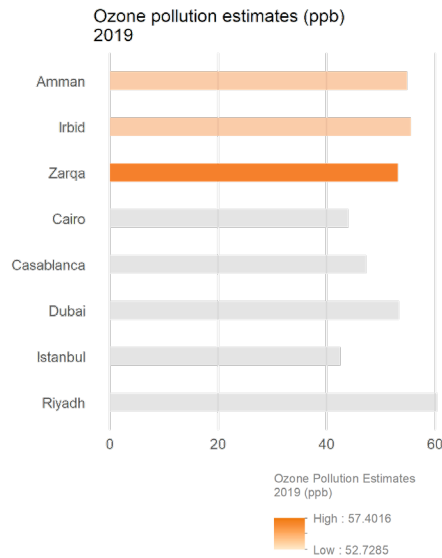
Zarqa suffers from the heaviest air pollution among the three Jordanian cities in this analysis. Judging by the PM2.5 concentration, Zarqa has a concentration of **43 µg/m3**, far outstripping the second place, Amman, by 11 µg/m3. Zarqa’s PM2.5 concentration surpasses the WHO standard by **330%**, which implies serious health risks to its residents. Furthermore, in the period from 1990 to 2019, pollution from PM2.5 concentration has exacerbated considerably, increasing by an average of **7.6 µg/m3**, or **22%**, across the city. As climate change potentially reduces rainfall, PM2.5 particles could linger in the air longer and worsen the pollution.



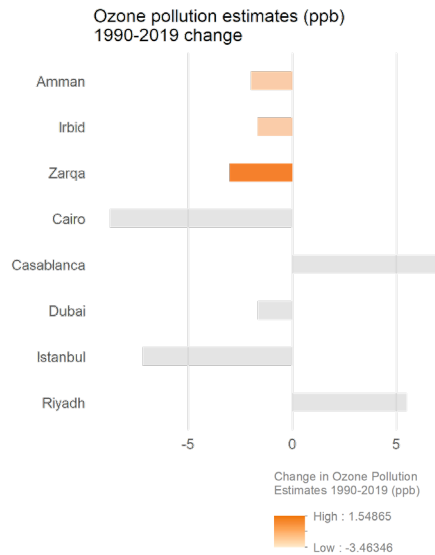
Air Pollution: Ozone

Ground-level ozone is linked to health issues such as aggravated lung diseases and asthma attacks, especially on hot sunny days when ozone can reach unhealthy levels. Even relatively low levels of ozone can cause health problems.

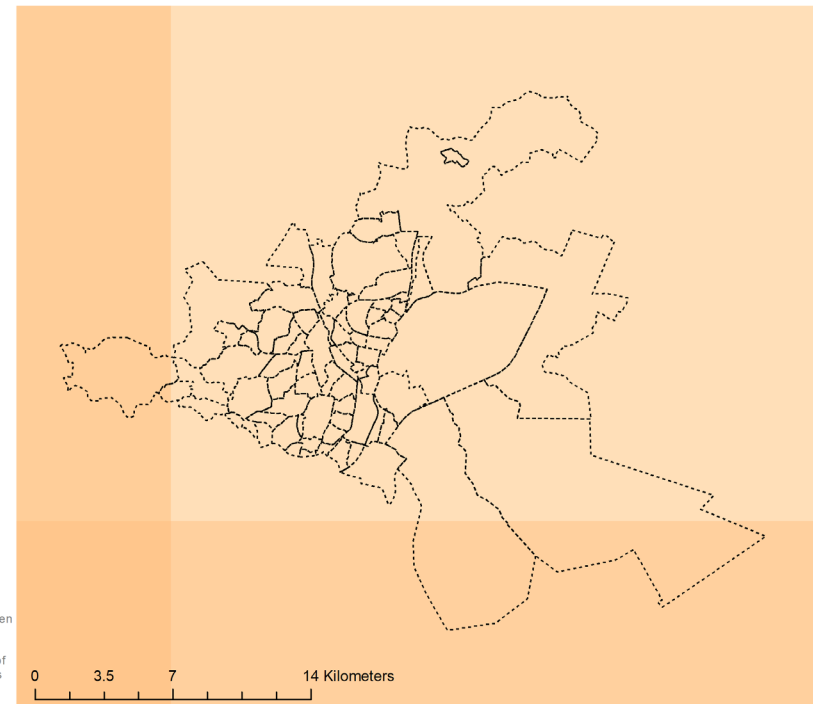
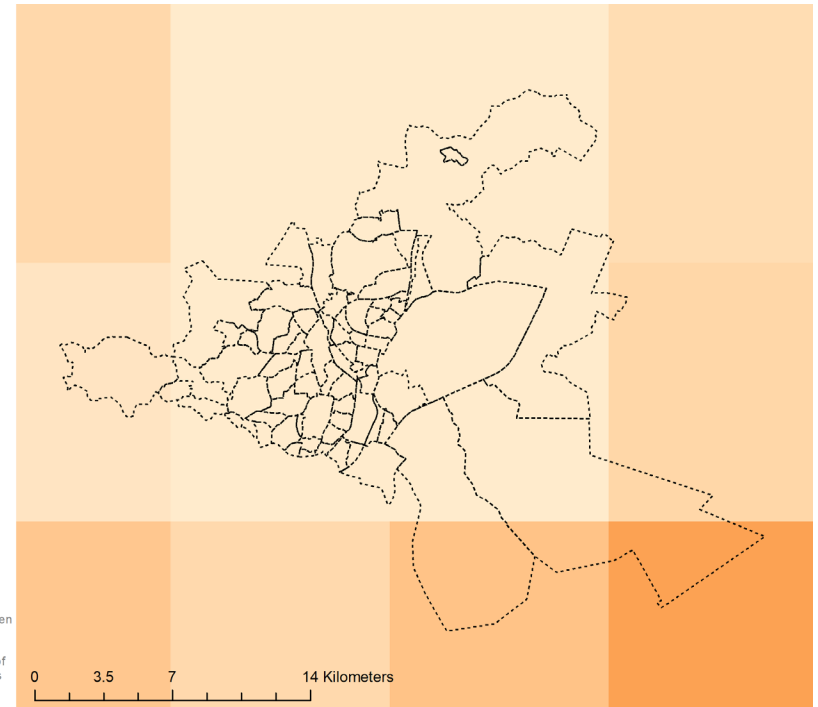
In terms of ozone pollution, the average ozone level in Zarqa is **53 parts per billion (ppb)**, about the same as the other two cities, and below the US EPA standard of 70 ppb. Since 1990, the ozone pollution in Zarqa has decreased by **3 ppb**.



Source: Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Air Pollution Exposure Estimates 1990-2019. Seattle, United States of America: Institute for Health Metrics and Evaluation (IHME), 2021.

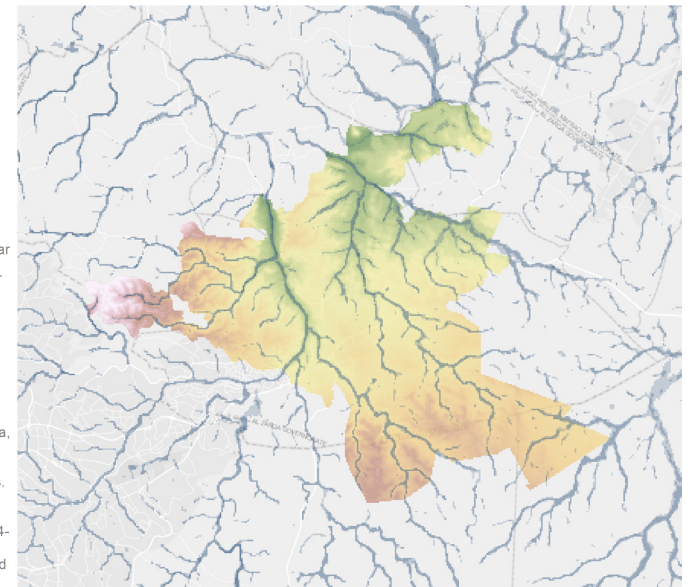
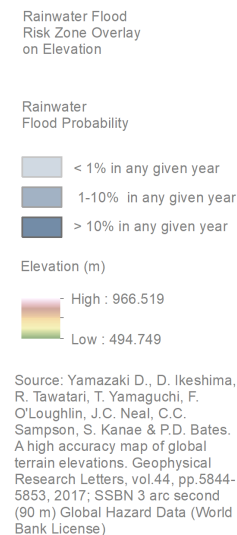
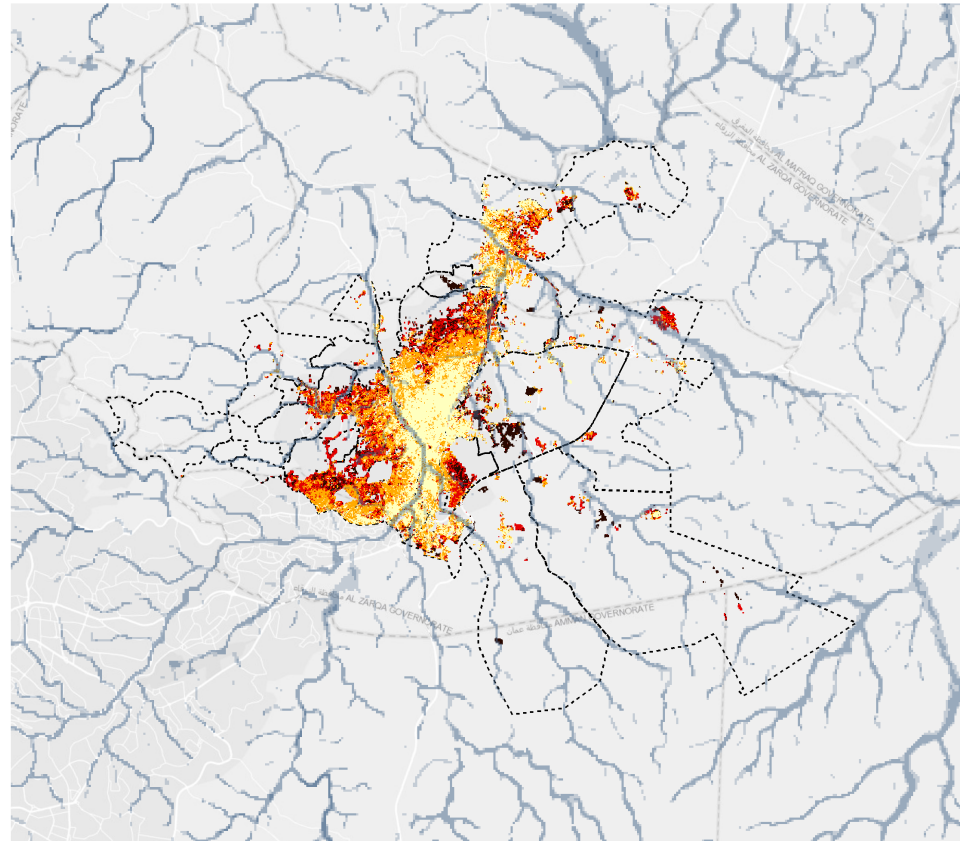
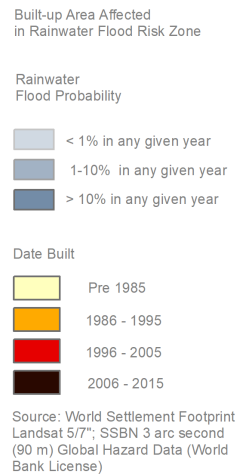
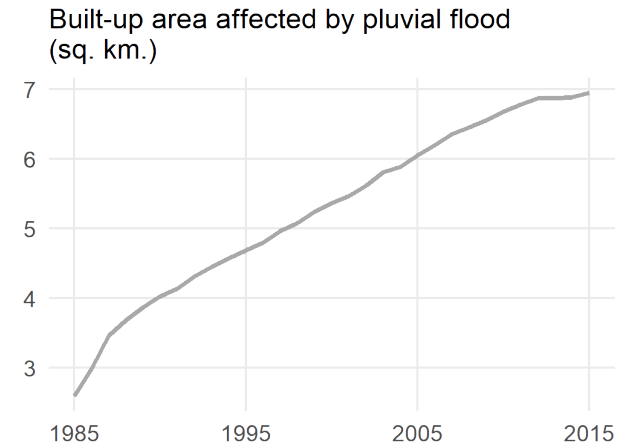


Source: Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Air Pollution Exposure Estimates 1990-2019. Seattle, United States of America: Institute for Health Metrics and Evaluation (IHME), 2021.



Pluvial Flooding with Built-up Area

In Zarqa, pluvial flooding caused by precipitation jeopardizes around 13% of the settlement area as of 2015. Potential pluvial flood zones spread across different areas of the city, but seem to have especially visible impacts on the older settlements near the city center. From 1985 to 2015, the settlement areas exposed to pluvial flooding grew from **2.6** to **6.9** square kilometers, an average annual rate of **5.6%** and a **168%** increase in total. While this figure may seem extraordinary, it is in fact still lower than the overall settlement growth rate of **190%**.



Pluvial Flooding with Population

In Zarqa, **6%** of the densest settlement areas (at least 77 persons per 100 square meters, or the two densest bins on the map) are exposed to pluvial flooding. People are particularly sensitive to flooding in cases where population density is high, zoning regulations are absent or not enforced, flood controls are weak, and emergency response infrastructure and early warning systems are lacking. One consequence of increased population density in cities is an increase in impermeable surfaces, which leads to an increase in stormwater runoff. When populations are exposed, vulnerable, dense, and ill-prepared, the effects of climate change on them are exacerbated along with the increased intensity and frequency of harmful flood events.

Population Affected in Rainwater Flood Risk Zone

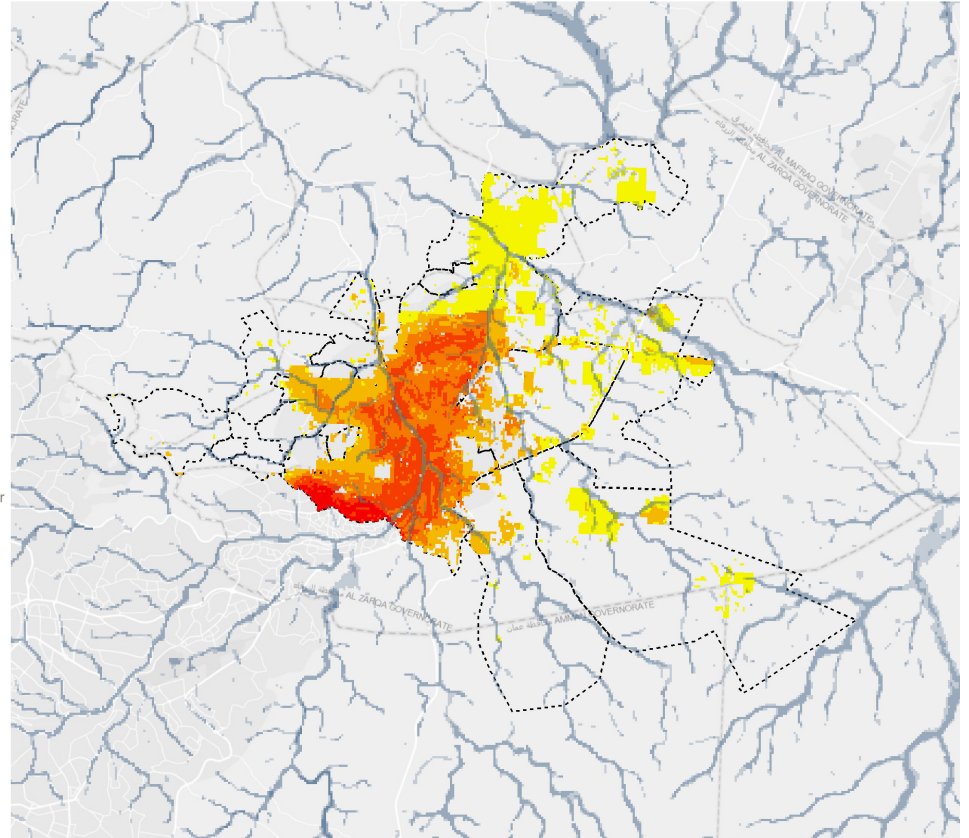
Rainwater Flood Probability

< 1% in any given year
1-10% in any given year
> 10% in any given year

Number of persons per 100 sq. m.

8 - 33
34 - 54
55 - 76
77 - 105
106 - 148

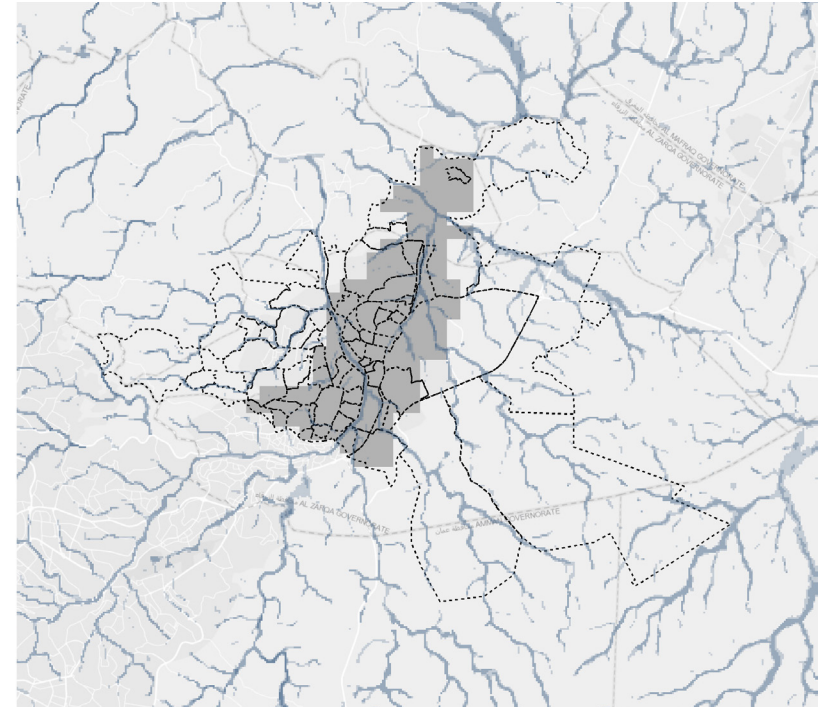
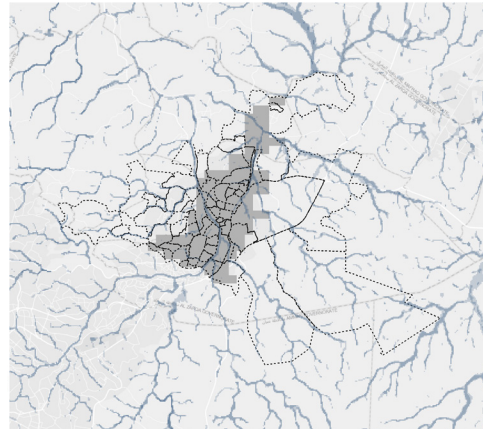
Source: WorldPop
<https://www.worldpop.org/>;
SSBN 3 arc second (90 m)
Global Hazard Data (World Bank License)



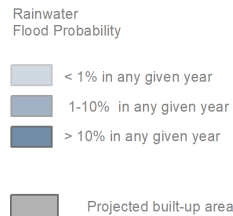
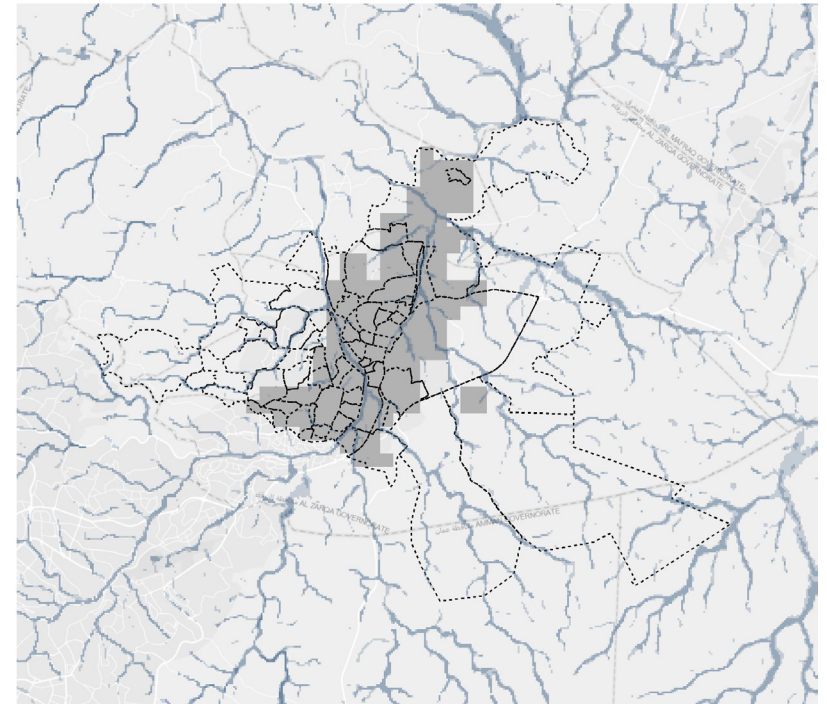
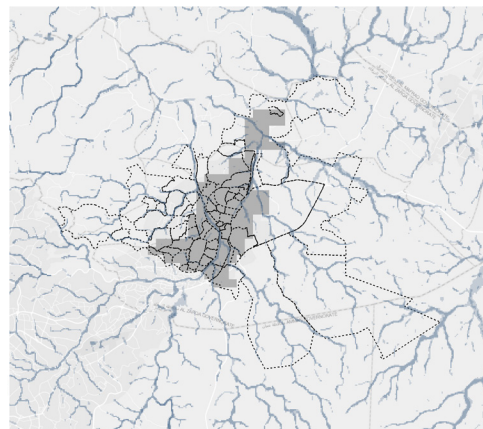
Pluvial Flooding with Built-up Projections

Zarqa's settlements are projected to further expand into places facing current flood risks by 2050. Under SSP1 and SSP5, the area of at-risk settlements will reach **7.7** and **8.1** square kilometers by 2050, respectively. Compared to the urban growth pattern in the 31-year period between 1985 and 2015, the projections predict slower expansion of built-up area into flood hazard zones in the future. However, this analysis assumes a flood hazard unchanged from the present one; climate change and urban development may increase the future exposure of land and built-up area to flooding further.

SSP1
2030 (bottom) and
2050 (right)



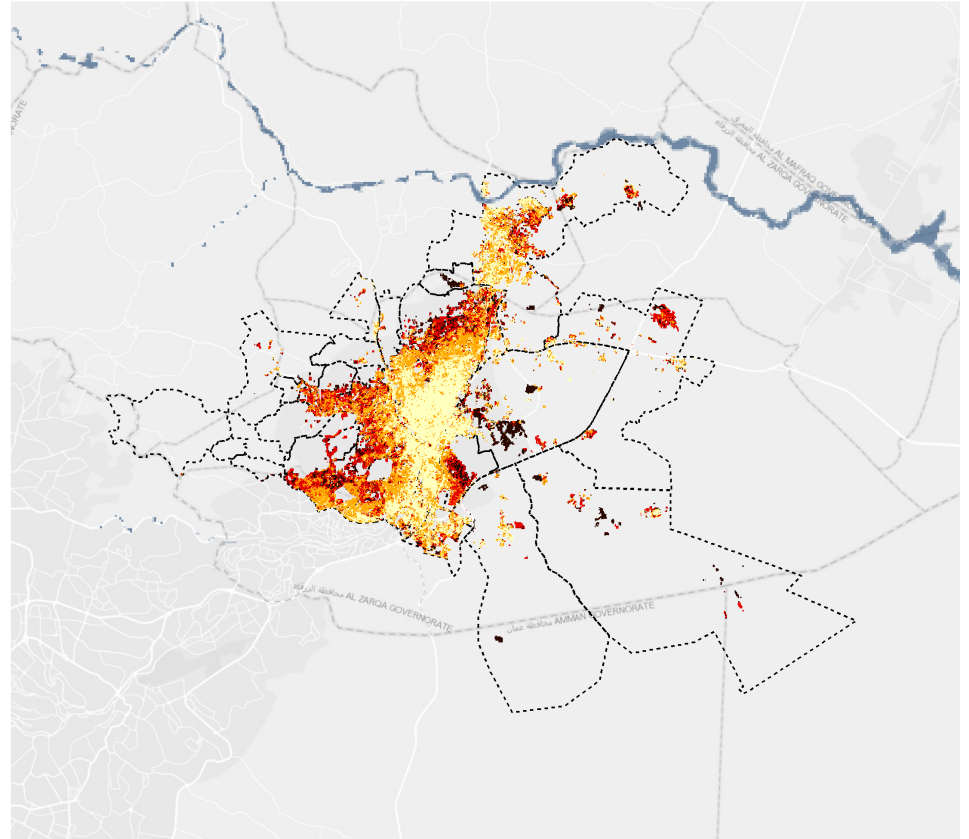
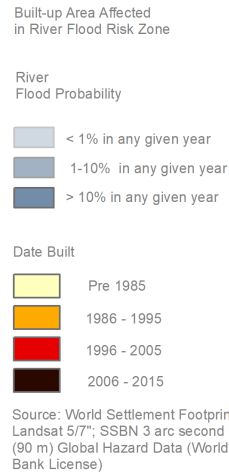
SSP5
2030 (bottom) and
2050 (right)



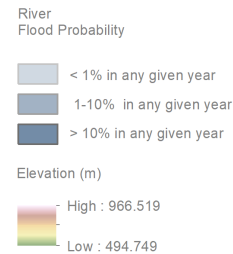
Source: SSBN 3 arc second (90 m) Global Hazard Data (World Bank License); Chen, G., Li, X., Liu, X. et al. "Global projections of future urban land expansion under shared socioeconomic pathways." *Nat Commun* 11, 537 (2020). <https://doi.org/10.1038/s41467-020-14386-x>

Fluvial Flooding with Built-up Area

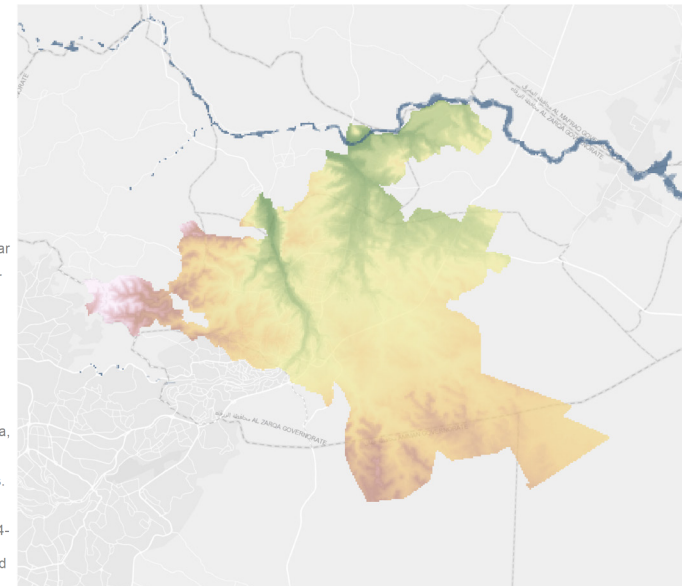
Fluvial flooding is not a source of concern in Zarqa. The potential fluvial flood zone does not show any overlap with existing settlements, including those on the banks of the Zarqa River.



River Flood Risk Zone Overlay on Elevation

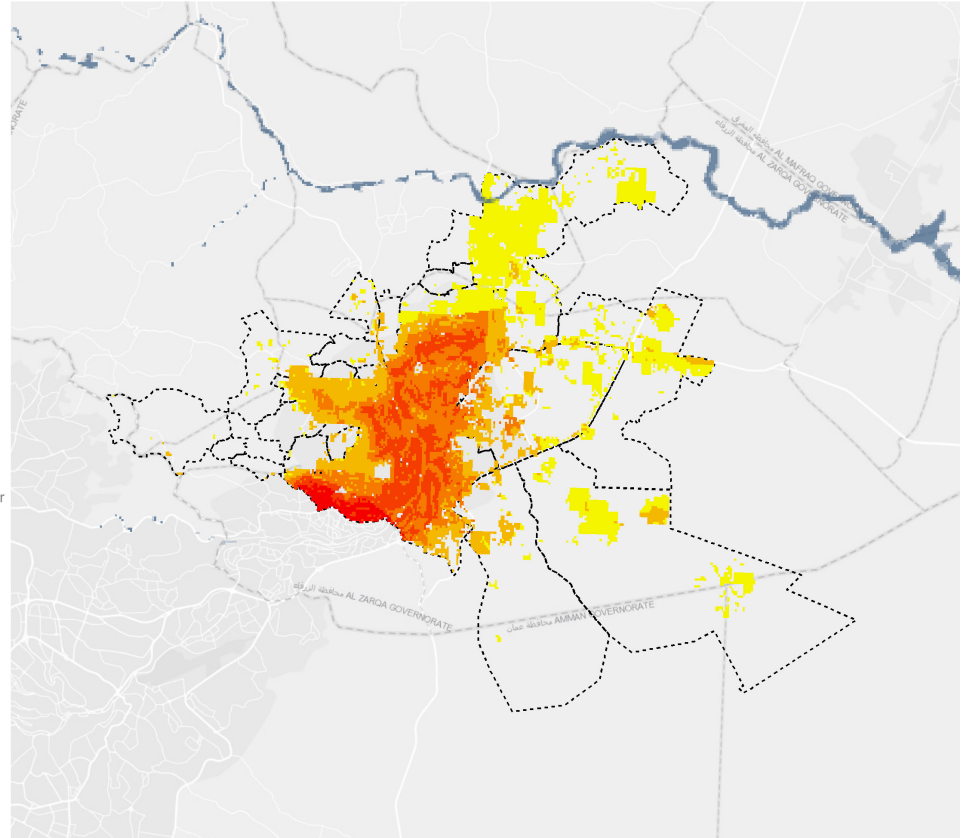
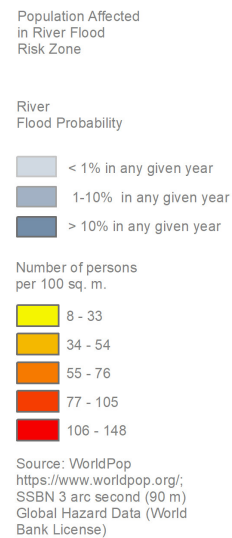


Source: Yamazaki D., D. Ikeshima, R. Tawatari, T. Yamaguchi, F. O'Loughlin, J.C. Neal, C.C. Sampson, S. Kanai & P.D. Bates. A high accuracy map of global terrain elevations. Geophysical Research Letters, vol.44, pp.5844-5853, 2017; SSBN 3 arc second (90 m) Global Hazard Data (World Bank License)



Fluvial Flooding with Population

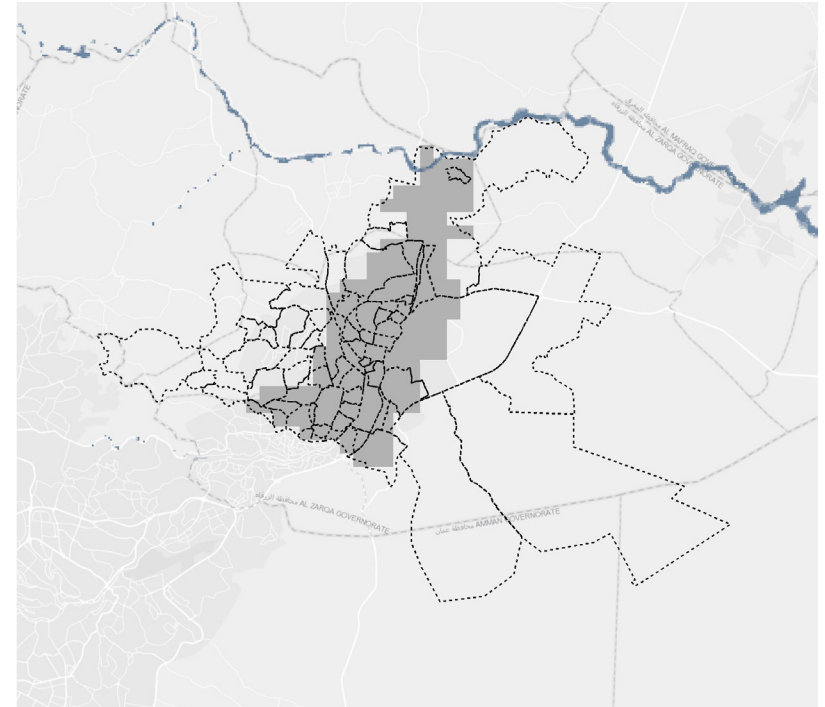
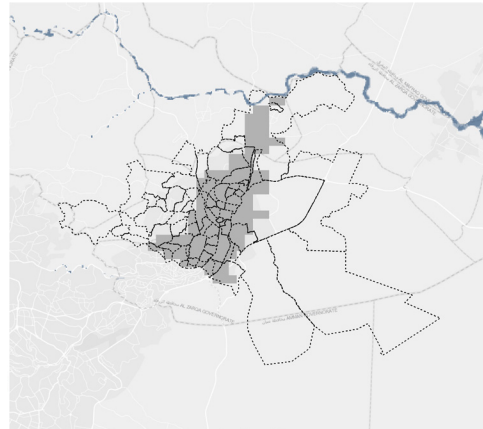
None of the densest settlements in Zarqa are exposed to potential fluvial flooding.



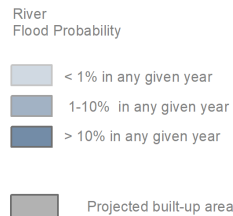
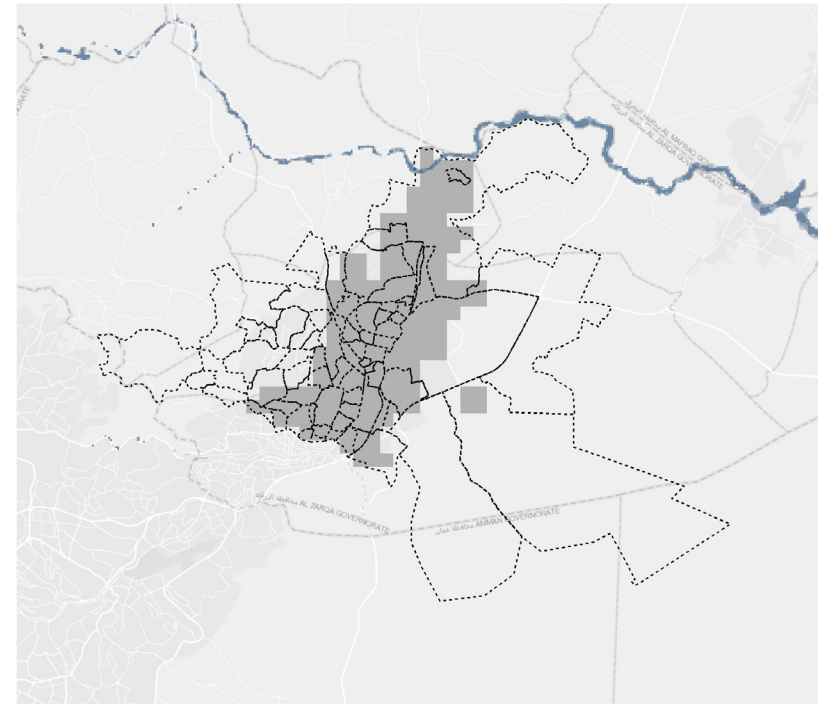
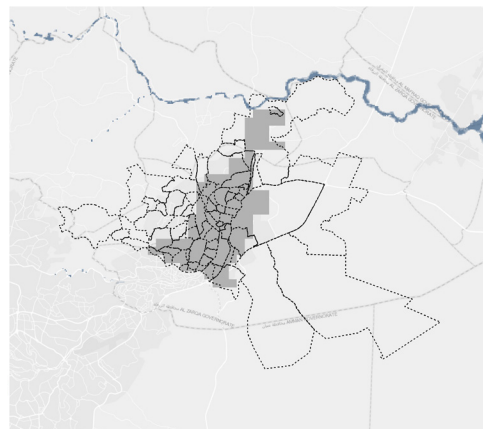
Fluvial Flooding with Built-up Projections

This safe condition is predicted to remain in following decades, at least until 2050, according to projections for both SSP1 and SSP5.

SSP1
2030 (bottom) and
2050 (right)



SSP5
2030 (bottom) and
2050 (right)

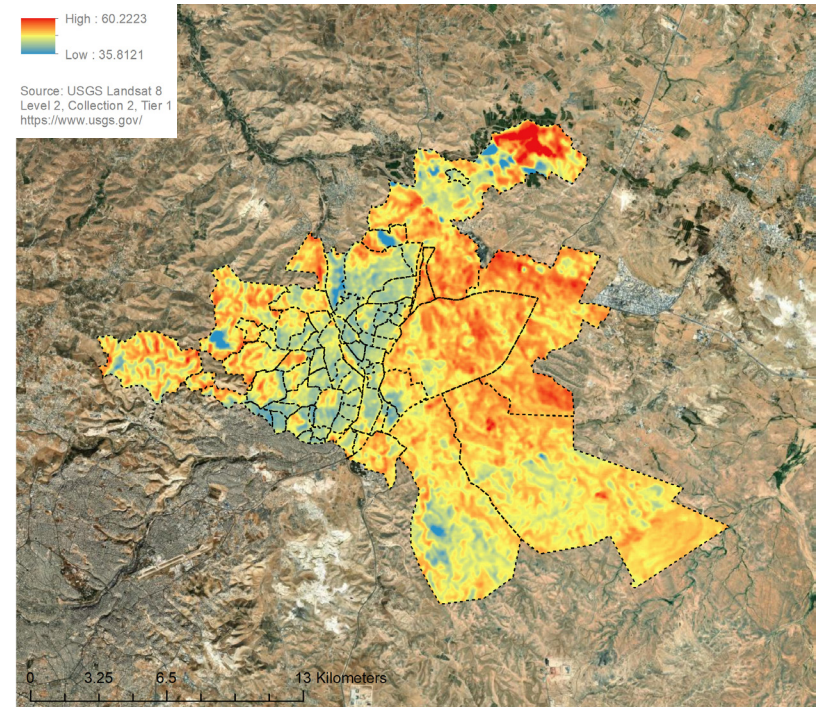
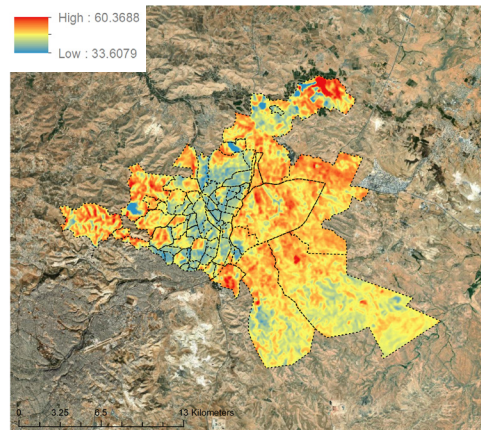


Source: SSBN 3 arc second (90 m) Global Hazard Data (World Bank License); Chen, G., Li, X., Liu, X. et al. "Global projections of future urban land expansion under shared socioeconomic pathways." Nat Commun 11, 537 (2020). <https://doi.org/10.1038/s41467-020-14386-x>

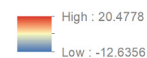
Urban Heat

In Zarqa, the settled areas tend to be cooler than the rural outskirts, likely due to the desert landscape surrounding the city. Nevertheless, the average surface temperature in the urban center is still high, exceeding **35** degrees Celsius. Moreover, within a short time span of eight years, the average summer temperature of the entire city has gone up from **46.4** degrees in 2013 to **49.4** degrees in 2021, a **3.0**-degree difference, the largest in the three cities. To complicate the matter further, the heat intensification is highly uneven. Eastern Zarqa has seen the most dramatic temperature increases, while the city center has experienced smaller increases of **2-3** degrees. Notably, a well-delineated area at the northern tip of the AOI has had its surface temperature rise by **10-20** degrees to almost **60** degrees since 2013, and an examination of satellite imagery reveals an expansion on a wastewater treatment plant that covered the land with asphalt. Given the high density of factories in Zarqa, it is critical to pay attention to the environmental externalities of industrial land uses, such as heat intensification.

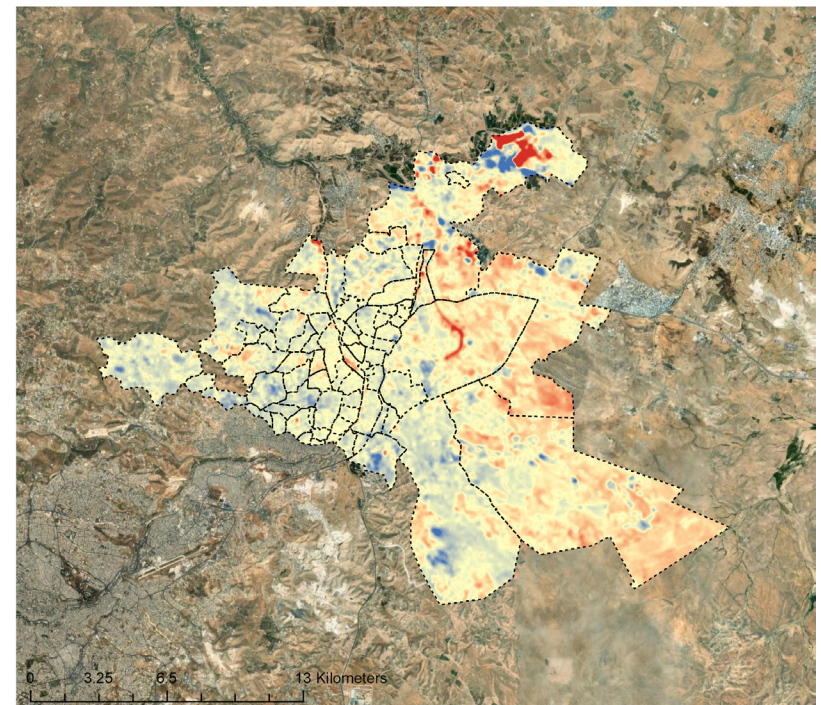
Average Summer Surface Temperature (°C)
2013 (bottom) and 2021 (right)



2013-2021 Summer Surface Temperature Change (°C)



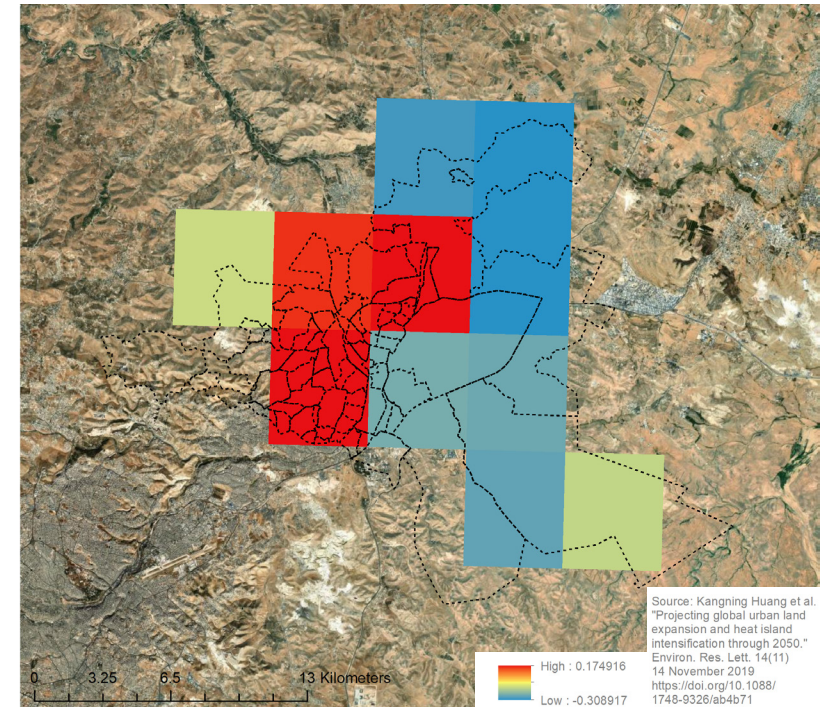
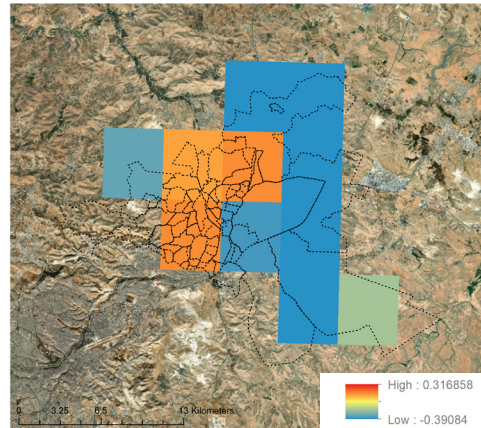
Source: USGS Landsat 8 Level 2, Collection 2, Tier 1
<https://www.usgs.gov/>



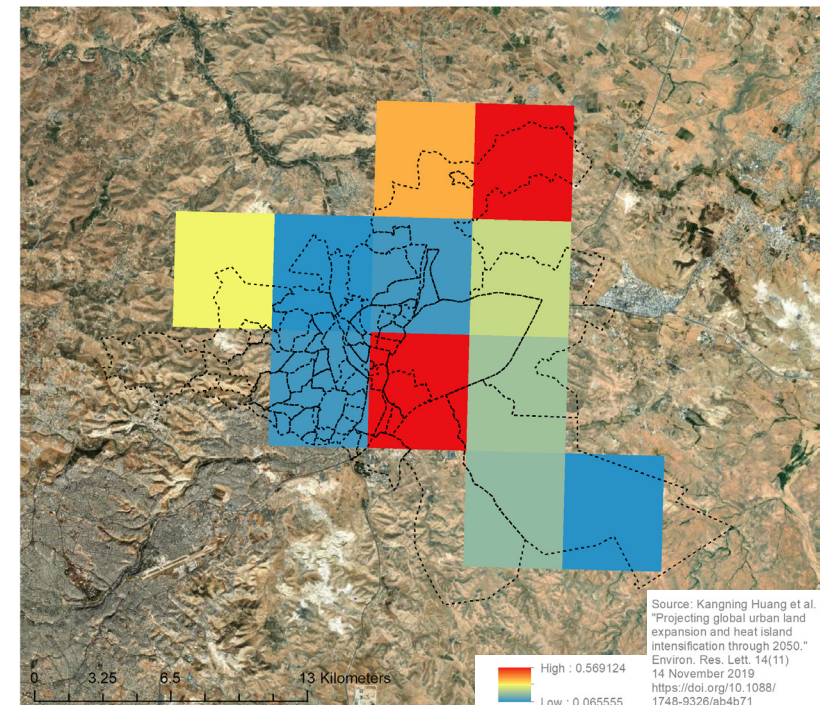
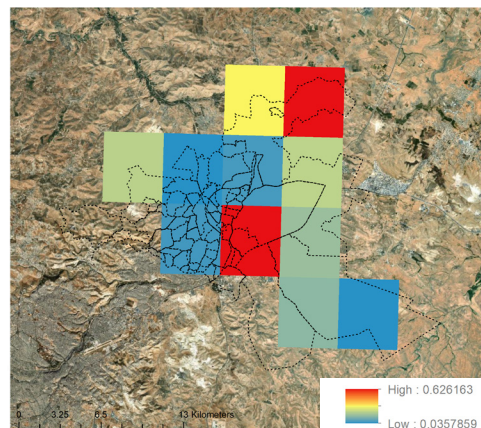
Urban Heat Projections

Given the close link between urban land cover and summer temperature, it is crucial to explore how continued urbanization will impact temperature in the future. Therefore, the projections here isolate the effects of urban land expansion on air temperature from other confounding factors. According to the projections, by 2050, settled areas of Zarqa will see slight summer daytime temperature rises from urban land expansion of up to **0.3** degrees under SSP1 and up to **0.2** degrees under SSP5, whereas the more rural areas could expect small drops in temperature. Nighttime temperature change is more dramatic, though urban areas are not necessarily the most strongly affected. Places with **0.6**-degree nighttime temperature rise due to urban land expansion are located near the borders of Zarqa, while the urban center is projected to experience mild warming.

Projected Change in Summer Daytime Air Temperatures Due to Urban Land Expansion under SSP1 (bottom) and SSP5 (right) (2050) (°C)



Projected Change in Summer Nighttime Air Temperatures Due to Urban Land Expansion under SSP1 (bottom) and SSP5 (right) (2050) (°C)

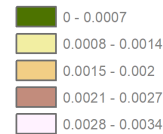


Landslide

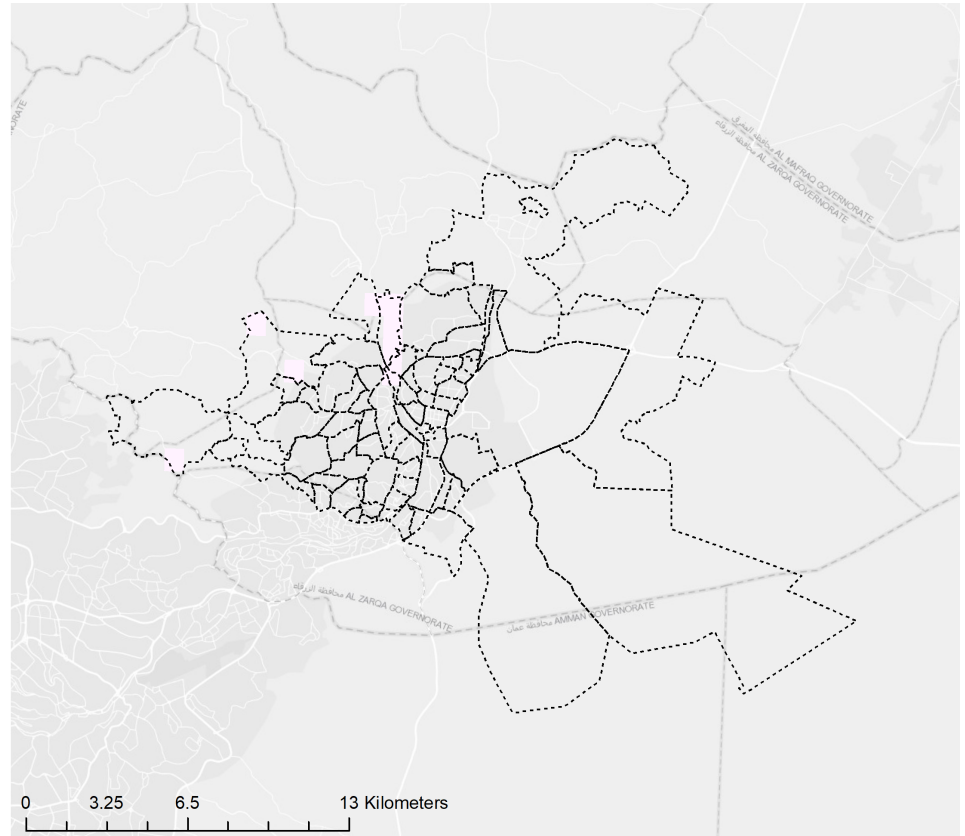
Among the three cities, Zarqa enjoys the lowest level of rainfall-triggered landslide hazard. Across the whole city, the average value of the median annual frequency is just **0.00007**, roughly corresponding to a return period of over **10,000 years**. This extremely small landslide hazard is present in just **2%** of the city, mostly near the northwest boundary.

With this Report's focus on climate change, the landslide analysis here examines rainfall-triggered landslides. The rainfall-triggered landslide hazard is measured by the median average annual frequency in a gridded format.

Rainfall-triggered
Landslide Hazard
(Median Average
Annual Frequency)



Data Source: Global Landslide
Hazard Map (1 km)
<https://datacatalog.worldbank.org/search/dataset/0037584/global-landslide-hazard-map>



CHAPTER 5

ADDITIONAL ANALYSES: DROUGHT & FLOOD-RELATED CLIMATE PROJECTIONS

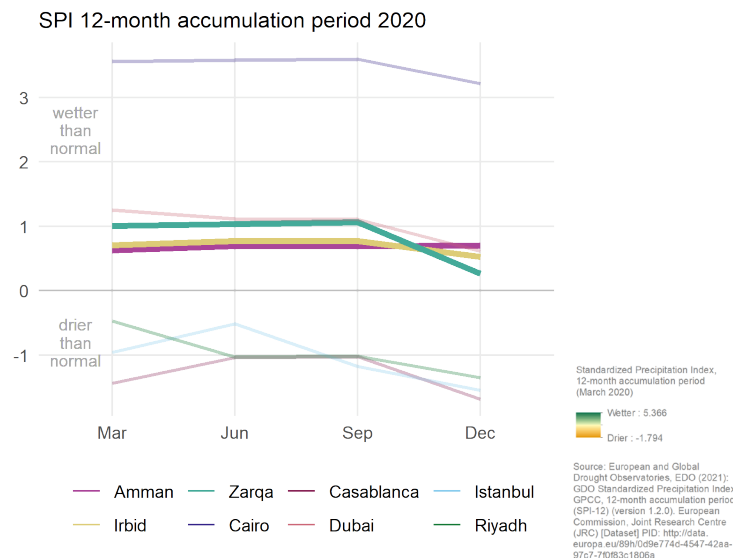
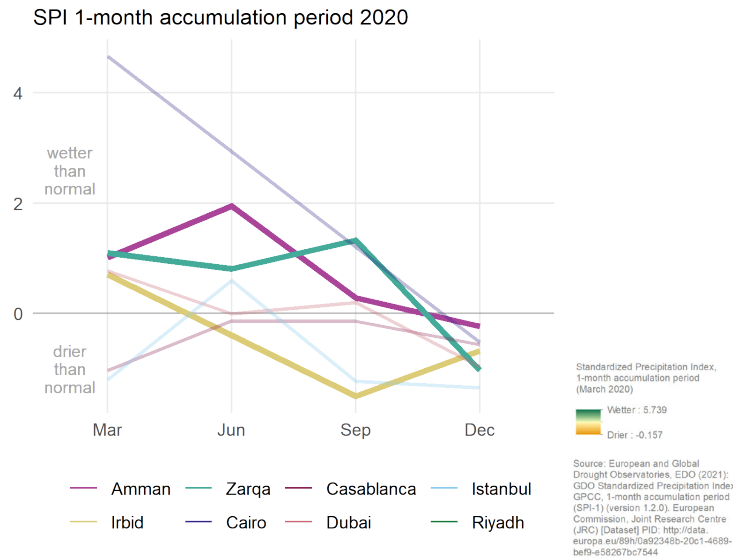


Drought Hazard

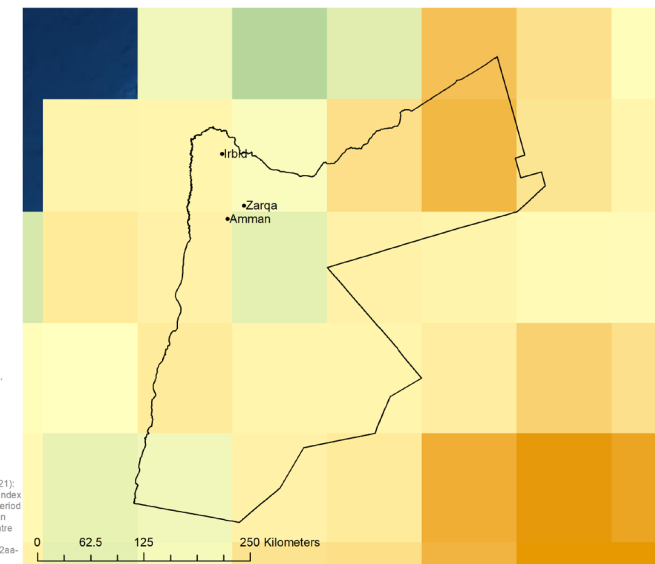
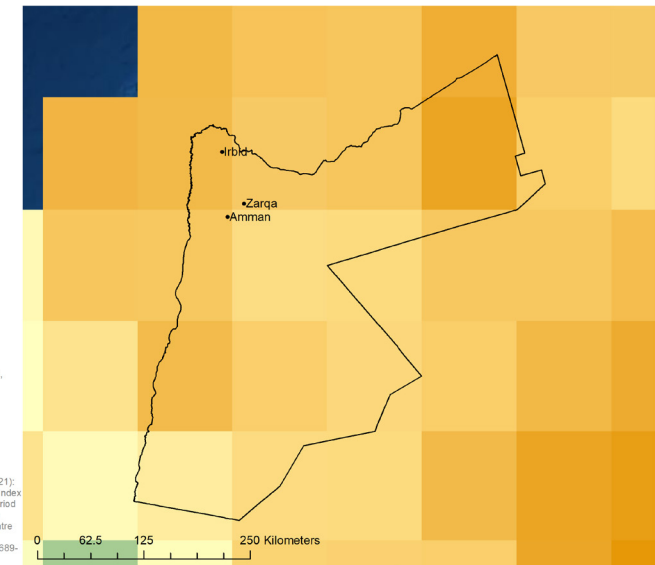
Drought conditions could be caused by a range of factors, and this analysis zooms into two types of drought: meteorological drought and hydrological drought. The former is defined by rainfall deficit over an extended period, while the latter is measured by the proxy indicator of total water storage (TWS) anomaly.

Meteorological drought is determined by the Standardized Precipitation Index (SPI) and is further broken down into two time scales. SPI-1, with an accumulation period of one month, reveals the immediate effects of rainfall deficit, while SPI-12 (12-month accumulation period) corresponds to medium- to long-term effects.

The drought indicators convey mixed signals for drought conditions in Jordanian cities. In 2020, the two SPI indicators mostly show wetter conditions in all three cities, which means they have largely received more precipitation than normal in terms of both short- and medium-term aggregations. Only in December 2020 did the three cities fall under the drier category, an example of seasonal fluctuations of drought conditions.

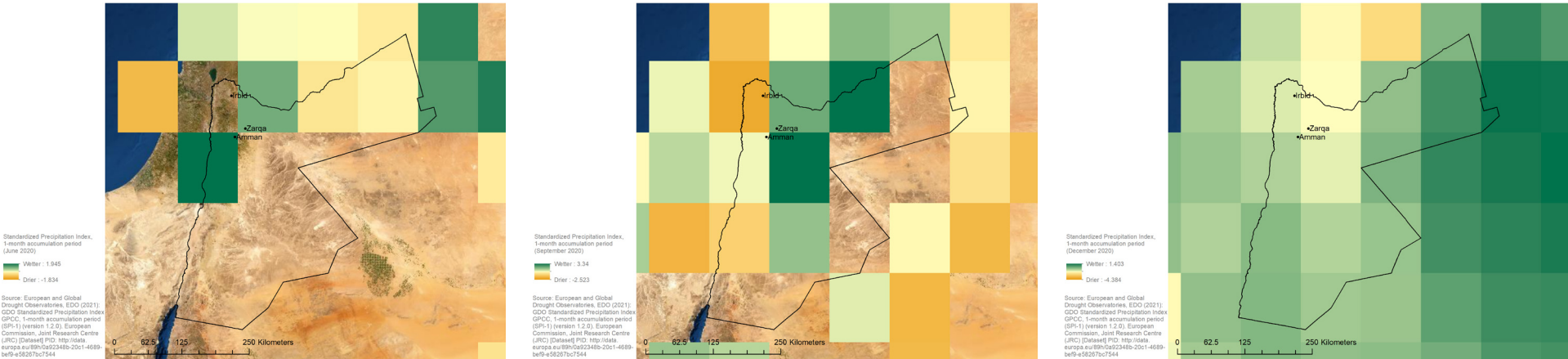


Meteorological Drought Conditions in March 2020, Measured by SPI-1 (top) and SPI-12 (bottom)

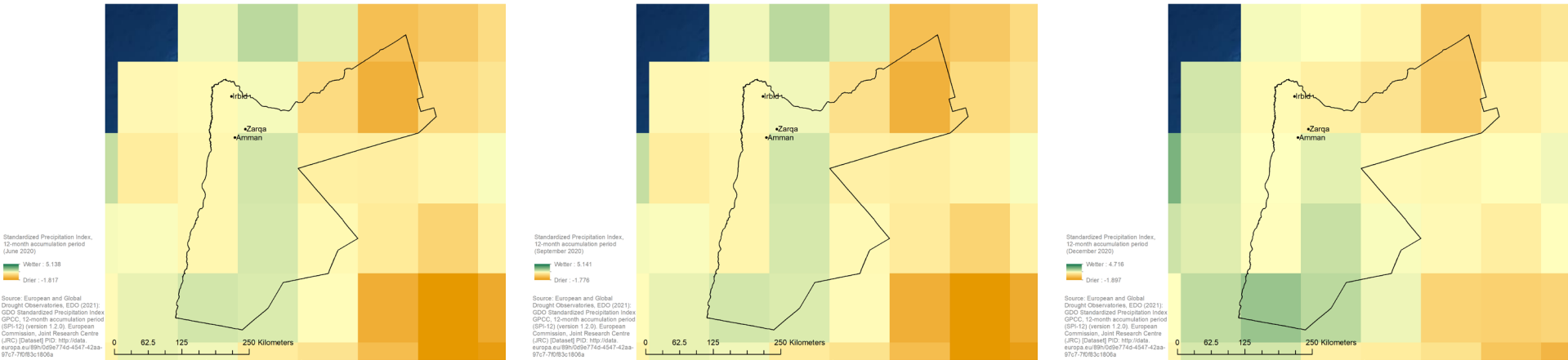


Drought Hazard

Seasonal Changes in SPI-1 (from left to right: June, September, and December 2020)

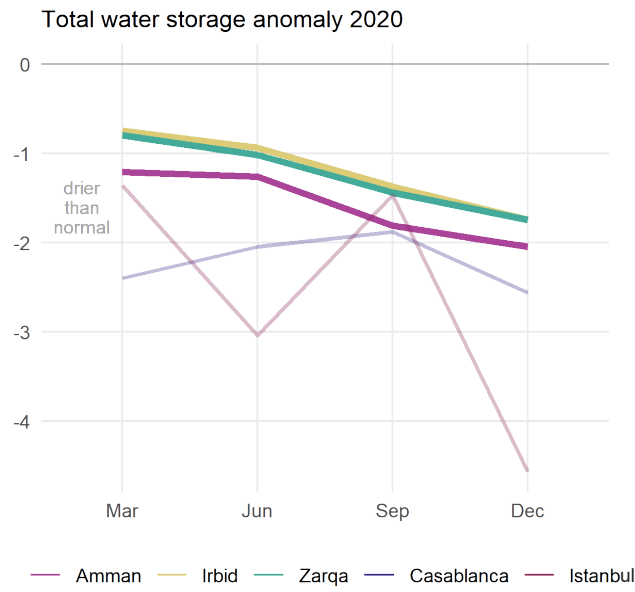


Seasonal Changes in SPI-12 (from left to right: June, September, and December 2020)

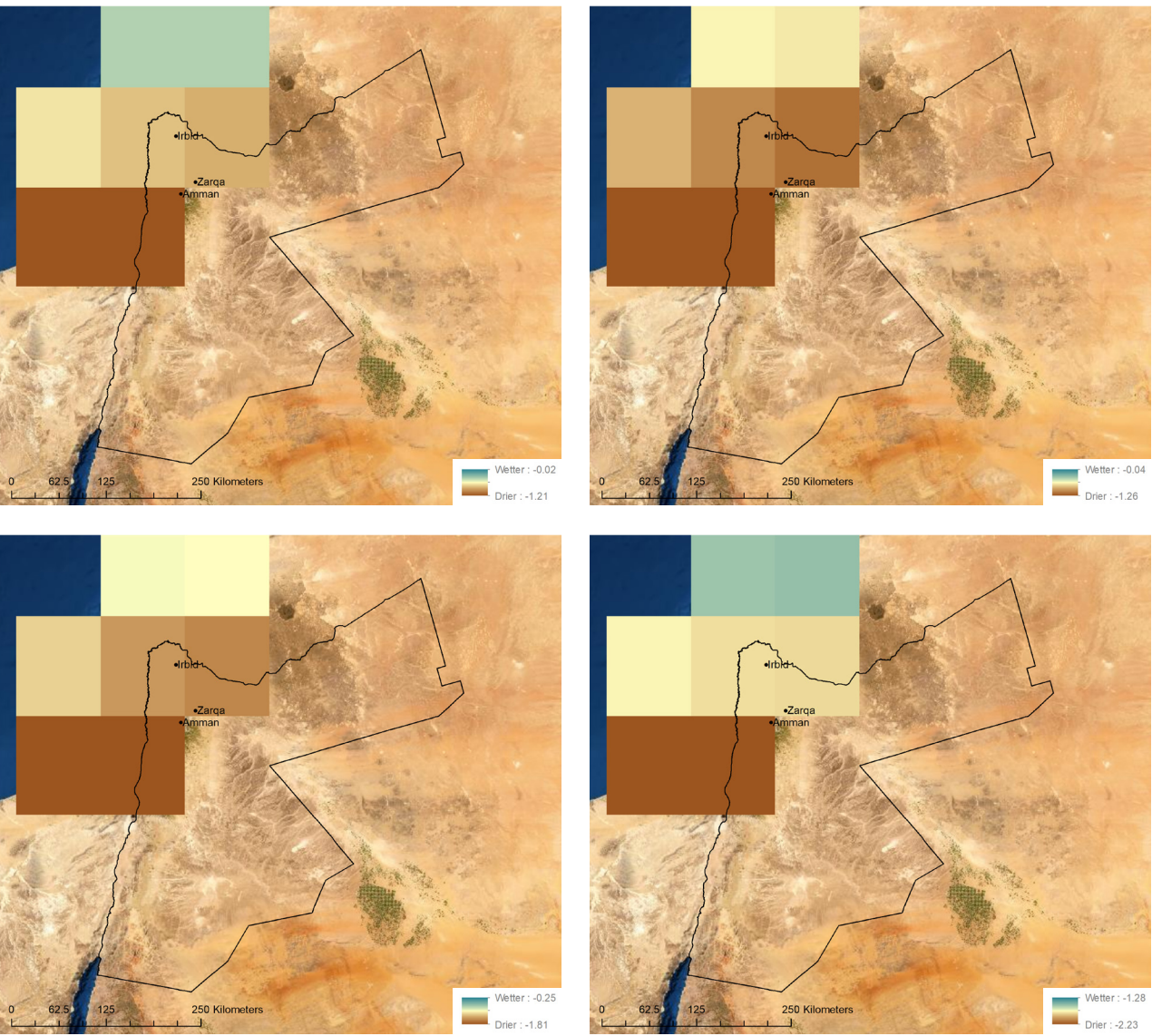


Drought Hazard

While precipitation was mostly abundant, the TWS level continued to decline throughout the year, pointing to potential existence of groundwater drought. The three cities reached the low point of groundwater storage in December, and Amman was consistently drier than Irbid and Zarqa. The diverging indicators could be due to anomalies in the hydrological processes involved in the transformation of precipitation into TWS.



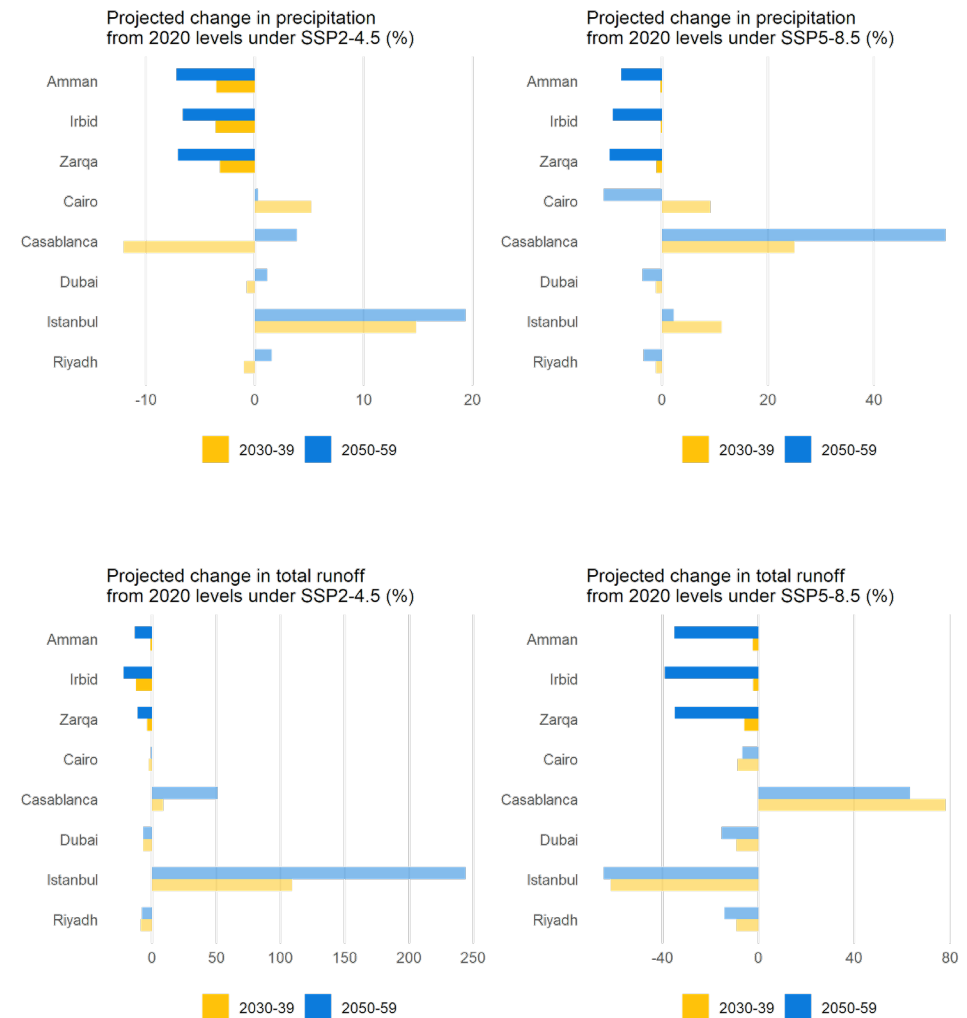
Seasonal Total Water Storage Anomaly in 2020
March (top left) June (top right)
September (bottom left) December (bottom right)



Flood-Related Climate Projections: Precipitation and Total Runoff

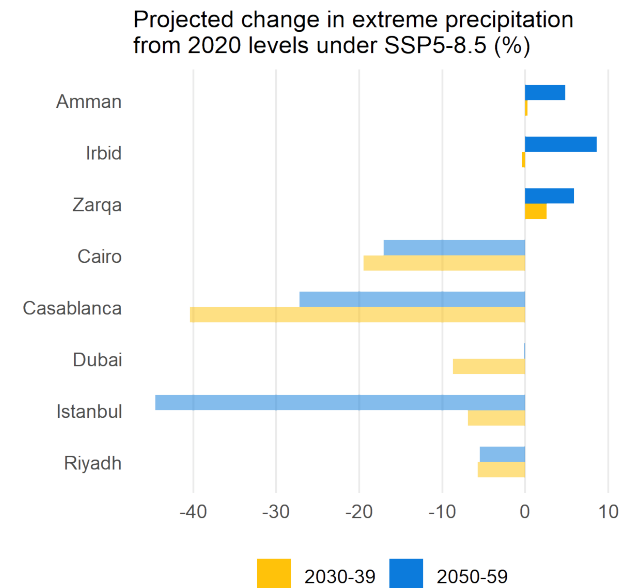
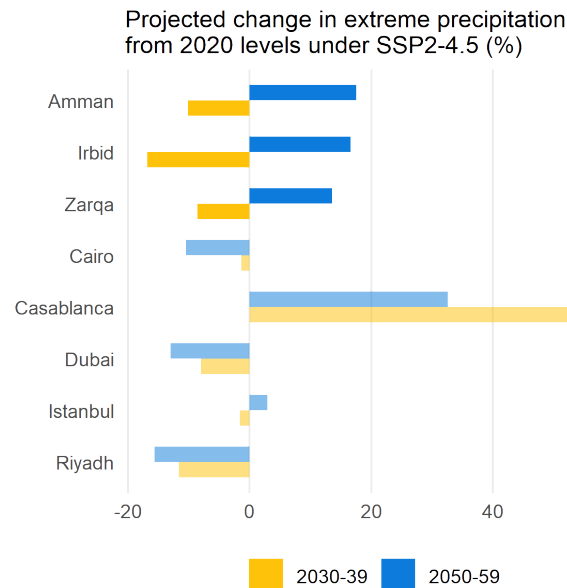
The flood-related projection data come from CMIP6 projections, a collection of climate models with daily and monthly global data that underpin the 6th IPCC assessment report. Among the variables provided by CMIP6 projections, two are selected to shed light on flood risk patterns: precipitation and total runoff. Precipitation refers to the sum of liquid and frozen water, comprising rain and snow, that falls to the Earth's surface, while excluding fog or dew. It is measured by the amount of water per unit area and time. Based on daily precipitation projections, a secondary indicator, the annual sum of daily precipitation above the 99th percentile, is computed to gauge the magnitude of precipitation extremes. Total runoff, on the other hand, is the amount per unit area of surface and subsurface liquid water which drains from land.

On average, under SSPs 2 and 5, all three cities are projected to become drier in the future, as precipitation and water runoff are expected to decline by up to 10% and 40%, respectively. Yet, clearly, SSP5 spells out a significantly drier future compared to SSP2. This could mean longer and more serious drought conditions, negatively impacting urban residents, industries, and agriculture. Compared to other regional cities, the three Jordanian cities are in the middle of the range. They may not experience as many changes as Casablanca and Istanbul, for example, but the climate impacts compared to those of Dubai will be much more drastic, according to the projections.



Flood-Related Climate Projections: Extreme Precipitation

At the same time, while this may seem to offer some relief for flood risks, a closer scrutiny of the climate models demonstrates that extreme precipitation is actually predicted to increase, especially in the 2050s, by up to more than 10%. The trajectories, however, differ between the two SSPs. Under SSP2, the cities first see a reduction in extreme precipitation in the 2030s before it bounces back to a >10% increase in the 2050s. This differs from the trajectories of most regional cities, which are seeing either an uptick or a reduction in extreme precipitation. Under SSP5, Amman and Irbid may not experience much change up to the 2030s, but all three cities eventually suffer from greater extremes in the long run, though the magnitude is smaller than under SSP2. Moreover, the three Jordanian cities would be in stark contrast with other nearby cities, all of which would have much less heavy rainfall. In both scenarios, this could lead to worse pluvial flood and rainfall-triggered landslide hazards for Jordanian cities, because flash floods could intensify and the drier soil, degraded from drought, would be less capable of fending off the floodwater.



CHAPTER 6

SUMMARY

This section summarizes the mapping and analysis on the foregoing sections of this Report. Synthesizing Key Findings of this summary are encapsulated in Chapter 1.

It is clear that Jordan experiences distinct spatial variation in the exposure to climate hazards of its largest cities of Amman, Irbid, and Zarqa, with current and projected increases in exposure across all three. In particular, precipitation, pluvial flooding, air pollution, heat, and drought emerge as the most significant analyzed climate challenges facing this set of Jordanian cities.



Summary

Precipitation

Projections of precipitation in Jordan's three largest cities illustrate how they are all expected to be drier in the future. Under both Shared Socioeconomic Pathways 2 and 5, overall precipitation and total rainfall runoff are expected to decline substantially, by up to 10% and 40% respectively across the cities. Compared to a benchmark sample of five other regional cities, Amman, Irbid, and Zarqa all fare poorly. Less precipitation is likely to have significant negative effects on water and sanitation, agriculture and food security, industry, and other areas. At the same time, extreme precipitation events are expected to intensify by 2050 under these SSPs; and by 2050, under SSP5, the Jordanian cities are the only ones to experience a rise in extreme precipitation from 2020 compared to the five benchmark cities. A reality of more extreme rainfall under less overall precipitation can exacerbate flooding and its associated risks.

Pluvial Flooding

Pluvial, or rainwater, flooding is one of the most significant hazards Jordanian cities face. All three cities experienced significant increases in their built-up area exposed to a pluvial flood hazard of up to a 1-in-1000-year event with a minimum depth of 15cm

since 1985. In the 31-year period to 2015, the built-up area exposed to this flood hazard in Irbid nearly doubled, from 3.5 sq. km to 6.6; in Amman, it more than doubled, from 12.1 sq. km to 22.4; and in Zarqa, it nearly tripled, from 2.6 sq. km to 6.9. This exposure is projected to rise further: under SSPs 1 and 5 in Amman, for example, growing urban settlements increase the built-up area exposed to pluvial flooding to 26 sq. km by 2030 and to 31 sq. km by 2050—before even considering increased flood risk due to climate change, which is expected to push these figures even higher. Also in Amman, for which census data are available, as of 2015 about 66,900 households were exposed to pluvial flood hazard with a minimum depth of 15cm, including 34,300 low-income households.

Fluvial Flooding

Across all three cities, fluvial flood hazard with a minimum depth of 15cm, even up to a 1-in-1000-year event, does not present as a key concern.

Rainfall-Triggered Landslide

The landslide hazard from rainfall in Amman, which evinces the highest risk among the three cities, is present in about 19% of the city, reaching a maximum of approximately 1-in-60-year return period

Summary (continued)

in its westernmost, uninhabited areas, and about a 1-in-700-year return period average across the city. Rainfall-triggered hazard in Irbid and Zarqa are also minimal, appearing slightly along the cities' edges.

Air Pollution

Air pollution is a serious concern in Jordan's three largest cities. In Zarqa, average PM_{2.5} concentration reaches 43 micrograms per cubic meter, while in Amman the figure goes up to 32 µg/m³ and in Irbid up to 21 µg/m³. All fall well above the WHO guideline of a 10 µg/m³ threshold for health outcomes. Further, since 1990 the PM_{2.5} concentration has increased in all three cities, most notably in Zarqa, where it grew by an average across the city of 7.6 µg/m³.

Heat

With Jordan's hot desert climate, its cities especially concentrate the heat residents experience. Surface temperatures in cities can reach extremely high levels, especially in the summer. As this study measures surface temperatures—the heat people experience on their feet, rather than their face—the desert outskirts of all three cities can appear hotter than urban

settlements. Nevertheless, average surface temperatures in urban centers are high, for example, in Amman, exceeding 33 degrees Celsius. And while parts of western Amman have cooled in the past decade, most of the settled area has experienced marked temperature increases, particularly in east Amman. Surface temperatures overall have similarly increased in Irbid and Zarqa—the latter has seen a remarkable 3-degree rise in surface temperature over the past eight years. Under SSPs 1 and 5, all three cities are expected to experience increased temperatures during daytime due to urban land expansion alone; overall climate change is likely to heighten urban heat further.

Drought

In 2020, Amman, Irbid, and Zarqa all experienced wetter conditions than normal by both short- and medium-term aggregated figures. However, total water storage anomaly for each city declined over the course of the year, indicating possible hydrological and groundwater drought. Throughout the year, Amman was consistently drier than Irbid and Zarqa as all three declined in water storage.

CHAPTER 7

POLICY RECOMMENDATIONS FOR ENHANCING CLIMATE ADAPTATION AND RESILIENCE

As urbanization increases and is projected to continue in Amman, Irbid, and Zarqa, growing their populations and expanding their boundaries, the challenges elucidated in the preceding chapters demand a strategic set of targeted policies and interventions. Adapting to these threats can boost the resilience of Jordanian cities' populations, economies, and environments to climate change.



Policy Recommendations

Recommendation 1: Localize Climate Adaptation

Jordan has adopted a 2021 National Climate Change Adaptation Plan (NAP), the country's first climate action plan. The NAP reviews the country's climate hazards and identifies adaptation measures across various sectors along six strategic objectives. To help its cities adapt to climate change, Jordan should create Governorate- and city-level adaptation plans in line with the national strategic objectives of strengthening institutions and governance, supporting coordination between stakeholders, and raising awareness and communication. The voices of urban residents and municipal officials should be heard at the levels of the Governorate and city and incorporated into local plans and actions. Developing climate resilience plans for specific cities will help bring sustainable urban development closer to the local people who are most affected by climate change and its effects in urban environments. The existing Amman Resilience Strategy can serve as an example for Irbid, Zarqa, and other cities.

Recommendation 2: Complement Urban Adaptation with Urban Mitigation

The NAP includes integrating climate mitigation into adaptation actions, such

as increasing renewable energy for more secure electricity, wastewater treatment, and drinking water access. An urban orientation should be incorporated into these measures, especially since the greatest demand for these services comes from cities. Generating renewable energy at the city level could create locally sustainable systems in which energy created is energy used, improving the efficiency of energy transmission and creating redundancy with larger regional or national grids. Other planned mitigation measures, such as reforestation, should be considered in peri-urban areas to promote urban cooling and resilience to floods and landslides.

Recommendation 3: Prioritize Green Infrastructure Development

With the forces of rising heat through both climate change and urbanization affecting Jordan's cities, along with desertification, drought, dwindling water supply, and increased flood risk, urban areas are becoming less livable. Jordan should invest in urban green infrastructure and nature-based solutions to improve urban resilience and achieve sustainable environmental and economic development. Green infrastructure can significantly enhance urban cooling and health outcomes,

Policy Recommendations (continued)

reduce localized pollution, mitigate the destructive effects of floodwaters, and resist drought and desertification. Nature-based solutions can be deployed to facilitate key needs, such as rainwater harvesting, water retention and treatment, thermal regulation, and more. It will be critical to improve land management to restore both environmentally protected and usable green urban spaces, which will be crucial to enhancing the green adaptability of Jordan's cities to the extreme effects of the changing climate. In industrial areas, heat and pollution are especially serious; targeting green measures here and accompanying further industrialization with greening will help to offset surface sealing that raises heat and capture ambient heat and air pollution, alleviating their effects on urban residents.

Recommendation 4: Improve Urban Water Resources Management

Water is a critical resource in Jordan, one of the world's driest countries. In cities, water sustainability is severely threatened because desertification depletes the groundwater, poor management contaminates water supply sources, and flooding pollutes water and destructs its infrastructure. Particularly in the Amman-Zarqa basin, overpumping of water,

urbanization, and poor management of resources by both households and farmers have depleted the water and polluted what remains. And as climate-driven heatwaves increase and city populations climb, demand for water continues to rise. Jordan should implement water saving programs in its cities, for individual consumers, businesses, and industry. The country should target investment programs that facilitate water storage, treatment, recycling, and reuse, so that cities can maintain the water they need for daily needs, cultivation of food, and efficient and accessible urban services. And significant investments should be made in the management of integrated urban water resources, so that freshwater, wastewater, and storm water work together to maintain existing groundwater, improve drinking water delivery and consumption, and resist damage from flooding and other hazards to ensure continuity of supply and limit water resource conflict.

Recommendation 5: Build on Strengths

Amman's Urban Agriculture Office promotes the farming of idle land in the city, peri-urban land, and rooftops. The municipality offers residents agricultural and entrepreneurial skills training, farming and crop materials, and access to credit

Policy Recommendations (continued)

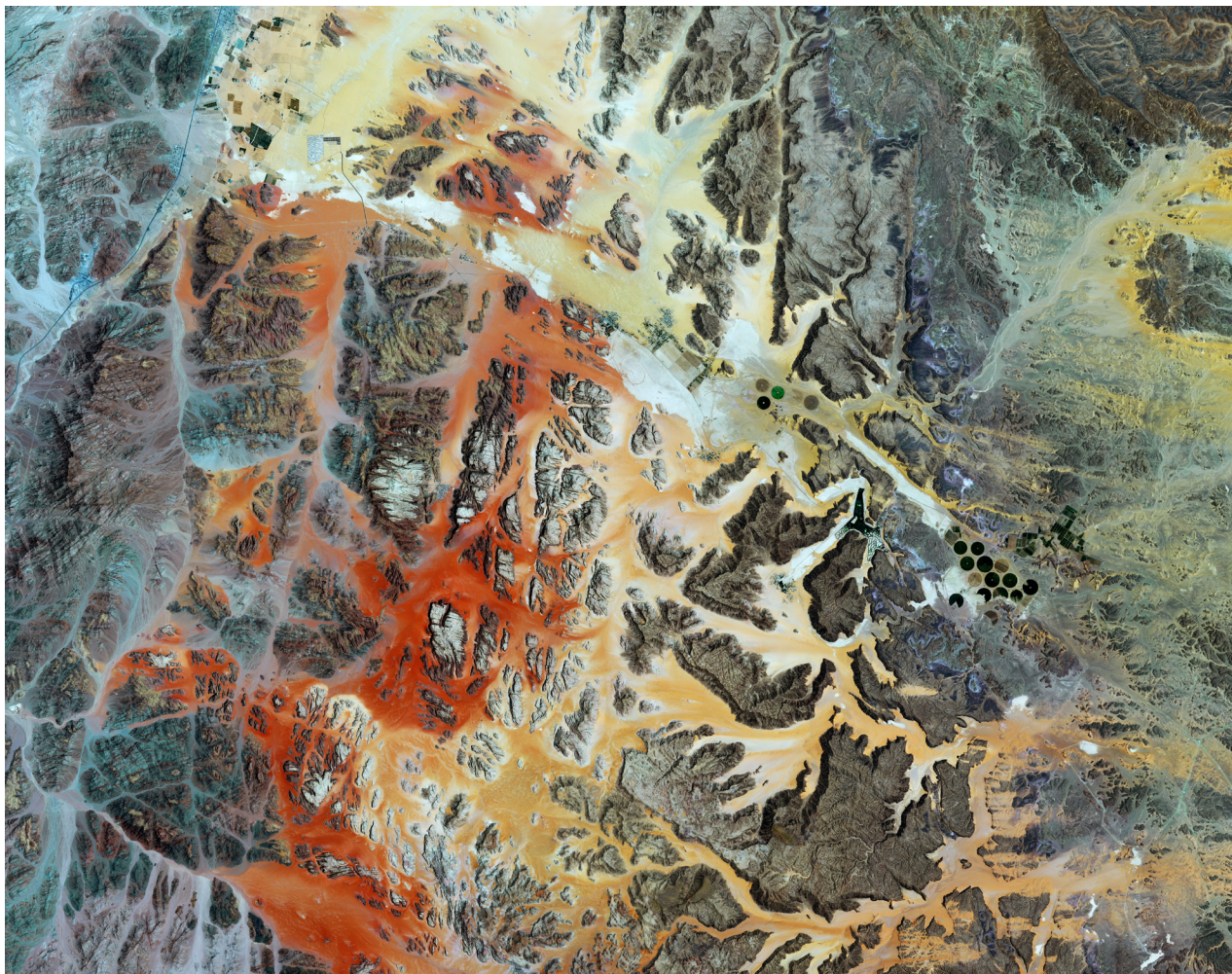
for urban agriculture. It also integrated recycling of solid waste and programs for efficient use of water into its agriculture policies and practices, such as gray water reuse, drought-tolerant plants, rainwater harvesting, and water reservoirs. Home-growing food in Amman makes it more affordable to the urban poor in low-income settlements, avoids fragmentation of settlement, prevents construction in flood plains, and alleviates water scarcity. Land use guidelines in Amman now stipulate a minimum 15% of each plot allocated for greening or agriculture. Urban agriculture in Amman has thus enhanced food and water security while enhancing urban cooling. Amman should continue to build both climate adaptation investments and community engagement and awareness using its urban agriculture assets and social capital as a foundation. In turn, Irbid and Zarqa should identify key existing adaptive strengths in the urban physical and social fabric from which they can build out further integrated climate resilience programs and investments.

Recommendation 6: Integrate Climate Interactions into Planning

The changing climate is complex and difficult to decipher, with innumerable factors interacting and affecting it in different ways. This is especially true in cities, where agglomeration concentrates activities, assets, emissions, and risks, and is notably borne out in Jordanian cities. For example, drought, anticipated to worsen in Jordan, degrades the soil, making floodwaters—less frequent but more intense when they do come—less absorbable and more destructive. The decrease in overall frequency and quantity of rainfall makes the pollution cities experience worse, as it does not get washed out by rain as often. Urban greening, a key priority for climate adaptation in Jordan's cities, is much more difficult with poor levels of groundwater supply. As cities in Jordan plan to adapt to the changing climate, the systematic knock-on effects of each climate issue on others necessitates an integrated, cross-sectoral planning perspective.

ANNEX

DATA SOURCES



Data Sources

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