AN INVESTIGATION INTO THE USE OF NATURAL ADDITIVES TO IMPROVE WATER RESILIENCE OF EARTHEN PLASTERS

Dinajpur District, Bangladesh / August - September 2012

The study aims to compare the water resilience of various natural additives with synthetic options. The focus will be on freely available, raw materials sourced locally within Sundarban Union in Dinajpur District, northwest Bangladesh.

Low-income households are not always able to provide stabilisation with the addition of such additives as cement. The research endeavours to identify sustainable, low-cost alternatives to vernacular architecture and construction in order to improve quality and increase longevity of earthen plasters.

Environmental Initiatives

Research Collaboration

ORGANISATIONS

Simple Action For the Environment (SAFE)

SAFE aims to reduce the vulnerability of low-income households in northern Bangladesh to environmental hazards such as flooding and strong winds. This is achieved through the promotion of improved housing techniques by offering 'building for safety' workshops within the district and construction of demonstration houses in collaboration with the community.

Contact: Azit Roy
Tel: +88 (0) 1726007343
Email: azit_sorkar@yahoo.com
Website: www.safebangladesh.wordpress.com
Address: Sundarban Village,
PO: Ramdubihat,
Upazila: Sadar Dinajpur,
Bangladesh

Engineers Without Borders-UK (EWB-UK)

EWB is an international development organisation that aims to remove barriers to development through engineering, offering opportunities for young professionals to learn about technology's role in tackling poverty. The interdisciplinary approach involves holistic engineering, active partnerships, demand-led development, sustainable use of natural resources and appropriate technology.

Contact: EWB-UK Placements Team
Tel: +44 (0) 1223305888
Email: placements@ewb-uk.org
Website: www.ewb-uk.org
Address: c/o The Humanitarian Centre,
Fenner's, Gresham Road,
Cambridge, CB1 2ES,
United Kingdom

Map of Bangladesh

COUNTRY PROFILE: BANGLADESH

Bordered by India, Myanmar and the Bay of Bengal, Bangladesh is one of the world's most densely populated countries. The low-lying nature of the terrain (with a large percentage of the land less than 12m above sea level) means that Bangladesh is vulnerable to flooding and is now widely recognised as one of the countries most at risk from climate change.

Geography

Location:	Southern Asia
Area:	143,998 sq km
Climate:	Tropical Mild winter (October-March) Hot, humid summer (March-June) Humid, warm monsoon (June-October)
Terrain:	Flat alluvial plain, hilly in southeast
Land use:	Arable land: 55.39% Permanent crops: 3.08% Other: 41.53%
Natural hazards:	Droughts, cyclones, earthquakes, floods, landslides, tidal surges

People

Population:	161,083,804 (72% rural)
Population growth:	1.579%
Median age:	23.6 yrs
Life expectancy:	70.06 yrs
Literacy:	56.8% (age 15 and over)
Unemployment:	9.3%
Below poverty line:	31.51%

Economy

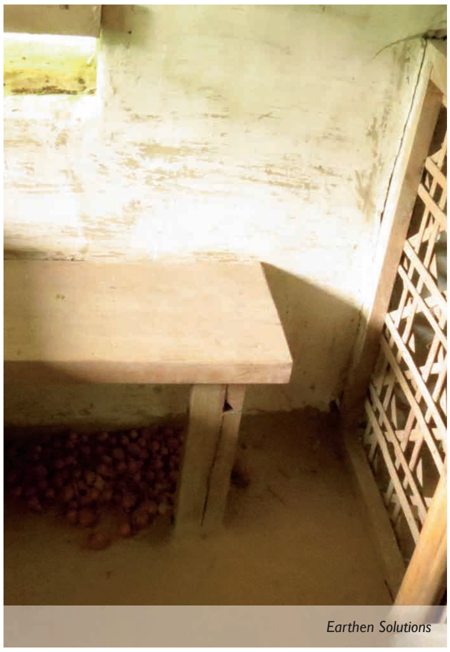
GDP (PPP):	$285.8 billion
GDP (real growth rate):	6.1%
GDP (per capita):	$1700

Data sourced from CIA online
https://www.cia.gov/library/publications/the-world-factbook/geos/bg.html


Landscape


Kantaji Temple


METI School: Architect Anna Heringer


Earthen Solutions

DISTRICT PROFILE: DINAJPUR

Area

Dinajpur District, in northwest Bangladesh suffers from localised flooding and particularly strong winds during September and October, which regularly cause damage to houses and infrastructure. Dinajpur also lies in one of the highest earthquake risk zones in Bangladesh. The local population depends largely on agriculture and the region is widely acknowledged for its rice production, with 40% of its population landless labourers.

Earthen Architecture

There are a number of notable buildings within the district, which celebrate earthen architecture and its diversity of solutions.

Kantaji Temple, built in 1952 by Maharaja Pran Nath, is located in Ramsagar. This 50ft square, three-storeyed building sits on a raised curved plinth constructed of sandstone blocks and features thousands of handmade terracotta tiles, which represent flora, fauna, geometry and mythological scenes.

METI Handmade School, which won the Aga Khan Award, was built in 2007 and designed by architect Anna Heringer. Located in Rudrapur, the building's thick loam walls (local clay / sand / straw) are supported by a brick foundation. The consistency of the earthen mixture was achieved by using water buffalo to combine the raw materials. A bamboo second storey offers views over manicured gardens and the forests beyond.

Various organisations including BRAC University and SAFE have built a number of improved residential houses across the district which exhibit raised stabilised earthen plinths, plasters and internal finishes.


Traditional House Construction In Sundarban Village


Drying Cowdung For Fuel

RESEARCH LOCATION: SUNDARBAN VILLAGE

Area & Community

Sundarban village is the largest of 14 villages located within Sundarban Union in Dinajpur District. Typically in such rural areas, families own the land their homestead is built upon (even the functionally landless who have little or no agricultural land assets). The village consists of over 100 hamlets or 'paras' (25 or so homesteads grouped together) with no central focus other than Benkali market/junction and blending into neighbouring residential areas. The population of Sundarban village is predominantly Hindu and Muslim. With agriculture the main source of income, farming is a key occupation (rice, jute, sugarcane...). Other occupations include fishing (as the community is located close to Atrai river), rickshaw driving, basket weaving and handicraft production.

Construction & Materials

Traditional houses within the village are single storey. A basic bamboo frame supports a pitched roof with leaf covering. Various materials such as split bamboo or jute are weaved to provide a base for an earthen plaster finish. The structure is raised on an earthen plinth above floodwaters and features few small openings for ventilation and views. Those households with increased assets may use material alternatives such as timber, fired bricks, CI sheets and/or cement stabilisation as well as improved techniques such as katlas (pad foundations), crossbracing, bamboo treatment and/or hurricane roof strapping,

The Home

Homesteads are arranged around a courtyard, with the main house often south-facing, including a veranda. Some households feature a separate kitchen, cow house and/or other buildings associated with farming. The courtyard layout allows daily activities such as husking of cereals and drying of clothes, with the permanent buildings reserved for sleeping and shelter.

Advantages of earthen plasters:
- Provide protection against wind, rain and abrasion;
- Offer a level of thermal mass to temper the internal environment;
- Improve the appearance of a wall;
- Complement traditional/natural materials, allowing the wall to breathe;
- Do not require expensive tools or technical knowledge.

Disadvantages of earthen plasters:
- At risk of erosion and impact;
- Require regular maintenance;
- Need local knowledge of climate, weather patterns and soil suitability;
- Should be combined with appropriate design such as adequate footings, basements, eaves, roof overhang and shade.

Houseowner In Sundarban Village

INVESTIGATION

Background

Earthen architecture and construction is common practice both in Sundarban village and the wider district, as well as across Bangladesh. Techniques include earthen plinths, adobe walls, wattle and daub construction and plasters. Interestingly, the latest Household Income and Expenditure (HIES) completed by the Bangladesh Bureau of Statistics (BBS) clearly indicates the importance of earth as a construction material for residences both in rural and urban areas. In total 80% of housing structures use brick as the primary wall material (17% mud/unburnt brick, 25% brick/cement, 38% CIS/brick/wood) with the remaining 20% using other materials, including bamboo.

Aims & Objectives

Earthen solutions can be sustainable, low-cost and beautiful, however there is a high level of maintenance required. Without stabilisation or water resilience measures, earthen architecture and construction is at risk from monsoon rains, flash foods, standing water and humidity.

This investigation focuses on earthen plasters and additives that may be used to improve their water-resilience. Predominantly the local population uses a 'sticky mud', which is a simple mixture of clay and water (sometimes with the addition of straw or cowdung to act as a stabiliser). The mud is thrown onto the wall surface (brick, bamboo weave, jute sticks...) and smoothed by hand to create an uninterrupted finish. There are various synthetic additives that offer improved water resilience such as bitumen, soap, lime and cement, however many low-income households are unable to afford these additional costs. With this in mind the investigation seeks to test freely available natural additives, sourced locally within Sundarban Union.

A control sample using typical 'sticky mud' will be compared to a range of samples with varying natural additives, alongside typical synthetic alternatives.

Earthen Architecture Across Bangladesh

Earthen Solutions Across Bangladesh

WATER RESILIENCE TESTING TECHNIQUES

Options

In order to accurately compare sample sets the following testing methodologies were considered:

1 – Drip test

The sample is placed on a sloping board, with a full container of water located on a shelf approximately 2.5m above. A piece of string is soaked in water and placed in the container with one end hanging out so that drips continuously fall from it onto the sample below.

The time is recorded until a hole has been created.

This test may require a level of ongoing supervision for an extended period of time and a relatively thin sample set.

2 – Spray test

A showerhead of approximately 100mm diameter is set at a distance of 180mm from the sample. The surface is sprayed at a pressure of 1.4kg/cm^2 for two hours and the results interpreted.

Pitting 6-12mm deep is acceptable in areas with infrequent storms; pitting 0-6mm is acceptable in areas with 500 to 1250mm rainfall per annum; no pitting is acceptable in areas with rainfall higher than 1250mm; materials which fail require rendering; renders which fail will require regular maintenance or alternative measures.

3 – External conditions

Test-walls are constructed with varying additives and subject to external conditions. They should be located away from any objects or vegetation that may interfere with rainfall or cause inaccurate results between samples.

Examination and documentation of state changes (appearance / weight) should be taken at regular intervals and accompanying weather conditions noted. This test can be undertaken to establish which sample performs best within a specific timeframe or until collapse.

Field Test Equipment

Samples Subject To External Conditions

THE FIELD TEST

Chosen Technique

The results of laboratory tests often cannot be transferred directly to field practice. The spray test for example can only be indicative as factors such as changes in scale, influence of true climatic conditions, building usage and maintenance practices are not easily replicated. It was therefore decided that 'Test 3' would be the most appropriate technique. This test is a good indicator of the durability of different plasters and allows a realistic comparison between compositions and/or methods of application.

One of the drawbacks of constructing small test-walls is the length of time needed to obtain meaningful results. With this in mind and in light of available equipment, staff, parallel projects and timescale a version of this field test was designed. 10 plaster samples with varying additives were created alongside a control sample of 'sticky mud'. The samples were placed at an angle of 20° and subject to natural weather conditions over a period of 30 days.

This 'extreme' test (in reality earthen finishes should be offered a level of protection through appropriate design measures such as extended eaves and adequate footings) offered a rapid examination and comparison between the samples. The appearance and state change was noted on a daily basis and photographs taken after each rainfall.

SAMPLE 1

CACTUS JUICE (TYPE A)
Cactus pads were harvested, cut into manageable chunks with spines removed. The pieces were transferred to a plastic bucket, submerged in water and sealed. Cactus juice preparation continued for 14 days.

Locally sourced clay was crushed to obtain a fine-medium sized aggregate and combined with sufficient cactus juice to create a 'sticky mud'. The mixture was thrown into a cured timber mould, manually compressed and smoothed to finish. The mould was removed and the sample left to dry out of direct light for 25 days.

SAMPLE 2

CACTUS JUICE (TYPE B)
Cactus pads were harvested, cut into manageable chunks with spines removed. The pieces were transferred to a plastic bucket, submerged in water and sealed. Cactus juice preparation continued for 14 days.

Locally sourced clay was crushed to obtain a fine-medium sized aggregate and combined with sufficient cactus juice to create a 'sticky mud'. The mixture was thrown into a cured timber mould, manually compressed and smoothed to finish. The mould was removed and the sample left to dry out of direct light for 25 days.

SAMPLE 3

BANANA LEAF JUICE - RASH SHAGOL KOLA
Banana leaves were harvested and cut into small chunks. The pieces were transferred to a plastic bucket, submerged in water and sealed. Banana leaf juice preparation continued for seven days.

Locally sourced clay was crushed to obtain a fine-medium sized aggregate and combined with sufficient banana leaf juice to create a 'sticky mud'. The mixture was thrown into a cured timber mould, manually compressed and smoothed to finish. The mould was removed and the sample left to dry out of direct light for 25 days.

SAMPLE 4

OIL
Locally sourced clay was crushed to obtain a fine-medium sized aggregate and combined with sufficient water to create a 'sticky mud'. The mixture was thrown into a cured timber mould, manually compressed and smoothed to finish.

The mould was removed and while still wet the sample was coated with oil. It was left to dry for 20 days, after which a second coating of oil was applied. A further five days, out of direct light was allowed for adequate drying.

SAMPLE 5

COAL
Coal was manually crushed to a medium sized aggregate and sifted to acquire a fine powder.

Locally sourced clay was crushed to obtain a fine-medium sized aggregate, combined with coal (3:1) and starch water to create a 'sticky mud'. The mixture was thrown into a cured timber mould, manually compressed and smoothed to finish. The mould was removed and the sample left to dry out of direct light for 25 days.

RAW MATERIAL HARVESTING & SAMPLE CREATION

Choice
A series of additives were chosen according to their availability in the local area, appropriate harvesting measures and perceived water resilience qualities. Each mixture was thrown into a cured timber mould (12inches x 12inches x 2inches) to obtain samples of the same size and proportion.

CONTROL

'STICKY MUD'
Locally sourced clay was crushed to obtain a fine-medium sized aggregate and combined with sufficient water to create a 'sticky mud'. The mixture was thrown into a cured timber mould, manually compressed and smoothed to finish. The mould was removed and the sample left to dry out of direct light for 25 days.

SAMPLE 6

EUCALYPTUS TREE TANNIN

Outer bark from a series of Eucalptus trees was collected, dried over a period of three days and crushed to a fine powder. The powder was mixed with water and boiled. Tannin extraction took 4-5 hours.

Locally sourced clay was crushed to obtain a fine-medium sized aggregate and combined with sufficient tannin decoction to create a 'sticky mud'. The mixture was thrown into a cured timber mould, manually compressed and smoothed to finish. The mould was removed and the sample left to dry out of direct light for 25 days.

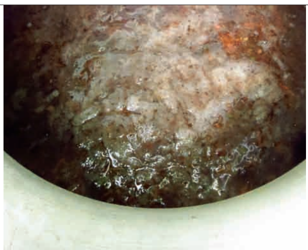
SAMPLE 7

BIJLA TREE TANNIN

Outer bark from a series of Bijla trees was collected and dried over a period of three days. The pieces were added to water and boiled. Tannin extraction took 4-5 hours.

Locally sourced clay was crushed to obtain a fine-medium sized aggregate and combined with sufficient tannin decoction to create a 'sticky mud'. The mixture was thrown into a cured timber mould, manually compressed and smoothed to finish. The mould was removed and the sample left to dry out of direct light for 25 days.

SAMPLE 8



BIJLA TREE MULCH

A proportion of bark (roughly chopped) and tree sap was collected from a series of Bijla trees and added to water to create a thick viscous substance.

Locally sourced clay was crushed to obtain a fine-medium sized aggregate and combined with sufficient tree mulch to create a 'sticky mud'. The mixture was thrown into a cured timber mould, manually compressed and smoothed to finish. The mould was removed and the sample left to dry out of direct light for 25 days.

SAMPLE 9

SOAP

A decoction was obtained from manually rubbing a soap sample in a rough container. After one hour the remaining pieces were left to disintegrate in the liquid over a period of 24 hours.

Locally sourced clay was crushed to obtain a fine-medium sized aggregate and combined with sufficient soap water to create a 'sticky mud'. The mixture was thrown into a cured timber mould, manually compressed and smoothed to finish. The mould was removed and the sample left to dry out of direct light for 25 days.

SAMPLE 10

4% CEMENT

Locally sourced clay was crushed to obtain a fine-medium sized aggregate, combined with sand and cement (20:4:1) and sufficient water to create a 'sticky mud'.

The mixture was thrown into a cured timber mould, manually compressed and smoothed to finish. The mould was removed and the sample left to dry out of direct light for 25 days.

SAMPLE 1 *Cactus Juice (Type A)*

SAMPLE 2 *Cactus Juice (Type B)*

SAMPLE 3 *Banana Leaf Juice*

SAMPLE 4 *Oil*

SAMPLE 5 *Coal*

RESULTS

Recording Data

State changes were recorded over a period of 30 days, with photographs taken at 9am following significant periods of rainfall. The pitting, deterioration and/or failure of each of the samples can be directly compared to the control to ascertain their water resilience performance.

Day 1	Day 6	Day 11	Day 30
(25/08/2012) Photograph taken at 9am	*(30/08/2012)* Photograph taken at 9am Following light rain from 2.30am - 3.30am	*(04/09/2012)* Photograph taken at 9am	*(23/09/2012)* Photograph taken at 9am Following a prolonged period of rainfall from 17/09/2012 - 20/09/2012

CONTROL *'Sticky Mud'*

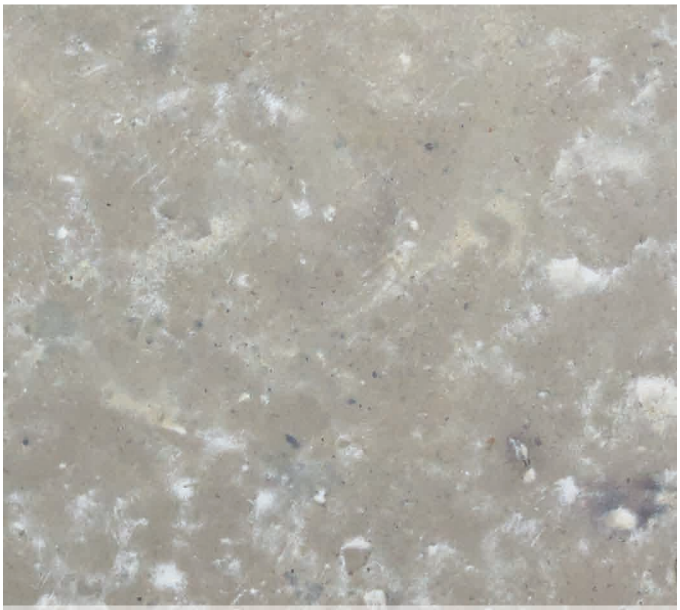
SAMPLE 6
Eucalyptus Tree Tannin

SAMPLE 7
Bijla Tree Tannin

SAMPLE 8
Bijla Tree Mulch

SAMPLE 9
Soap

SAMPLE 10
4% Cement



Sample 8 (Bijla Tree Mulch) After 30 Days Subjected To External Conditions

Bijla Tree

Sample 10 (4% Cement) After 30 Days Subjected To External Conditions

Harvesting Bijla Tree Bark

ANALYSIS

Sample creation

During sample creation it was noted that plaster workability improved when using cactus juice and tannins. It was more difficult to work with soap and cement as the mixture was rapidly hardening, resulting in the need for further water, particularly to achieve a smooth finish.

Water Resilience

Following the first light rainfall on day 6 of the experiment all samples remained intact. Cracking and medium pitting was noted on the control sample ('sticky mud') and sample 4 (oil). Minor pitting was noted on sample 3 (banana leaf juice) and sample 9 (soap), with sample 10 (4% cement) exhibiting surface flaking. This early indication suggests various natural additives offer an increased level of water resilience due to their improved performance over the control ('sticky mud').

The second rainfall on day 11 was significantly heavier lasting 8 hours. Again the entire sample set remained intact. The control sample ('sticky mud') performed the least well, with significant loss of surface material. Further pitting was noted on sample 4 (oil) and sample 9 (soap). Sample 3 (banana leaf juice) and sample 7 (Bijla tree tannin) experienced minor surface loss. Sample 1 (cactus juice - A), sample 2 (cactus juice - B), sample 5 (coal), sample 6 (Eucalyptus tree tannin), sample 8 (Bijla tree mulch) and sample 10 (4% cement) performed particularly well under such conditions, with minimal state change.

Between 17/09/2012 and 20/09/2012 Sundarban village experienced a prolonged period of heavy rainfall, with intermittent showers over the following few days. Under such extreme conditions all samples failed apart from sample 8 (Bijla tree mulch), sample 9 (soap) and sample 10 (4% cement). Despite significant deterioration sample 9 (soap) remained intact. Sample 8 (Bijla tree mulch) and sample 10 (4% cement) showed little state change or material loss after 30 days.

CONCLUSION

As expected the synthetic additives provided increased water resilience, with the addition of 4% cement proving to be the most effective additive. However the investigation highlighted that a number of natural additives performed better than the traditional earthen plaster; a basic combination of clay and water.

Natural Additives With Minor Increased Water Resilience
Cactus juice, coal, and Eucalyptus tannin performed well under light intermittent rainfall.

CACTI
Cacti are members of the *Cactacea* plant family and are native to the Americas, although they are increasingly found across the world primarily due to human intervention. Juice from the pads and stems serve many functions, including within earthen plaster. Many organisations such as the Adobe Alliance in Texas and the restoration of Mission San Xavier Del Bac in Arizona have highlighted the potential benefits of cactus pad juice as an alternative additive to synthetic options.

Cactus juice is reported to:
- Improve workability (this being dependent on water content, the size and shape of aggregate, the age of plaster and amount of natural binders)
- Increase adhesion (helping plaster set)
- Serve as a stabiliser (improving water resilience and durability)
- Prevent dusting

Two types of cactus have been identified in the local area. The community utilise these living plants as natural 'fences' ensuring various animals are kept at bay. At present cacti are not used within Sundarban village as sources of food, for medicinal purposes, within construction or for ornamentation. It was therefore deemed appropriate to harvest a small sample of both types.

EUCALYPTUS TREE
Eucalyptus trees are members of the *Myrtaceae* family, predominantly native to Australia with various species found throughout the world. Eucalyptus is often referred to as an invasive species. They draw large amounts of water from the soil, which may help reduce soil salination but may also have adverse side effects for other plant species and wildlife habitats. However, they are often prized as a cash crop, with fast growth and the ability to re-grow following cut-back.

In Sundarban village Eucalyptus is primarily used for fuel both for individual use and to sell at market. All mature trees grow an annual layer of bark (rich in tannin) and in some species the outer layer is shed to reveal a satiny finish beneath. This can be seen on trees across the community.

Tannins are reported to:
- Disperse clay particles (coating sand grains evenly)
- Break down lumps of clay
- Reduce permeability and improve water resilience

In order to extract the tannin, the flaking outer bark was harvested from a large number of trees. The investigation team was keen not to destroy any trees, as they are integral to existing livelihoods.

COAL
Although coal performed better than the traditional 'sticky mud', it is not readily available and the cost to obtain a sufficient quantity for use in earthen plasters (15-20% of a build) may mean that it is not suitable for households with limited assets. It was noted however that the significant colour change to the material might offer an aesthetic alternative. Various members of the community commented on the similarity to stone.

More research is needed to ascertain whether cactus juice and Eucalyptus tannin offer sufficient improvement to the water resilience of earthen plasters in an area which experiences monsoon rains and is at risk from flash floods and standing water.

A Natural Additive To Improve Quality and Longevity Of Earthen Plasters
Bijla tree mulch performed particularly well during the test period, with the sample remaining intact exhibiting only minor pitting. The sample was darker in colour than the traditional 'sticky mud' and the small bark fragments offered a new aesthetic.

BIJLA TREE
The Bijla tree (a direct translation from the Bangla name) is local to Sundarban Union. The sticky substance was previously used within the district as a source of glue to make kites. As this pastime is in decline, alternative synthetic substances have superceded this traditional technique and as the species is not sought after for fuel, the number of trees existing across the landscape is diminishing. However if it was to be accepted as an alternative to cement stabilisation then there is an opportunity to reintroduce this species.

The investigation covered a period of 30 days, however the sample set was revisited on a weekly basis. Following heavy rainfall over the next month all three remaining samples showed signs of severe deterioration. Sample 8 (Bijla tree mulch) and sample 9 (soap) failed on a central unsupported axis, exhibiting weathering at the edges, although sample 8 (Bijla tree mulch) retained its shape and smooth surface. Sample 10 (4% cement) remained intact but experienced major pitting and corner failure.

Coupled with appropriate design solutions such as extended eaves and adequate footings, this natural substance may offer low-income families who are unable to afford the addition of cement, lime or bitumen an alternative, improving the quality and longevity of their earthen walls. Further investigation is required to ascertain a suitable Bijla tree decoction (proportion vs. water resilience) to ensure this is an appropriate additive with regards to harvesting requirements.

Author: Jo Ashbridge
EWB-UK Placement 2012