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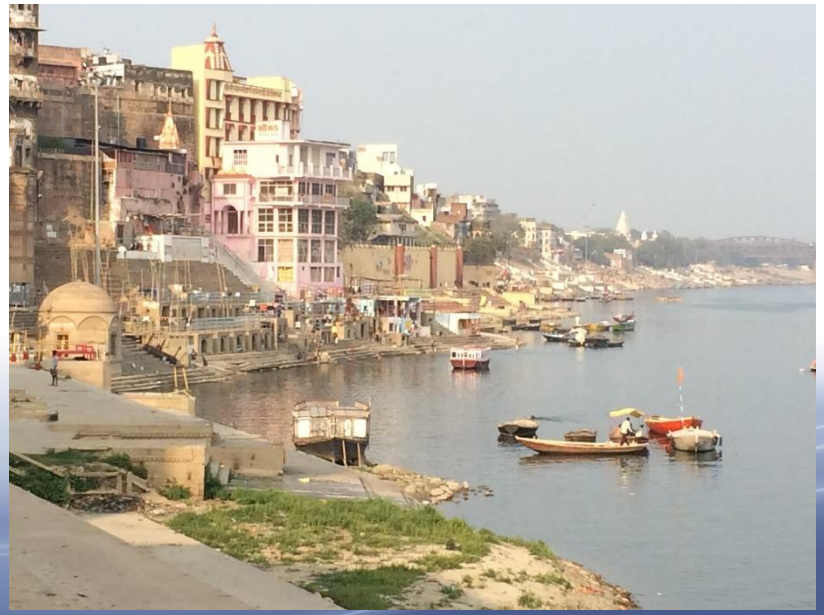
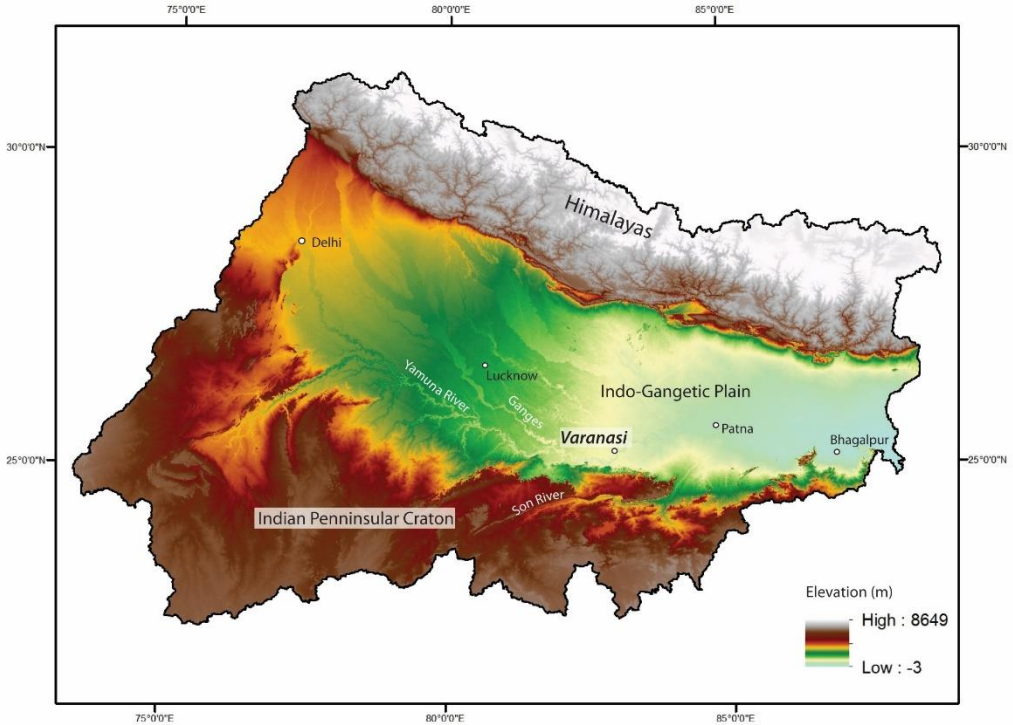
A geological framework for urban sustainability on the River Ganges: Varanasi, India





One of the oldest continually inhabited cities in the world

- Cultural importance
- Smart city mission

Challenges:

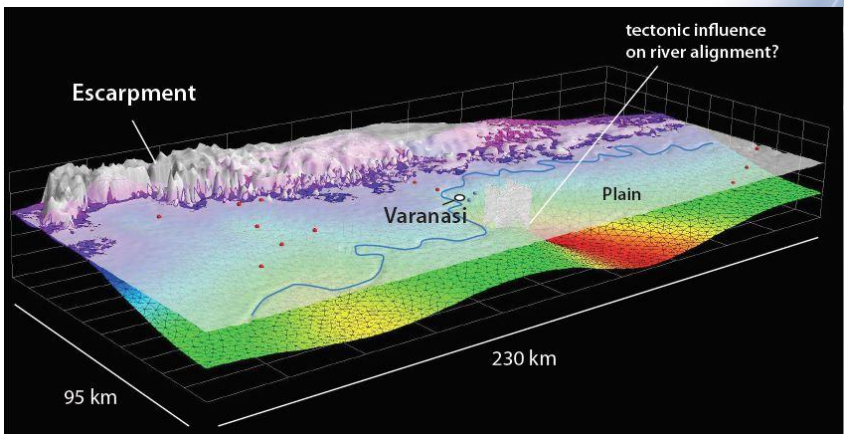
- Out-dated infrastructure
- Overcrowding
- Surface water contamination
- Flooding
- Groundwater security

Objectives of IIT Kharagpur – BGS partnership:

- Develop a city scale subsurface model to aid urban planning

- Characterise contamination & recharge in the groundwater system

- landscape change and controls on river dynamics



A geological framework for urban sustainability on the banks of the River Ganges: Varanasi, India

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Background

Situated on the banks of the River Ganges, Varanasi is one of the oldest continually inhabited cities in the world. With significant cultural importance its future sustainability is a priority in India, and it is short-listed in the county's Smart city Mission.

However, Varanasi faces a number of **challenges** including: out-dated infrastructure, overcrowding, severe surface water contamination, flooding, and uncertainty over the sustainability of heavily used groundwater resources.

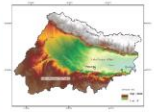
To help address these challenges, BGS are working in partnership with IIT-Kharagpur to develop a geological framework for the city. The main project objectives are to:

1. Undertake a city-scale drilling programme, and develop a 3D geological model of Varanasi's subsurface that can be used to aid urban planning.

2. Characterise contamination and recharge in the groundwater system.

3. Improve understanding of regional controls on river dynamics.

View looking north along the ghats of Varanasi. With new bridge crossings, plans for a metro system and improvements to water and sewerage facilities, retro-fitting such a densely populated city (right) to modern technology represents a major challenge.



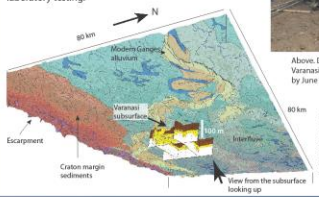
The location of Varanasi within the River Ganges drainage basin. Elevation data from SRTM 90 data set.

Varanasi city centre. Traffic flow and movement is challenging.

1. The subsurface of Varanasi

Varanasi's subsurface is being investigated through an extensive programme of drilling, field mapping, and logging of natural river sections. By June 2016, eighty-five boreholes had been completed to 50-100 m depth, with a large number of samples collected for geotechnical testing, sediment provenance analysis, and Optically Stimulated Luminescence (OSL) dating. Boreholes have also been targeted for downhole geophysical studies.

BGS have been working with IIT Kharagpur to develop an initial conceptual model of the subsurface. Geostatistical models will also be developed at a later stage following laboratory testing.



Above. Drilling rig in the northern side of Varanasi. 85 boreholes had been completed by June 2016.

Left. A Quaternary geological map has been developed for Varanasi and the surrounding region. Cross sections derived from borehole logs are 'hung' from the surface map to develop a conceptual model of the subsurface.

2. Groundwater Investigations

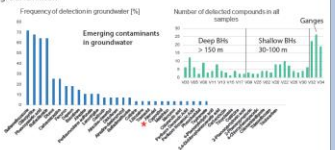
A. Noble gas sampling. B. Field chemistry and filtering samples for analysis. C. Solid phase extraction of micro-organics from groundwater in the field.

Varanasi obtains much of its drinking water from the sediment aquifer system beneath the city. Treatment for groundwater is limited and there are concerns regarding water quality security for the city and impact on public health.

The impact of anthropogenic contaminant loading to the groundwater system in unknown. A field campaign to characterise the hydrogeochemistry of the aquifer was undertaken in March 2016 with two key objectives:

- Characterise the distribution of groundwater residence times and sources of groundwater recharge.
- Characterise the quality of drinking water sources including analysis for key inorganic contaminants and broad screening for micro-organic contaminants.

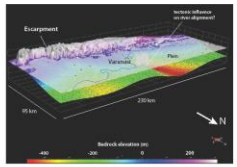
Twenty-nine paired shallow and deep groundwater samples were taken from public and private boreholes. Surface water samples from the River Ganges were also collected for comparison of micro-organics with the groundwater.



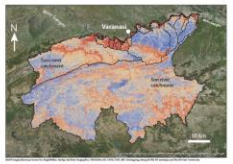
3. Landscape change and river dynamics

A programme of work is underway to improve understanding of the role that tectonics and environmental change have on the dynamics of the River Ganges at Varanasi. Geomorphological and geological field investigation, together with remote sensing analyses, were focused on the plains and peninsular escarpment to the south of the River Ganges. Sample were collected for analysis of sediment provenance and for OSL dating, in order to determine the source of sediments, and the constrain the timing of sediment deposition and subsequent river incision to modern base level.

Preliminary bedrock and structural geological map for the plateau to the south of Varanasi. Base map is false colour Landsat 8 imagery.



Preliminary modelled rockhead elevation, based on existing published borehole and geophysical data, communications from local drillers, and mapped bedrock exposure at the escarpment edge and as inselbergs on the plain. The next phase of fieldwork aims test and refine this model.



Initial spatial sediment connectivity map for catchments on the southern side of the Ganges between the Son and Tons rivers. Sediment from the areas in red has a higher relative probability of making it into the River Ganges.

Sampling for sediment provenance and OSL dating along river cliff sections above the River Ganges.

5. Next stage

The next phase of field investigation is planned for November 2016, with the drilling of three deep (300-400m boreholes), which will be fully cored down and into bedrock, providing for the first time, full core recovery through sediments and bedrock in the area. This will provide a rich resource for detailed research into the hydrogeology (aquifer complexity) and sediment provenance and history, and test developing hypotheses on tectonic controls on the river system in the area.

Acknowledgements

The BGS Team gratefully acknowledge the excellent advice and support, and good company from the IIT Kharagpur Team in Varanasi. Prompt and effective assistance was provided by BGS project and business support staff, ensuring this first phase of the project was completed in time. This project is co-funded by the Newton Bhabha programme for UK-India research collaboration.